Nutrient Effects in Small Brazos Basin Streams Final Report

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Acronyms

ACI	Algal Cover Index
AFDM	Ash Free Dry Mass
ALU	Aquatic Life Use
ANOSIM	Analysis of Similarity
ANOVA	Analysis of Variance
BIBI	Benthic macroinvertebrate Index of Biotic Integrity
BRA	Brazos River Authority
$CBOD_5$	5-Day Carbonaceous Biochemical Oxygen Demand
CFS	cubic feet per second
CR	County Road
CV	Coefficient of Variation
DO	Dissolved Oxygen
EPA	United States Environmental Protection Agency
FDC	Flow Duration Curve
FFG	Functional Feeding Group
FM	Farm-to-Market
HQI	Habitat Quality Index
IBI	Index of Biotic Integrity
LCRA	Lower Colorado River Authority
MDS	Multidimensional Scaling
MGD	million gallons per day
N	Nitrogen
NCDC	National Climate Data Center
NOAA	National Oceanographic and Atmospheric Administration
P	Phosphorus
PCA	Principal Components Analysis
PDI	Palmer Drought Index
QAPP	Quality Assurance Project Plan
R-IBI	Regionalized fish Index of Biotic Integrity
RPD	Relative Percent Difference
SD	Standard Deviation
SH	State Highway
SIMPER	Similarity Percentages
SIMPROF	Similarity Profile
SWQM	Surface Water Quality Monitoring
TCEQ	Texas Commission on Environmental Quality
TDS	Total Dissolved Solids
TIAER	Texas Institute for Applied Environmental Research

TLE	Tributary of Little Elm Creek
TOC	Total Organic Carbon
TPWD	Texas Parks and Wildlife Department
TSS	Total Suspended Solids
TSSWCB	Texas State Soil and Water Conservation Board
USGS	United States Geological Survey
VSS	Volatile Suspended Solids
WMA	Wildlife Management Area

Executive Summary

This project adds to the body of data relating to the effects of nutrient enrichment in small streams and will assist the process of developing numeric criteria for nutrient parameters that are protective of aquatic resources. A secondary objective is to increase knowledge about the distribution and status of freshwater mussels in the Brazos River Basin.

Water quality, fish, benthic macroinvertebrates, mussels, and periphyton were sampled four times at each of six sites in North Central Texas streams. Habitat and flow information were collected to characterize sites and aid in interpreting the other data. The study included three independent measurements of nutrient impacts on the benthic algae community: a rapid aquatic vegetation assessment technique, measurements of biomass (as ash-free dry mass and benthic algae chlorophyll-*a* density), and quantitative taxonomic identification of the soft algae and diatom benthic communities.

Fish were sampled using seine and electrofishing techniques. Data were analyzed using the regionalized index of biotic integrity (Linam *et al.* 2002). One collection effort, Willis Creek in May 2007, was rated at a limited aquatic life use. The other fish collections were rated intermediate or high. No fish collection events were rated exceptional during this study. When the four sampling events were averaged, Little Elm, Tributary of Little Elm, Duck and Walnut Creeks rated intermediate and Willis and Clear Creeks rated high.

Benthic macroinvertebrates were sampled with kick-nets or snag/woody debris collection and analyzed using the statewide benthic index of biotic integrity (Harrison 1996). Two collection efforts, Little Elm and Willis Creeks in May 2007, were rated as limited aquatic life use. Most benthic macroinvertebrates collections were rated intermediate or high. Collections at Clear Creek and Walnut Creek in May 2007 and Willis Creek in July 2008 were rated exceptional. When the four sampling events were averaged, Little Elm and Tributary of Little Elm Creeks rated intermediate and Willis, Clear, Duck and Walnut Creeks rated high. Scrapers were the dominant functional feeding group found in each stream.

Mussels were sampled using timed, random searches. No live mussels were collected during this study. Ages of shells ranged from relatively recently dead to very long dead. Willis Creek had the highest species richness (nine species) and Walnut Creek had six species. The other study streams had three species or fewer.

Physicochemical and water chemistry measurements were made. For most sampling events, mean dissolved oxygen levels for all streams exceeded 5.0 mg/L and minima exceeded 3.0 mg/L. Three exceptions occurred when streams were not flowing. Additionally, Duck Creek failed to meet mean or minimum dissolved oxygen criteria in June 2008. Pronounced diel cycling characteristic of algal photosynthesis and respiration was observed in the Tributary of Little Elm Creek. Average specific conductance values tended to increase from May 2007 through August 2008 for Ecoregion 32 streams, and Ecoregion 33 average specific conductance values were variable.

Nitrate levels were higher in Ecoregion 32 streams than Ecoregion 33 streams, consistently exceeding TCEQ screening levels. Tributary of Little Elm Creek and Willis Creek had the highest total phosphorus levels in the study, consistently exceeding TCEQ screening levels. Water column chlorophyll-*a* levels, however, were not excessive and only exceeded TCEQ screening levels on two occasions in Willis Creek.

Habitat information was collected and analyzed using a Habitat Quality Index. All collection efforts were rated as intermediate or high. When the four sampling events were averaged, Little Elm and Tributary of Little Elm Creeks rated intermediate and Willis, Clear, Duck and Walnut Creeks rated high. All streams had a high percentage of canopy cover (62-92%), which is known to be a key limiting factor on algal and macrophyte growth.

The aquatic vegetation survey showed that aquatic vegetation cover and thickness were low throughout the study and all macro- and microalgae composite scores are below one-third the maximum possible score, which corresponds well with the absence of visual observations of nuisance algae growth. Sediment cover on algae was rarely observed at the sampling points. Macrophytes were not observed in any abundance.

Periphyton biomass was analyzed and reported in two ways: chlorophyll-*a* and ash-free dry mass (AFDM). Reported values were scaled to the original area of woody debris scraped to obtain a value representing periphyton biomass per area of substrate. Mean benthic algae chlorophyll-*a* values ranged from 8.4 to 39 mg/m^2 and ash-free dry mass values ranged from 0.72 to 1.6 mg/cm^2, which are well below threshold nuisance values of 70 mg/m^2 and 5 mg/cm^2, respectively. Wastewater-dominated Tributary of Little Elm Creek had the highest mean chlorophyll-*a* and ash-free dry mass levels.

Soft algae and diatom communities were identified and enumerated independently. Cyanobacteria dominated the soft algae samples, along with pennate diatoms and green algae (Chlorophyta). Diatoms were identified to species and ANOSIM revealed that diatom communities were significantly different between the two ecoregions. Community composition of the diatom samples was analyzed by applying known diatom attributes and looking for patterns among the streams. This analysis distinguished the Tributary of Little Elm Creek as having the highest percentage of tolerant and eutrophic taxa and the lowest percentage of sensitive taxa.

Stream flow influenced the biological communities in the study streams and differences between Ecoregions 32 and 33 are a dominant pattern in this study. Nutrient criteria for wadeable streams will need to acknowledge ecoregional differences. In the small data set collected, it is difficult to distinguish effects of nutrient enrichment from other effects.

All three techniques used to characterize levels of attached algal density, aquatic vegetation surveys, periphyton biomass measurements and quantitative algal taxonomic identification, show promise for use in assessing nutrient effects in wadeable streams. Effluent-dominated Tributary of Little Elm Creek stood out in both periphyton biomass and algal cell density measurements. It may be possible to refine easy, rapid aquatic vegetation survey methods to differentiate among streams by technique modifications or index development.

Introduction

Background

Increased pollutant loadings resulting from urban and agricultural development can lead to nutrient enrichment. Nutrient enrichment in streams may increase levels of dissolved nutrients in surface water, or algal, macrophyte, and bacterial communities can assimilate the added nutrients. Excessive growth of algae and aquatic macrophytes can cause diel swings in dissolved oxygen (DO) and pH to levels that are harmful to aquatic life. To address these issues, the United States Environmental Protection Agency (EPA) is requiring the states to establish numeric criteria for nutrient parameters. While considerable data is available for reservoirs, very little is known about nutrient effects in smaller streams.

The project will add to the body of data relating to the effects of nutrient enrichment in small streams. Similar studies have been conducted in East Texas (Kiesling *et al*. 2006) and the Edwards Plateau (Mabe 2007). No published data exist for the proposed study area, although Ryan King and Bryan Brooks of Baylor University and Kirk Winemiller of Texas A & M University are conducting studies in the area (King 2009, Winemiller 2009). Data will be shared with the Texas Commission on Environmental Quality (TCEQ) to assist the EPA-mandated process of developing numeric criteria for nutrient parameters that are protective of aquatic resources and water for wildlife. Data will also be shared with the Brazos River Authority (BRA) to assist in their management efforts.

A secondary objective is to increase knowledge about the distribution and status of freshwater mussels in the Brazos River Basin. Overall, mussel species are in decline and there are several species of concern in the Brazos Basin (TPWD 2005).

Approach

Water quality, fish, benthic macroinvertebrates, mussels, and periphyton were sampled at six sites in North Central Texas streams. Habitat and flow information were collected to characterize sites and aid in interpreting the other data. The study sampled wadeable streams where little data exists linking nutrient levels to dissolved oxygen and biological communities.

Six sampling sites were selected along small perennial North Central Texas streams (Figure 1). A goal in stream selection was to choose water bodies with different land uses or pollutant loadings in an effort to identify nutrient impacts.

The study included three independent measurements of nutrient impacts on the benthic algae community: a rapid aquatic vegetation survey technique, measurements of biomass (as ash-free dry mass and benthic algae chlorophyll-*a* density), and quantitative taxonomic identification of the soft algae and diatom benthic communities (Lowe and Pan 1996).

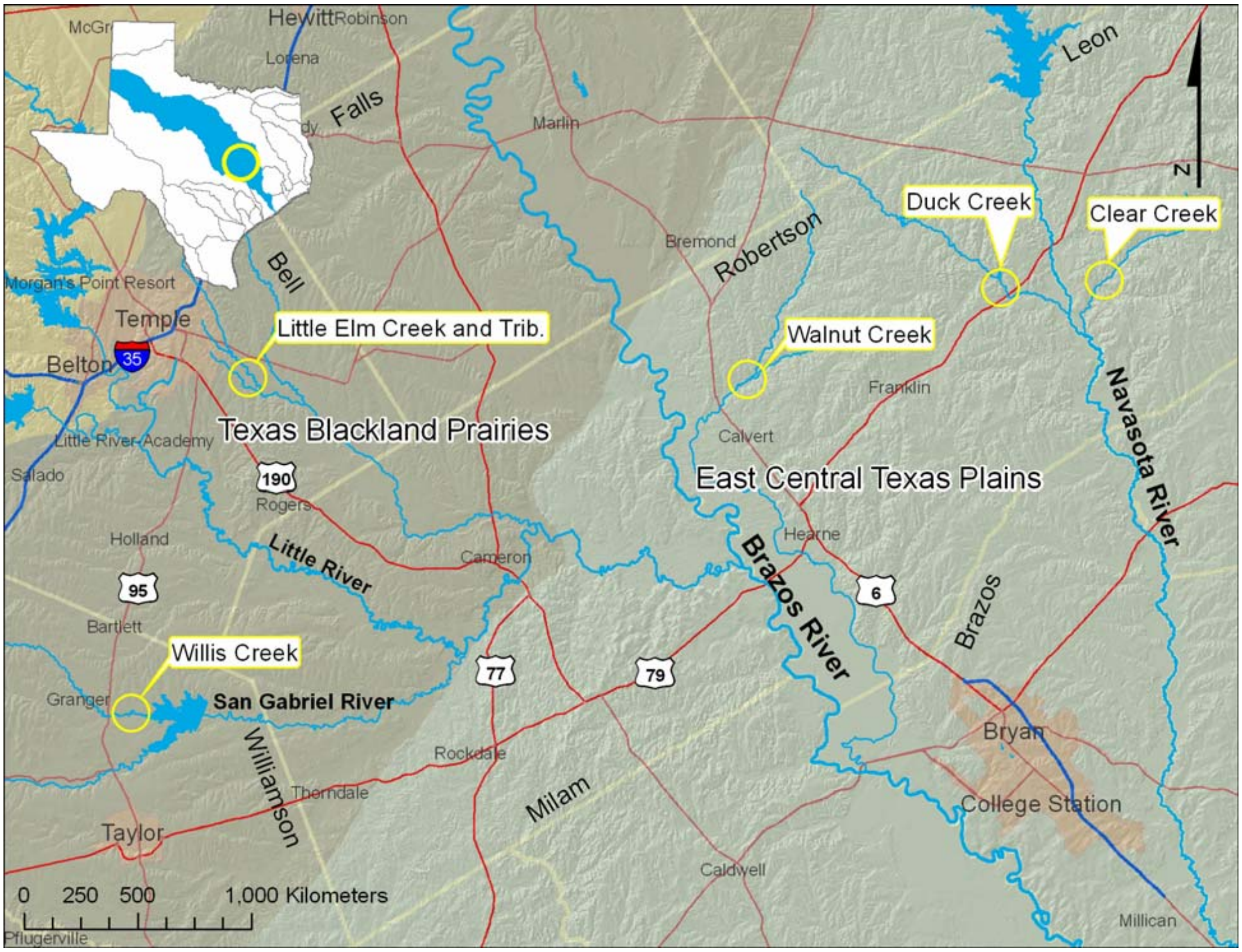

Figure 1. Stream locations.

Project Area

Site Selection

The site selection process focused on creeks in the central Brazos River Basin east of Interstate Highway 35. This portion of the central Brazos River Basin falls within two EPA Level III Ecoregions, Texas Blackland Prairies (32) and East Central Texas Plains (33). A total of 30 potential sites were considered. An attempt was made to select sites that provided a gradient of human impacts, were wadeable and maintained perennial flow for most of the year. To help in site selection the Texas Surface Water Quality Inventory ("305(b) report") was reviewed, reconnaissance trips were made to potential sites, and BRA, TCEQ, Texas Institute for Applied Environmental Research (TIAER), and Texas State Soil and Water Conservation Board (TSSWCB) were consulted during the site selection process. Sites of special interest were also considered, including Texas Parks and Wildlife Department (TPWD) property. The goal was to select one station on each stream that best represents conditions of the entire water body. Six creeks, three from each ecoregion were selected (Table 1). The Navasota River at SH 7 was originally selected as one of the six sites. Due to heavy rainfall in the spring of 2007, this site was not wadeable and was dropped from the sampling schedule. Duck Creek at SH 79 replaced this site in the sampling schedule.

Table 1. Study site attributes.

Location	Abbreviated name	TCEQ station ID	TCEQ water body segment	County	EPA ecoregion		Drainage area (km^2)	Stream order	Bed slope (m/km)	Study reach length (km)	Total bends	Inlets
Little Elm Creek upstream of FM 3117	Little Elm	13538	Tributary of 1213	Bell	Texas Blackland Prairies	32	49	3	1.9	0.2	3	1
Tributary of Little Elm Creek upstream of FM 3117	TLE	13539	Tributary of 1213	Bell	Texas Blackland Prairies	32	20	3	2.5	0.2	11	0
Willis Creek downstream of CR 348	Willis	20022	1247A	Williamson	Texas Blackland Prairies	32	164	5	1.4	0.3	9	1
Clear Creek upstream of CR 977	Clear	20019	Tributary of 1209	Leon	East Central Texas Plains	33	78	4	2.7	0.2	6	3
Duck Creek upstream of Hwy 79	Duck	16389	1209H	Robertson	East Central Texas Plains	33	342	4	0.5	0.3	5	1
Walnut Creek upstream of Sunnyside Rd.	Walnut	20021	1242O	Robertson	East Central Texas Plains	33	320	5	1.1	0.3	4	0

Little Elm Creek

Little Elm Creek upstream of Farm-to-Market 3117 is southeast of the City of Temple and is a tributary of Little River (Figure 2). It receives urban runoff and is characterized by landowners as being flashy when Temple receives rainfall. Land uses include rangeland and row crops. Corn fields were common along the study site. Debris from corn fields (Figure 3) were common on the banks and in the stream in 2007 after many of the crops failed during the drought in 2006. The site was initially categorized as having light nutrient impacts from urban areas. After completion of the study it was clear that the creek is moderately influenced by urban and agricultural land uses.

Tributary of Little Elm Creek

The Tributary of Little Elm Creek upstream of Farm-to-Market 3117 (Figure 4) runs parallel to Little Elm Creek. It is effluent dominated due to a municipal wastewater discharge from the City of Temple, which is permitted for an annual average flow of 7.5 million gallons per day (MGD). Land uses include rangeland and row crops. The immediate area surrounding the study site is used by cattle. Debris from corn fields was common on the banks and in the stream in 2007 after many of the crops failed during the drought in 2006. The site was initially categorized as having nutrient impacts from a permitted wastewater discharge. Once the study began, it became clear that the surrounding rangeland and row crops also contribute to the nutrient loading, as cow manure and crop debris were common in the creek.

Figure 2. Little Elm Creek looking upstream (Jul 2008).


Figure 3. Piles of agricultural debris in Little Elm Creek at FM 3117 (Apr 2007).


Figure 4. Tributary of Little Elm Creek looking upstream (Jul 2008).

Willis Creek

Willis Creek downstream of Williamson County Road 348 (Figure 5) is located east of the City of Granger and is upstream of Granger Lake on the San Gabriel River. It is also located within the TPWD Granger Wildlife Management Area (WMA). The majority of the watershed is agricultural with rangeland and row crops. The most downstream portion also receives urban runoff and municipal wastewater from the City of Granger via inflow from a tributary. The City of Granger is permitted to discharge an annual average flow of 0.20 MGD. Debris from corn fields was common on the banks and in the stream in 2007 after many of the crops failed during the drought in 2006. Willis Creek was reported by the Texas Water Commission (a predecessor agency to TCEQ) in 1992 as one of the state's least disturbed streams (Bayer *et al*. 1992). A portion of the creek is currently managed by TPWD as part of the Granger WMA. The creek is routinely monitored by BRA through the Clean Rivers Program and TSSWCB and BRA are developing a Watershed Protection Plan for the Granger Lake watershed to minimize sediment and nutrient loadings (TSSWCB 2009). The site was initially categorized as having moderate nutrient impacts from agricultural activities. The initial categorization of the creek seemed to hold true throughout the study.

Figure 5. Willis Creek looking upstream (Jul 2008).

Clear Creek

Clear Creek upstream of Leon County Road 977 (Figure 6) is south of the City of Marquez and is a previously unmonitored creek in the Navasota River watershed. Land use is predominantly rangeland and there are poultry houses in the upper portion of the watershed (Figure 7). Cattle have access to the creek within the study site. The site was initially categorized as having light nutrient impacts from agricultural activities. The initial categorization was consistent with what was observed during the study.

Figure 6. Clear Creek looking upstream (Sep 2007).

Figure 7. New chicken houses in Clear Creek watershed approximately six miles upstream of the study site (Jun 2008).

Duck Creek

Duck Creek upstream of State Highway 79 (Figure 8) is northeast of the City of Franklin and is a tributary of the Navasota River. Land uses include range and pasture land and a growing poultry industry. Poultry litter is applied to substantial portions of the hay land and pasture land in the watershed as a substitute for commercial fertilizer (TIAER 2002). Although comprising only 10 percent of the watershed land area, areas fertilized by poultry litter accounted for 19 percent of the nitrogen balance and 40 percent of the phosphorus balance (TIAER 2001). There are three permitted industrial discharges in the watershed; however two are not active discharges. A tributary of Duck Creek receives effluent from a poultry feed mill that is permitted to discharge up to 0.029 MGD of boiler blow down and truck wash water. The creek is routinely monitored by the BRA through the Clean Rivers Program. The site was initially categorized as having moderate nutrient impacts from agricultural activities. During the study it was difficult to determine how the agricultural activities impacted the creek, although exotic species were observed (Figure 9). The study area had a very natural setting and the nutrient impacts in the immediate area seemed to be minimal

Figure 8. Duck Creek looking upstream (Aug 2008).

Figure 9. Feral swine at Duck Creek (Jun 2008).

Walnut Creek

Walnut Creek upstream of Sunnyside Road (Figure 10) is north of the City of Calvert and is a tributary of the Little Brazos River. The upper portion of the creek's watershed receives industrial and municipal wastewater including lignite mine discharges and domestic waste from the lignite mine and the City of Bremond. The City of Bremond is permitted to discharge up to 0.22 MGD of treated domestic wastewater. The lignite mine permit authorizes the intermittent, flow variable discharge of storm water and mine pit water, as well as 0.017 MGD of treated domestic wastewater. In addition to the mining activities, there is rangeland near the study site. The creek is routinely monitored by BRA through the Clean Rivers Program. The site was initially categorized as having light nutrient impacts from agricultural activities. The initial categorization seemed to hold true throughout the study.

Figure 10. Walnut Creek looking upstream (Aug 2008).

Methods

Data collected included instantaneous physicochemical measurements, diel physicochemical measurements, water chemistry, flow, habitat, fish, benthic macroinvertebrates, mussels, periphyton biomass and taxonomic identification, and aquatic vegetation surveys.

Water quality, algal, benthic, mussel, and fish community assessments were conducted twice per year at each site in 2007 and 2008. One sampling trip each year was conducted in the index period outside of the critical period (March 15 – June 30 and October 1 – 15) and one in the critical period (July 1 – September 30) (TCEQ 2003). Due to high flow conditions in Little Elm Creek and the Tributary of Little Elm Creek, it was not possible to conduct critical period sampling there in 2007. Instead two index period sampling events were completed in 2007 and two critical period sampling events in 2008. For Willis Creek, high flows prevented a second sampling trip in 2007, and three sampling events were conducted in 2008 (Table 2).

Table 2. Stream sampling dates and event IDs.

Stream	Sampling start date	Hydro ID	LINKTREE ID	Period	Season
Little Elm Creek	7 May 2007	6	2	Index	Spring
	2 Oct 2007	13	8	Index	Fall
	7 Jul 2008	25	18	Critical	Summer
	11 Aug 2008	26	19	Critical	Summer
Tributary of Little Elm Creek	7 May 2007	5	1	Index	Spring
	2 Oct 2007	12	7	Index	Fall
	7 Jul 2008	24	17	Critical	Summer
	11 Aug 2008	27	20	Critical	Summer
Willis Creek	7 May 2007	7	3	Index	Spring
	3 Jun 2008	17	12	Index	Spring
	7 Jul 2008	23	16	Critical	Summer
	11 Aug 2008	28	21	Critical	Summer
Clear Creek	21 May 2007	8	4	Index	Spring
	4 Sep 2007	14	9	Critical	Summer
	9 Jun 2008	18	13	Index	Spring
	4 Aug 2008	29	22	Critical	Summer
Duck Creek	21 May 2007	10	6	Index	Spring
	4 Sep 2007	16	11	Critical	Summer
	9 Jun 2008	19	14	Index	Spring
	4 Aug 2008	30	23	Critical	Summer
Walnut Creek	21 May 2007	9	5	Index	Spring
	4 Sep 2007	15	10	Critical	Summer
	9 Jun 2008	20	15	Index	Spring
	4 Aug 2008	31	24	Critical	Summer

Sampling methods in general follow the TCEQ Surface Water Quality Monitoring (SWQM) Procedures Manual, Volumes 1 and 2 (TCEQ 2003, TCEQ 2005) as specified in the project Quality Assurance Project Plan (QAPP) (TPWD 2007). For sample types not described in the

TCEQ SWQM manuals, other protocols were used. Brief descriptions of the methods are provided in the following paragraphs.

Instantaneous and Diel Physicochemical Parameters

A YSI 600 XLM multi-parameter datasonde was used to measure instantaneous and diel physicochemical parameters. Instantaneous and diel data were recorded for dissolved oxygen, temperature, pH and specific conductance at each of the six streams during the two-year study. Data recording, instrument calibration, and post-calibration procedures can be found in TCEQ (2003).

Instantaneous physicochemical measurements were generally made on the first day of sampling at the lowest portion of the reach at the same location where water chemistry samples were collected. In some instances where the water collection sites were shallow and the water was clear, Secchi depth measurements were taken upstream of the water sample collection site. In general, diel measurements were made above the uppermost section of the study reach to avoid interference from concurrent biological measurements. For each stream, datasondes were deployed for at least 24 hours, typically beginning on the first day of sampling, following the water chemistry sampling and instantaneous physicochemical measurements. However, in some instances when datasondes either failed to record data or failed post-calibration, it was necessary to redeploy the datasondes and the diel data does not coincide with other sample collections.

Water Chemistry

Water chemistry sample collections occurred before biological sampling and samples were transported to the Lower Colorado River Authority (LCRA) laboratory within required holding times. Secchi depth readings were recorded for each station.

Flow

Marsh-McBirney electric meter flow measurements follow the TCEQ SWQM Volume 1 (2003) procedures. Flow readings were taken at the same time the water chemistry samples were collected.

Habitat

Physical habitat data collection followed the protocol in TCEQ SWQM Vol. 2 (2005) for each visit. Habitat transects were established once at the beginning of the study.

Fish

Fish collections followed standards set by TCEQ SWQM Vol. 2 (2005). Fish sampling gear types include a Smith-Root LR-24 backpack electrofisher, a 1.8 m seine with 5 mm delta-weave mesh, 4.6 m seine with 5 mm delta-weave mesh or a 9.1 m seine with 6 mm delta-weave mesh depending on the width of the stream being sampled. Fish assemblage data was recorded in the field for common fishes that were easily identifiable to the lowest taxonomic level. The larger fish were identified in the field and photo vouchers taken. Small voucher specimens and unidentified fish were placed in clearly labeled jars with 10% formalin and identified in the laboratory. The voucher collection contains two fish of each species preserved in 10% formalin and larger specimens were photographed. For quality assurance, 10% of the voucher collection was reviewed by an experienced ichthyologist.

Benthic Macroinvertebrates

Benthic macroinvertebrate collection included sampling with kick-nets or from snag/woody debris following TCEQ SWQM Vol. 2 (2005) protocols. The level of effort was recorded in five-minute intervals of kick-netting or snag/woody debris sampling. The snag/woody debris samples were rinsed into a sieve bucket and then portions of the material rinsed off the snags were sorted for macroinvertebrates. All samples were processed in the field to ensure that enough benthic macroinvertebrates were collected at each station. The target number was 175 organisms ± 20%. The benthic macroinvertebrates were placed into labeled jars with 70% isopropyl alcohol. Preserved specimens were identified in the laboratory by Jack Davis, environmental consultant.

Mussels

Freshwater mussels were collected during each site visit following the Inland Fisheries Freshwater Mussel Survey Procedures (TPWD 1998) for random, timed searches. A team of two to four personnel visually searched the creek bed and banks for five minutes at each of the five transects established for physical habitat measurements. The total level of effort equals the number of personnel by total time spent by each person. All live and dead mussels were collected and identified to species and the number of shells, number of valves and shell condition were recorded. Samples were placed in pre-labeled bags for each sampling event and stored in-house until sent for identification. Identification of mussel species and shell condition was performed by Marsha May (TPWD).

Periphyton

Periphyton (benthic algae) was sampled using three independent techniques to characterize levels of attached algal density: biomass measurements, quantitative taxonomic identification and aquatic vegetation surveys. Periphyton collection followed the USGS protocol (USGS 2002). Biomass analysis, ash-free dry mass (AFDM) and chlorophyll-*a*, followed the protocols of Hauer and Lamberti (1996). Aquatic vegetation surveys followed Utah State University protocols (Hawkins *et al.* 2001).

For each of the six streams, one piece of woody debris was collected from each of the five transects along the designated reach. Woody debris was chosen for periphyton sampling, rather than cobble or sediment due to the consistent availability at each creek. Using a toothbrush, the periphyton was brushed off the woody debris and rinsed into a pan with deionized water. Once all five pieces of woody debris were brushed, the circumference and length of the brushed area was measured, recorded and totaled for each stream.

Biomass

At each station, periphyton samples were diluted with deionized water to about 300 mL and the volume recorded. The samples were then homogenized using a blender and four 5 mL samples were filtered for each station using a vacuum filter. Two filters for AFDM and two filters for chlorophyll-*a* were processed for each station (the second filter was a replicate to ensure consistency). The filters were individually wrapped in foil and frozen until transferred to the laboratory for processing.

Taxonomic Identification

For algal identification and enumeration, approximately 60 mL of the remaining sample was placed in a glass jar and preserved with 2 mL of glutaraldehyde. One-half of the sample was set aside for soft algae identification and enumeration. At least 300 units (individual cells, or in some cases multiple cells of colonial forms of algae) were counted, using a modified Palmer-Maloney counting chamber. Each field in the counting chamber had a volume of 0.0154 mL^3. Documentation was made of the number of fields counted, including any dilutions or concentrations needed. Representative soft algae material was retained from each of the soft algal taxa identified. The enumeration included counts of diatoms categorized solely as pennate or centric. Knowledge of the actual volume analyzed, as well as the area scraped, allowed algal cell densities to be calculated. The other half of the sample was cleaned by boiling in acid and slides were fixed for diatom identification and enumeration. Five hundred cells were counted for each sample. This represents a qualitative tabulation of the first 500 diatoms encountered in sequential random fields on a slide. Permanent voucher slides of each taxon were retained. Barbara Winsborough of Winsborough Consulting conducted the identification and enumeration of the algal communities.

Figure 11. TPWD employee scraping periphyton from woody debris on Willis Creek.

Aquatic Vegetation Survey

A survey of aquatic vegetation was conducted during each sampling event to characterize the available algal and macrophyte cover and thickness attached to the stream bottom (Hawkins *et.*

al. 2001). At each stream, 25 evenly spaced sampling points were selected in a zigzag pattern to cover the available water depths within the study reach. At each sampling point observations (visual and tactile) were recorded for habitat type (glide, riffle, *etc*.), substrate, flow severity, depth, macroalgae cover and thickness, microalgae thickness, macrophyte cover and water surface cover, macroalgae surface cover and sediment cover on algae. Each type of aquatic vegetation observation was given a score based on amount of cover or thickness. A composite score was calculated for each type.

Low Flow Procedures

Little Elm Creek (July and August 2008) and Duck Creek (August 2008) had periods of no flow. In August 2008 most of the study reach in Willis Creek had no flow and the flow at the most downstream transect was less than 0.1 cfs. Since these creeks had little or no flow, but had perennial pools, modifications were made to sampling methods as described below.

Instantaneous and diel physicochemical parameters were collected for each stream. The diel measurements for Little Elm, Willis and Duck Creeks were collected at the most upstream perennial pool to reduce possible interference from biological sampling. Instantaneous parameters were recorded at the same location where water samples were collected. The water chemistry samples obtained when Little Elm Creek was not flowing were collected in the largest pool within the reach, which was located just upstream from transect 1. For Willis Creek, the water chemistry samples were collected from the largest pool located between transects 1 and 2. This pool receives the wastewater discharge from the City of Granger, while upstream pools do not. For Duck Creek, water chemistry samples were collected just upstream of transect 1.

In low or no flow conditions, flow data was not collected for Little Elm Creek and Duck Creek. Willis Creek had no flow at the four upstream transects, but had a small flow at the most downstream transect due to the City of Granger’s permitted wastewater discharge that entered immediately upstream of transect 1. The flow measurement for Willis Creek in August 2008 represents only the most downstream portion of the stream reach and transects 2 through 5 were not flowing.

For habitat, the low-flow or dry condition protocol was used for creeks with low or no flow (TCEQ 2005). Reach lengths and the distance between transects within the reach were modified during sampling using best professional judgment in order to capture as much data as possible. The transect placement depicted the best characterization of the pools and existing water. Information recorded at the dry transects included bank slope (based on the appearance of normal flow conditions), substrate type, riparian vegetation, canopy cover, bank erosion potential, buffer vegetation, and percent gravel or larger.

Periphyton collections occurred from multiple pools within the reach during periods of low or no flow.

Data Analysis

The PRIMER v6.1.12 (Plymouth Routines in Multivariate Ecological Research) software program was used for community-based exploration of some of the biological data sets. This was especially helpful with the diatom and soft algae community data, since little ecological information or indices of biotic integrity are available for diatom communities in Texas. Multivariate analysis was also useful in exploring ecoregional differences in the benthic macroinvertebrate data, since a regionalized index of biotic integrity has not yet been developed for Texas. Multidimensional scaling (MDS), or non-metric ordination of the samples, constructs a two-dimensional graphical representation of the sample patterns. The basis of the MDS is the similarity matrix among all the samples.

Similarities between each pair of samples are calculated using the Bray-Curtis similarity measure (for biological data). The Bray-Curtis measure, S_{jk}, is defined as:

$$S_{jk} = 100 \left\{ 1 - \frac{\sum_{i=1}^{p} |y_{ij} - y_{ik}|}{\sum_{i=1}^{p} (y_{ij} + y_{ik})} \right\}$$

where y_{ij} is density of the *i*th species in the *j*th sample, and y_{ik} is the density of the *i*th species in the k^{th} sample. In the Bray-Curtis measure, S = 0 if the two stations have no species in common, and S = 1 if the community composition is identical, because $| y_{ij} - y_{ik} | = 0$ for all *i*. Dissimilarity (δ) is the converse of the Bray-Curtis similarity, and since it implies distance between samples, is the starting point for constructing ordinations and other multivariate procedures as described below. For biological data, non-metric multidimensional scaling was used to construct a configuration of the samples in two dimensions. The configuration was based on the computation of a dissimilarity matrix between every possible pair of samples, followed by ranking the dissimilarities, and plotting the samples in two-dimensional space with samples ranked close together depicted as closer on the plot.

Analysis of Similarity (ANOSIM) is analogous to the parametric-based Analysis of Variance (ANOVA) in that it requires the same *a priori* designations of groups of samples, but unlike ANOVA there are no parametric assumptions placed on the data. The multivariate form of the similarity matrix, as in MDS, is the basis for this test. ANOSIM is built on a non-parametric permutation procedure, applied to the (rank) similarity matrix underlying the ordination of the samples. The procedure constructs a test statistic R based on the ranks of the similarities within and between sample groups. This value is then tested for significant differences against a null distribution constructed from random sampling of all possible permutations of the sample labels (Clarke and Warwick 2001). Values of R close to unity show that the community compositions of the samples are very different, whereas those close to zero demonstrate that they are very similar.

The SIMPER (SIMilarity PERcentages) routine was used to reveal the contribution of individual species (*i*) to the community structure seen in each sample group. Values of dissimilarity, $\delta_{jk}(i)$, are averaged over all pairs of samples (*j*,*k*) between groups to give the average contribution from the i^{th} species to the overall dissimilarity between the two groups. The ratio of $\delta avg(i)$ to its standard deviation indicates how consistently a species discriminates among the assemblages. If a species is found at consistent levels (*i.e.*, densities) across all samples in a group, then the standard deviation of its contribution is low, and the ratio is high (Clarke and Warwick 2001).

Such a species will contribute more to the intra-group similarity, and can be thought of as typifying that group.

The LINKTREE routine of PRIMER v6.1.12 (Clarke and Gorley 2006) is a non-parametric adaptation of multivariate classification and regression trees (De'ath 2002). This produces a divisive, constrained, hierarchical cluster analysis of samples, based on their assemblage data, termed a linkage tree. The constraint is that each binary division of the tree corresponds to a threshold on one of the environmental variables and, consistent with related non-parametric routines, maximizes the high-dimensional separation of the two groups, as measured by the ANOSIM R statistic. Such linkage trees therefore provide abiotic 'explanations' for each biotic subdivision of the samples but, as with unconstrained clustering, the LINKTREE routine requires objective stopping rules to avoid over-interpretation, these being provided by a sequence of similarity profile (SIMPROF) tests. SIMPROF tests for the presence of sample groups (or more continuous sample patterns) in *a priori* unstructured sets of samples.

The BIO-ENV procedure is designed to identify the environmental variables which have the most influence on the patterns of biological samples. Dissimilarity matrices for environmental variables (based on Euclidean distance) and biological community data (based on the Bray-Curtis statistic) are compared by ranking and invoking the Spearman coefficient (Clarke and Warwick 2001). The Spearman coefficient ρ is iteratively calculated for each environmental variable to see which one is best at explaining patterns in the biological data. Next, the best two-variable set is calculated, and so on. BIO-ENV works best on a subset of variables selected so that only one of any highly mutually-correlated set of variables enters into the analysis.

Environmental data was also analyzed using principal components analysis (PCA) and Spearman rank correlations.

Results

Weather

Climatological conditions prior to and during sampling events can influence the information collected. Rainfall amounts and flow conditions were monitored prior to sampling to ensure it was safe to sample and to track watershed conditions. Monthly rainfall and drought condition information was collected to help with data interpretation (Appendix A, Table 29 - Table 31).

Monthly rainfall data was gathered from nearby National Oceanographic and Atmospheric Administration (NOAA) National Climate Data Center (NCDC) weather stations. Little Elm Creek, Tributary of Little Elm Creek and Willis Creek had near normal rainfall amounts prior to the May 2007 index period sampling. The rainfall amounts in the months preceding the scheduled sampling in the 2007 critical period were above normal by several inches. As a consequence, sampling at Little Elm Creek and Tributary of Little Elm Creek was delayed until October 2007 and fell outside the critical period. The 2007 critical period sampling for Willis Creek was postponed until 2008 due to Granger Lake inundating the sampling site for the remainder of 2007 (Figure 12). Granger Lake was 19 feet above conservation pool level in July and August of 2007. Clear Creek, Duck Creek and Walnut Creek had above normal rainfall amounts prior to the May 2007 index period sampling and near normal rainfall amounts prior to the September 2007 critical period sampling. Rainfall amounts were below normal prior to sampling at each creek in 2008. Rainfall amounts were greater than three inches below normal for the July 2008 sampling at Little Elm Creek, Tributary of Little Elm Creek and Willis Creek.

Monthly Palmer Drought Index (PDI) data from NCDC provided a regional overview of climate and hydrologic conditions. The PDI north central region (Little Elm Creek, Tributary of Little Elm Creek and Willis Creek) had normal conditions during the 2007 index period followed by very moist and extremely moist conditions during the 2007 critical period. The PDI east region (Clear Creek, Duck Creek, and Walnut Creek) had normal conditions during the 2007 index period followed by moderately moist to very moist conditions during the 2007 critical period. Drought conditions were categorized as normal at all creeks during sampling in 2008.

Overall, 2007 was a wet year creating high instream flows during the index period sampling. The higher flows influenced the results of many measurements and caused sampling events to be rescheduled. The 2008 rainfall amounts and drier conditions were close to normal. Drier conditions were evident by way of below normal rainfall, no flow and diminishing perennial pools at Little Elm Creek in July and August of 2008, Duck Creek in August 2008 and Willis Creek in August of 2008 (Figure 13). Although Ecoregion 32 was not yet in a drought as measured by the PDI, the low and no flow conditions did influence sampling results. The PDI takes into account meteorological and hydrological conditions and is a regional and long-term assessment. It is not intended to describe localized conditions at small watersheds such as these streams. The NCDC did not report drought conditions for the north central region until December 2008.


Figure 12. Willis Creek near the upstream habitat transect looking downstream (Sep 2007).


Figure 13. Willis Creek at the upstream habitat transect looking upstream (Aug 2008).

Flow

Instantaneous flow data for each sampling trip is listed in Table 3 and depicted in Figure 14. As discussed above, Ecoregion 32 stream flows were high in 2007. In 2008, Little Elm and Willis Creeks each experienced periods of no flow. Flow variation was not as extreme for the Tributary of Little Elm Creek, which is dominated by effluent from the City of Temple (Table 4). Ecoregion 33 streams experienced normal flows in 2007. Clear and Walnut Creeks had normal-to-low flows in 2008, and Duck Creek stopped flowing in August 2008. All six streams showed effects from May 2007 rain events, but Willis Creek showed signs of heavy scouring as noted in the benthic macroinvertebrate data.

Table 3. Instantaneous stream flow.

Creek	Date	Instantaneous flow (cfs)	Flow severity	Watershed size (km^2)	Stream order
Little Elm	7 May 2007	13	5	49	3
Little Elm	2 Oct 2007	1.5	3	49	3
Little Elm	7 Jul 2008	0	1	49	3
Little Elm	11 Aug 2008	0	1	49	3
TLE	7 May 2007	8	5	20	3
TLE	2 Oct 2007	1.4	3	20	3
TLE	7 Jul 2008	1.7	2	20	3
TLE	11 Aug 2008	2.2	3	20	3
Willis	7 May 2007	43	5	164	5
Willis	3 Jun 2008	6.7	3	164	5
Willis	7 Jul 2008	0.47	2	164	5
Willis (transects 2-5)	11 Aug 2008	0	1	164	5
Willis (transect 1)	11 Aug 2008	0.08	2	164	5
Clear	21 May 2007	5.9	3	78	4
Clear	4 Sep 2007	3.9	3	78	4
Clear	9 Jun 2008	1.6	3	78	4
Clear	4 Aug 2008	0.52	2	78	4
Duck	21 May 2007	10	3	342	5
Duck	4 Sep 2007	4.5	3	342	5
Duck	9 Jun 2008	1.7	2	342	5
Duck	4 Aug 2008	0	1	342	5
Walnut	21 May 2007	37	3	320	5
Walnut	4 Sep 2007	14	3	320	5
Walnut	9 Jun 2008	11.5	3	320	5
Walnut	4 Aug 2008	9.8	2	320	5

Flow severity: 1 – no flow; 2 – low; 3 – normal; 4 – flood; 5 – high; 6 – dry.

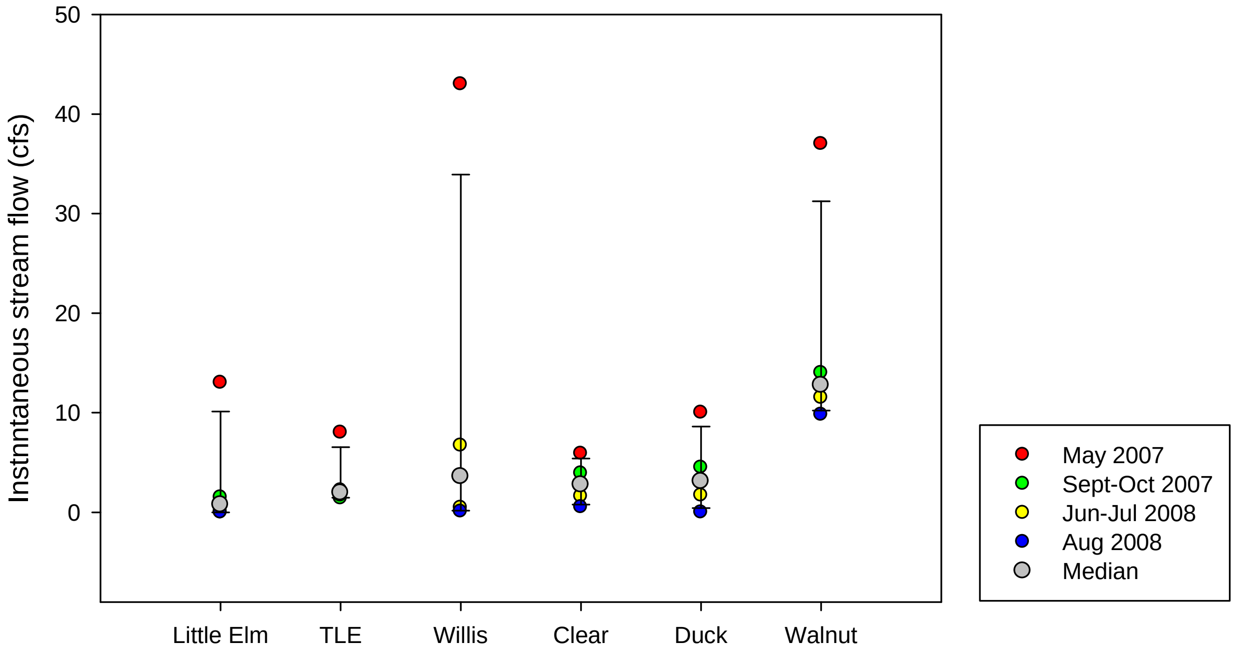

Figure 14. Instantaneous stream flow.
Bars represent 25th and 75th percentile values.

Permitted Wastewater Discharges

The six creeks were assessed to determine how much influence permitted wastewater discharges (domestic and industrial) exerted on flows measured during the study. Of the six creeks, two (Little Elm and Clear Creeks) do not receive any permitted wastewater discharge upstream of the study area. The Tributary of Little Elm, Willis and Duck Creeks each receive one wastewater discharge upstream of the study sites. Walnut Creek has three permitted wastewater discharges above the study area: two industrial discharges, KT Mining and Twin Oaks Power, and a single domestic discharge from the City of Bremond.

Self-reporting data for all permitted discharges was requested from TCEQ (TCEQ 2009). The reported discharge data from the month prior to the sampling date and the month of the sampling date was averaged and compared to the instantaneous flow measurement at each study site (Table 4). If the averaged self-reporting data was greater than or equal to 75% of the measurement, the creek was considered to be effluent-dominated for that sampling event.

Two creeks appear to be effluent-dominated. As noted above, the Tributary of Little Elm Creek receives wastewater from the City of Temple. For all months during the study, the reported discharge was larger than the instantaneous measured flow.

Table 4. Self-reported flow data compared to instantaneous flow measurements.

Creek	Permittee	TCEQ permit number	Permittee report date	Averaged reported flow[a] (MGD / cfs)	TPWD flow measurement date	TPWD measured flow (cfs)	Effluent-dominated
Little Elm	No permitted discharges	-	-	-	7 May 2007	13.0	No
			-	-	2 Oct 2007	1.5	
			-	-	7 Jul 2008	0.0	
			-	-	11 Aug 2008	0.0	
TLE	City of Temple	WQ0010470 -002	30 Apr 2007	3.6 / 5.6	7 May 2007	8.0	Yes
			31 May 2007	5.7 / 8.8	2 Oct 2007	1.4	
			30 Sep 2007	2.2 / 3.4	7 Jul 2008	1.7	
			31 Oct 2007	1.7 / 2.6	11 Aug 2008	2.2	
			30 Jun 2008	2.2 / 3.4			
			31 Jul 2008	2 / 3.1			
			31 Aug 2008	2.1 / 3.3			
Willis	City of Granger	WQ0010891 -001	30 Apr 2007	0.123 / 0.190	7 May 2007	43.0	No
			31 May 2007	0.174 / 0.268	3 Jun 2008	6.7	
			30 Jun 2008	0.076 / 0.118	7 Jul 2008	0.5	
			31 Jul 2008	0.073 / 0.113	11 Aug 2008	0.1	
			31 Aug 2008	0.079 / 0.122			
Clear	No permitted discharges	-	-	-	21 May 2007	5.9	No
			-	-	4 Sep 2007	3.9	
			-	-	9 Jun 2008	1.6	
			-	-	4 Aug 2008	0.5	
Duck	Sanderson Farms Feed Mill	WQ0003847 -000	30 Apr 2007	0.004 / 0.006	21 May 2007	10.0	No
			31 May 2007	0.006 / 0.009	4 Sep 2007	4.5	
			31 Aug 2007	0.020 / 0.030	9 Jun 2008	1.7	
			30 Sep 2007	0.016 / 0.025	4 Aug 2008	0.0	
			31 May 2008	0.018 / 0.028			
			30 Jun 2008	0.023 / 0.036			
			31 Jul 2008	0.015 / 0.023			
			31 Aug 2008	0.022 / 0.034			
Walnut	KT Mining - Calvert Lignite Mine[b]	WQ0002881 -000	2007	6.9 / 10.6	21 May 2007	37.0	Yes
			2008	7.2 / 11.1	4 Sep 2007	14.0	
	Twin Oaks Power	WQ0002877 -000	31 Aug 2008	0.250 / 0.387	9 Jun 2008	11.5	
	City of Bremond	WQ0010917 -001	30 Apr 2007	0.044 / 0.068	4 Aug 2008	9.8	
			31 May 2007	0.12 / 0.186			
			31 Aug 2007	0.050 / 0.077			
			31 Oct 2007	0.054 / 0.084			
			31 May 2008	0.051 / 0.079			
			30 Jun 2008	0.029 / 0.045			
			31 Jul 2008	0.030 / 0.046			
			31 Aug 2008	0.063 / 0.097			

[a] Average of self-reported flow from the month prior to the sampling date and the month of the sampling date, except for KT Mining, where only annual data were available.

[b] Includes only dewatering discharge.

Walnut Creek also shows influence from permitted discharges upstream of the sampling site. KT Mining operates the Calvert Lignite Mine, which regularly discharges groundwater that accumulates in mining areas (mine pit dewatering) (Kowalski 2009). In the fall of 2007 and 2008, the measured flows were comparable to the average mine dewatering discharge, suggesting that Walnut Creek is influenced or dominated by this discharge.

While the discharge from the City of Granger to Willis Creek was observed to influence data collected at the downstream portion of the reach (see Physicochemical, Diel and Water Chemistry sections), under normal conditions the discharge is too small to significantly influence the study site. Similarly, the Sanderson Farms discharge seems to be too small to affect the study site in Duck Creek.

Flow Analysis

A simple analysis of the 24 available data points suggests that all the May 2007 flow measurements were higher than "normal" (where normal is defined as falling between the 25th and 75th percentiles) and all the August 2008 data, with the exception of the Tributary of Little Elm Creek, were lower than "normal." With such a limited number of data points, it is helpful to compare the data to gauged streams to give insight about whether this crude analysis is meaningful.

USGS gage station data provide an opportunity to look at instantaneous flow data on a larger scale by calculating flow duration curves (FDCs). A flow duration curve provides an overview of the percentage of time a given stream flow was equaled or exceeded during a specified period (Vogel and Fennessey 1994). Gauged "reference" streams were selected based on proximity to the study creeks, watershed size and flow similarity. Two USGS gauged streams best fit these parameters for the six study creeks (USGS 2009). Big Creek near Freestone, Texas, best represented Little Elm, Tributary of Little Elm, Clear, Duck and Walnut Creeks. Willis Creek instantaneous flow readings varied the most of the six creeks and observations made during site visits supported flow variability. Due to these factors Berry Creek at Airport Road near Georgetown, Texas, was considered most representative of Willis Creek. All available data for Big and Berry Creeks (July 1978 to January 2008 and October 2003 to January 2009, respectively) was used. Instantaneous flow measurements and USGS gauged reference stream mean daily flows are presented in Table 5. Once the FDCs were calculated and plotted, the sampling dates from the six study creeks were marked on the curve.

Ecoregion 33 stream flows in May 2007 ranged from 5.9 to 37 cfs and occurred at a time when the reference stream, Big Creek, was flowing at 6 cfs, corresponding to its 38% exceedance level (*i.e.*, 38% of the time the flow in Big Creek exceeds 6 cfs). Flows were lower in the Ecoregion 33 creeks on September 4, 2007, when Big Creek was flowing at its 59% exceedance level, and lower still on June 9 and August 4, 2008, when Big Creek was not flowing. The percent exceedances that correspond to dates of instantaneous flow measurements for Ecoregion 33 streams are shown on a Big Creek flow duration curve (FDC) (Figure 15). This analysis suggests that the flow regime was normal for both the May and September 2007 measurements for Ecoregion 33 streams, in that the flow values for Big Creek fall between the 25th and 75th percentiles. The analysis suggests that these streams were drier than normal in 2008.

Table 5. Instantaneous stream flow measurements and gauged stream mean daily flows.

Creek	Date	Instantaneous flow (cfs)	USGS gage station	Measured discharge[a] (cfs)	Percent exceeded
Little Elm	7 May 2007	13	Big Creek	51	12
	2 Oct 2007	1.5		0	80
	7 Jul 2008	0		0	80
	11 Aug 2008	0		0	80
Tributary of Little Elm	7 May 2007	8	Big Creek	51	12
	2 Oct 2007	1.4		0	80
	7 Jul 2008	1.7		0	80
	11 Aug 2008	2.2		0	80
Willis	7 May 2007	43	Berry Creek	44	11
	3 Jun 2008	6.7		0	44
	7 Jul 2008	0.47		0	44
(transect 1)	11 Aug 2008	0.08		0	44
Clear	21 May 2007	5.9	Big Creek	6.0	38
	4 Sep 2007	3.9		1.2	59
	9 Jun 2008	1.6		0	80
	4 Aug 2008	0.52		0	80
Duck	21 May 2007	10	Big Creek	6.0	38
	4 Sep 2007	4.5		1.2	59
	9 Jun 2008	1.7		0	80
	4 Aug 2008	0		0	80
Walnut	21 May 2007	37	Big Creek	6.0	38
	4 Sep 2007	14		1.2	59
	9 Jun 2008	11.5		0	80
	4 Aug 2008	9.8		0	80

[a] When measured discharge was zero the lowest percent exceeded value of all zero flow days was used.

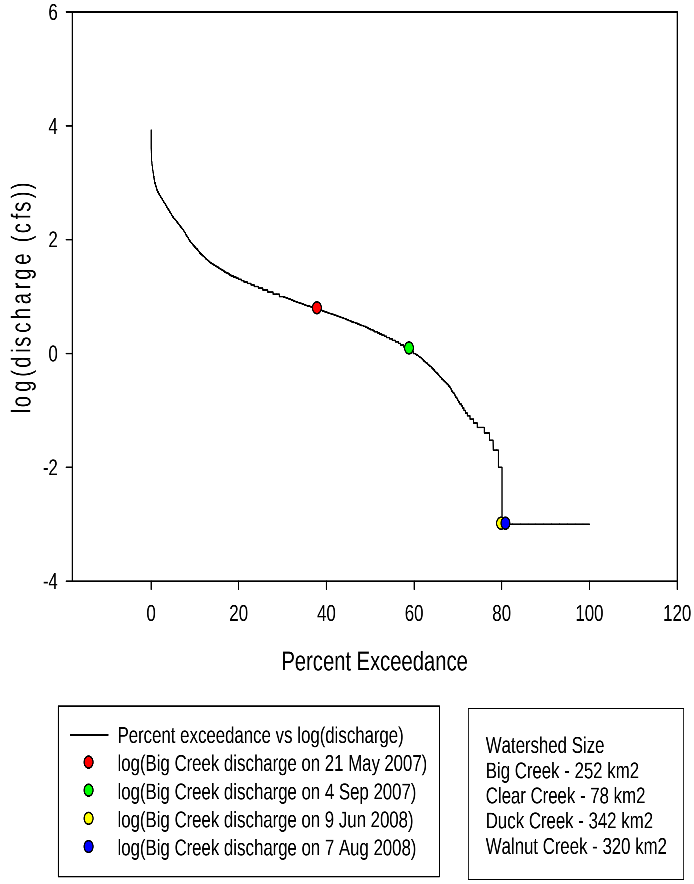

Figure 15. Big Creek flow duration curve with reference to sampling Ecoregion 33 streams: Clear, Duck and Walnut Creeks.

Little Elm and the Tributary of Little Elm Creeks flows were 13 and 8 cfs, respectively, in May 2007. The flow at the reference stream, Big Creek, 51 cfs, was exceeded 12% of the time. Little Elm Creek instantaneous flow in October 2007 was 1.5 cfs and the flow was zero in July and August 2008. Big Creek flow was zero for these events. The Tributary of Little Elm Creek was flowing for all four sampling events and flow increased during the last event in August 2008 while Big Creek had zero flow. The percent exceedances that correspond to dates of instantaneous flow measurements for Little Elm and the Tributary of Little Elm Creeks are shown on a Big Creek flow duration curve (Figure 16). This analysis suggests that the flow regime was high for May 2007 and that these streams were drier than normal in October 2007 and all of 2008.

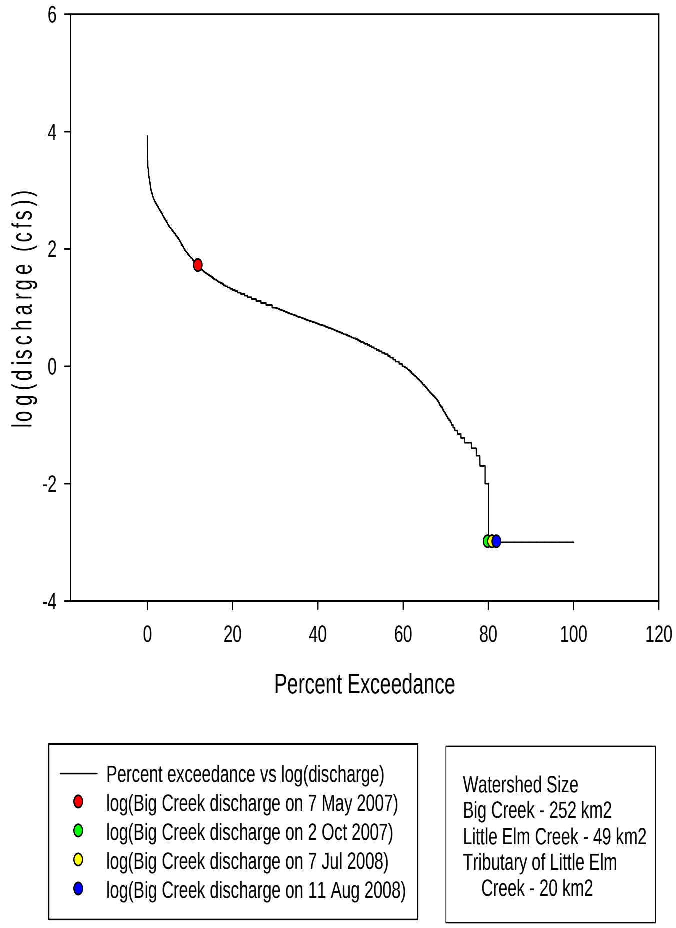

Figure 16. Big Creek flow duration curve with reference to sampling Ecoregion 32 streams: Little Elm and Tributary of Little Elm Creeks.

Berry Creek at Airport Road near Georgetown, Texas, is the reference stream for Willis Creek. In May 2007, Willis Creek's measured flow was 43 cfs and Berry Creek's flow was 44 cfs, corresponding to an 11% exceedance rate for Berry Creek. While Willis Creek flowed at 6.7 cfs in June 2008 and then dropped to 0.47 and 0.08 cfs in July and August 2008, Berry Creek was not flowing. The percent exceedances that correspond to dates of instantaneous flow measurements for Willis Creek are shown on a Berry Creek flow duration curve (Figure 17). This analysis suggests that the flow regime in Willis Creek was high in May 2007. However, it is difficult to draw any conclusions about the 2008 flow regime, since the reference stream, Berry Creek, was not flowing over 50% of the time.

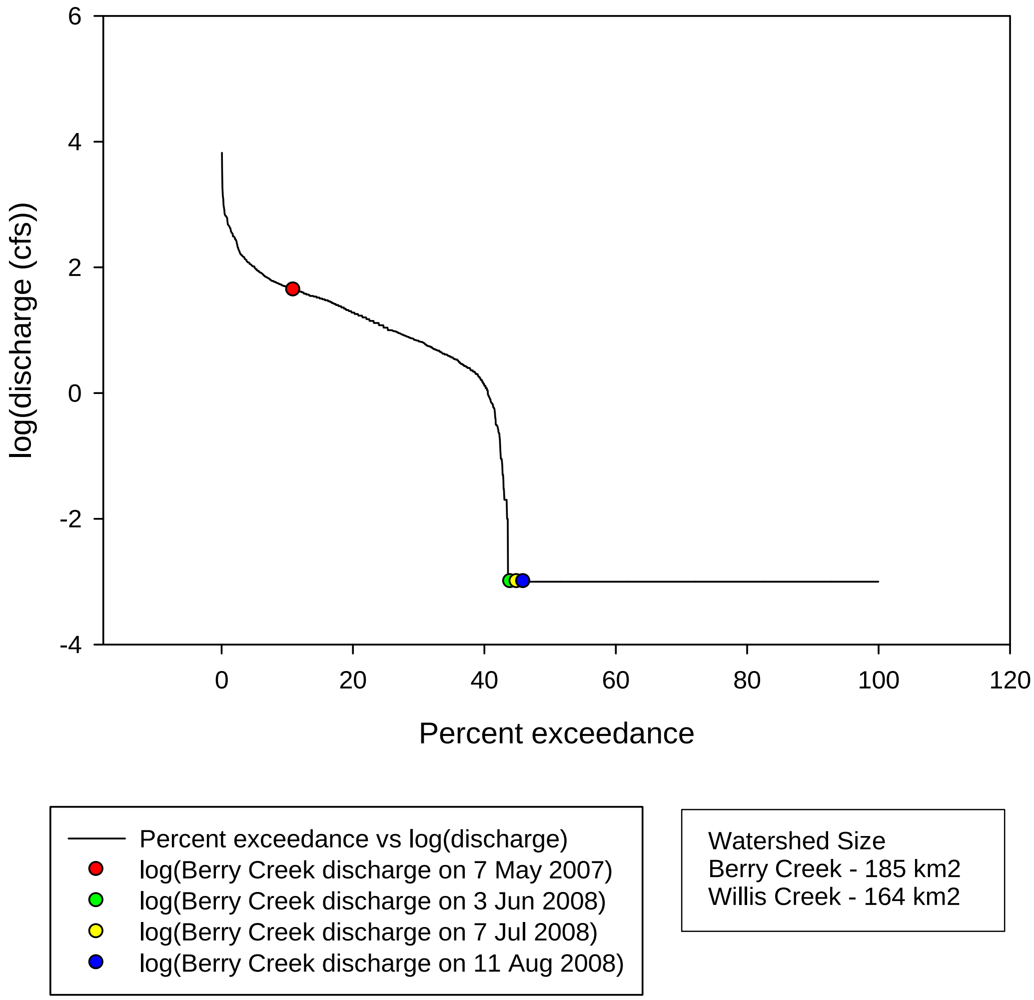

Figure 17. Berry Creek flow duration curve with reference to sampling Ecoregion 32 stream: Willis Creek.

Fish

A total of 3,798 individuals comprising 42 species were collected during the course of the study (Table 6). More individuals were collected in Ecoregion 32 streams (2,588) than in Ecoregion 33 streams (1,210). The largest number of individuals collected was in Willis Creek (1,549), followed by Little Elm Creek (523), Tributary of Little Elm Creek (516), Clear Creek (495), Walnut Creek (416), and Duck Creek (299).

Species collected in greatest numbers were red shiner *Cyprinella lutrensis* (609), longear sunfish *Lepomis megalotis* (574), blacktail shiner *Cyprinella venusta* (549), ribbon shiner *Lythrurus fumeus* (368), green sunfish *Lepomis cyanellus* (322), bluegill *Lepomis macrochirus* (285), western mosquitofish *Gambusia affinis* (248), and bullhead minnow *Pimephales vigilax* (235). Species collected in every stream were longear sunfish, blacktail shiner, green sunfish, bluegill, yellow bullhead *Ameiurus natalis*, and largemouth bass *Micropterus salmoides*.

More species were collected in Ecoregion 33 (36) than in Ecoregion 32 (26). The stream with the largest number of species collected was Clear Creek (26), followed by Willis Creek (23), Walnut Creek (22), Duck Creek (20), Little Elm Creek (15) and Tributary of Little Elm Creek (15). Five species were collected in Clear Creek that were not collected in the other streams: bowfin *Amia calva* (Figure 18), redfin pickerel *Esox americanus vermiculatus*, goldstripe darter *Etheostoma parvipinne*, spotted sucker *Minytrema melanops*, and freckled madtom *Noturus nocturnus*. Two of these species are intolerant and three are benthic invertivores, all of which contribute to higher index of biotic integrity (IBI) scores for those samples. Willis Creek produced three species not collected in the other study streams: white bass *Morone chrysops*, orangespotted sunfish *Lepomis humilis,* and gizzard shad *Dorosoma cepedianum.* Willis Creek was the only stream located just upstream of a reservoir, which may explain the presence of these species. Duck Creek had three species that were not collected in the other streams: banded pygmy sunfish *Elassoma zonatum*, blackstripe topminnow *Fundulus notatus*, and pugnose minnow *Opsopoeodus emiliae.* Bluntnose darter *Etheostoma chlorosoma* was collected only in Walnut Creek. Little Elm and Tributary of Little Elm Creeks did not produce any species that were not also collected in another stream during the study. Detailed results of fish sampling can be found in Appendix A.

Figure 18. Bowfin collected by seine in Clear Creek (May 2007).

Table 6. Total numbers of fish collected by backpack electrofisher and seine (2007-2008). Names according to Nelson *et al*. 2004.

Taxon	Common name	Little Elm	TLE	Willis	Clear	Duck	Walnut
Ameiurus melas	black bullhead	4				1	
Ameiurus natalis	yellow bullhead	28	7	17	7	4	6
Amia calva	bowfin				1		
Aphredoderus sayanus	pirate perch				3	5	1
Campostoma anomalum	central stoneroller	12	30	61			
Cyprinella lutrensis	red shiner	3	172	431			3
Cyprinella venusta	blacktail shiner	6	4	238	92	18	191
Cyprinus carpio	common carp		2	4			
Dorosoma cepedianum	gizzard shad			19			
Elassoma zonatum	banded pygmy sunfish					2	
Esox americanus	redfin pickerel				3		
Etheostoma chlorosoma	bluntnose darter						1
Etheostoma gracile	slough darter	3			4	3	4
Etheostoma parvipinne	goldstripe darter				2		
Fundulus notatus	blackstripe topminnow					11	
Fundulus olivaceus	blackspotted topminnow				45	6	
Gambusia affinis	western mosquitofish	66	89	51	2		40
Hybognathus nuchalis	Mississippi silvery minnow				65	11	
Ictalurus punctatus	channel catfish	3	19	32		1	8
Lepisosteus oculatus	spotted gar			1		1	2
Lepomis cyanellus	green sunfish	159	91	18	16	21	17
Lepomis gulosus	warmouth			6	5	5	1
Lepomis humilis	orangespotted sunfish			1			
Lepomis macrochirus	bluegill	154	18	50	23	38	2
Lepomis megalotis	longear sunfish	62	13	430	13	42	14
Lepomis microlophus	redear sunfish			4	2		
Lepomis sp.	hybrid sunfish	1				2	
Lythrurus fumeus	ribbon shiner				169	112	87
Micropterus punctulatus	spotted bass				6	3	4

Taxon	Common name	Little Elm	TLE	Willis	Clear	Duck	Walnut
Micropterus salmoides	largemouth bass	12	1	24	6	11	13
Minytrema melanops	spotted sucker				2		
Morone chrysops	white bass			1			
Moxostoma congestum	gray redhorse	1		8	3		
Notemigonus crysoleucas	golden shiner			1	1		
Notropis texanus	weed shiner				1		1
Notropis volucellus	mimic shiner		5	2			8
Noturus gyrinus	tadpole madtom	5	3				2
Noturus nocturnus	freckled madtom				2		
Opsopoeodus emiliae	pugnose minnow					1	
Percina sciera	dusky darter			2	2	1	1
Pimephales vigilax	bullhead minnow	4	60	145	19		7
Pomoxis annularis	white crappie				1		3
Pylodictis olivaris	flathead catfish		2	3			

Regionalized index of biotic integrity (R-IBI) scores were computed for each fish collection event during the study (Table 7) (Linam *et al.* 2002). The R-IBI calculation takes into account the fish collected by seine and by electrofishing, which were separately enumerated and identified after collection. One collection effort (Willis Creek in May 2007) was rated at a limited aquatic life use (ALU) by the R-IBI. The other fish collections were rated intermediate or high. No fish collection events were rated exceptional during this study.

TPWD and TCEQ biologists have discussed how to evaluate aquatic life use when multiple fish collections at a stream are not in agreement due to natural variability at a site over time. One approach is to apply an ecoregion-specific coefficient of variation to the mean R-IBI score calculated from the various collection events (Harrison 2007). The highest ALU category attained by adding the scaled coefficient of variation to the mean is considered to be appropriate for the stream when assessing attainment or establishing an ALU. Using this approach, three of the six study streams moved from intermediate to high ALU (Tributary of Little Elm Creek, Duck Creek and Walnut Creek) (Figure 19, Figure 20). In the case of Duck Creek, there was no disagreement between the four IBI scores, even though scores for individual metrics varied among the samples. A case could be made for not adjusting the mean IBI score since all the individual scores were identical. For the purpose of consistency, the CV adjustment was applied to all means from the study, and results are presented for each stream with and without the CV adjustment.

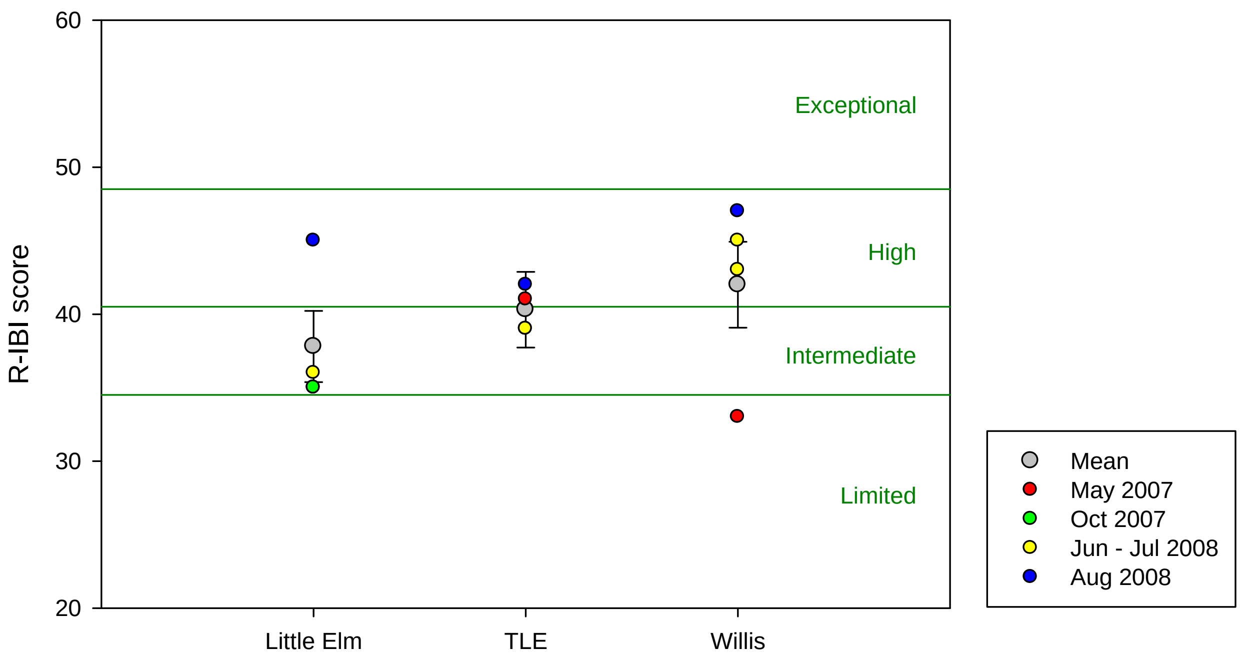

Figure 19. Regionalized fish IBI (R-IBI) means (+/- scaled ecoregion CV) and event scores for Ecoregion 32 streams.

Table 7. Regionalized index of biotic integrity (R-IBI) scores for fish collections.
CV = coefficient of variation for fish R-IBI scores based on ecoregion and the ALU category associated with the mean R-IBI score (Harrison 2007).

Stream	Date	R-IBI score	ALU	Mean R-IBI	Mean ALU	CV	Adjusted score	Adjusted ALU
Little Elm	9 May 2007	35	Intermediate	37.8	Intermediate	6.4%	40.2	Intermediate
	3 Oct 2007	35	Intermediate					
	8 Jul 2008	36	Intermediate					
	12 Aug 2008	45	High					
TLE	9 May 2007	41	High	40.3	Intermediate	6.4%	42.8	High
	3 Oct 2007	39	Intermediate					
	9 Jul 2008	39	Intermediate					
	13 Aug 2008	42	High					
Willis	8 May 2007	33	Limited	42.0	High	6.95%	44.9	High
	4 Jun 2008	43	High					
	8 Jul 2008	45	High					
	12 Aug 2008	47	High					
Clear	23 May 2007	47	High	43.3	High	5.61%	45.7	High
	5 Sep 2007	39	Intermediate					
	10 Jun 2008	44	High					
	5 Aug 2008	45	High					
Duck	23 May 2007	40	Intermediate	40.0	Intermediate	5.86%	42.3	High
	6 Sep 2007	40	Intermediate					
	11 Jun 2008	40	Intermediate					
	6 Aug 2008	40	Intermediate					
Walnut	22 May 2007	42	High	41.3	Intermediate	5.86%	43.7	High
	5 Sep 2007	41	Intermediate					
	10 Jun 2008	42	High					
	5 Aug 2008	40	Intermediate					

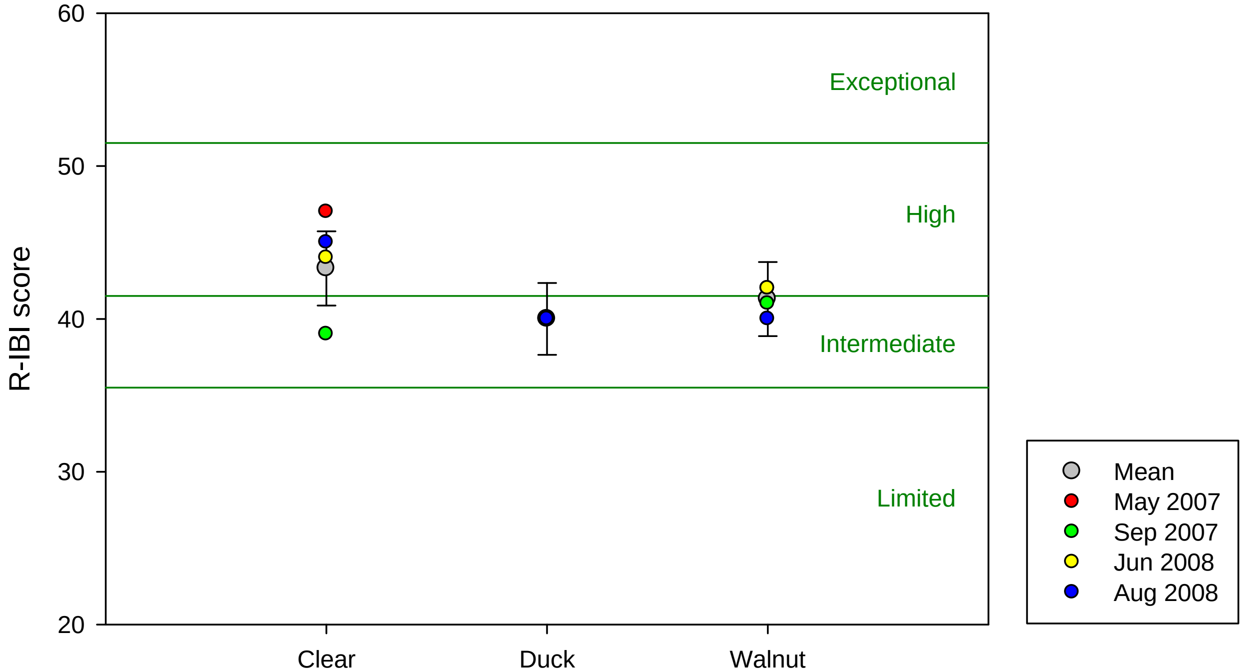

Figure 20. Regionalized fish IBI (R-IBI) means (+/- scaled ecoregion CV) and event scores for Ecoregion 33 streams.

Benthic Macroinvertebrates

Benthic macroinvertebrates collected during the study totaled 4,814 individuals from 128 taxa (Table 8). The total number of collected individuals was higher in Ecoregion 33 (2,733) than in Ecoregion 32 (2,081). Walnut Creek had the highest number of individuals collected (967), followed by Duck Creek (942), Clear Creek (824), Willis Creek (779), Tributary of Little Elm Creek (663) and Little Elm Creek (639).

Table 8. Total number of individuals identified.

Creek	2007	2008	Creek total	Total taxa per creek
Little Elm	276	363	639	52
TLE	266	397	663	40
Willis	99[a]	680	779	53
Clear	436	388	824	45
Duck	540	402	942	58
Walnut	561	406	967	54
Total individuals	2178	2636	4814	128[b]

[a] The low number was due to a recent scouring of the creek by rain storms, making collection difficult.
[b] Total number of taxa collected during the study.

The most abundant taxa collected during the study were Chironomini (Family Chironomidae) and *Stenacron* (Family Heptageniidae). The five most abundant taxa make up almost half (42%) of the total number of individuals collected (Table 9).

The most frequently observed taxa during the study was Chironomini (Family Chironomidae), collected at 23 of the 24 sampling events, and *Stenelmis* (Family Elmidae) and Tanypodinae (Family Chironomidae), which were both collected at 20 of the 24 sampling events. A summary of taxa collected from each of the six streams is located in Table 10. Detailed results from benthic macroinvertebrate sampling can be found in Appendix A.

Table 9. Number of individuals of most abundant taxa (2007-2008).

Taxon	Little Elm	TLE	Willis	Clear	Duck	Walnut	Total
Chironomidae, Chironomini	129	82	7	76	229	41	564
Heptageniidae, *Stenacron*	72	18	5	93	280	33	501
Baetidae, *Fallceon*	12	213	27	-	-	89	341
Leptophlebiidae, *Farrodes*	6	14	19	1	-	209	249
Elmidae, *Stenelmis*	10	79	8	65	8	65	235

Table 10. Total number of benthic macroinvertebrates collected (2007-2008).

ORDER, Family	Taxon	Little Elm	TLE	Willis	Clear	Duck	Walnut
AMPHIPODA							
Gammaridae	*Gammarus*	35			1		
Talitridae	*Hyalella*	44	3	42	1	19	
ARCARINA							
Arrenuridae	*Arrenurus*	6		1			
Hydrachnidae	*Hydrachna*	6		1			
Lebertiidae	*Lebertia*				3	7	
Sperchonidae	*Sperchon*	1	1				
Torrenticolidae	*Torrenticola*	4					
BASOMMATOPHORA							
Ancylidae	*Ferrissia*	2					
Physidae	*Physella*	14	1	21	2	3	2
COLEOPTERA							
Carabidae	Carabidae	1		2			
Curculionidae	Curculionidae		1				
Dryopidae	*Helichus*		2	2	1		1
	Copelatus	1					2
	Hydroporus	14				2	
	Oreodytes	3					
Elmidae	*Ancyronyx*				14	10	
	Dubiraphia	14			2	26	2
	Heterelmis		36				34
	Hexacylloepus			2			
	Macronychus				16		

ORDER, Family	Taxon	Little Elm	TLE	Willis	Clear	Duck	Walnut
	Microcylloepus		13	2			
	Neoelmis			2			
	Stenelmis	10	79	8	65	8	65
Gyrinidae	*Dineutus*				11	7	3
	Gyretes			1		2	4
	Gyrinus						1
Haliplidae	*Peltodytes*						2
Hydraenidae	*Hydraena*	1	1				
Hydrophilidae	*Berosus*			1			1
	Enochrus		3			1	
	Tropisternus			1			
Scirtidae	*Cyphon*	46	1	11	2	1	
	Scirtes	7	2	1		12	
Hydrochidae	*Hydrochus*		1	1		1	
Staphylinidae	Staphylinidae			1			
COLLEMBOLA							
Isotomidae	*Isotomurus*				1		
Sminthuridae	*Sminthurides*					1	
DECAPODA							
Cambaridae	Cambaridae	2				2	
DIPTERA							
Ceratopogonidae	*Bezzia*		2			2	1
	Probezzia					1	
Chironomidae	Chironomini	129	82	7	76	229	41
	Orthocladiinae	1	6	2		6	6
	Tanypodinae	22	11	8	13	15	5
	Tanytarsini		1	1	9	17	2
Culicidae	*Culex*	1					
Dolichopodidae	Dolichopodidae	1					
Empididae	*Hemerodromia*						2
Simuliidae	*Simulium*	10	10	1	30		4
Tabanidae	*Chrysops*	2					
	Tabanus		1	1			
Tipulidae	*Geranomyia*						1
	Limnophila				1	1	
EPHEMEROPTERA							
Baetidae	*Acentrella*				3		
	Acerpenna				2	8	13
	Baetis	2			63	64	74
	Callibaetis	3		4			
	Fallceon	12	213	27			89
	Labiobaetis				5		9
	Paracloeodes		5				12
	Procloeon	1			4	1	
Caenidae	*Brachycercus*					1	
	Caenis	84	4	53	12	19	
Ephemerellidae	*Eurylophella*				1		
Ephemeridae	*Hexagenia*						1
Heptageniidae	*Stenacron*	72	18	5	93	280	33

ORDER, Family	Taxon	Little Elm	TLE	Willis	Clear	Duck	Walnut
	Stenonema	1		12	184	30	2
Isonychiidae	*Isonychia*			15	69		
Leptophlebiidae	*Farrodes*	6	14	19	1		209
	Neochoroterpes			69			
	Thraulodes			26			
Tricorythidae	*Leptohyphes*			54			
	Tricorythodes	5	26	25			88
HAPLOTAXIDA							
Tubificidae	*Branchiura*	3		2		5	1
Lumbricidae	Lumbricidae			12	6	1	7
Naididae	*Dero*					6	
	Pristina					3	
	Slavina					7	
Tubificidae	*Limnodrilus*				2	1	
HEMIPTERA							
Belostomatidae	*Belostoma*						3
Corixidae	*Trichocorixa*			1			3
Gerridae	*Rheumatobates*	1					
Mesoveliidae	*Mesovelia*	1					
Naucoridae	*Ambrysus*			1			
Veliidae	*Rhagovelia*	1	5	2			16
ISOPODA							
Asellidae	*Asellus*				1		
LEPIDOPTERA							
Pyralidae	*Petrophila*		1				
MEGALOPTERA							
Corydalidae	*Chauliodes*					4	
	Corydalus				15	2	1
Sialidae	*Sialis*					9	2
NEMATODA	Nematoda					1	
NEMATOMORPHA	Nematomorpha			1			
NEOTAENIOGLOSSA							
Hydrobiidae	Hydrobiidae	1	2				
ODONATA							
Aeshnidae	*Boyeria*		2		3	1	2
	Nasiaeschna	2					
Calopterygidae	*Calopteryx*					1	
	Hetaerina	3	10		3	1	16
Coenagrionidae	*Argia*	23	11	35	8	40	5
	Enallagma	6		2		3	1
	Ischnura					1	
Corduliidae	*Didymops*	1					
Gomphidae	*Arigomphus*					1	
	Dromogomphus					3	
	Erpetogomphus	6	4	40			4
	Hagenius				5		
	Progomphus				11	5	
Libellulidae	*Brechmorhoga*			49			2
	Perithemis	1					

ORDER, Family	Taxon	Little Elm	TLE	Willis	Clear	Duck	Walnut
Macromiinae	*Macromia*	6			2	12	1
PHARYNGOBDELLIDA							
Erpobdellidae	*Mooreobdella*					1	
PLECOPTERA							
Perlidae	*Neoperla*				1		
	Perlesta	13		47		13	
RHYNCHOBDELLIDA							
Glossiphoniidae	*Placobdella*		5			2	2
TRICHOPTERA							
Hydropsychidae	*Cheumatopsyche*	3	4	113	17	15	15
	Hydropsyche		11		18	2	37
	Smicridea		65	10			112
Hydroptilidae	*Hydroptila*						1
	Ochrotrichia			1			
Leptoceridae	*Nectopsyche*		2	2			2
	Oecetis				8		3
	Triaenodes						1
Limnephilidae	*Pycnopsyche*					1	
Philopotamidae	*Chimarra*	2		19			
Polycentropodidae	*Cyrnellus*					4	4
	Nyctiophylax				15	8	15
	Polycentropus			1	16	13	2
TRICLADIDA							
Planariidae	*Dugesia*		1	3	8		
VENEROIDA							
Corbiculidae	*Corbicula*	1	3	9			
Sphaeriidae	*Sphaerium*	2					

The most common functional feeding groups (FFGs) in the benthic macroinvertebrate collections were scrapers, filtering collectors and predators (Table 11 and Figure 21). The mean percentage of the total collected individuals as scrapers ranged from 33 to 59%. The second most abundant FFG, filtering collectors, ranged from 2 to 22%, and the third most abundant FFG, the predators, ranged from 5 to 24%. The smallest FFG, the shredders, represents less than 1% of the population. Collector gatherers ranged from 5 to 17%. A significant portion of the collection, ranging from 4 to 32%, is uncategorized (TCEQ 2005).

Table 11. Mean percentage of benthic macroinvertebrates by functional feeding group.

Creek	Percent collector gatherer	Percent filtering collector	Percent predator	Percent scraper	Percent shredder	Percent uncategorized
Little Elm	14	3	13	42	1	27
TLE	5	14	5	59	1	16
Willis	17	22	24	33	0	4
Clear	1	20	8	56	1	13
Duck	3	4	12	47	1	32
Walnut	11	20	7	55	1	7

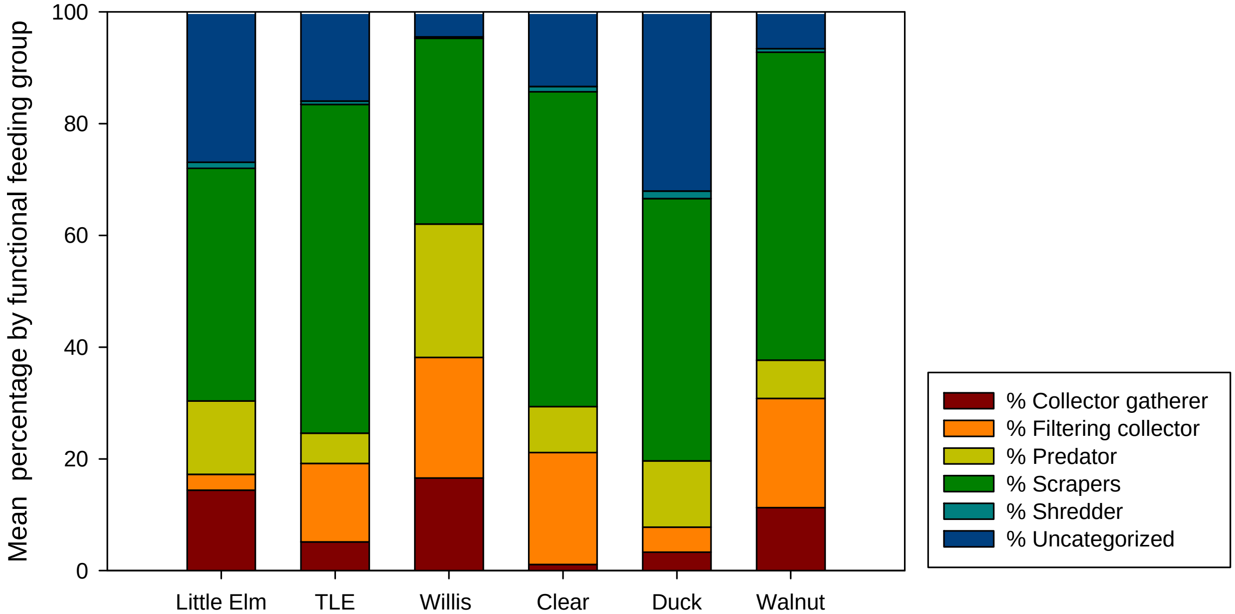

Figure 21. Mean percentage of benthic macroinvertebrates by functional feeding group.

The benthic index of biotic integrity (BIBI) was calculated for each sampling event (Harrison 1996). The individual sampling event scores were examined separately, grouped by creek and the mean BIBI score calculated for each creek (Table 12). Ecoregion 32 streams scored lower the first sampling trip in May 2007 than the other trips (Figure 22). This was likely due to recent heavy rains that scoured the streams. Although sampling was delayed almost a week after the rain event, stream flows were still high at the time of sampling, which may have prevented the benthic community from being fully reestablished.

As was done for the fish R-IBI scores, an ecoregion-specific coefficient of variation was applied to the mean BIBI score calculated from the various collection events (Harrison 2007). Of the six streams sampled, only two streams' scores changed when the ecoregion CV was applied (Table 12). The mean score for Clear Creek was 34.3, or high ALU, and the adjusted ALU score was 36.4. With an adjusted score of 36.4, Clear Creek moved to the exceptional ALU category. The adjusted score for the Tributary of Little Elm Creek moved it from the intermediate to the high ALU category. Adjusted scores for the other streams fell within the same ALU.

Table 12. Benthic index of biotic integrity (BIBI) scores for benthic macroinvertebrate collections. CV = coefficient of variation for benthic macroinvertebrate BIBI scores based on ecoregion and the ALU category associated with the mean BIBI score (Harrison 2007).

Creek	Date	BIBI score	ALU	Mean BIBI	Mean ALU	CV	Adjusted score	Adjusted ALU
Little Elm	9 May 2007	20	Limited	26.3	Intermediate	6.06%	27.9	Intermediate
	3 Oct 2007	31	High					
	8 Jul 2008	25	Intermediate					
	12 Aug 2008	28	Intermediate					
TLE	9 May 2007	25	Intermediate	28.0	Intermediate	6.06%	29.7	High
	3 Oct 2007	33	High					
	9 Jul 2008	26	Intermediate					
	13 Aug 2008	28	Intermediate					
Willis	8 May 2007	19	Limited	31.3	High	5.22%	32.9	High
	4 Jun 2008	36	High					
	8 Jul 2008	38	Exceptional					
	12 Aug 2008	32	High					
Clear	23 May 2007	39	Exceptional	34.3	High	6.28%	36.5	Exceptional
	5 Sep 2007	33	High					
	10 Jun 2008	32	High					
	5 Aug 2008	33	High					
Duck	23 May 2007	33	High	30.0	High	6.28%	31.9	High
	6 Sep 2007	33	High					
	11 Jun 2008	28	Intermediate					
	6 Aug 2008	26	Intermediate					
Walnut	22 May 2007	37	Exceptional	32.3	High	6.28%	34.3	High
	5 Sep 2007	33	High					
	10 Jun 2008	27	Intermediate					
	5 Aug 2008	32	High					

Benthic Macroinvertebrates Point Score Ranges:

Exceptional:	> 36
High:	29 - 36
Intermediate:	22 - 28
Limited:	< 22

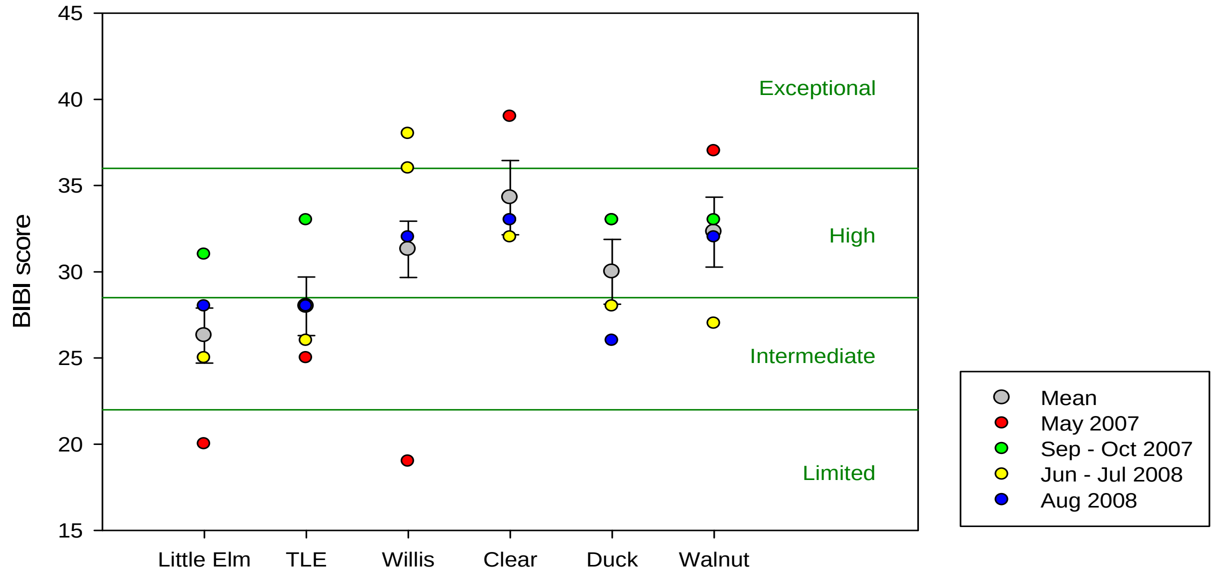

Figure 22. Benthic IBI (BIBI) means (+/- scaled ecoregion CV) and event scores.

Benthic macroinvertebrate samples were different between ecoregions (Figure 23). ANOSIM showed significant difference between the two ecoregion groups (p<0.04, Global R = 0.26). SIMPER analysis detailed difference in taxa abundances between the two ecoregions. *Stenacron*, *Farrodes*, *Stenonema* and *Baetis* were more abundant in Ecoregion 33. *Fallceon* and *Cheumatopsyche* had higher abundances in Ecoregion 32.

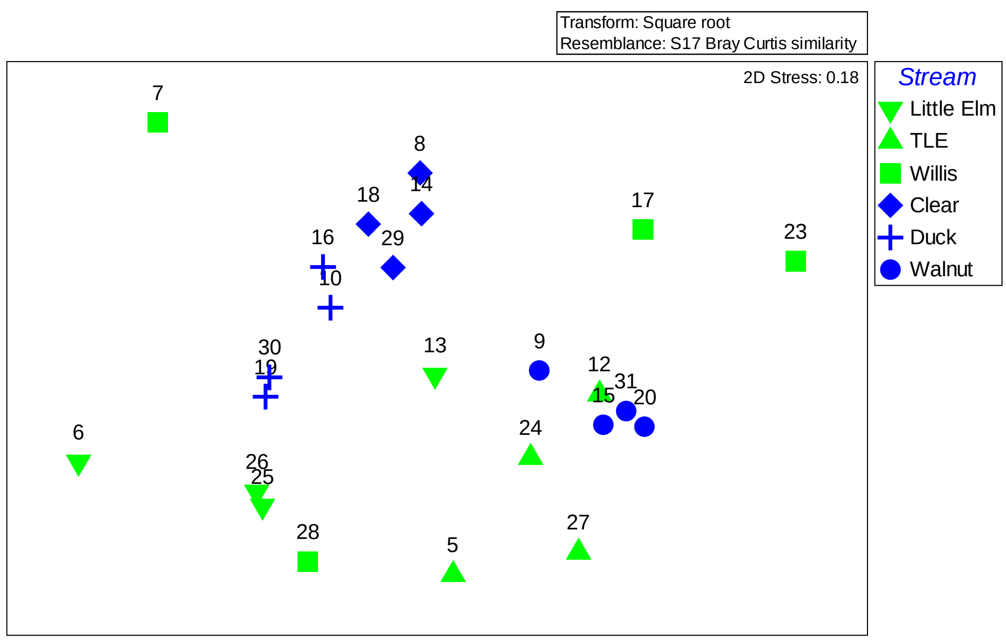

Figure 23. MDS plot of benthic macroinvertebrate data by sampling event.
The symbols designate streams and the colors designate ecoregions (Ecoregion 32 is green and Ecoregion 33 is blue). Labels for points are sample numbers (Hydro ID).

Mussels

No live mussels were collected during this study. Ages of shells ranged from relatively recently dead to very long dead (Table 13). Willis Creek had the highest species richness (nine species), and Walnut Creek had six species. The other study streams had three species or fewer. Willis Creek had five species not found in any of the other creeks (Tampico pearlymussel *Cyrtonaias tampicoensis*, yellow sandshell *Lampsilis teres*, pondmussel *Ligumia subrostrata*, southern mapleleaf *Quadrula apiculata* and smooth pimpleback *Quadrula houstonensis*). Walnut Creek had three species not found in any of the other creeks (bleufer *Potamilus purpuratus*, giant floater *Pyganodon grandis* and paper pondshell *Utterbackia imbecillis*). Only Willis and Walnut Creeks had Louisiana fatmucket *Lampsilis hydiana* and Texas lilliput *Toxolasma texasiensis*. Only Willis, Walnut and Clear Creeks had pistolgrip *Quadrula verrucosa* (the only species found in Clear Creek, on a reconnaissance trip only). Pistolgrip has been described as preferring "oxygen-rich" environments (Howells *et al*. 1996). Pondhorn or tapered pondhorn *Uniomerus* spp. were found in all three of the Ecoregion 32 streams and none of the Ecoregion 33 streams. Both species are described as tolerant of drought or desiccation (Howells *et al*. 1996). Duck Creek did not produce any mussels. Asian clam *Corbicula* spp. was frequently found in the streams. The most commonly encountered species was Louisiana fatmucket, followed by Texas lilliput, pondhorn, smooth pimpleback, and tapered pondhorn. Smooth pimpleback and pistolgrip are considered species of special concern tracked in the Texas Natural Diversity Database (TPWD 2009). Smooth pimpleback is listed as a Priority Species in the *Texas Comprehensive Wildlife Conservation Strategy* (TPWD 2005).

Robert Howells (Howells 2009) searched his Texas mussel database, mussel publications, and museum databases and did not find records of other mussel surveys in the study streams. In 1998 he surveyed Walnut Creek at a location downstream of this study site, but did not find any mussels (Howells 1999).

Table 13. Freshwater mussels collected.
Names according to Turgeon *et al*. 1998 and Serb *et al*. 2003 for *Quadrula verrucosa*.

Stream	Date	Taxon	Common name	Mussels per hr.	Condition
Little Elm	10 May 2007	*Toxolasma parvus*	lilliput	0.75	long dead
	10 May 2007	*Uniomerus declivis*	tapered pondhorn	3.75	long dead
	4 Oct 2007	*Toxolasma parvus*	lilliput	0.8	very long dead
	4 Oct 2007	*Uniomerus declivis*	tapered pondhorn	2.4	very long dead
	4 Oct 2007	*Uniomerus tetralasmus*	pondhorn	0.8	very long dead
	9 Jul 2008	*Uniomerus* spp.	pondhorn species	1.2	long dead
TLE	4 Oct 2007	*Uniomerus declivis*	tapered pondhorn	1.6	very long dead
	4 Oct 2007	*Uniomerus tetralasmus*	pondhorn	3.2	long to very long dead
	9 Jul 2008	*Uniomerus* spp.	pondhorn species	1.2	long dead
Willis	11 Apr 2007	*Cyrtonaias tampicoensis*	Tampico pearlymussel	1	very long dead
	11 Apr 2007	*Lampsilis hydiana*	Louisiana fatmucket	1	very long dead
	11 Apr 2007	*Lampsilis teres*	yellow sandshell	0.5	long dead
	11 Apr 2007	*Quadrula houstonensis*	smooth pimpleback	2	very long dead
	11 Apr 2007	*Quadrula verrucosa*	pistolgrip	0.5	long dead
	11 Apr 2007	*Uniomerus tetralasmus*	pondhorn	1	long dead
	10 May 2007	*Cyrtonaias tampicoensis*	Tampico pearlymussel	0.8	very long dead
	10 May 2007	*Lampsilis hydiana*	Louisiana fatmucket	0.8	very long dead
	10 May 2007	*Lampsilis teres*	yellow sandshell	0.8	very long dead
	10 May 2007	*Ligumia subrostrata*	pondmussel	2.4	relatively recently to very long dead
	10 May 2007	*Quadrula apiculata*	southern mapleleaf	0.8	very long dead
	10 May 2007	*Quadrula houstonensis*	smooth pimpleback	4.8	very long dead
	4 Jun 2008	*Cyrtonaias tampicoensis*	Tampico pearlymussel	0.6	very long dead
	4 Jun 2008	*Lampsilis hydiana*	Louisiana fatmucket	3.6	very long dead
	4 Jun 2008	*Ligumia subrostrata*	pondmussel	1.2	long dead
	4 Jun 2008	*Quadrula houstonensis*	smooth pimpleback	1.2	very long dead
	9 Jul 2008	*Lampsilis hydiana*	Louisiana fatmucket	4	long to very long dead
	9 Jul 2008	*Lampsilis teres*	yellow sandshell	0.8	very long dead
	9 Jul 2008	*Quadrula apiculata*	southern mapleleaf	0.8	very long dead

Stream	Date	Taxon	Common name	Mussels per hr.	Condition
	9 Jul 2008	*Quadrula houstonensis*	smooth pimpleback	1.6	long to very long dead
	9 Jul 2008	*Toxolasma texasiensis*	Texas lilliput	5.6	long to very long dead
	13 Aug 2008	*Uniomerus* spp.	pondhorn species	2.4	long dead
Clear	12 Apr 2007	*Quadrula verrucosa*	pistolgrip	1.2	long dead
Walnut	7 Sep 2007	*Pyganodon grandis*	giant floater	0.8	relatively recently dead
	7 Sep 2007	*Toxolasma texasiensis*	Texas lilliput	0.8	relatively recently dead
	11 Jun 2008	*Utterbackia imbecillis*	paper pondshell	1.2	relatively recently dead
	6 Aug 2008	*Lampsilis hydiana*	Louisiana fatmucket	6	very long dead
	6 Aug 2008	*Potamilus purpuratus*	bleufer	1.2	very long dead
	6 Aug 2008	*Toxolasma texasiensis*	Texas lilliput	3.6	very long dead
	6 Aug 2008	*Quadrula verrucosa*	pistolgrip	1.2	very long dead

Periphyton Chemistry

Periphyton biomass was analyzed and reported in two ways: chlorophyll-*a* and ash-free dry mass (AFDM). As noted in the methods section, reported values were scaled to the original area of woody debris scraped to obtain a value representing periphyton biomass per area of substrate. For most sampling events, duplicate samples were sent to the laboratory as a quality control measure. Duplicates were compared to each other using relative percent difference (RPD) to evaluate consistency. A RPD of 30% was used, consistent with data quality objectives for evaluating field splits of water samples as described in the QAPP (TPWD 2007). Four sets of chlorophyll-*a* measurements exceeded 30% RPD, although the RPD for two sets fell below 40% (Table 14). AFDM was obtained through gravimetric methods, and better agreement was seen between duplicates. Only two sets of AFDM measurements exceeded 30% RPD.

Table 14. Periphyton biomass measurements (benthic AFDM and benthic chlorophyll-*a*).
Values in italics indicate pairs of duplicate measurements exceeding the 30% relative percent difference benchmark.

Stream	Date	AFDM (mg/cm^2)	Chlorophyll-*a* (mg/m^2)
Little Elm	9 May 2007	1.1	5.8
	2 Oct 2007	1.4	17
	2 Oct 2007	1.3	16
	8 Jul 2008	1.4	45
	8 Jul 2008	1.3	36
	12 Aug 2008	1.4	9.8
	12 Aug 2008	1.5	9.9
TLE	9 May2007	1.6	79
	2 Oct 2007	0.83	18
	2 Oct 2007	0.88	20
	8 Jul 2008	2.5	86
	8 Jul 2008	2.5	90
	13 Aug 2008	1.5	20
	13 Aug 2008	1.4	19
Willis	8 May 2007	0.79	*7.6*
	8 May 2007	0.79	*5.4*
	3 Jun 2008	0.82	8.4
	3 Jun 2008	0.82	8.5
	7 Jul 2008	1.1	30
	7 Jul 2008	1.1	26
	12 Aug 2008	1.4	20
	12 Aug 2008	1.6	20
Clear	12 Apr 2007	*0.43*	3.5
	12 Apr 2007	*0.91*	3.0
	23 May 2007		*0.67*
	23 May 2007		*1.6*
	5 Sep 2007	0.89	26
	5 Sep 2007	0.94	23
	10 Jun 2008	0.82	7.7
	10 Jun 2008	0.82	7.8

Stream	Date	AFDM (mg/cm^2)	Chlorophyll-*a* (mg/m^2)
	5 Aug 2008	0.43	5.4
	5 Aug 2008	0.54	5.2
Duck	24 May 2007		0.45
	24 May 2007		0.59
	6 Sep 2007	0.54	7.8
	6 Sep 2007	0.52	8.0
	11 Jun 2008	1.0	17
	11 Jun 2008	1.0	18
	6 Aug 2008	1.0	11
	6 Aug 2008	0.97	11
Walnut	22 May 2007		*1.9*
	22 May 2007		*5.9*
	5 Sep 2007	1.4	51
	5 Sep 2007	1.4	38
	9 Jun 2008	1.4	*16*
	9 Jun 2008	1.4	*23*
	5 Aug 2008	*0.6*	18
	5 Aug 2008	*1.2*	18

Ash-free dry mass ranged from 0.43 to 2.5 mg/cm2. Benthic chlorophyll-*a* ranged from 0.45 to 90 mg/m^2. For comparison, a recent Edwards Plateau study reporting benthic algal biomass found that benthic algal chlorophyll-a ranged from 11.2 to 148 mg/m^2 (Mabe 2007). High variability is to be expected in estimations of periphyton biomass, as much as three orders of magnitude (Stevenson 1996, Biggs 1996), so the values observed in the Edwards Plateau study and this work can be considered to fall in the same range. Mabe collected periphyton from rocks in the Edwards Plateau region, which may contribute to differences from biomass levels measured in this study. From 2003 to 2005 USGS sampled a number of East Texas streams to investigate relationships between dissolved oxygen levels and aquatic life use (Kiesling *et al*. 2006). Parameters collected included many of the same collected for this work: diel dissolved oxygen, dissolved nutrients, fish, benthic macroinvertebrates, habitat and periphyton. Benthic algal biomass estimates were obtained from the periphyton sampling, but the study did not include taxonomic identification of the periphyton community.

When all measurements were averaged by stream, Tributary of Little Elm Creek showed the highest biomass, whether estimated by chlorophyll-*a* or AFDM, followed by Little Elm Creek (Table 15). Clear and Duck Creeks had the lowest biomass estimates. Benthic chlorophyll-*a* was highly variable; standard deviations were large, approaching or exceeding the mean. Standard deviations for AFDM were much smaller.

Table 15. Periphyton chemistry means and standard deviations by stream.

Stream	Chlorophyll-*a* (mg/m^2) mean	Chlorophyll-*a* (mg/m^2) SD	AFDM (mg/cm^2) mean	AFDM (mg/cm^2) SD
Little Elm	26	22	1.3	0.26
TLE	39	34	1.6	0.63
Willis	16	9.4	1.0	0.32
Clear	8.4	8.8	0.72	0.22
Duck	9.5	6.3	0.95	0.30
Walnut	19	16	1.1	0.32

Comparing the six study streams, AFDM was highest and most variable in the Tributary of Little Elm Creek (Figure 24). In a study of over 400 New Zealand streams, Biggs and Price (1987) attempted to determine which levels of benthic algal biomass represented nuisance conditions. They observed that if benthic algal AFDM was >5 mg/cm^2, conditions were such that bed sediments were smothered and the periphyton growth was conspicuous to observers on the bank. In comparison with this threshold (Figure 24), AFDM levels from this study were low.

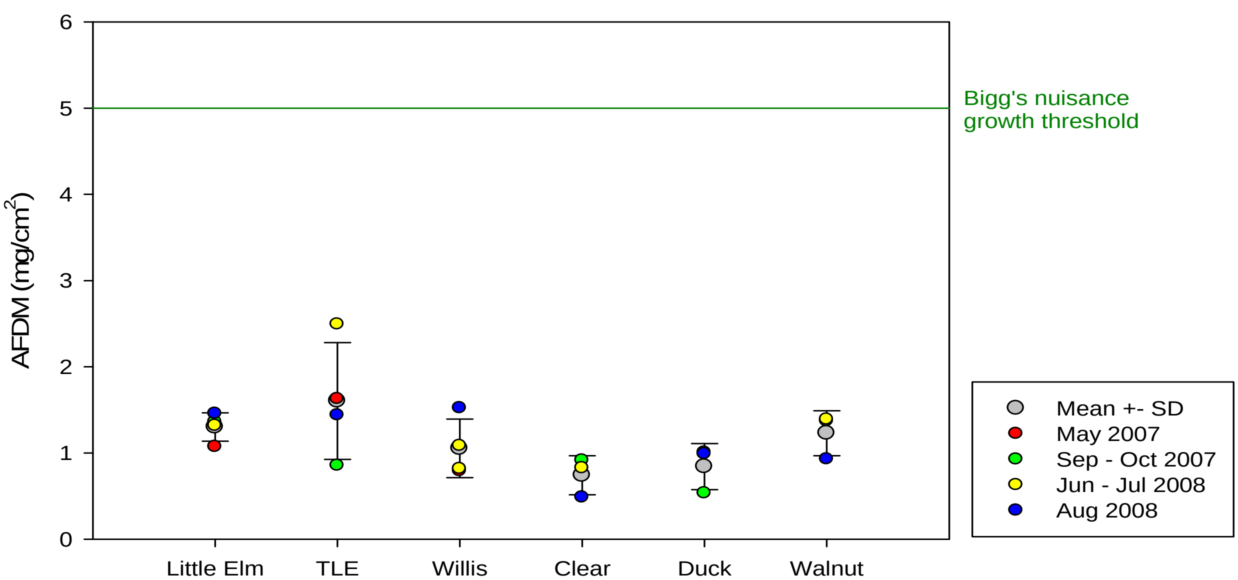

Figure 24. AFDM means, standard deviations and event results.
Individual event samples were averaged when duplicates were available.

Another study reviewed periphyton data from over 200 North American and New Zealand streams and set thresholds delineating three categories of stream trophic state: oligotrophic, mesotrophic, and eutrophic (Dodds *et al*. 1998). Based on that scheme, much of the benthic chlorophyll-*a* data from this study fell into the oligotrophic category (Figure 25). Tributary of Little Elm Creek and Walnut Creek had mean benthic algal chlorophyll-*a* in the mesotrophic category. Some of the Little Elm Creek samples even extended into the eutrophic category.

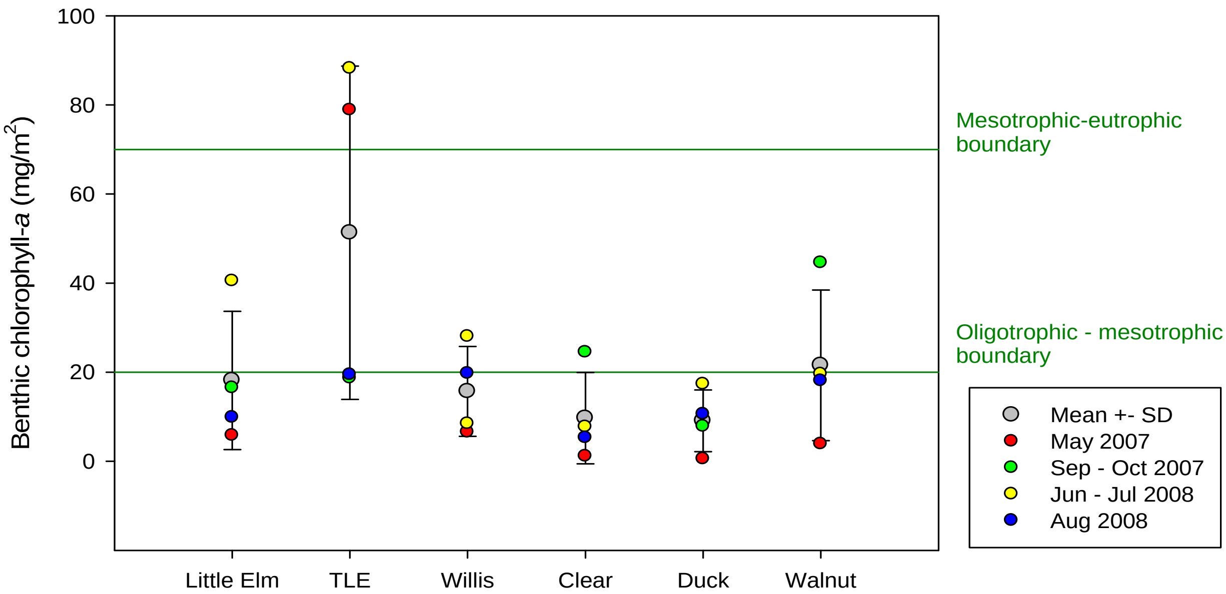

Figure 25. Benthic chlorophyll-*a* means, standard deviations and event results. Individual event samples were averaged when duplicates were available. Reference lines based on stream trophic state thresholds from Dodds *et al*. (1998).

Soft Algae Community

Soft algae analysis included non-diatom algal taxa. Diatoms in the samples were also identified as either pennate (bilaterally symmetrical) or centric (typically radially symmetrical) and enumerated (Table 16). Cell counts were scaled to the original area of substrate scraped; yielding species cell densities (cells/cm^2). Cyanobacteria dominate the soft algal community, along with pennate diatoms and green algae (Chlorophyta) (Figure 26). Other groups were present at low levels (less than 3% of the total number of units counted). This is consistent with the observation of Stevenson (1996) that the ubiquitous benthic algae in freshwater tend to be cyanobacteria, chlorophytes, diatoms or red algae Rhodophyta. While red algae were not a significant component of the soft algae community in this study, the red alga *Audouinella* was identified and enumerated in two samples from Clear and Duck Creeks. Detailed results of soft algae sampling can be found in Appendix A.

Table 16. Number of units counted by taxon in soft algae samples by stream (2007-2008). Approximately 300 units were counted from each sample.

Division or group	Taxon	Little Elm	TLE	Willis	Clear	Duck	Walnut
Centric diatoms	Centric diatoms	5	16	5	2	17	46
Chlorophyta	*Ankistrodesmus falcatus*			1			4
	Characium sp.	10	6	4	9	5	5
	Chlamydomonas sp.	9	7	9	1	1	
	Chlorococcum sp.	6		3			
	Cladophora sp.	180	146	134	172	105	70
	Closterium sp.		2				
	Cosmarium sp.		3	2	1		2
	Hormidium sp.	26	8				
	Kirchneriella sp.	8		3			
	Mougeotia sp.		40				
	Oedogonium sp.		26	10	53	60	
	Oocystis sp.		2				
	Scenedesmus sp.		2	2			
	Schroderia setigera		1				5
	Sphaerocystis sp.					11	
	Staurastrum sp.						1
	Tetraedron regulare				2	1	
	Ulothrix zonata					3	
Chrysophyta	*Gloeoskene turfosa*	74	44	3			
Cryptophyta	*Cryptomonadaceae*	5	2			4	4
	Cryptomonas sp.			1	1	1	1
Cyanobacteria	*Calothrix sp*					3	
	Chroococcus sp.	94	76	163	14	22	18
	Lyngbya sp.				264		
	Merismopedia glauca			1			
	Nostoc sp.				15		
	Oscillatoria sp.	178	107	39	37	94	51
	Raphidiopsis curvata			3			3
	Schizothrix sp.	347	290	191	317	554	375
	Spirogyra sp.			90	67		25

Division or group	Taxon	Little Elm	TLE	Willis	Clear	Duck	Walnut
	Spirulina sp.		4	11		3	36
	Synechococcus sp.	16	30	38	2	9	9
Euglenozoa	*Euglena* sp.	15	12	5	2	3	2
	Phacus sp.						1
	Trachelomonas sp.					1	
	Trachelomonas volvocina						5
Ochrophyta	*Dinobryon* sp.			3			
	Mallomonas sp.					1	
Pennate diatoms	Pennate diatoms	279	358	538	252	277	569
Pyrrhophyta	Unknown dinoflagellate	2	1	1	1	1	
Rhodophyta	*Audouinella hermannii*				20	55	
Unknown alga	Unknown alga	71	42	10	20	17	11

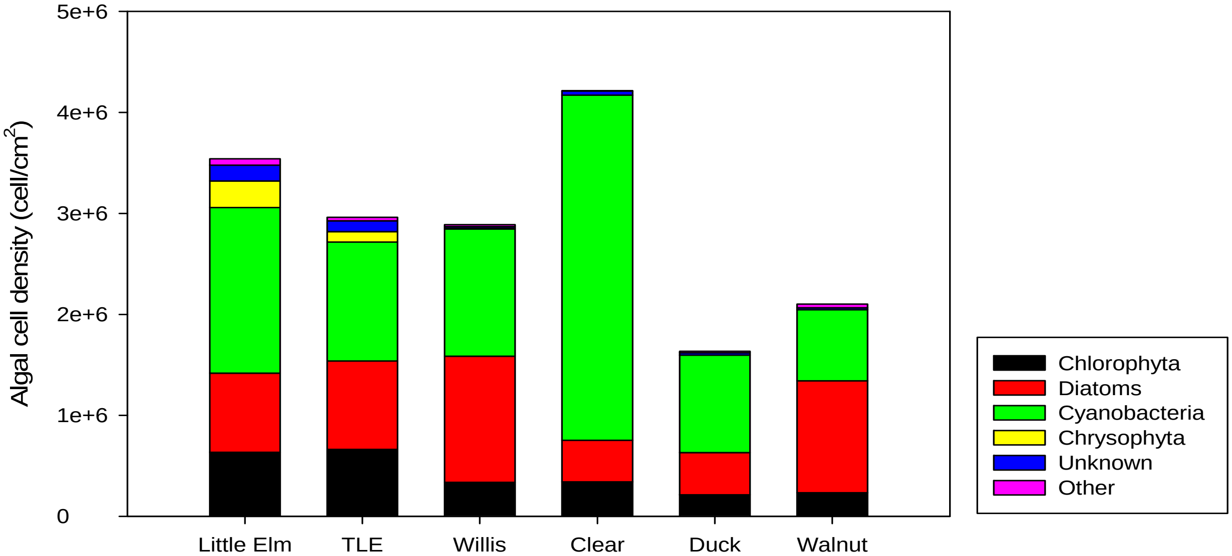

Figure 26. Algal cell density by algal division for each stream.

Individual samples comprised three to six algal divisions. Duck Creek samples comprised the highest number of algal divisions, with six algal divisions in two of four samples. Most soft algae were identified only to genus, or in some cases only to family. Taxa richness based on this level of identification ranged from 6 to 14 (Figure 27). Duck and Tributary of Little Elm Creeks had the highest mean taxa richness, while Willis Creek had the highest number of observed taxa.

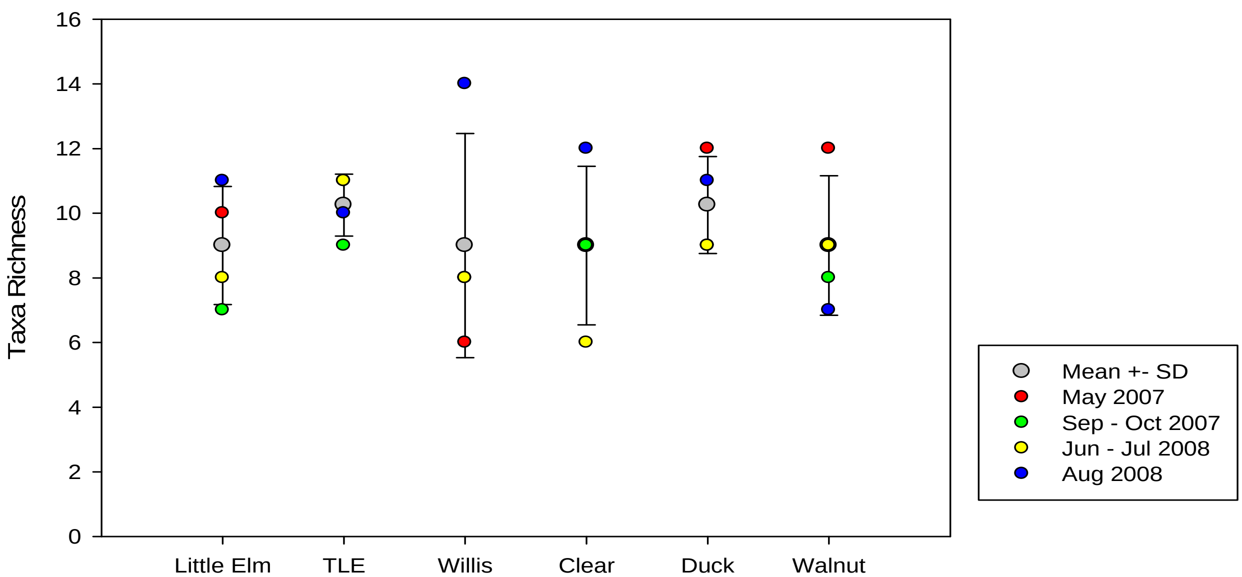

Figure 27. Soft alga taxa richness means, standard deviations and event results.

Cladophora is a filamentous green alga that can proliferate to nuisance levels when nutrients are elevated and dominance of *Cladophora* has been used as an indicator of nutrient enrichment in streams. Only 3 of 24 samples had *Cladophora* as the dominant taxon and they were from three different streams, Little Elm Creek in May 2007, Tributary of Little Elm Creek in May 2007 and Clear Creek in August 2008.

For purposes of multivariate statistical analysis, the soft algae samples were analyzed using cell density on the original substrate rather than merely the cell counts, as this provides a measure of species abundance in the environment. An MDS plot of the soft algae samples shows that most of the samples are very similar (Figure 28). (Sample numbers and sampling dates are correlated in Table 2.) Sample 14 from Clear Creek is different mainly because of a dominance of *Lyngbya*, the only occurrence of that genus during the study. Samples 8, 9 and 10 are also clustered in a group apart from the other samples. Samples 8 and 10 were the only ones containing the red alga *Audouinella hermanii* and sample 8 had the only occurrence of *Nostoc* as well. Sample 9 had the only occurrence of *Staurastrum* and one of the only two occurrences of *Ankistrodesmus falcatus.*

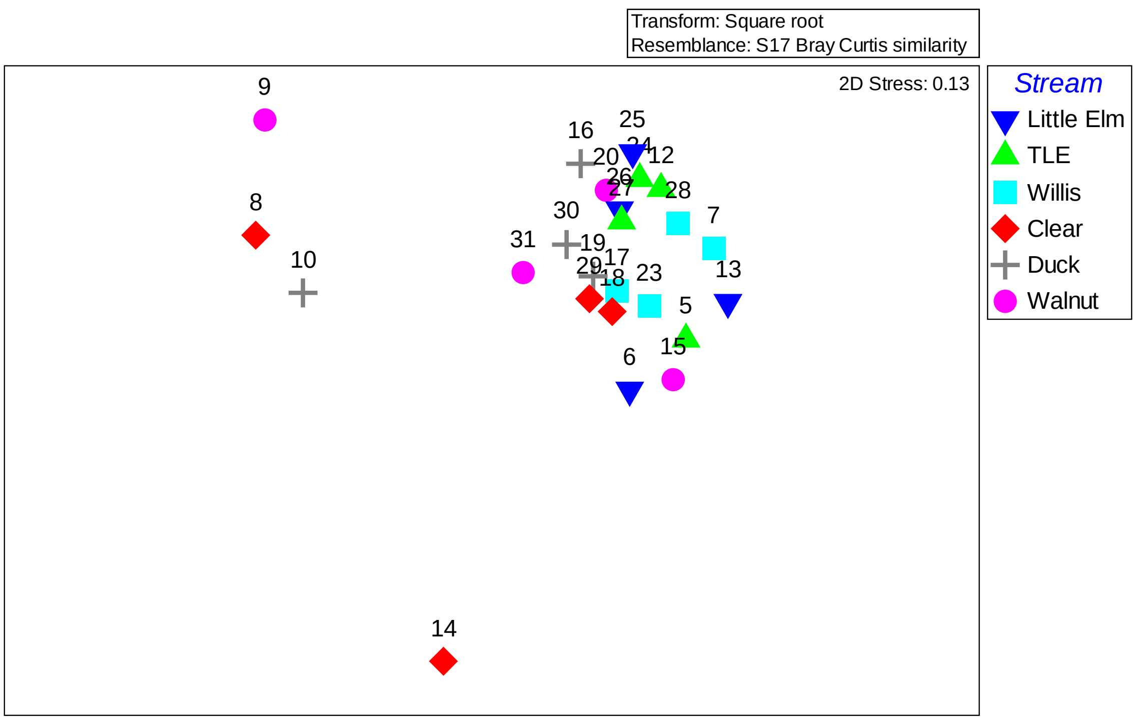

Figure 28. MDS plot of soft algae samples by stream.
Labels for points are sample numbers (Hydro ID).

Ecoregional differences appear distinct when samples on the MDS plot are labeled by ecoregion (Figure 29). ANOSIM reveals a statistically significant difference ($p<0.005$) between samples from the two ecoregions, but the small Global R (0.16) indicates that the two groups are not very distinct. SIMPER analysis indicates one reason for the difference is higher overall abundances in Ecoregion 32, as opposed to differing abundances of specific taxa between the two ecoregions.

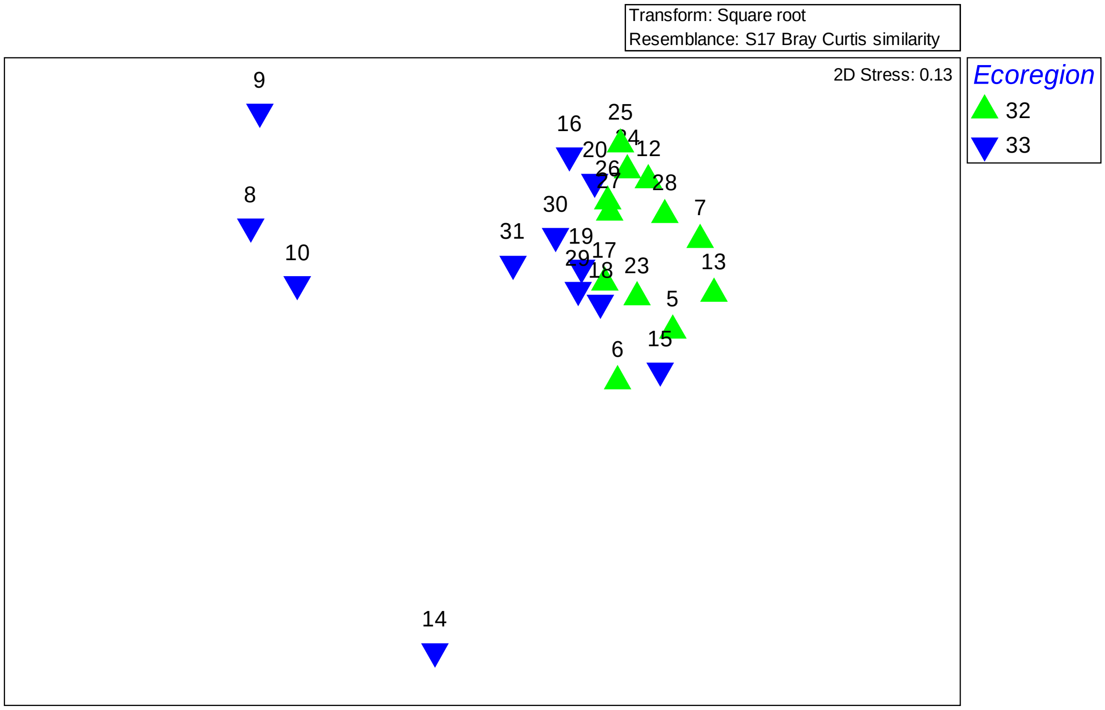

Figure 29. MDS plot of soft algae samples by ecoregion.
Labels for points are sample numbers (Hydro ID).

LINKTREE analysis was run on the soft algae samples with a subset of environmental variables (Figure 30). Environmental variables were selected based on best professional judgment. An attempt was made to select only one variable from each group of highly correlated variables. Some variables were included because they are of special interest to this study, whether or not they were correlated with another variable (for example, nitrate, total phosphorus, water column chlorophyll-*a*, benthic algal chlorophyll-*a*). Other variables were added which were thought or known to be important in the study streams (for example, ecoregion). Variables chosen for the LINKTREE analysis were dominant substrate type, mean percent instream cover, watershed size, ecoregion, benthic algal chlorophyll-*a*, water column chlorophyll-*a*, nitrate, total phosphorus, sulfate, total suspended solids, mean dissolved oxygen, maximum pH, mean temperature, macroalgae cover, mean stream width, mean percent bank erosion, mean percent tree canopy, mean percent gravel, instantaneous flow, and the departure from average rainfall.

At the first node the May 2007 samples from the Ecoregion 33 streams sorted separately from the other soft algae samples. This was related to high departures from average rainfall and low benthic chlorophyll-*a*. Two of these three samples had the only occurrences of red algae in the soft algae samples, which was one factor in these samples being distinguished from the rest. At node B, the May 2007 samples from Ecoregion 32 separated along with two samples from Little Elm Creek (October 2007 and July 2008) and one from Clear Creek (September 2007). Water temperature was lower for all these samples. The split at node C is related to ecoregion or ecoregion surrogate variables such as sulfate, maximum pH or nitrate, and simply separates the one Clear Creek sample from the other five Ecoregion 32 samples. Of the other group of samples from the split at node B, some samples split off at nodes F and G due to habitat parameters (mean stream width, mean percent gravel, or instantaneous flow).

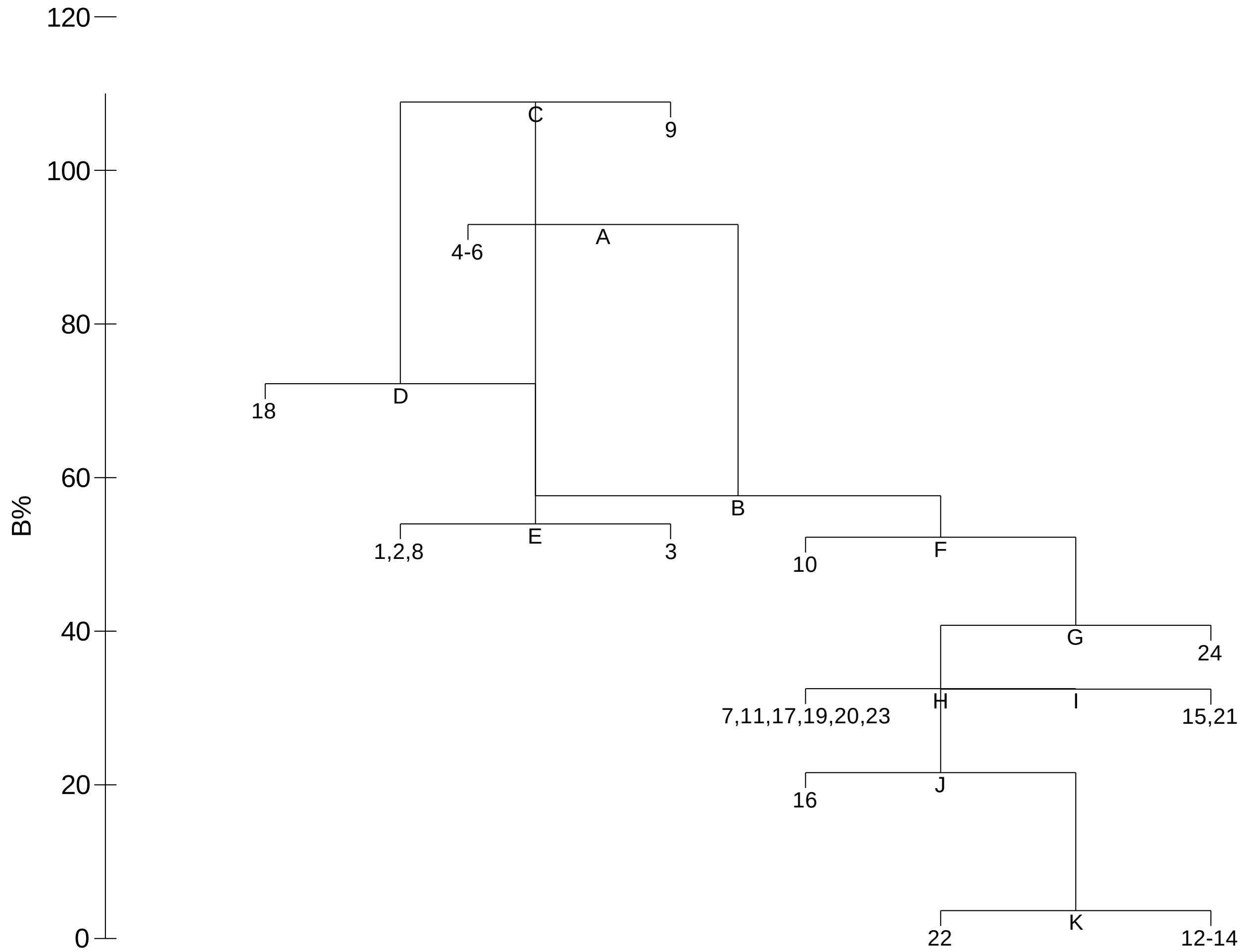

Figure 30. LINKTREE analysis of soft algae samples.
Note that sample numbers are renumbered by LINKTREE procedure and are not the same as the Hydro ID numbers for the study samples.

A: R=0.84; B%=93; Delta Avg Rain>3.46(<0.74) or Benthic Chl-a<3.89(>5.28)
B: R=0.42; B%=58; Mean temp<24.3(>24.4)
C: R=1.00; B%=109; Ecoregion<32(>33) or Sulfate>28.3(<8.43) or pH Max>7.29(<7.18) or Nitrate>0.504(<0.276) or Mean temp<24.3(>24.3)
D: R=0.83; B%=72; Mean DO<0.674(>5.83) or Macroalgae cover>26(<9) or pH Max<7.29(>7.73) or Mean % instream cover>32(<24) or Delta Avg Rain<-3.38(>-1.39) or Nitrate<0.504(>2.27) or Sestonic chl-a>1.95(<0.9) or Flow cfs<0(>1.5)
E: R=1.00; B%=54; Flow cfs<13(>43) or Watershed size<49(>164) or Mean % Bank Erosion<51(>55.5) or Mean Stream Width<5.48(>6.71) or Mean % Tree Canopy<89.7(>91.8) or Mean % Gravel<41(>44) or Mean DO<7.49(>7.76) or Sestonic chl-a<0.5(>0.9) or pH Max<8.01(>8.04) or Delta Avg Rain>-1.29(<-1.39) or Nitrate<5.5(>5.53)
F: R=0.54; B%=52; Mean Stream Width>8.24(<7.16) or Flow cfs>14(<11.5)
G: R=0.40; B%=41; Mean % Gravel>1.8(<0)
H: R=0.42; B%=33; Mean dominant substrate type<2.6(>2.8)
I: R=0.89; B%=32; pH Max<7.94(>7.95)
J: R=1.00; B%=22; Sestonic chl-a>14.9(<1.4) or Sulfate>163(<60.6) or Macroalgae cover>7(<0) or Delta Avg Rain<-3.7(>-1.95) or Benthic Chl-a>28(<17.3) or TP>0.274(<0.103) or Mean % Gravel>62(<54) or Mean % Tree Canopy>92.1(<89.4) or TSS>28(<21) or Nitrate>7.99(<7.6) or Flow cfs<0.47(>0.52)
K: R=0.56; B%=4; pH Max<6.62(>6.85) or Mean % Gravel<4(>6.4) or Benthic Chl-a<5.28(>7.74) or Flow cfs<0.52(>1.6) or Mean Stream Width<3.32(>3.46) or Sulfate<7.02(>10.1) or TP>0.103(<9.7E-2)

Diatoms

For each sample, 500 diatom cells were identified and enumerated. Over the course of the study, 201 diatom species were identified (Table 17). *Gyrosigma nodiferum, Cocconeis placentula, Gomphosphenia grovei, Gomphosphenia lingulatiformis, Navicula recens* and *Navicula sanctaecrucis* were the most abundant species and together comprised about a third of the cells counted. Detailed results of diatom sampling can be found in Appendix A.

Table 17. Number of cells counted for each diatom taxon by stream (2007-2008).
500 cells were counted from each of 24 samples.

Taxon	Little Elm	TLE	Willis	Clear	Duck	Walnut
Achnanthes inflata					5	
Achnanthidium biassolettianum	3			34		
Achnanthidium exiguum					7	
Achnanthidium minutissimum	120	2	193	33	1	2
Adlafia bryophila				3		20
Amphipleura pellucida			2	5		
Amphora acutiuscula		1				
Amphora bullatoides		2		2	2	15
Amphora coffeaeformis		5		1		19
Amphora copulata	11		6	1	22	18
Amphora inariensis	31		9			1
Amphora montana	7		9	8		5
Amphora pediculus	43		48			2
Amphora veneta		120		2		
Aulacoseira granulata			2		1	6
Aulacoseira granulata var *angustissima*						25
Bacillaria paradoxa	34	1	15	73	88	52
Caloneis bacillum	8		8	10	4	4
Caloneis schumanniana			1			
Caloneis silicula					6	1
Campylodiscus clypeus	1					
Capartogramma crucicula				7	5	
Cocconeis pediculus	28	4	5			
Cocconeis placentula	75	364	250	1		92
Cocconeis placentula var *euglypta*	8	18		16	6	95
Cocconeis placentula var *pseudolineata*	12				68	
Cocconeis scutellum				13	13	
Craticula (Navicula) halophila				5	21	17
Craticula (Navicula) minusculoides		1				
Craticula buderi				2		
Craticula cuspidata	2	3	2		4	
Cyclotella meneghiniana	16		2		2	
Cymatopleura elliptica	2				6	
Cymbella aspera				3		
Cymbella cistula				14		

Taxon	Little Elm	TLE	Willis	Clear	Duck	Walnut
Cymbella excisa				80		
Cymbella hustedtii		2				
Denticula kuetzingii			13	7	1	
Denticula subtilis				2	2	
Diadesmis (Navicula) confervacea	20	2			17	23
Diadesmis (Navicula) contenta					12	
Diploneis elliptica	2	4	6	11	24	5
Diploneis oblongella						1
Diploneis ovalis				1	2	
Diploneis puella	12	24	5	9	40	30
Encyonema (Encyonopsis) evergladianum				25		
Encyonema (Encyonopsis) microcephala	4			12		
Encyonema delicatula				110		
Encyonema elginensis				9	2	2
Encyonema silesiacum	7	27	27	46	2	6
Encyonema triangulum		4				
Encyonopsis minuta			7		1	
Eucocconeis (Achnanthes) flexella				21		
Eunotia bilunaris	4			45	4	
Eunotia formica				2	4	
Eunotia pectinalis	22			282	77	3
Fallacia pygmaea						2
Fallacia tenera					12	1
Fragilaria capucina				14		4
Fragilaria tenera				32	1	2
Frustulia rhomboides				17		
Frustulia vulgaris				36	14	
Frustulia weinholdii	5					
Geissleria decussis				8	2	
Gomphonema affine	46		10	1		2
Gomphonema angustatum (micropus)	2			67	10	3
Gomphonema angustum			1			
Gomphonema gracile	1	1	1		4	
Gomphonema intricatum var *vibrio*				8		
Gomphonema mclaughlinii			2	12	4	2
Gomphonema parvulum	2	4	3	51	4	8
Gomphonema patrickii	6			28	16	
Gomphonema pumilum	2	13	38	50	135	42
Gomphonema rhombicum				2		
Gomphosphenia (Gomphonema) lingulatiformis	381	6		62	19	30
Gomphosphenia grovei	281	54		39	283	74
Gyrosigma nodiferum	155	67	60	86	464	242
Gyrosigma obtusatum	7				6	9

Taxon	Little Elm	TLE	Willis	Clear	Duck	Walnut
Gyrosigma scalproides	2	2		2	2	
Gyrosigma spencerii					1	
Hantzschia amphioxys	2			3	4	10
Hippodonta (Navicula) hungarica				9	21	21
Hippodonta capitata				10	11	4
Luticola goeppertiana		12			3	5
Luticola mutica	8	3		1	2	3
Mastogloia smithii				16		
Melosira varians				4		4
Navicula (Eolimna) minima			2	3		10
Navicula (Eolimna) subminuscula		30	2		2	
Navicula aikenensis			1	6		
Navicula angusta	1	4				
Navicula antonii	4	1	3			
Navicula capitatoradiata			12			
Navicula cf. *fauta*		32				6
Navicula cf. *pseudanglica*				3	2	2
Navicula cincta					1	
Navicula constans						5
Navicula cryptocephala				1		7
Navicula cryptotenella	7	7	8	4	3	16
Navicula erifuga		5		8	9	1
Navicula exigua var *capitata*					13	
Navicula incertata		16		2	15	4
Navicula ingenua	1	2			6	2
Navicula kotschii (texana)	13		37	2	18	4
Navicula leptostriata				10		
Navicula libonensis		7		8	2	
Navicula margalithii						4
Navicula orangiana				7		4
Navicula peregrina						4
Navicula radiosa	3		4	4	1	2
Navicula recens	6	120	158	4	45	165
Navicula sanctaecrucis	72	27	146		30	131
Navicula schadei						2
Navicula schroeteri var *escambia*	20	12	97	61	10	
Navicula soehrensis (hassiaca)					8	
Navicula symmetrica		6	6	6	6	23
Navicula tenelloides			6	2		
Navicula tridentula						3
Navicula tripunctata		8	25			
Navicula trivialis						2
Navicula veneta	11	27	28	27	6	10
Navicula viridula					2	

Taxon	Little Elm	TLE	Willis	Clear	Duck	Walnut
Navicula viridula var. *rostellata*	6	105	2	19	21	8
Neidium ampliatum				2		
Nitzschia (Tryb. apiculata) constricta	4	17	2	2	2	15
Nitzschia (Tryblionella) calida	15			2	2	1
Nitzschia (Tryblionella) coarctata					13	
Nitzschia (Tryblionella) levidensis		14	7	6	7	19
Nitzschia (Tryblionella) littoralis				8		
Nitzschia acicularioides				1		1
Nitzschia amphibia	51	36	149	1	6	23
Nitzschia amphibioides	2					
Nitzschia angustata	11				2	1
Nitzschia angustatula	2	2	11		12	
Nitzschia brevissima		24	1	7		4
Nitzschia clausii		2	14	12		
Nitzschia compressa var *balatonis*	3					
Nitzschia dissipata	22	15	33	6	10	2
Nitzschia filiformis	6				2	
Nitzschia frustulum	2	93		7	9	
Nitzschia geitleri		10				
Nitzschia homburgiensis					1	
Nitzschia inconspicua	119	30	169	1		5
Nitzschia linearis	7	7	7	14	24	2
Nitzschia lorenziana		3		13	12	7
Nitzschia microcephala			1			
Nitzschia nana				6	2	
Nitzschia obtusa					4	3
Nitzschia palea		71	8	38	12	14
Nitzschia panduriformis					2	
Nitzschia recta	11	4	10			4
Nitzschia scalpelliformis				6	6	
Nitzschia sigma	12	13		4	33	5
Nitzschia solita		4	2	8	3	
Nitzschia tropica				11	4	
Nitzschia vermicularis				6		
Nitzschia vitrea			3			
Pinnularia acrosphaeria				8	2	
Pinnularia appendiculata					4	
Pinnularia borealis				4	2	4
Pinnularia braunii					1	
Pinnularia gibba	26	3	4	7	8	1
Pinnularia hemiptera					1	
Pinnularia interrupta				3		
Pinnularia microstauron	20	1	8	40	17	2
Pinnularia obscura					2	

Taxon	Little Elm	TLE	Willis	Clear	Duck	Walnut
Pinnularia subcapitata					2	
Pinnularia viridis	12			6	2	3
Placoneis clementis				6		
Placoneis elginensis						1
Plagiotropis lepidoptera			2		2	
Planothidium (Achnanthes) biporomum						2
Planothidium (Achnanthes) delicatulum						15
Planothidium (Achnanthes) lanceolatum	6	1		6	6	19
Planothidium apiculatum				7		
Pleurosigma salinarum	1					
Pleurosira (Ceratulina) laevis		44			4	57
Pseudostaurosira brevistriata		6				5
Reimeria sinuata	48	27	287		2	
Rhoicosphenia abbreviata	10	2			4	43
Rhopalodia gibba				2		7
Rhopalodia gibberula				1		
Sellaphora (Navicula) stroemii			10	4	2	2
Sellaphora pupula	3	1		2	6	
Sellaphora seminulum	52	30	3		10	12
Seminavis (Amphora) strigosa		90				17
Simonsenia delognei			3			
Stauroneis phoenicentron	2					2
Stauroneis smithii	1				3	
Stauroneis smithii var *sagitta*				2		
Surirella angusta		1		8	9	
Surirella brebissonii	3	103		2	18	1
Surirella minuta					3	
Surirella splendida						1
Surirella tenera	7		2		1	
Synedra (Fragilaria) acus						2
Synedra (Fragilaria) ulna			2	99	10	270
Terpsinoe musica	6	133			32	93
Tryblionella (Nit. tryb.) gracilis						5
Tryblionella (Nitzschia) acuminata		5			6	1
Tryblionella debilis	20	53		2	6	2

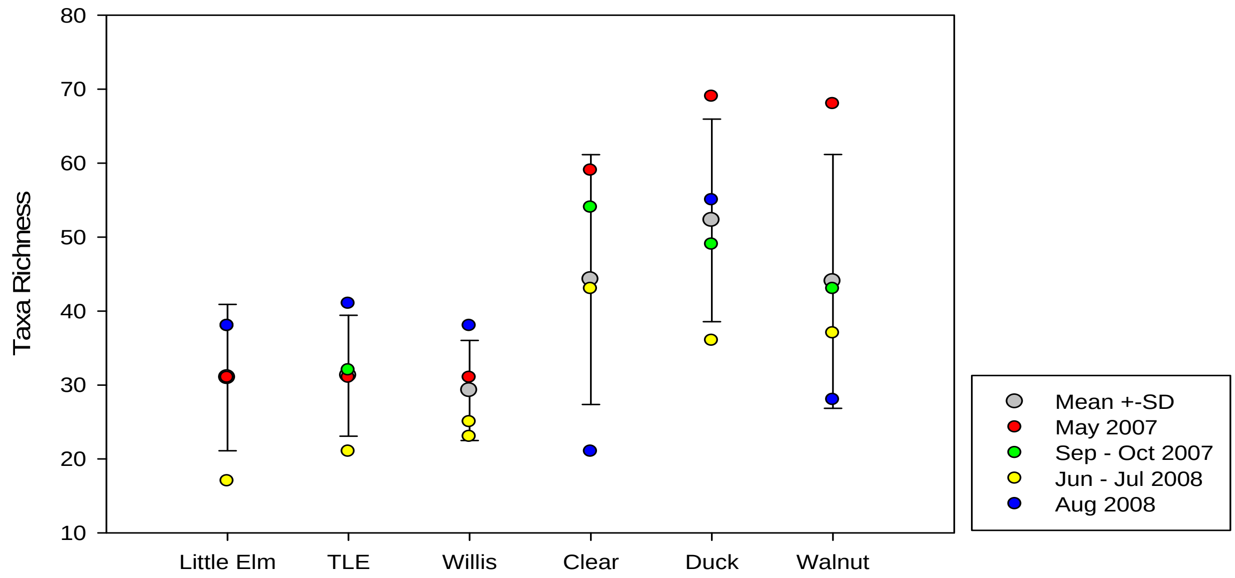

Figure 31. Diatom taxa richness means, standard deviations and event results.

Over the course of the study, 181 species were found in the Ecoregion 33 streams and 125 species in the Ecoregion 32 streams. Ecoregion 33 streams showed higher taxa richness (Figure 31).

Cell counts were extrapolated to the original area of substrate scraped, yielding species cell densities (cells/cm^2). For purposes of multivariate statistical analysis, the diatom samples were analyzed using cell densities in order to include the component of species abundance in the environment.

MDS plotting provides a graphical display of similarities between samples. The more similar samples are, the closer together they appear in the two-dimensional space of the plot (Figure 32). (Sample numbers and sampling dates are correlated in Table 2.) Four diatom samples from Willis Creek were fairly close together on the plot, showing that the four samples were fairly similar to each other in species composition and abundance. Samples from Duck Creek appeared relatively consistent with each other over the course of the study. Samples from the other four streams were more variable over time, with at least one sample plotting at a distance from the other samples for that stream.

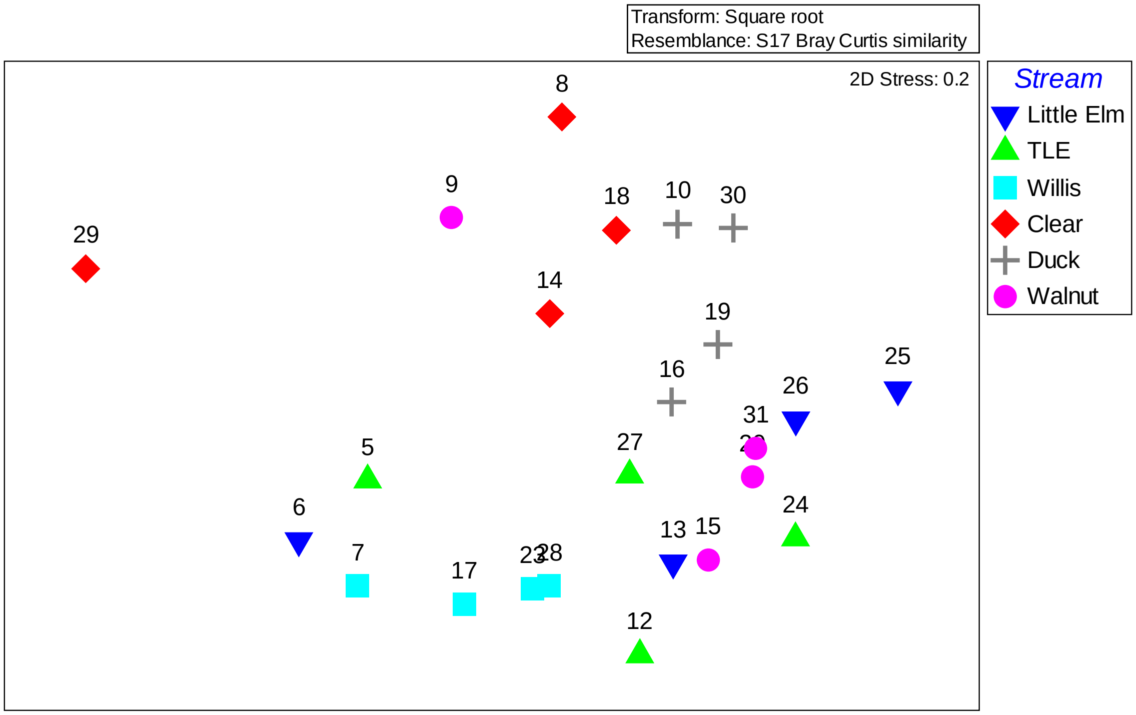

Figure 32. MDS plot of diatom samples by stream.
Labels for points are sample numbers (Hydro ID).

ANOSIM revealed that diatom communities were significantly different between the two ecoregions ($p<0.001$, Global $R=0.74$). SIMPER calculation of average dissimilarity between the ecoregion samples was 81. Species contributing to the differences included those more abundant in Ecoregion 32 sites (for example, *Cocconeis placentula*, *Reimeria sinuata*, *Navicula recens*, *Navicula sanctaecrucis* and *Gomphosphenia lingulatiformis*) and those more abundant in Ecoregion 33 sites (*Gyrosigma nodiferum*, *Synedra ulna* and *Gomphonema pumilum).* Average abundances and contributions of taxa to the average dissimilarity are presented in Table 18.

LINKTREE analysis was run on the diatom samples with the same subset of environmental variables as was used for the soft algae (Figure 33). Major environmental factors causing the diatom sample groupings were pH, water temperature, and sulfate. This reflects mainly seasonal (water temperature), ecoregional (sulfate) and wastewater (sulfate) effects.

Table 18. Diatom community differences between Ecoregion 32 and 33 streams, as determined using SIMPER analysis.
Average abundance for each taxon is shown for each ecoregional group, along with average dissimilarity, and the cumulative percent of dissimilarity contributed by the taxon. Table represents an excerpt of the SIMPER results showing only results contributing to the first 51% of dissimilarity.

Taxon	Average abundance Ecoregion 32	Average abundance Ecoregion 33	Average dissimilarity	Cumulative percent
Cocconeis placentula	125	37.7	3.2	4.0
Gyrosigma nodiferum	84.5	127	2.9	7.6
Reimeria sinuata	95.8	1.09	2.5	11
Navicula recens	93.4	57.9	2.2	13
Gomphosphenia grovei	50.6	55.0	2.1	16
Navicula sanctaecrucis	78.6	54.1	2.1	19
Gomphosphenia (Gomphonema) lingulatiformis	63.2	27.1	2.0	21
Nitzschia amphibia	83.4	16.1	2.0	24
Achnanthidium minutissimum	68.6	11.4	1.8	26
Synedra (Fragilaria) ulna	3.28	75.4	1.8	28
Nitzschia inconspicua	56.5	2.72	1.6	30
Bacillaria paradoxa	28.6	57.8	1.5	32
Terpsinoe musica	34.0	33.8	1.4	34
Gomphonema pumilum	31.5	59.6	1.4	35
Navicula schroeteri var *escambia*	51.8	14.5	1.3	37
Eunotia pectinalis	10.8	49.4	1.3	39
Navicula viridula var. *rostellata*	35.8	20.1	1.0	40
Surirella brebissonii	33.7	10.1	1.0	41
Amphora pediculus	35.2	0.69	0.96	42
Diploneis puella	28.2	35.5	0.93	43
Navicula veneta	36.2	11.6	0.91	44
Nitzschia dissipata	33.8	13.6	0.90	46
Pleurosira (Ceratulina) laevis	18.9	24.8	0.89	47
Encyonema silesiacum	28.8	17.8	0.88	48
Navicula kotschii (texana)	30.3	10.8	0.80	49
Nitzschia (Tryblionella) debilis	27.0	5.76	0.75	50
Nitzschia palea	21.3	9.85	0.74	51

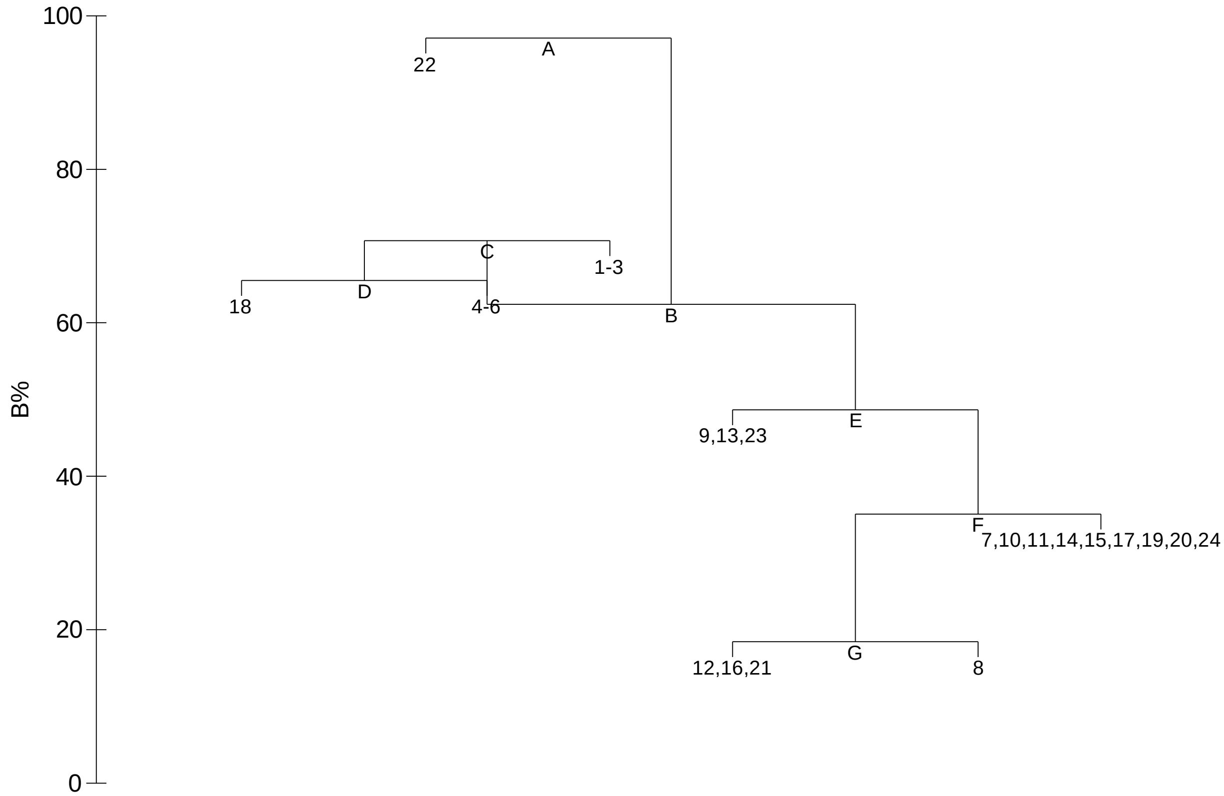

Figure 33. LINKTREE analysis of diatom samples.
Note that sample labels have been renumbered by the LINKTREE procedure and are not the same as the Hydro ID numbers for the samples (See Table 2). R = ANOSIM R statistic calculated between each pair of sample groups at each node. B% represents the strength of the difference between the two groups at each node.

A: R=0.94; B%=97; pH Max<6.62(>6.79) or Sulfate<7.02(>8.43)
B: R=0.53; B%=62; Mean temp<23.6(>24.3)
C: R=0.70; B%=71; pH Max<7.48(>7.95) or Mean % instream cover>27(<21) or Nitrate<0.532(>2.27)
D: R=1.00; B%=66; Macroalgae cover>26(<0) or Mean DO<0.674(>5.84) or Delta Avg Rain<-3.38(>3.46) or Ecoregion<32(>33) or Benthic Chl-a>40.5(<3.89) or Flow cfs<0(>5.9) or Mean dominant substrate type<2.8(>3) or Watershed size<49(>78) or Mean temp>23.6(<23.3) or Mean % Tree Canopy>88.5(<88.2)
E: R=0.55; B%=49; Sulfate<21(>28.3)
F: R=0.50; B%=35; Mean % Gravel>41(<16) or Mean dominant substrate type>3.4(<3)
G: R=1.00; B%=18; Mean % Bank Erosion>60(<51) or Watershed size>164(<49) or TSS>18(<4) or Mean temp>25.3(<24.3) or Sulfate>60.6(<28.3) or Mean DO>6.71(<5.83) or Mean % instream cover<20(>24) or pH Max>7.9(<7.73) or Delta Avg Rain<-0.26(>0.74) or Sestonic chl-a>1.4(<0.2) or TP>2.7E-2(<8E-3)

LINKTREE provides a series of binary divisions of samples based on thresholds on one or more environmental factors at each split. The first split (node A on Figure 33) is explained by maximum pH from the 24-hour datasonde deployments. At this split one sample, Clear Creek in August 2008 is distinct from the rest of the samples. The pH max was 6.6 for this sample, while that for all the other samples ranged from 6.8 to 8.3. The diatom community had much lower taxa richness (only 21 species) than in the three other samples collected from Clear Creek (43 to 59 species). The split at node B is based on mean temperature from the 24-hour datasonde deployments, with samples at lower temperatures on the left side of the graph and samples with higher temperatures on the right. The samples on the left side of the graph are all from May

2007 with the exception of sample 18, which is the July 2008 sample at Little Elm Creek. It might be inferred from this result that there are seasonal differences in the diatom community; in fact ANOSIM of the diatom samples by season confirmed differences ($p < 0.002$, Global $R = 0.30$) among samples when they are divided into "spring" (May) "summer" (June through August) and "fall" (September and October) groups based on the month the samples were collected. Additional analysis with September included in the "summer" sample gives similar results. This is because the seasonal difference is driven by spring samples, all from May 2007, which had much lower abundances than the other samples. The apparent seasonality may be driven by flow conditions and the time required for recolonization.

Diatoms are useful indicators of water quality conditions (Winsborough 2009a), included as Appendix B). The group is diverse and well-studied, and ecological characteristics and tolerances have been determined for many species. Diatom community composition has been used as a tool to evaluate environmental impacts in many water body types, especially rivers and lakes. Less work has been done in small streams. Potapova and Charles (2002) found a strong geographic component to diatom samples from across the nation and recommended that interpretation of diatom community composition be calibrated regionally.

Diatom indices of biotic integrity (IBIs) have been developed in various regions as a component of water quality monitoring. As part of the Kentucky Department for Environmental Protection's IBI, pollution tolerance values for diatom species were assigned (Wang *et al*. 2005). Using the Kentucky IBI system, Metzmeier ranked the diatom communities of the study streams in descending order from better to lower quality: Duck, Clear, Walnut, Willis, Little Elm, and Tributary of Little Elm (Metzmeier 2009a). One constraint with using the Kentucky IBI was that many of the diatom species found in this study did not have pollution tolerance index (PTI) values assigned in the Kentucky IBI. The City of Austin sought to incorporate diatom community evaluation in their Environmental Integrity Index program by assigning pollution tolerance values to species found in this area which did not have Kentucky PTI values. Only about a third of central Texas diatom species had PTI values assigned in the Kentucky IBI. Through literature review and calculations, PTI values were assigned to almost all of the Austin-area taxa (Muscio 2002). The data from this study were not analyzed using the Austin index, although that could be done.

Using best professional judgment, Winsborough (Winsborough 2009b) ranked the study streams separately by ecoregion in increasing order of nutrient enrichment. For Ecoregion 32 she ranked Little Elm Creek as the least eutrophic, followed by Willis Creek, then the Tributary of Little Elm Creek. For Ecoregion 33 she ranked Clear Creek as the least eutrophic, followed by Walnut Creek, then Duck Creek.

For this study an attempt was made to interpret the community composition of the diatom samples by applying known diatom attributes and looking for patterns among the streams. Attributes were obtained from published studies, with special attention to studies done in or near Texas (Winsborough 2009a). Based on this information, broad categories of diatom characteristics were compiled as a way of looking for effects of nutrient enrichment on the diatom community. We named these categories of diatoms alkaliphilic, eutrophic, halophilic, motile, nitrogen heterotrophs, polysaprobic, sensitive and tolerant. Species were included in a category if certain conditions were met for that species in the published studies (Appendix A, Table 44). For example, diatom species were categorized "eutrophic" if they were identified in pollution class 1 (most tolerant) by Bahls (1993), listed with a Pollution Tolerance Index value of 1 for the Kentucky Diatom Bioassessment Index (Wang *et al*. 2005), or given an ecological indicator value of 4 ("obligate nitrogen-heterotrophic taxa") by Van Dam *et al*. (1994), and so on. Next the data were explored by calculating percentages of individuals from each diatom sample which fell into each category. Means and standard deviations were calculated for these percentages for each category. Despite the small sample size from this study, diatom characteristics showed promise for differentiating between streams.

One category that seemed useful for identifying wastewater impacts was "tolerant" taxa (Figure 34). Tributary of Little Elm Creek had the highest percentage by far (23%) of tolerant taxa. Individual samples ranged from 18-28%. Samples from the other five streams ranged from 0-16% tolerant taxa.

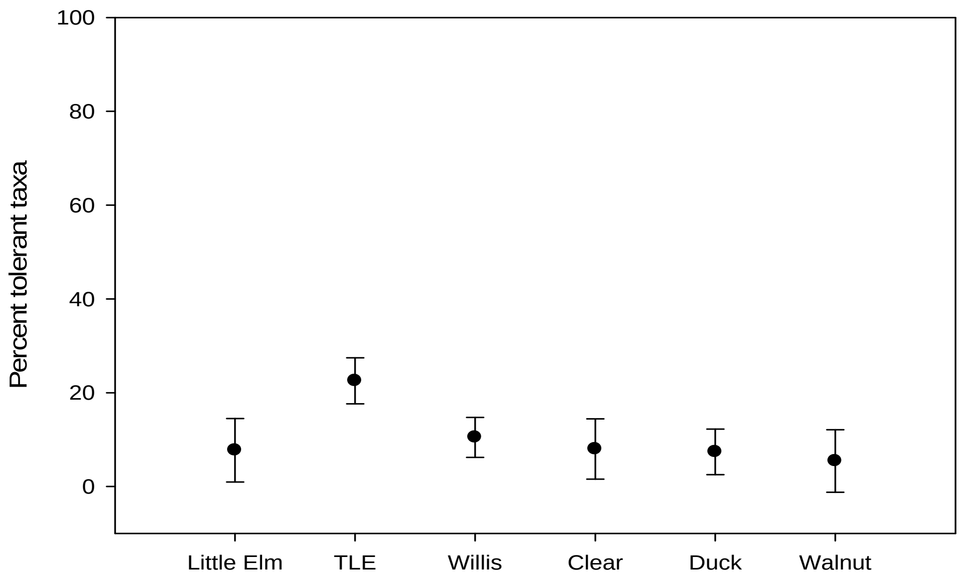

Figure 34. Percent individuals belonging to tolerant diatom taxa (mean and standard deviation) by stream.

The category "eutrophic" taxa also showed an elevated percentage for Tributary of Little Elm Creek, although not as dramatically as "tolerant" taxa (Figure 35).

Other categories indicative of nutrient enrichment did not discriminate the streams as well, for example, "nitrogen heterotrophs" (Figure 36) or "polysaprobic" (Figure 37). However, some ecoregional differences are observed using the percent nitrogen heterotrophs classification, since the samples from the Ecoregion 33 streams have lower values and less variability than the samples from Ecoregion 32.

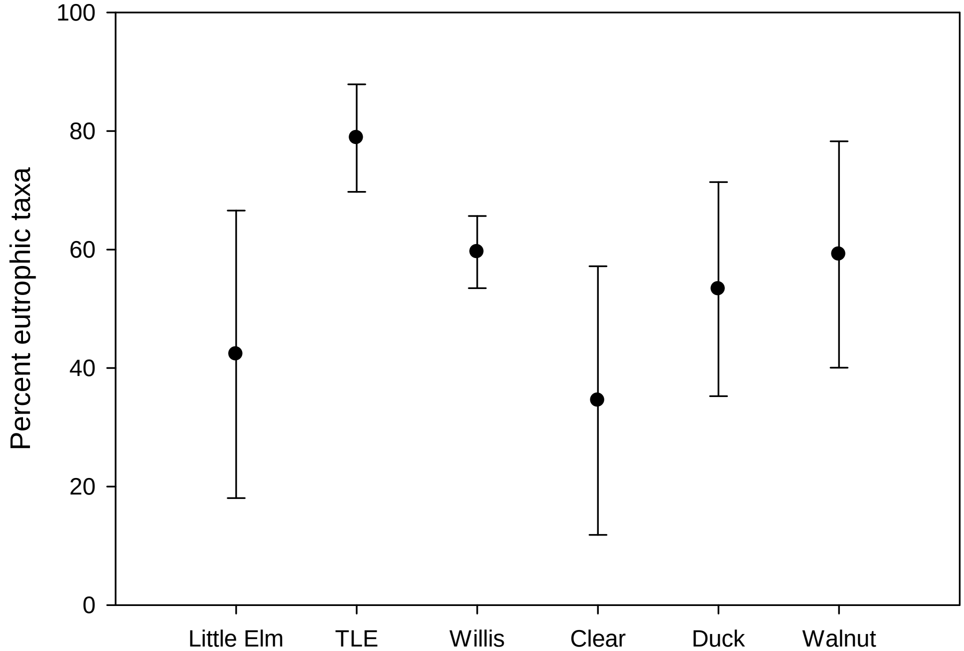

Figure 35. Percent individuals belonging to eutrophic diatom taxa (mean and standard deviation) by stream.

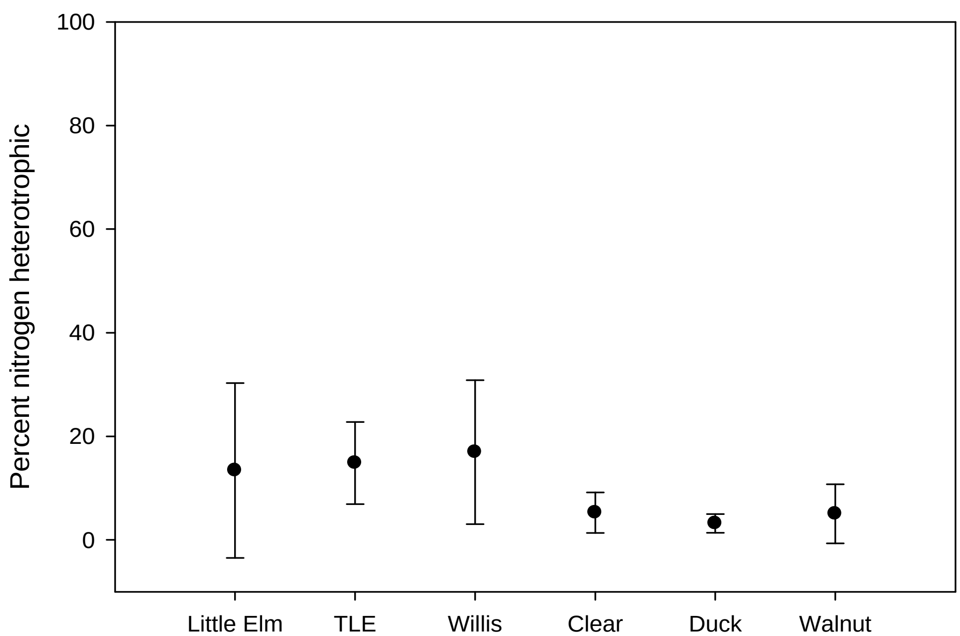

Figure 36. Percent individuals belonging to nitrogen-heterotroph diatom taxa (mean and standard deviation) by stream.

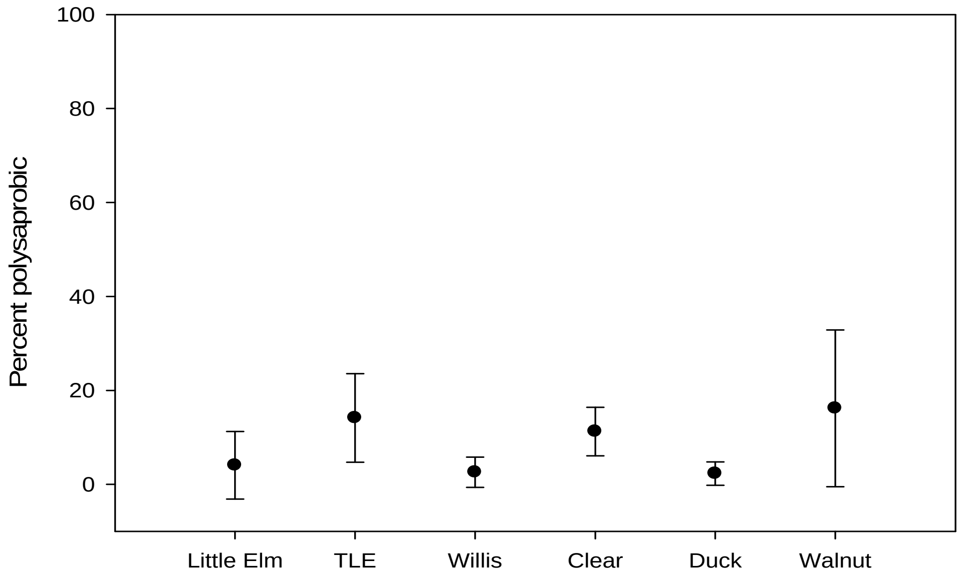

Figure 37. Percent individuals belonging to polysaprobic diatom taxa (mean and standard deviation) by stream.

The category "sensitive" taxa showed lower values for both Tributary of Little Elm Creek and Walnut Creek, although there was a considerable amount of variability as well (Figure 38).

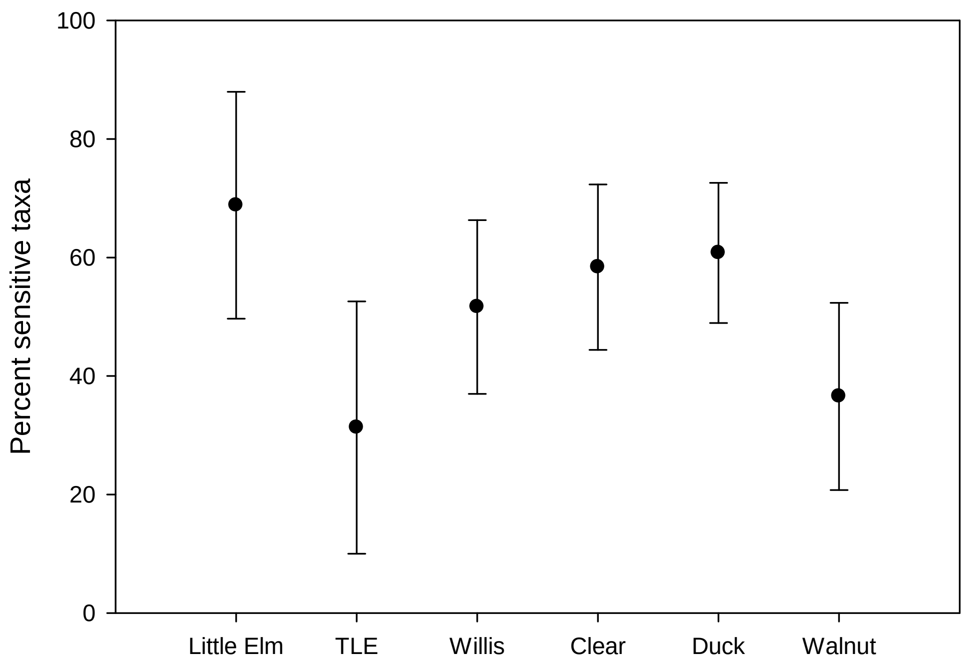

Figure 38. Percent individuals belonging to sensitive diatom taxa (mean and standard deviation) by stream.

“Motile” taxa are of interest because of the concept that motile taxa may be more successful in environments with lots of sedimentation than attached taxa. Often nutrients are elevated along with sediment when a stream’s watershed is disturbed. However, this characteristic did not distinguish any patterns among the streams. Instead it varied so much among samples that it was difficult to extract any pattern (Figure 39).

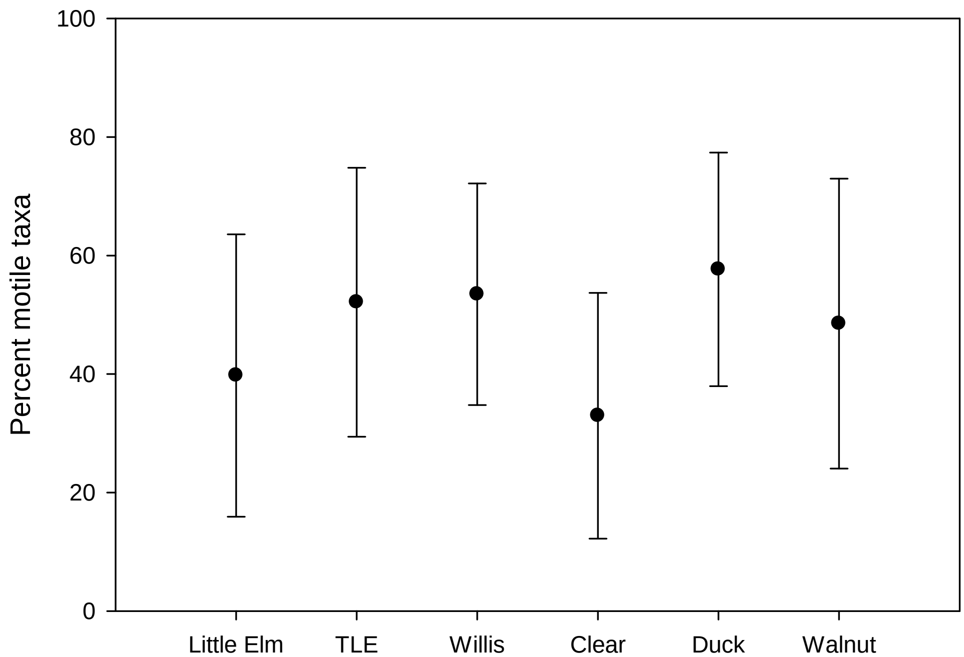

Figure 39. Percent individuals belonging to motile diatom taxa (mean and standard deviation) by stream.

“Halophilic” taxa were of interest since work was done in two ecoregions, one of which (Ecoregion 33) tends to have softer water that is lower in specific conductance than Ecoregion 32. This measure showed a lot of variability, although streams with generally high specific conductance did have higher percentages of halophilic diatoms (Figure 40).

Finally, there was an expectation that Ecoregions 32 and 33 may exhibit a difference in percent “alkaliphilic” diatom taxa, since pH tends to be lower in Ecoregion 33 than in Ecoregion 32. In general, a pattern was observed with Ecoregion 32 having a higher percentage of alkaliphilic taxa than Ecoregion 33. The exception was Little Elm Creek, which had much more variability than the other streams, including one sample with only 5% alkaliphilic taxa (Figure 41).

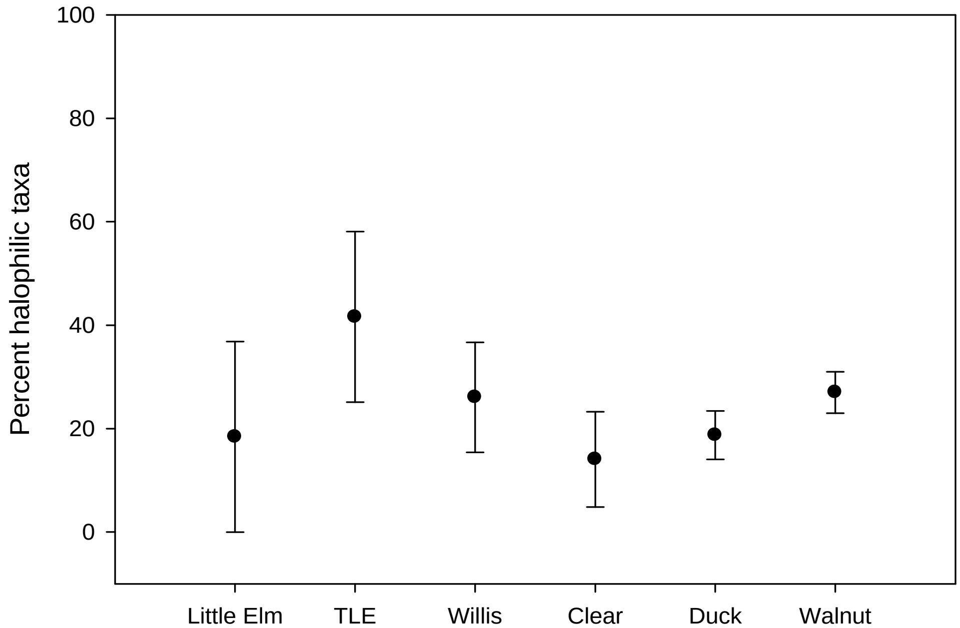

Figure 40. Percent individuals belonging to halophilic diatom taxa (mean and standard deviation) by stream.

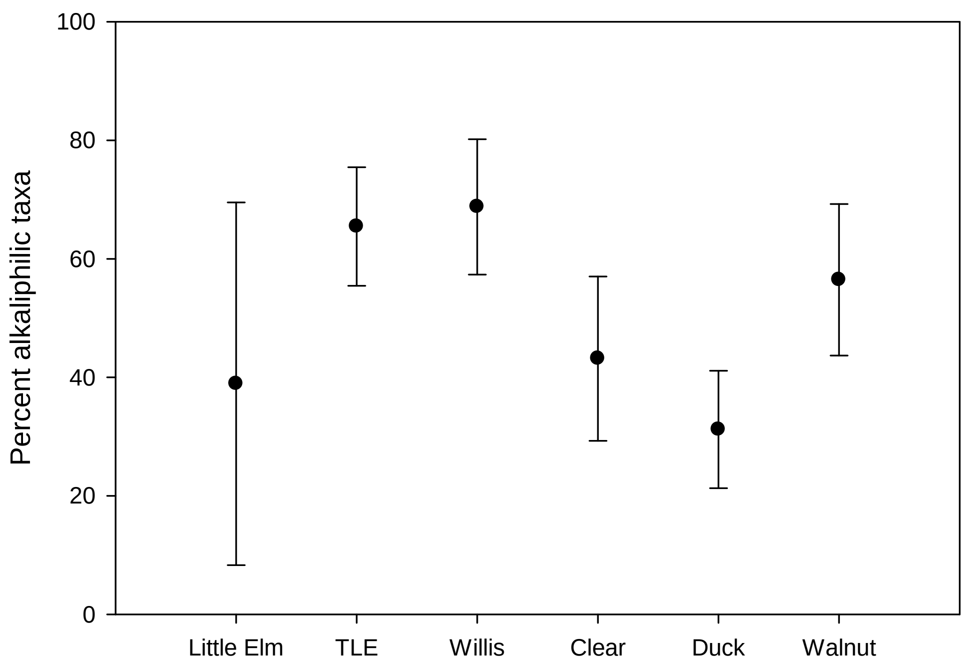

Figure 41. Percent individuals belonging to alkaliphilic diatom taxa (mean and standard deviation) by stream.

Aquatic Vegetation

There was not a clear difference in aquatic vegetation by ecoregion. All streams had a high percentage of canopy cover, which is known to be a key limiting factor on algal and macrophyte growth. An assessment of 225 minimally impacted streams in the western United States found that the probability of finding macroalgal growth decreased significantly when canopy cover exceeded 73.5% (Rollins *et al*. 2002). Canopy cover in this study ranged from 62% in May 2007 at the Tributary of Little Elm Creek, which was the only measurement below 75%, to 92% in May 2007 and July 2008 at Willis Creek.

Table 19. Aquatic vegetation survey scoring.

Macroalgae cover and thickness	Microalgae cover	Sediment cover	Macrophyte cover	Surface macroalgae and macrophytes
0 (none)	0 (rough with no apparent growth)	0 (no apparent sediment)	0 (none)	0 - Absent
1 (<5% cover)	0.5 (slimy, but biofilm is not visible)	1 (minimal film visible)	1 (<5% cover)	1 - Present
2 (5-25%)	1 (thin layer of microalgae is visible)	2 (film evident on all algal surfaces)	2 (5-25%)	
3 (25-50%)	2 (accumulation of microalgae to a thickness of 0.5-1 mm)	3 (heavy, obscures color of most algae)	3 (25-50%)	
4 (50-75%)	3 (accumulation of microalgae from 1 mm to 5 mm thick)	4 (heavy, algal growth clearly limited by sedimentation)	4 (50-75%)	
5 (75-100%)	4 (accumulation of microalgae from 5 mm to 20 mm)		5 (75-100%)	
6 (~100% & thick)	5 (layer of microalgae is greater than 2 cm)		6 (~100% & thick)	
Maximum composite score: 150	Maximum composite score: 125	Maximum composite score: 100	Maximum composite score: 150	Maximum composite score: 25

Sediment cover on algae was rarely observed at the sampling points. Aquatic macrophytes were not observed at any of the aquatic vegetation sampling points throughout the study. Sparse macrophytes were observed outside the aquatic vegetation sampling points in the Tributary of Little Elm Creek and Walnut Creek. Although some of the vegetation measures were not abundant in these six streams, they remain important for streams with other habitat and periphyton characteristics.

Aquatic vegetation survey scoring is summarized in Table 19. The scoring range for microalgae thickness is 0-5 with a maximum composite score of 125. Zero corresponds to no growth, while a score of 5 implies microalgae thickness greater than 2 cm. Other categories follow similar patterns with the greater the number the more growth observed. Detailed results for the aquatic vegetation survey can be found in Appendix A.

Aquatic vegetation cover and thickness were low throughout the study (Figure 42). All macro- and microalgae composite scores are below one-third the maximum possible score, which corresponds well with the absence of visual observations of nuisance algae growth. Macroalgae cover and macroalgae thickness had virtually identical scores, and the largest scores were observed in July and August 2008 (Figure 43). This is likely due to the lower flows in the later part of 2008. Microalgae thickness was consistently low across study sites.

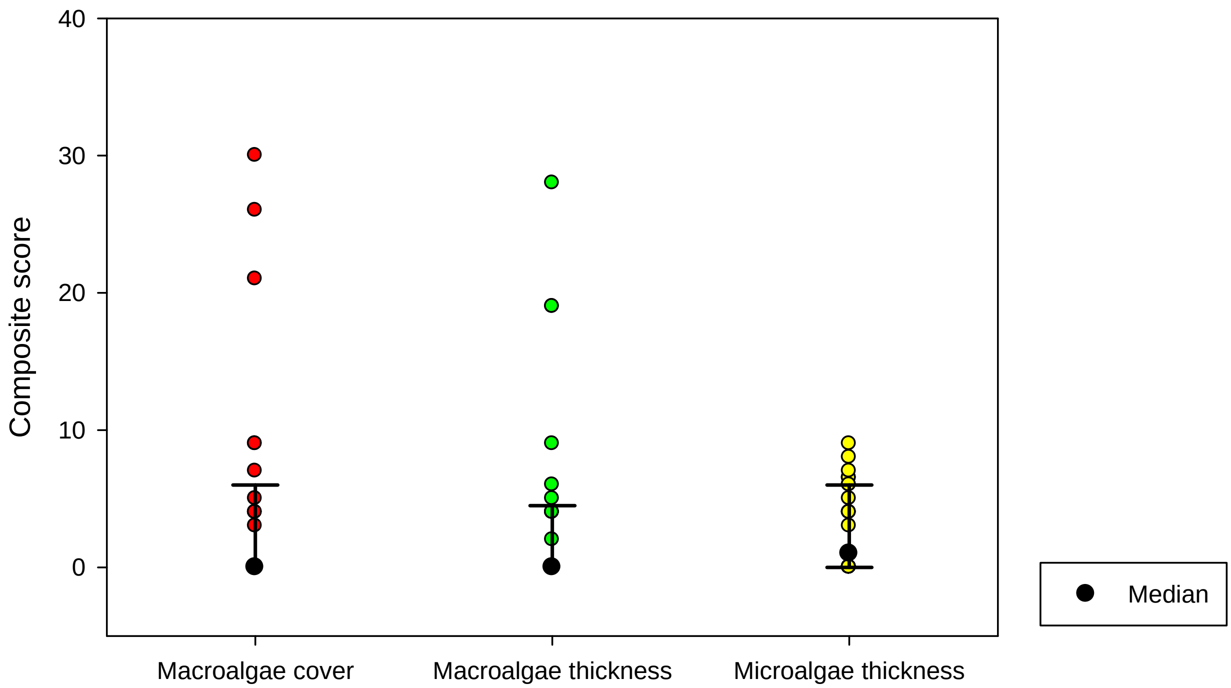

Figure 42. Aquatic vegetation survey composite scores and median values (2007 – 2008). Error bars represent 75th percentile (upper) and 25th percentile (lower).

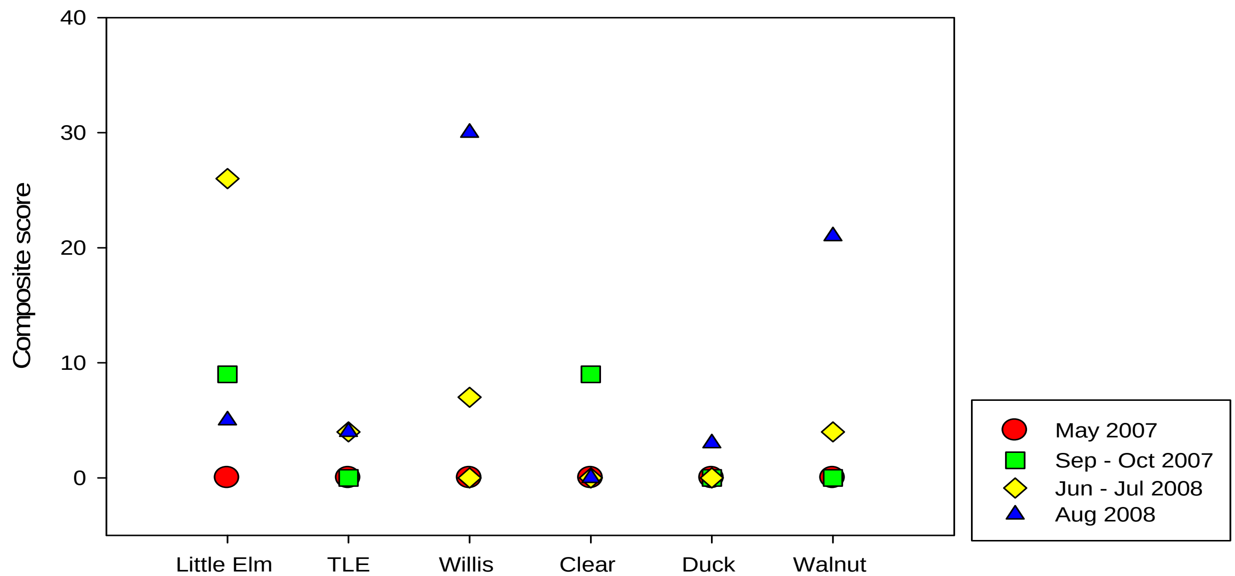

Figure 43. Aquatic vegetation survey macroalgae cover composite scores.

Habitat

Information was collected at each stream to characterize the available riparian and instream habitat. The habitat data, including instream cover, substrate types, bank slope and canopy cover, provide supplemental information that can be used to interpret biological data such as fish, benthic macroinvertebrates and periphyton. A summary of the habitat data is provided in Appendix A (Table 50 - Table 52).

The Habitat Quality Index (HQI) was developed for Texas wadeable streams. It uses several measures to assess the potential of habitat to support aquatic life (TCEQ 2005). The habitat data collected was used to calculate a HQI score for each creek and sampling event (Table 20 and Figure 44).

Little Elm Creek and the Tributary of Little Elm Creek generally had intermediate HQI scores and were similar each sampling trip. The August 2008 Little Elm Creek HQI score was limited due to the stream’s diminished habitat (no flow; perennial pools). Willis Creek scored high three times with one intermediate score during August 2008 when the creek had diminished to perennial pools.

Clear Creek bordered on intermediate and high HQI scores throughout the study. In August 2008, much of the creek’s bank and bottom had been altered by feral pigs (Figure 45). This reduced the bank stability measure in the HQI, which is an average of bank slope and erosion potential. Duck Creek also bordered consistently on intermediate and high scores and the mean score was high. The Walnut Creek scores were consistently in the high category.

Principal components analysis (PCA) of the habitat parameters for each sample showed that each stream had unique habitat characteristics (Figure 46). Overall the habitat at each stream was consistent between samples and only deviated in the critical summer months in 2008 when flows decreased. A positive change in the first principal component axis (PC1) represents decreasing stream width, riparian zone width, watershed size and stream order (moving from left to right). A positive change in the second axis (PC2) represents increasing total number of bends, number of well-defined bends, number of poorly-defined bends, and number of riffles. A positive change in PC3 represents increasing average dominant substrate size, mean percent gravel, mean percent of channel occupied by the largest pool, and mean percent trees; and decreasing mean bank slope and mean percent grasses in the riparian zone. A positive change in PC4 represents increasing mean bank slope, and decreasing number of inlets, mean percent shrubs and instantaneous flow. The first four principal components of the analysis explain 73.2% of the variation in the habitat parameters. In this analysis, the creeks did not separate by ecoregion.

Table 20. Habitat Quality Index (HQI) scores.

Creek	Date	HQI score	HQI category [a]	Mean HQI score
Little Elm	9 May 2007	16.5	Intermediate	14.9 - Intermediate
	3 Oct 2007	17.0	Intermediate	
	9 Jul 2008	14.5	Intermediate	
	12 Aug 2008	11.5	Limited	
TLE	7 May 2007	15.0	Intermediate	15.9 - Intermediate
	4 Oct 2007	16.5	Intermediate	
	9 Jul 2008	15.0	Intermediate	
	13 Aug 2008	17.0	Intermediate	
Willis	8 May 2007	23.0	High	22.5 - High
	3 Jun 2008	24.0	High	
	8 Jul 2008	23.0	High	
	12 Aug 2008	20.0	High	
Clear	23 May 2007	20.0	High	20.3 - High
	6 Sep 2007	20.0	High	
	10 Jun 2008	22.0	High	
	5 Aug 2008	19.0	Intermediate	
Duck	23 May 2007	20.0	High	19.8 - High
	6 Sep 2007	20.0	High	
	11 Jun 2008	19.0	Intermediate	
	5 Aug 2008	20.0	High	
Walnut	22 May 2007	20.0	High	20.9 - High
	5 Sep 2007	21.5	High	
	10 Jun 2008	21.5	High	
	5 Aug 2008	20.5	High	

[a] HQI Point Score Ranges:

Exceptional:	26 - 31
High:	20 - 25
Intermediate:	14 - 19
Limited:	< 13

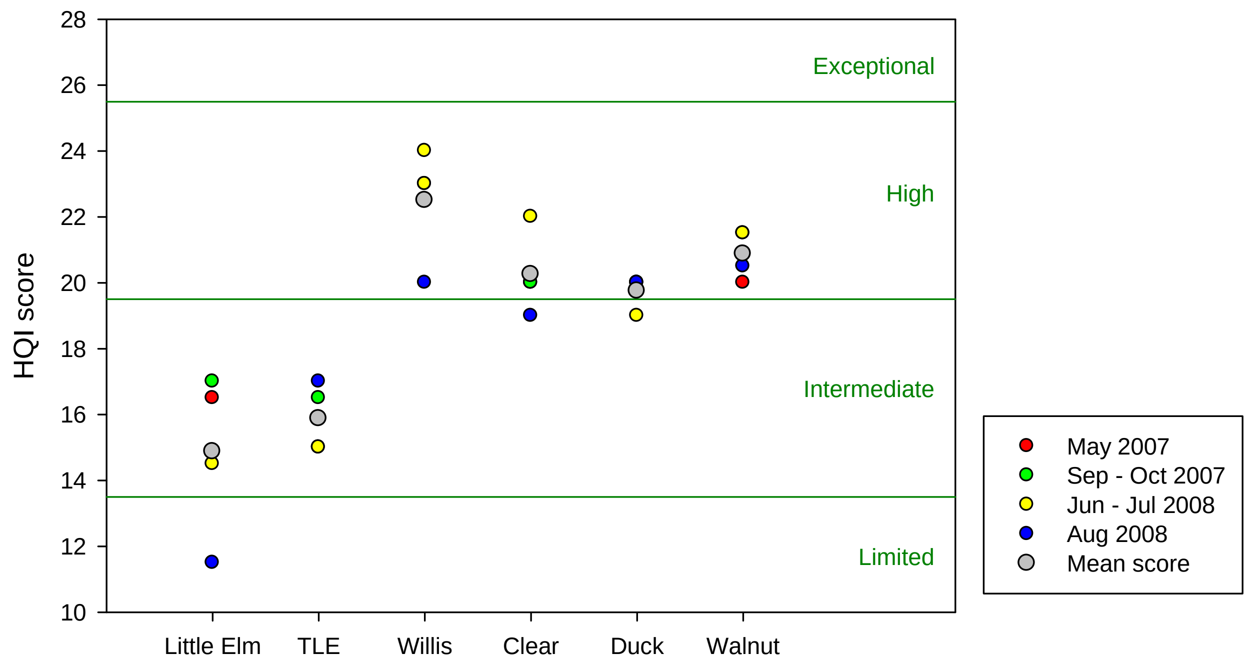

Figure 44. Habitat Quality Index (HQI) mean and event scores.

Figure 45. Evidence of feral pigs altering stream bed and banks at Clear Creek (Aug 2008).

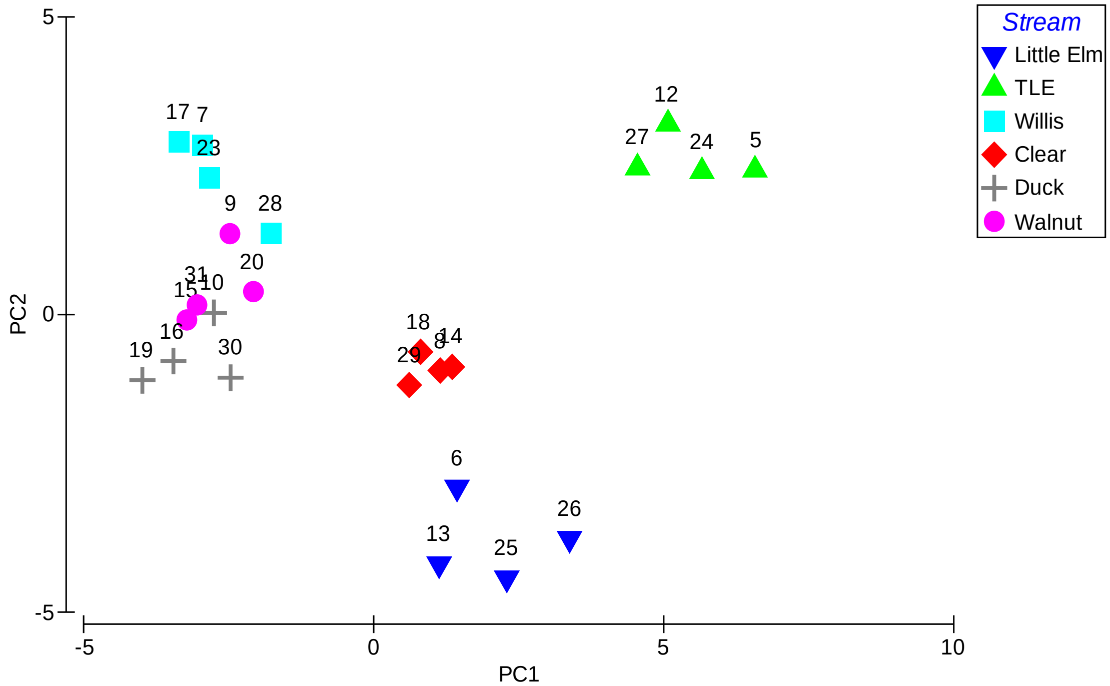

Figure 46. Principal component analysis of habitat parameters.
Labels for points are sample numbers (Hydro ID).

Physicochemical Data

Instantaneous Measurements

Instantaneous physicochemical measurements were taken on the first day of sampling for each stream at the most downstream portion of the reach immediately after water chemistry samples were obtained (Table 21). Secchi depth varied from 0.15 m (Willis Creek in August 2008) to 1 m (Walnut Creek in September 2007). pH measurements for Ecoregion 32 streams and Walnut Creek were alkaline while Duck and Clear Creeks showed small fluctuations around neutral pH. Instantaneous dissolved oxygen values were consistently above 6 mg/L for all streams except Little Elm and Duck Creeks, which had lower values at the September-October 2007, June-July 2008 and August 2008 sampling events. Only the Tributary of Little Elm Creek had a dissolved oxygen value exceeding 100% saturation. Instantaneous specific conductance in Ecoregion 32 streams increased from May 2007 through August 2008. Instantaneous specific conductance in Ecoregion 33 streams was variable, decreasing in the summer months for Clear and Duck Creeks. Specific conductance values in Willis Creek in July and August 2008 were high, likely due to no-flow conditions in the upstream reach and the City of Granger's permitted wastewater that entered immediately upstream of the measurement location.

Diel Measurements

Average, maximum and minimum diel measurements are listed in Table 22. pH measurements for Ecoregion 32 streams and Walnut Creek were alkaline while Duck and Clear Creeks showed small fluctuations around neutral pH.

Dissolved oxygen means were above 5 mg/L for Ecoregion 32 sampling events except Little Elm Creek in July and August 2008 (Figure 47). Dissolved oxygen values differed greatly between Little Elm Creek and the Tributary of Little Elm Creek in those months. In July and August 2008, Little Elm Creek was reduced to isolated pools, while the Tributary of Little Elm Creek maintained steady flow due to the permitted wastewater discharge from the City of Temple. The low dissolved oxygen values observed for Little Elm Creek are characteristic of isolated, diminished pools, while both the dissolved oxygen values and diel swings observed for the Tributary of Little Elm Creek are indicative of a nutrient-rich, flowing stream. In Ecoregion 33, Duck Creek showed low dissolved oxygen levels in June and August 2008. The August 2008 sample for Duck Creek corresponds to a no-flow period when the stream was reduced to perennial pools, but the June 2008 corresponds to a measured flow of 1.7 cfs. Despite low stream flows, Clear and Walnut Creeks maintained high dissolved oxygen levels in July and August 2008.

Average specific conductance values tended to increase from May 2007 through August 2008 for Ecoregion 32 streams, except for Willis Creek in August 2008, which had the lowest value recorded during the study. Ecoregion 33 average specific conductance values were variable, decreasing in the summer months for Clear and Duck Creeks (Figure 48).

None of the streams has been given a site-specific standard for dissolved oxygen, so presumed criteria of 5.0 mg/L (mean) and 3.0 mg/L (minimum) apply. In general, the streams met these standards. Exceptions occurred for Little Elm Creek in July and August 2008 and Duck Creek in June and August 2008, when both streams failed to meet criteria for both minimum and mean dissolved oxygen levels. Due to flow status, standards do not apply except possibly for Duck Creek in June 2008 (TCEQ 2000).

Instantaneous measurements of pH, temperature, dissolved oxygen and specific conductance varied from diel measurements (Appendix A, Table 53). Since all measurements were typically made on the same day, at locations about 300 meters apart, one might expect instantaneous measurements to fall within the range defined by the minimum and maximum of the diel measurements. For over half the measurements, this was not the case. In most cases (except for Willis Creek in July and August 2008, discussed above), the magnitude of the difference was not large. These values suggest a higher range of natural variability than expected and suggest caution in using "average" values as descriptive of small streams as a whole. Comparison of total dissolved solids levels from specific conductance values using a "standard" multiplier (0.67) results in TDS values that are systematically higher than measured water chemistry levels (Appendix A, Table 54).

Table 21. Instantaneous physicochemical measurements.
Flow severity scale: 1 = no flow; 2 = low; 3 = normal; 4 = flood; 5 = high; 6 = dry.

Creek	Date	Time	Days since rain	Flow severity	Flow (cfs)	Depth (m)	Secchi depth (m)	Bottom depth (m)	Temp (°C)	pH	DO (mg/L)	DO (percent saturation)	Specific cond. (µS/cm)
Little Elm	10 Apr 2007	10:17	< 3	5		0.3	0.81[a]	0.5	13.1	7.9	9.7	94	509
	7 May 2007	10:15	< 6	5	13	0.3	0.8[a]	0.45	22.6	7.6	7.9	92	581
	2 Oct 2007	9:30	> 7	3	1.5	0.3	0.9[a]	0.35	23.8	7.1	5.9	70	562
	7 Jul 2008	10:38	7	1	0	0.3	0.5	0.7	24.3	7.1	0.9	13	611
	11 Aug 2008	10:08	30	1	0	0.3	0.4	0.5	25.4	7.5	0.8	9	645
TLE	10 Apr 2007	13:30	3	5		0.3	0.25	0.6	17.1	8.0	8.8	91	852
	7 May 2007	11:00	< 6	5	8	0.2	0.21		23.0	7.6	7.5	88	831
	2 Oct 2007	12:00	> 7	3	1.4	0.2	0.5[a]	0.23	25.8	7.8	9.0	111	947
	7 Jul 2008	11:20	7	2	1.7	0.3	0.45	0.5	26.1	7.7	7.5	94	999
	11 Aug 2008	11:10	30	3	2.2	0.2	0.35	0.4	26.6	7.9	7.1	89	1092
Willis	7 May 2007	13:10	< 6	5	43	0.3	0.45	0.91	23.4	7.5	8.1	96	579
	3 Jun 2008	11:38	18	3	6.7	0.3	0.65	0.65	25.5	7.9	7.5	91	647
	7 Jul 2008	14:05	7	2	0.47	0.3	0.4	0.5	26.0	8.0	7.5	92	1,850
	11 Aug 2008	13:50	33	2	0.08	0.25	0.15	0.3	28.1	8.3	6.7	87	3,151
Clear	21 May 2007	12:35	< 14	3	5.9	0.3	0.3	0.55	20.5	6.8	8.1	90	195
	4 Sep 2007	9:53	< 1	3	3.9	0.3	0.8[a]	0.5	23.9	7.6	7.3	86	143
	9 Jun 2008	11:07	23	3	1.6	0.3	0.55	0.7	25.3	7.5	6.6	83	168
	4 Aug 2008	10:20	20	2	0.52	0.3	0.5	0.7	24.3	6.7	6.4	76	142
Duck	21 May 2007	14:07	< 14	3	10	0.3	0.8[a]	0.33	20.9	6.9	6.4	72	620
	4 Sep 2007	11:05	< 1	3	4.5	0.3	0.6	0.7	24.0	7.1	4.3	51	419
	9 Jun 2008	12:19	23	2	1.7	0.3	0.45	0.7	26.2	7.2	2.9	36	518
	4 Aug 2008	11:40	20	1	0	0.3	0.6	0.75	25.6	6.6	1.3	16	280
Walnut	21 May 2007	9:40	< 14	3	37	0.3	0.4	0.6	23.6	7.4	6.6	78	539
	4 Sep 2007	11:38	< 1	3	14	0.3	1	1	24.8	7.6	6.9	84	786
	9 Jun 2008	13:46	23	3	11.5	0.3	0.7[a]	0.4	26.2	7.9	7.2	89	871
	4 Aug 2008	13:35	20	2	9.8	0.2	0.8[a]	0.2	26.1	8.0	7.1	87	766

[a] Secchi depth measurement was taken at a deeper location upstream.

Table 22. Diel measurements of temperature, pH, dissolved oxygen and specific conductance.

Creek	Deployment Date	Depth (m)	Temperature (°C)			pH		Dissolved oxygen (mg/L)				Specific conductance (µS/cm)		
			Average	Min	Max	Min	Max	Average	Min	Max	Range	Average	Min	Max
Little Elm	10 Apr 2007	0.4	15.2	13.6	16.3	7.9	7.9	8.6	8.2	9.3	1.1	522	507	532
	7 May 2007	0.4	22.9	22.7	23	7.8	8	7.5	7.4	7.7	0.3	575	574	577
	2 Oct 2007	0.3	24.3	23	25.4	7.6	7.7	5.8	5.4	6.7	1.3	564	559	568
	7 Jul 2008	0.3	23.6	22.9	24	7.1	7.3	0.7	0.5	0.8	0.3	618	611	628
	11 Aug 2008	0.2	24.8	24.5	25.1	7.1	7.2	0.5	0.4	0.9	0.5	615	609	621
TLE	7 May 2007	0.2	23.6	22.3	24.9	7.9	8	7.1	6.9	7.4	0.5	817	806	827
	2 Oct 2007	0.3	25.3	23.5	27.6	7.9	8.3	7.4	6.5	9.2	2.7	960	943	972
	7 Jul 2008	0.2	25.8	24.6	27.9	7.8	8.1	7.9	7.6	9	1.4	992	968	1007
	11 Aug 2008	0.1	27.1	26.3	28.7	7.8	8.2	6.7	6.1	8.3	2.2	1075	1058	1084
Willis	7 May 2007	0.3	23.6	23	24.2	8	8	7.8	7.6	8	0.4	561	555	565
	3 Jun 2008	0.3	25.7	24.8	26.8	7.6	7.8					608	605	616
	12 Jun 2008	0.3	26.2	25.6	27.2	7.9	7.9	6.9	6.6	7.8	1.2	653	648	656
	7 Jul 2-08	0.3	25.3	24.7	26	7.6	7.9	6.7	6.1	7.7	1.6	710	678	724
	11 Aug 2008	0.2	26.3	25.8	26.7	7.6	8	7.8	5.5	10	4.5	543	539	549
Clear	22 May 2007	0.3	21.1	20.6	21.4	7	7	7.8	7.5	8	0.5	185	164	210
	4 Sep 2007	0.3	24.3	24	24.5	6.9	7.2	7	6.8	7.2	0.4	141	139	143
	9 Jun 2008	0.3	25.3	24.9	25.8	6.7	6.9					166	164	179
	25 Jun 2008	0.3	24.4	23.9	25.2	6.9	7	6.7	6.7	6.9	0.2	134	132	136
	4 Aug 2008	0.2	25.4	24.5	26.3	6.5	6.6	6	5.6	6.2	0.6	148	140	155
Duck	22 May 2007	0.3	20.9	20.7	21.2	7.1	7.2	5.8	5.5	6.2	0.7	607	587	616
	4 Sep 2007	0.3	24.7	24.2	25.2	7	7.1	5.6	5.2	5.8	0.6	481	437	508
	9 Jun 2008	0.3	26.3	26	26.6	6.7	6.9	2.3	2	2.6	0.6	533	527	540
	4 Aug 2008	0.3	25.8	25.6	26	6.7	6.8	2.6	2.3	2.8	0.5	262	257	268
Walnut	22 May 2007	0.3	23.3	23	23.5	7.4	7.5	6.4	6.3	6.6	0.3	543	532	561
	4 Sep 2007	0.3	24.8	24.7	25.1	7.7	7.8	6.6	6.3	6.7	0.4	798	782	810
	9 Jun 2008	0.3	26	25.7	26.4	7.9	8	6.6	6.2	7.2	1	815	695	878
	4 Aug 08	0.3	26	25.9	26.3	7.9	8	7.1	6.7	7.4	0.7	771	742	799

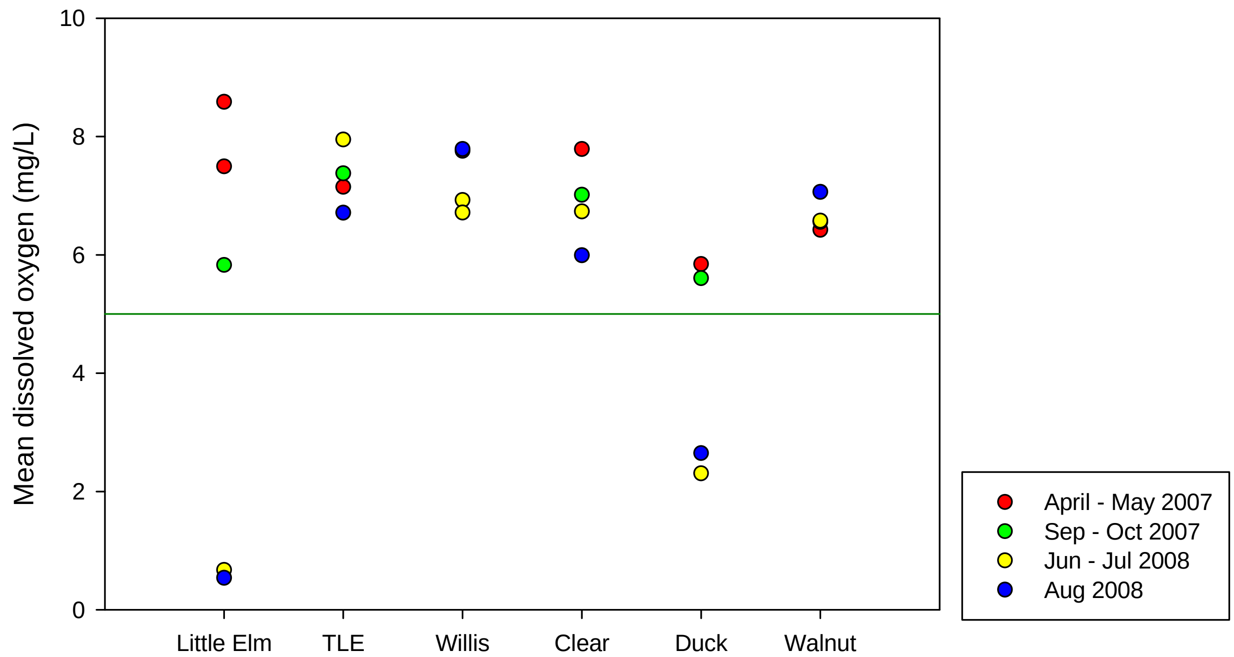

Figure 47. Mean dissolved oxygen values for 24-hour datasonde deployments.
The horizontal line represents the water quality standard (5 mg/L).

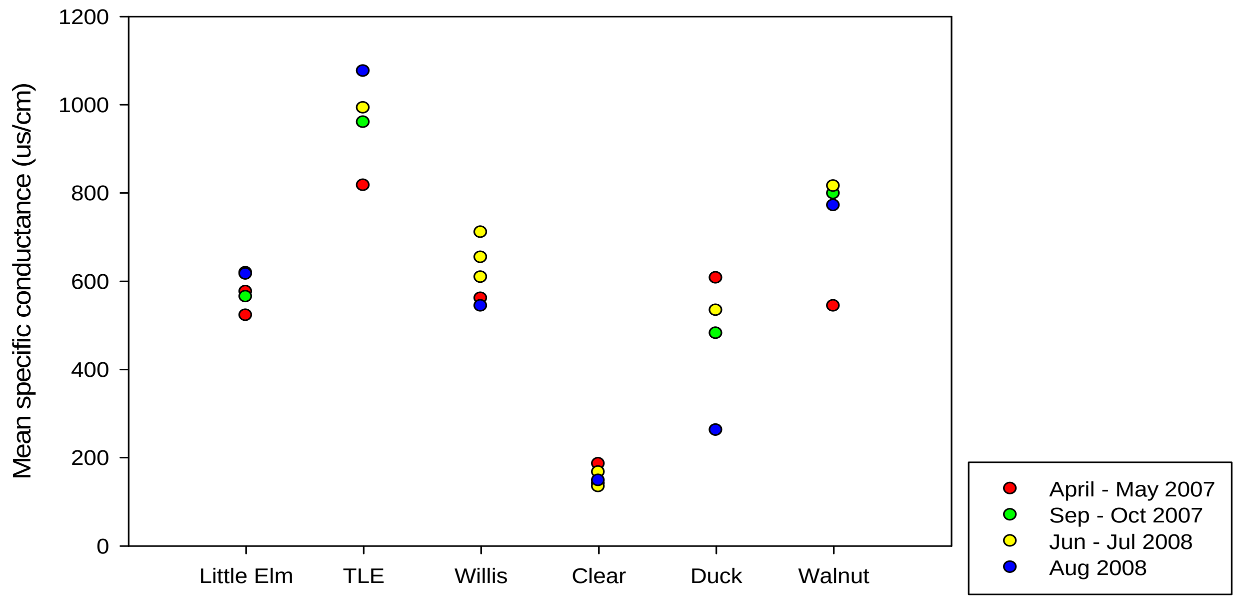

Figure 48. Mean specific conductance values for 24-hour datasonde deployments.

Dissolved oxygen values in the Tributary of Little Elm Creek showed a pronounced diel cycling characteristic of algal photosynthesis and respiration (Figure 49). Diel cycling with smaller swings was also consistently observed for Willis Creek and Walnut Creek. Weak swings were seen for Little Elm Creek in October 2007 and June 2008. Clear Creek and Duck Creek showed little, if any, diel cycling (Figure 50).

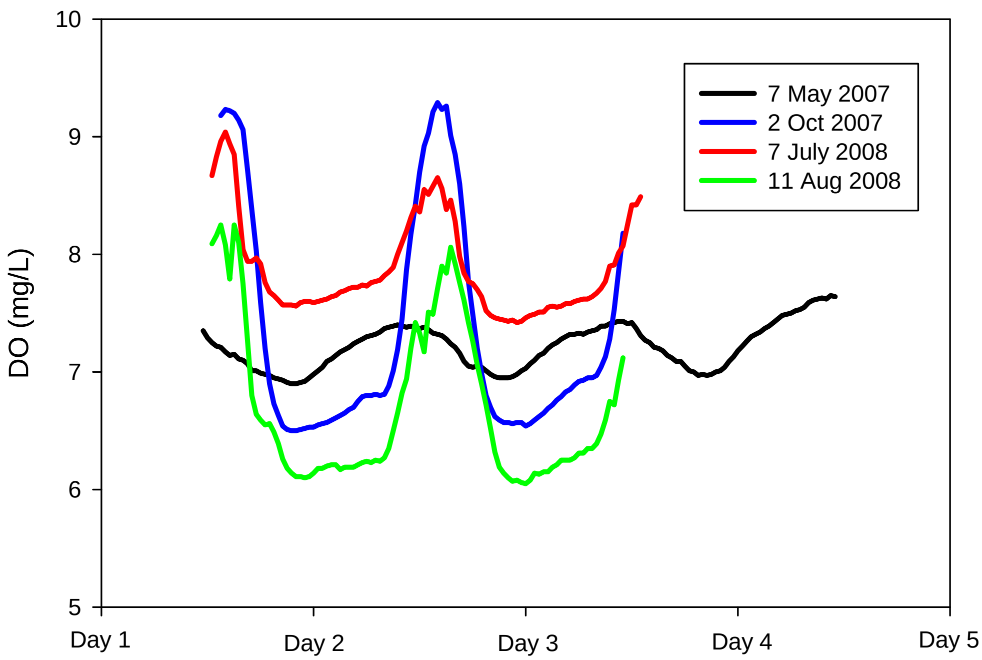

Figure 49. Diel dissolved oxygen levels in the Tributary of Little Elm Creek.

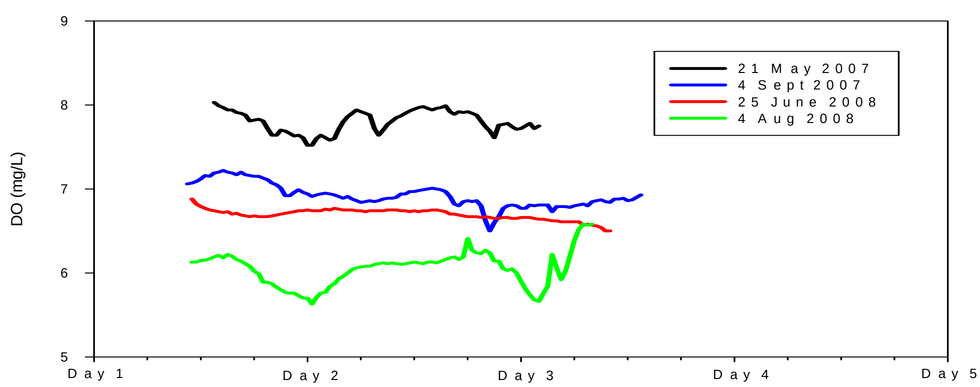

Figure 50. Diel dissolved oxygen levels in Clear Creek.

Water Chemistry

Water chemistry samples were taken at each sampling trip (Table 23 and Table 24). Values for nutrient parameters may be compared with various screening levels (Table 25). TCEQ screening levels represent the 85^{th} percentile of all stream data over a recent period (TCEQ 2008).

From May 2007 to August 2008, Little Elm Creek showed slightly increasing concentrations of total suspended solids (TSS) (Figure 51), volatile suspended solids (VSS), total dissolved solids (TDS) (Figure 52), chlorides and sulfates. Little Elm Creek had elevated nitrate concentrations in April, May and October of 2007 (Figure 53) that exceeded the TCEQ nitrate screening level of 1.95 mg/L (Table 25). Nitrate concentrations were lower in 2008. Ammonia, total phosphorus (Figure 54) and chlorophyll-*a* concentrations (Figure 55) were unremarkable in 2007 and 2008 with one exception. The August 2008 ammonia concentration exceeded the TCEQ screening level (0.33 mg/L). The elevated ammonia is likely due to the concentration of aquatic organisms in the diminishing perennial pool where the water sample was collected.

The Tributary of Little Elm Creek had higher concentrations of TSS in 2007 than 2008 (Figure 51). Concentrations of TDS, chlorides and sulfates increased from 2007 to 2008. The Tributary of Little Elm Creek had increasing concentrations of nitrate from 2007 to 2008 and each sample exceeded the TCEQ screening level of 1.95 mg/L (Figure 53). Phosphorus screening levels were exceeded for orthophosphate (0.37 mg/L) in April 2007, July 2008 and August 2008 and total phosphorus (0.69 mg/L) in April 2007 and August 2008 (Figure 54). Chlorophyll-*a* concentrations were all low throughout the study.

Willis Creek had increasing concentrations of chloride, sulfate, TSS, TDS and VSS from 2007 to 2008 with the largest increase between the July and August 2008 samples. Willis Creek was intermittent with large perennial pools in August 2008; however, the downstream pool receives treated domestic effluent from the City of Granger upstream of where the water chemistry samples were collected and it is apparent the City of Granger's discharge has influenced the water quality in a portion of the study reach. Ammonia concentrations were low throughout the study while nitrate concentrations exceeded the TCEQ screening level of 1.95 mg/L at each sampling event (Figure 53). A decrease in nitrate was observed in August 2008, while total phosphorus and orthophosphate increased in July and August 2008. The total phosphorus and orthophosphate concentrations exceeded the TCEQ screening levels of 0.69 mg/L and 0.37 mg/L, respectively (Figure 54). Chlorophyll-*a* concentrations in July and August 2008 exceeded the TCEQ screening level of 14.1 μg/L (Figure 55).

The water chemistry data from Clear, Duck and Walnut Creeks was consistent for measured parameters with only a few exceptions. Duck Creek had an ammonia concentration in May 2007 that was larger than subsequent measurements; however, it was below the TCEQ screening criteria of 0.33 mg/L. Walnut Creek had one elevated chlorophyll-*a* measurement in May 2007 and it was also below the screening level of 14.1 μg/L (Figure 55).

The total organic carbon (TOC), 5-day carbonaceous biochemical oxygen demand ($CBOD_5$), and nitrite measurements provided little information as most were at or near detection limits.

Table 23. Water chemistry data and means for each sampling event: suspended solids, dissolved solids and carbonaceous parameters.

Creek	Date	TDS (mg/L)	Chloride (mg/L)	Sulfate (mg/L)	TSS (mg/L)	VSS (mg/L)	TOC (mg/L)	$CBOD_5$ (mg/L)
Little Elm	10 Apr 2007	279	13	24	7	3	4.8	1 [b]
	7 May 2007	334	16	29	11	3	3.8	1 [b]
	2 Oct 2007	321	17	28	4	1	2.7	5
	7 Jul 2008	350	20	29	20	7	4.1	1 [b]
	11 Aug 2008	369	17	35	21	6	5.0	1 [b]
Mean		331	17	29	13	4	4.1	2
TLE	10 Apr 2007	500	69	78	84	6 [c]	6.9	2 [b]
	7 May 2007	479	60	79	102	11	5.7	1 [b]
	2 Oct 2007	574	131	89	14	2	7.4	2 [a]
	7 Jul 2008	581	130	98	24	6	7.1	1 [b]
	11 Aug 2008	617	164	109	26	6 [c]	7.5	1 [b]
Mean		550	111	90	50	6	6.9	1
Willis	7 May 2007	322	17	39	26	5	3.5	1 [b]
	3 Jun 2008	398	21	61	18	5	2.1	1 [b]
	7 Jul 2008	806	139	163	28	10	4.3	1 [b]
	11 Aug 2008	1900	501	372	53	12	7.9	1 [b]
Mean		857	170	159	31	8	4.4	1
Clear	24 May 2007	141	22	17	9	1	6.6	1 [a]
	4 Sep 2007	121	16	8	9	3	4.4	1 [a]
	9 Jun 2008	124	20	10	5 [c]	1 [b, c]	4.8	2 [b]
	4 Aug 2008	113	20	7	7	2	4.1	1 [b]
Mean		125	20	11	8	2	5.0	1
Duck	24 May 2007	375	78	83	3 [c]	1 [b, c]	7.1	0 [a, c]
	4 Sep 2007	249	51	48	9	3	7.4	1 [a]
	9 Jun 2008	306	68	55	21	4	6.2	2 [b]
	4 Aug 2008	162	35	21	16	3	5.1	1 [b]
Mean		273	58	52	12	3	6.4	1
Walnut	24 May 2007	330	52	81	21	4	5.0	1 [a]
	4 Sep 2007	480	79	94	16	4	2.3	1 [a]
	9 Jun 2008	550	73	138	11	3	1.5	1 [b]
	4 Aug 2008	454	75	85	12	5	1.4	1
Mean		454	70	100	15	4	2.6	1

[a] Concentration below laboratory Practical Quantitation Level (PQL).
[b] Non detection. Reported at half the Method Detection Limit (MDL).
[c] Ratio of Percent Difference (RPD) outside of quality control range for duplicate samples. Average concentrations reported.

Table 24. Water chemistry data and means for each sampling event: nutrient parameters.

				Nitrogen (mg/L)					Phosphorus (mg/L)	
Creek	Date	Chlorophyll-*a* (µg/L)	Pheophytin-*a* (µg/L)	Ammonia	Total Kjeldahl	Nitrate	Nitrite	Total (calculated)[d]	Orthophosphate	Total
Little Elm	10 Apr 2007	1.3	0.2[a]	0.09	0.58	2.39	0.004[a]	2.98	0.002[b]	0.021
	7 May 2007	0.3[a]	0.0	0.05[b, c]	0.80[c]	2.27	0.004[a]	3.07	0.010[a, c]	0.033
	2 Oct 2007	0.2[a]	0.0[b]	0.27	0.31	5.50	0.013	5.82	0.002[b]	0.008[a]
	7 Jul 2008	2.0[c]	0.5[a, c]	0.19	0.75	0.50	0.026	1.28	0.012[b, c]	0.069
	11 Aug 2008	3.0	1.7	1.13	1.79	0.56	0.051	2.40	0.053	0.111
Mean		1.4	0.5	0.34	0.84	2.24	0.020	3.11	0.016	0.048
TLE	10 Apr 2007	0.7	0.2[a]	0.22	0.84	4.75	0.108	5.70	0.804	0.952
	7 May 2007	0.5[a]	0.1[a]	0.18	1.19	2.92	0.153	4.26	0.106	0.200
	2 Oct 2007	0.6	0.2[a]	0.22	0.73	5.12	0.001[b]	5.86	0.266	0.280
	7 Jul 2008	0.2[a]	0.1[a]	0.05	1.34	9.04	0.013	10.39	0.394	0.438
	11 Aug 2008	0.7[c]	0.2[a, c]	0.04	1.27	9.31	0.002[b]	10.58	0.824	0.881
Mean		0.5	0.2	0.14	1.07	6.23	0.055	7.36	0.479	0.550
Willis	7 May 2007	0.9	0.2[a]	0.00[b]	0.58	5.53	0.007[a]	6.11	0.007[a]	0.033
	3 Jun 2008	1.4	0.3[a]	0.03	0.15	7.60	0.005[a]	7.75	0.009[a]	0.027
	7 Jul 2008	14.9	3.9	0.07	0.99	7.99	0.023	9.00	0.197	0.274
	11 Aug 2008	21.4	9.2	0.07	1.57	2.01	0.002[b]	3.58	1.43	1.71
Mean		9.6	3.4	0.04	0.82	5.78	0.009	6.61	0.41	0.51
Clear	24 May 2007	0.6	0.2[a]	0.08	0.84	0.41	0.007[a]	1.25	0.002[b]	0.062
	4 Sep 2007	0.2[a]	0.0[a]	0.09	0.14	0.28	0.001[b]	0.41	0.002[b]	0.027
	9 Jun 2008	0.3[a]	0.2[a]	0.05	0.32	0.36	0.002[b]	0.68	0.001[b]	0.040
	4 Aug 2008	0.3[a]	0.1[a]	0.00[b]	0.29	0.38	0.002[b]	0.66	0.001[b]	0.103
Mean		0.4	0.1	0.06	0.39	0.36	0.003	0.75	0.001	0.058
Duck	24 May 2007	0.4[a]	0.2[a, b, c]	0.20[c]	0.34	0.53	0.001[b]	0.87	0.002[b]	0.056
	4 Sep 2007	0.4[a]	0.1[a]	0.10	0.28	0.35	0.001[b]	0.63	0.022	0.075
	9 Jun 2008	0.1[a]	0.0[b]	0.09	0.54	0.38	0.002[b]	0.93	0.001[b]	0.097
	4 Aug 2008	1.0	0.2[a]	0.10	0.52	0.04	0.002[b]	0.56	0.037	0.170
Mean		0.4	0.1	0.12	0.42	0.32	0.001	0.75	0.015	0.100
Walnut	24 May 2007	4.1	1.3	0.12	0.36	0.11	0.001[b]	0.48	0.019	0.090
	4 Sep 2007	0.6	0.1[a]	0.12	0.14	0.13	0.001[b]	0.28	0.053	0.086
	9 Jun 2008	0.3[a]	0.2[a]	0.06	0.18	0.11	0.002[b]	0.30	0.072	0.131
	4 Aug 2008	0.4[a]	0.2[a]	0.00[b]	0.12	0.10	0.002[b]	0.22	0.054	0.076
Mean		1.4	0.4	0.08	0.20	0.11	0.001	0.32	0.050	0.096

[a] Concentration below laboratory Practical Quantitation Level (PQL).
[b] Non detection. Reported at half the Method Detection Limit (MDL).
[c] Ratio of Percent Difference (RPD) outside of quality control range for duplicate samples. Average concentrations reported.
[d] Total Nitrogen was calculated based on the sum of Total Kjeldahl Nitrogen + Nitrite + Nitrate.

As part of their effort to encourage states to develop numeric criteria for nutrients, EPA has published nutrient data for streams nationwide. The EPA reference value (25th percentile) for total phosphorus in Ecoregion 32 is 0.045 mg/L (Table 25). The mean total phosphorus value for Little Elm (0.048 mg/L) was close to this value, but mean values for Tributary of Little Elm and Willis Creeks exceeded the reference level by about an order of magnitude (0.55 and 0.51 mg/L, respectively). The EPA reference value for Ecoregion 33 is 0.100 mg/L and the total phosphorus values for all three Ecoregion 33 streams were at or below this level, with Clear Creek at 0.058 mg/L, Duck at 0.100 mg/L and Walnut at 0.095 mg/L. Mean total phosphorus values at Tributary of Little Elm, Willis, Duck and Walnut Creeks exceeded the mesotrophic-eutrophic boundary (0.075 mg/L) (EPA 2001a).

Total nitrogen values were calculated as the sum of total Kjeldahl nitrogen (TKN), nitrite and nitrate (Table 24, Figure 56) and were compared with reference values (Table 25). Calculated total nitrogen concentrations for Ecoregion 32 stream were variable and were dominated by nitrate values. All total nitrogen mean values exceeded both the Ecoregion 32 reference value (0.77 mg/L) and the mesotrophic-eutrophic boundary (1.5 mg/L) (EPA 2001a). Total nitrogen levels for Ecoregion 33 streams were low. Total Kjeldahl nitrogen and nitrate values were close, with TKN values slightly exceeding nitrate levels. Mean total nitrogen values for Clear and Duck Creeks (0.75 mg/L) slightly exceeded the proposed oligotrophic-mesotrophic boundary (0.7 mg/L), while the Walnut Creek mean (0.32 mg/L) was less than this boundary value.

All chlorophyll-a mean values in Ecoregion 32 exceeded the EPA reference condition value (0.2 µg/L) and fell below the oligotrophic-mesotrophic boundary (10 µg/L). In Ecoregion 33, Walnut Creek was the only stream with a chlorophyll-a mean value (1.4 µg/L) that exceeded the reference value (0.733 µg/L).

Table 25. Screening levels for nutrient parameters in freshwater streams.

Nutrient	Screening level (TCEQ 2008)	Ecoregion 32 EPA reference condition (EPA 2001a)	Ecoregion 33 EPA reference condition (EPA 2001b)	Oligotrophic-mesotrophic boundary (EPA 2001a)	Mesotrophic-eutrophic boundary (EPA 2001a)
Ammonia - N	0.33 mg/L				
Nitrate - N	1.95 mg/L				
Nitrite + Nitrate – N		0.39 mg/L	0.138 mg/L		
Orthophosphate	0.37 mg/L				
Total Phosphorus	0.69 mg/L	0.045 mg/L	0.100 mg/L	0.025 mg/L	0.075 mg/L
Total Nitrogen - reported		0.85 mg/L	0.935 mg/L	0.7 mg/L	1.5 mg/L
Total Nitrogen – calculated[a]		0.77 mg/L	0.681 mg/L		
Chlorophyll-*a*	14.1 µg/L	0.2 µg/L	0.733 µg/L	10 µg/L	30 µg/L

[a] Total Nitrogen was calculated based on the sum of Total Kjeldahl Nitrogen + Nitrite + Nitrate.

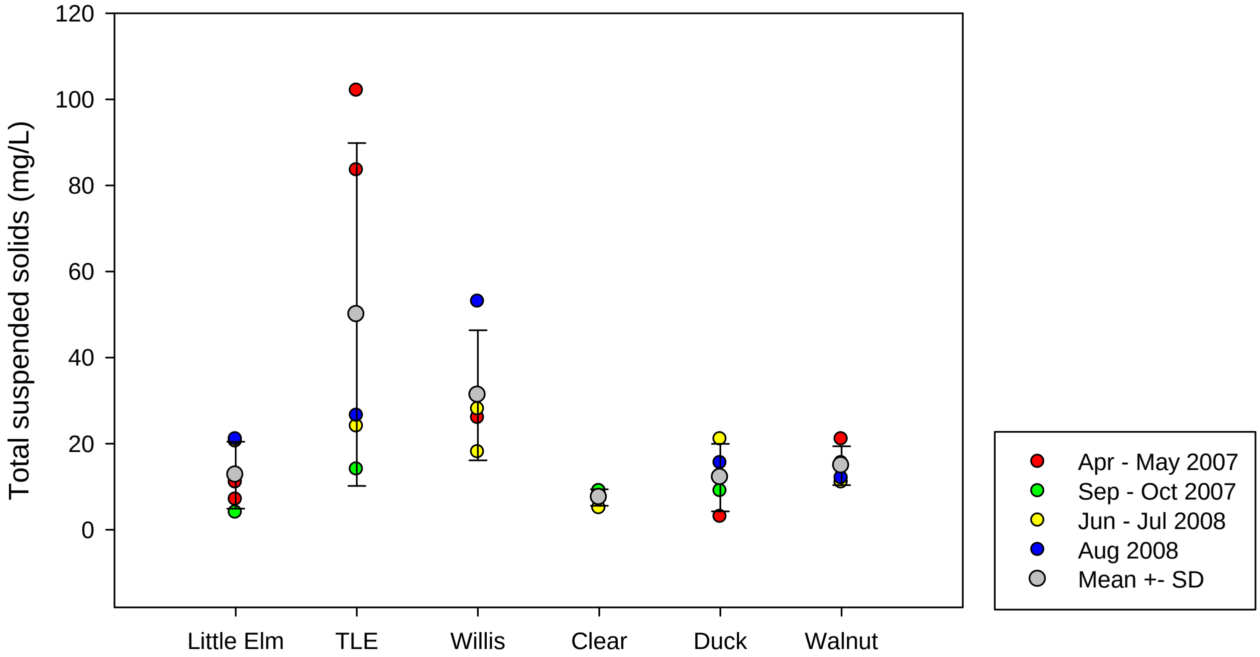

Figure 51. Total suspended solids means, standard deviations and event results.

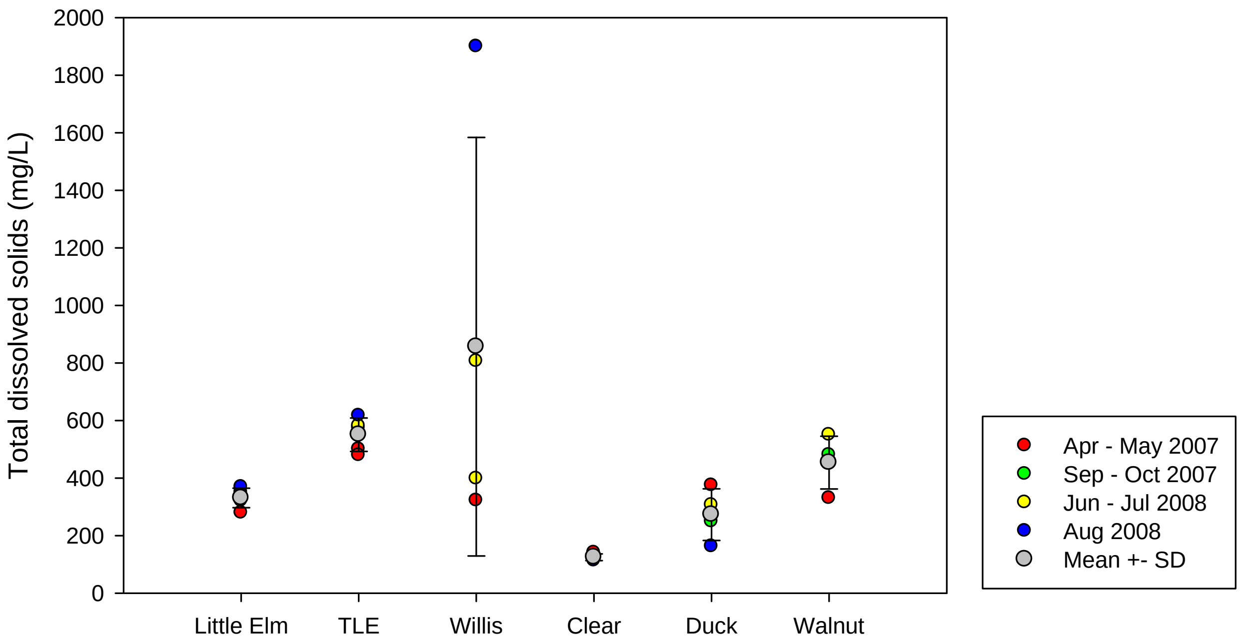

Figure 52. Total dissolved solids means, standard deviations and event results.

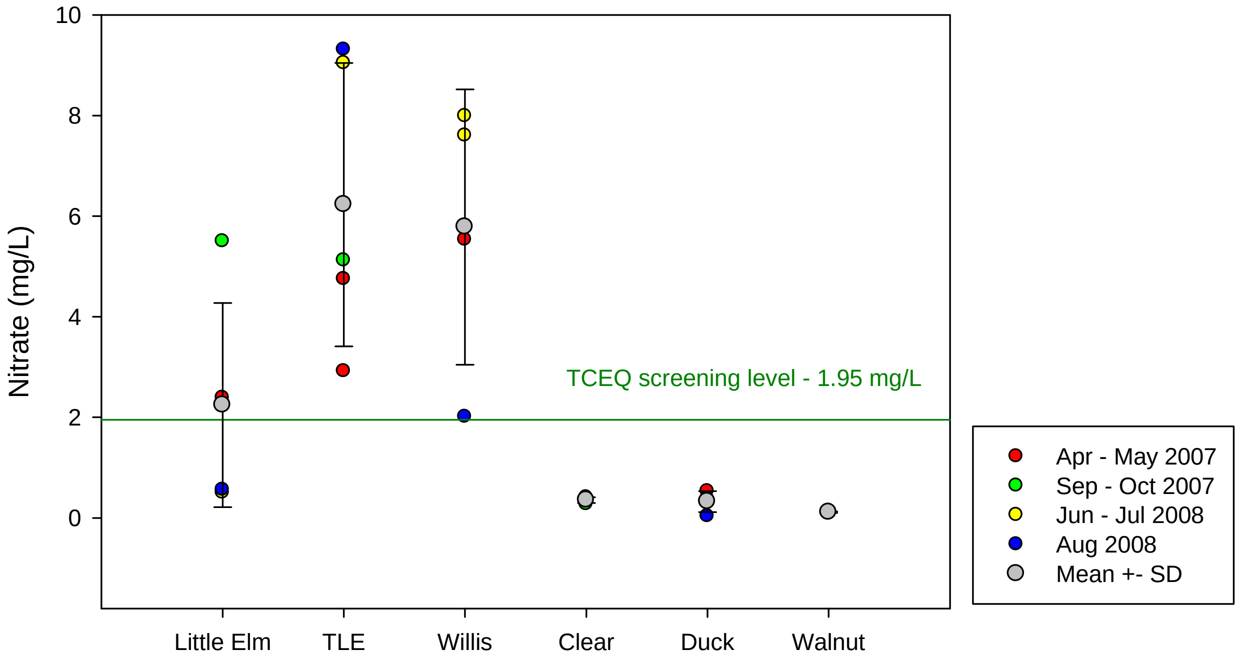

Figure 53. Nitrate means, standard deviations and event results.

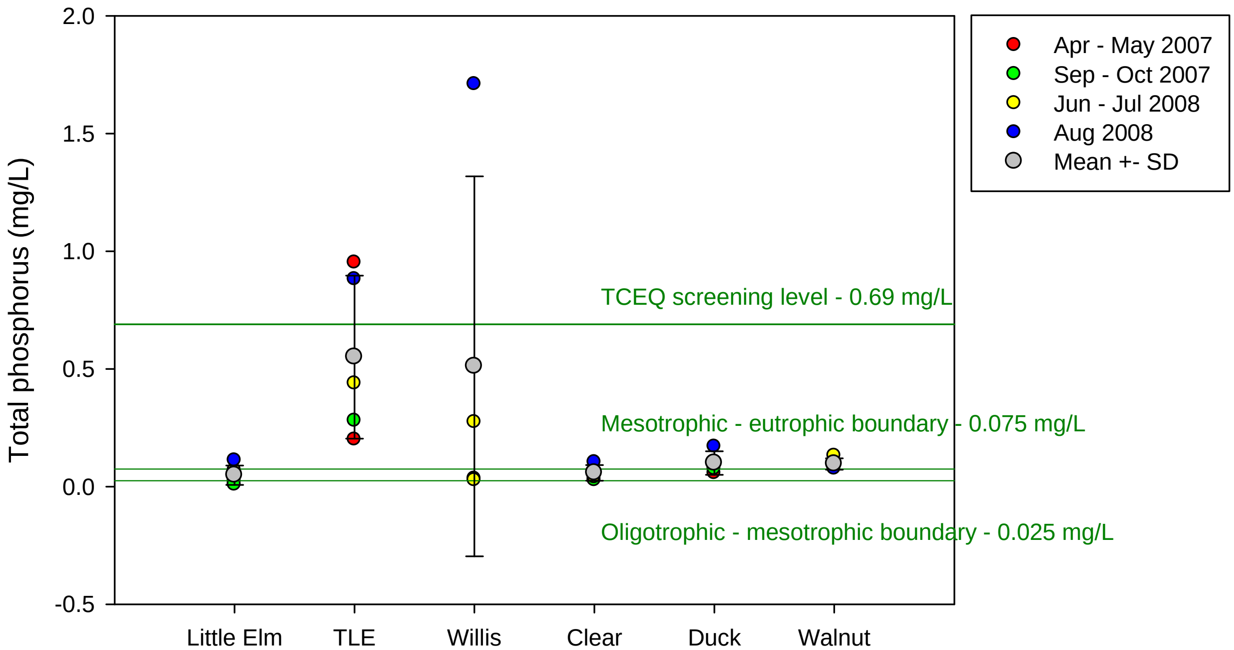

Figure 54. Total phosphorus means, standard deviations and event results.

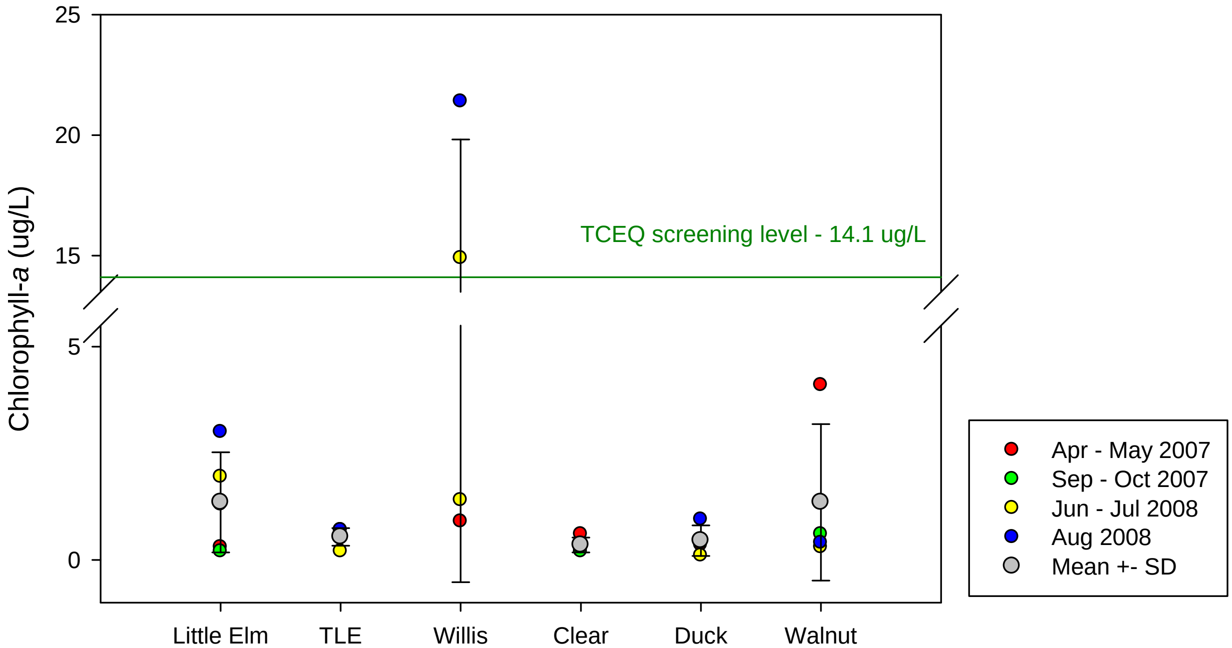

Figure 55. Chlorophyll-*a* means, standard deviations and event results.

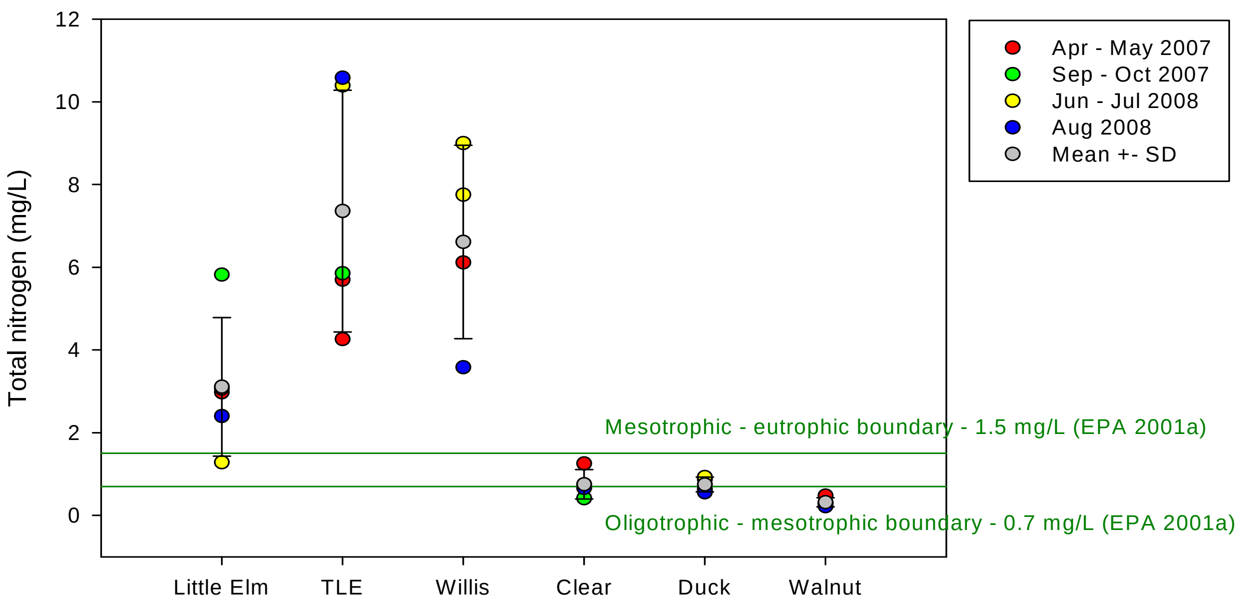

Figure 56. Total nitrogen means, standard deviations and event results.
Total nitrogen was calculated as the sum of total Kjeldahl nitrogen, nitrate and nitrite.

Flow and ecoregional characteristics appear to have contributed to the variability in water chemistry particularly in Ecoregion 32 creeks (Figure 57). The effects of high flow conditions in 2007 and dry conditions in 2008 appeared to have influenced the water chemistry in Ecoregion 32 more so than in Ecoregion 33.

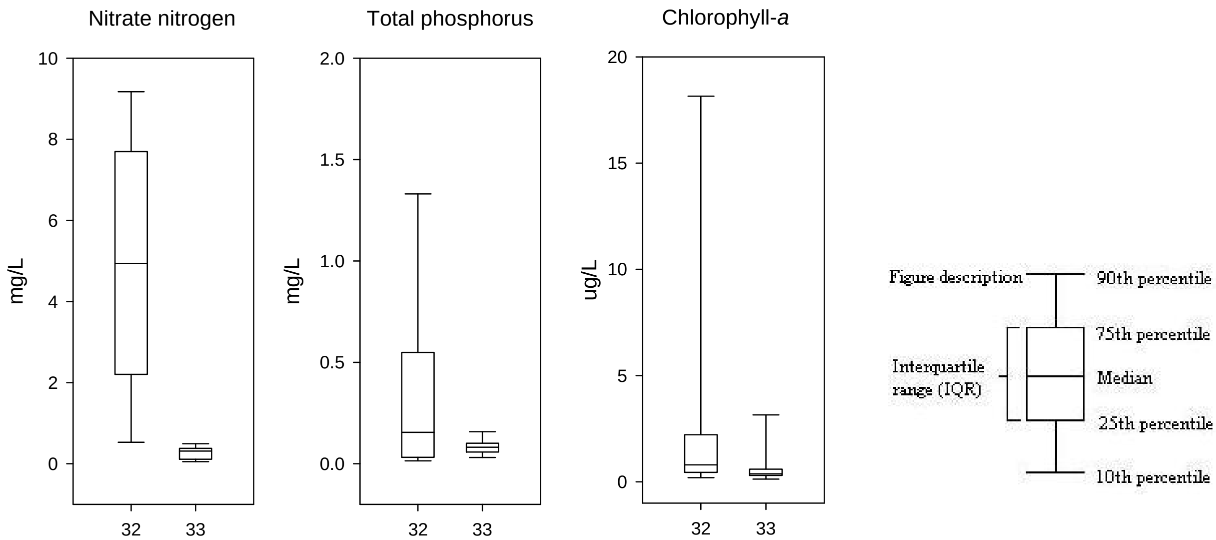

Figure 57. Nutrient and chlorophyll-*a* concentrations by ecoregion.
The top of the box is the 75th percentile, bottom of box is the 25th percentile, the line through the box is the median, the upper whisker is the 90th percentile and the bottom whisker is the 10th percentile.

Borchardt (1996) suggests that growth-limiting nutrient for benthic algae can be gauged roughly from the ambient nitrogen (N) to phosphorus (P) ratio, using dissolved inorganic nitrogen and orthophosphate. N:P ratios were calculated for all streams (Figure 58). Mean ratios varied from 12 (Walnut Creek) to 626 (Clear Creek) and ratios for individual events varied from 2 to 6650. N:P ratio values were generally higher in 2007 than 2008. The effluent-dominated streams, Tributary to Little Elm and Walnut Creeks, exhibit less variability in N:P ratios than other creeks (Figure 58). Even so, N:P ratios ranged from 3 to 46 for Walnut Creek and 11 to 54 for Tributary to Little Elm Creek. Borchardt (1996) indicates that benthic algae growth may be P-limited for ambient or cellular N:P ratios greater than 20:1, N-limited for ratios less than 10:1, and for ratios between 10:1 and 20:1 the situation is ambiguous. Based on this, Little Elm and Clear Creeks would appear to be consistently P-limited, while Tributary to Little Elm, Willis, Duck and Walnut Creeks may fluctuate among P-limitation, N-limitation, and co-limitation.

Table 26. Nitrogen to phosphorus ratios.

Creek	Date	Molarity (moles/L) Ammonia	Nitrate	Nitrite	Dissolved inorganic nitrogen[a]	Orthophosphate	N:P Ratio[b]
Little Elm	10 Apr 2007	0.0051	0.0385	0.000087	0.0438	0.000016	2771
	7 May 2007	0.0029	0.0366	0.000076	0.0396	0.000100	396
	2 Oct 2007	0.0160	0.0887	0.000283	0.1050	0.000016	6650
	7 Jul 2008	0.0112	0.0081	0.000565	0.0199	0.000128	156
	11 Aug 2008	0.0665	0.0090	0.001109	0.0766	0.000558	137
Mean		0.0203	0.0362	0.000424	0.0570	0.000163	349
TLE	10 Apr 2007	0.0126	0.0766	0.002337	0.0916	0.008463	11
	7 May 2007	0.0103	0.0471	0.003326	0.0607	0.001116	54
	2 Oct 2007	0.0132	0.0826	0.000026	0.0958	0.002800	34
	7 Jul 2008	0.0029	0.1458	0.000283	0.1490	0.004147	36
	11 Aug 2008	0.0023	0.1502	0.000033	0.1525	0.008674	18
Mean		0.0083	0.1005	0.001201	0.1099	0.005040	22
Willis	7 May 2007	0.0001	0.0892	0.000152	0.0895	0.000074	1215
	3 Jun 2008	0.0017	0.1226	0.000109	0.1244	0.000095	1313
	7 Jul 2008	0.0039	0.1289	0.000500	0.1333	0.002074	64
	11 Aug 2008	0.0042	0.0324	0.000033	0.0366	0.015053	2
Mean		0.0025	0.0933	0.000198	0.0959	0.004324	22
Clear	24 May 2007	0.0048	0.0066	0.000152	0.0115	0.000016	729
	4 Sep 2007	0.0052	0.0045	0.000026	0.0097	0.000016	615
	9 Jun 2008	0.0028	0.0059	0.000033	0.0087	0.000013	664
	4 Aug 2008	0.0001	0.0060	0.000033	0.0062	0.000013	475
Mean		0.0032	0.0057	0.000061	0.0090	0.000014	626
Duck	24 May 2007	0.0119	0.0086	0.000022	0.0205	0.000016	1299
	4 Sep 2007	0.0058	0.0056	0.000026	0.0115	0.000232	49
	9 Jun 2008	0.0055	0.0062	0.000033	0.0117	0.000013	893
	4 Aug 2008	0.0060	0.0006	0.000033	0.0066	0.000384	17
Mean		0.0073	0.0052	0.000028	0.0126	0.000161	78
Walnut	24 May 2007	0.0074	0.0018	0.000022	0.0092	0.000200	46
	4 Sep 2007	0.0069	0.0022	0.000026	0.0091	0.000558	16
	9 Jun 2008	0.0034	0.0018	0.000033	0.0053	0.000758	7
	4 Aug 2008	0.0001	0.0015	0.000033	0.0017	0.000568	3
Mean		0.0044	0.0018	0.000028	0.0063	0.000521	12

[a] Dissolved inorganic nitrogen is the sum of Ammonia + Nitrite + Nitrate

[b] N:P ratio estimated as molarity of Dissolved Inorganic Nitrogen / molarity of Orthophosphate

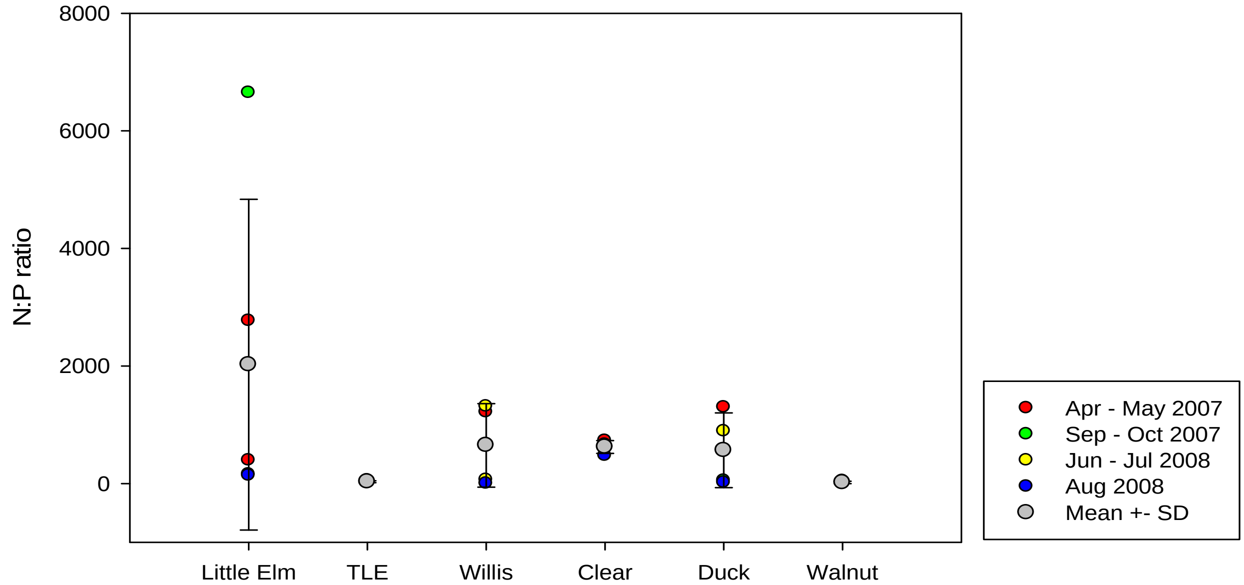

Figure 58. Nitrogen to phosphorus ratio means, standard deviations and event results.

Discussion

Effect of Flow

Stream flow influenced the biological communities in the study streams, especially at Willis and Little Elm Creeks. Spring 2007 was very wet, then rainfall essentially stopped in July 2007, beginning dry conditions which continued and intensified for the duration of the study. In all streams except for effluent-dominated Tributary of Little Elm Creek, instantaneous flows dropped lower with each sampling trip over the course of the study.

Sampling in Spring 2007 was delayed until at least two weeks after flooding, mainly to allow recolonization of macroinvertebrates and periphyton. Nonetheless, at Willis Creek in May 2007, the creek was clear and running fast. The richness and abundance of the fish community was very low; this was the only sampling event out of 24 which resulted in a limited aquatic life use for the fish community. It is possible that some of the fish in the sampling reach washed downstream to slower-flowing pools and other refugia during flooding and had not returned due to the continuing high stream flow. It is also possible that high flow hampered electrofisher sampling efficiency, carrying stunned fish quickly downstream before they could be spotted and netted. This seems unlikely, however, since the water was clear and it was easy to spot fish. Historically fish collections at Willis Creek have resulted in diverse assemblages (Contreras 2007). Subsequent fish collections during this study all scored high aquatic life use under the regionalized IBI. In hindsight, it would have been better to wait longer for the stream to recover before attempting to sample in spring 2007.

Stream flow also influenced the benthic macroinvertebrate sampling at Willis and Little Elm Creeks in May 2007, where macroinvertebrate density was low in the sampling reach. It is likely that the area was scoured by prior flooding and was in the process of recolonizing when sampled. Willis and Little Elm Creeks in May 2007 were the only sampling events out of 24 which resulted in a limited aquatic life use for the benthic macroinvertebrate community.

Another observation is the presence of *Achnanthidium minutissimum*, a small diatom which is a pioneering or colonizing species in the periphyton community. May 2007 samples showed significant numbers of *Achnanthidium minutissimum* in Willis and Little Elm Creeks, with a much smaller number observed in effluent-dominated Tributary of Little Elm Creek.

Due to the lack of rainfall, Little Elm Creek had no flow and was reduced to isolated pools in July and August 2008. Willis Creek was also reduced to isolated pools in August 2008. Flow variations were not as severe in Ecoregion 33. Clear and Walnut Creeks continued to flow throughout the study; only Duck Creek ceased flowing in August 2008. Tributary of Little Elm Creek is effluent-dominated and did not show any consistent flow pattern relative to weather over the course of the study.

Ecoregional Differences

Differences between Ecoregions 32 and 33 are a dominant pattern in this study. This is true not only for most of the biological datasets (fish, macroinvertebrates, diatoms) but for environmental data as well (water chemistry). Some data sets showed a weak or inconsistent pattern between ecoregions (soft algae, periphyton chemistry, aquatic vegetation, habitat). Ecoregional differences were expressed largely along an east-west gradient, which is represented in general by decreasing specific conductance, dissolved nutrients and pH (moving east).

Human Impacts

Anthropogenic influence was noted along the banks of Little Elm Creek as well as in the stream bed. The most noticeable effect was trash along the entire reach, including tires, shoes, human consumables, and corn crop products (Figure 3). Land use on both sides of the creek was farm land.

As noted above, the Tributary of Little Elm Creek maintains perennial flow since it is dominated by effluent from the City of Temple's wastewater treatment plant, while Little Elm Creek appears to be intermittent with perennial pools. Since the streams are close together and run approximately parallel, in the absence of anthropogenic influence, one would expect them to have very similar water chemistry and aquatic communities. Instead, one finds that the Tributary of Little Elm Creek has different water chemistry than Little Elm Creek, with higher levels of dissolved solids, suspended solids, nitrate, and total phosphorus and pronounced diel cycling of dissolved oxygen values. While water column chlorophyll-*a* levels are lower in the Tributary of Little Elm Creek, mean values of periphyton chlorophyll-*a* and ash-free dry mass were higher for the Tributary of Little Elm Creek than any other stream in the study. The diatom community was also different, with more tolerant and eutrophic taxa present in the Tributary of Little Elm Creek, and fewer sensitive taxa.

Both Little Elm Creek and the Tributary of Little Elm Creek ranked as intermediate ALU in the habitat quality, benthic macroinvertebrate and fish indices, with the Tributary of Little Elm Creek mean scores slightly higher for all indices. A number of factors may contribute to Little Elm Creek scoring lower, including nonpoint source pollution impacts, reduced physical habitat suitability (fewer bends) and seasonally intermittent flows. Another factor may be that the Tributary of Little Elm Creek is subject to an intermediate-disturbance. The intermediate-disturbance hypothesis suggests that moderate perturbations allow for a more diverse population due to intermediate disturbances that reduce species dominance and provide enough variation that the specialized species are less dominant (Ward and Stanford 1983). The Tributary of Little Elm Creek has perennial flow, but is subject to relatively high dissolved solids, suspended solids, nitrate, and total phosphorus loadings, which may constitute a perturbation.

Mussels

One of the goals of this study was to survey mussel communities in the study streams and determine if mussels were responding to differences in nutrient levels. Unfortunately no live mussels were documented during the study, which constrains the interpretation of the results of the survey. All the study streams had shells which were aged as recently dead to very long dead. Shells of different species were found in different streams, resulting in unique species lists for the study streams. The fact that live mussels were not documented makes it necessary to interpret the presence of shells with caution. We cannot assume that the shells represent live mussels who died in place. Gravel and other fill material is sometimes brought into water bodies from other places, along with shell material from the source area (Howells 2009). Species that occur in pond, backwater and canal environments include lilliput, Texas lilliput, pondhorn, tapered pondhorn, pond mussel, giant floater, and paper pondshell (Howells 2009). This describes all the taxa found in Little Elm and Tributary of Little Elm Creeks, and many of the taxa found in Willis and Walnut Creeks. Some degree of agriculture and rangeland occurs in the watersheds of all these streams, and there are likely small reservoirs in the watersheds which might contain mussels. Shells might be flushed to the streams when these reservoirs become flooded or dams fail. There is also the possibility that species were deliberately stocked in streams, or that fish containing glochidia of mussels were deliberately stocked. Live and dead specimens of the introduced Asian clam *Corbicula* sp. were found in all the study streams.

Correlations among Datasets

One way of analyzing data collected during the study is to calculate aquatic life use (ALU) categories for fish, benthic macroinvertebrates and habitat. As discussed in the Results section, an adjustment may be applied to both the fish and benthic macroinvertebrate IBIs to account for inherent sample variability (Table 27).

Comparison of the 24 uncorrected, individual sampling event scores for each stream shows that 25% of the sampling events scored the same ALU across all three indices. For 17 of the 24 individual sampling events (71%), two of the ALUs agree. Only one sampling event (4%), Little Elm Creek in August 2008, had three different ALUs.

When unadjusted mean scores for the six streams are compared, agreement is better, with four of six streams (Little Elm, Tributary of Little Elm, Willis, and Clear Creeks) having the same ALU for all three indices. For Duck and Walnut Creeks, two of three ALUs agree. When the CV adjustment is applied, only three of the six streams agree in all three indices, with three streams having two indices the same.

Table 27. Comparison of benthic macroinvertebrate, fish and habitat indices.

Creek	Date	Benthic Macroinvertebrates (BIBI)				Fish (R-IBI)				Habitat (HQI)		
		Total score	Aquatic life use	Mean score	Adjusted score	Total score	Aquatic life use	Mean score	Adjusted score	Total score	Aquatic life use	Mean score
Little Elm	9 May 2007	20	Limited	26 Intermediate	28 Intermediate	35	Intermediate	38 Intermediate	40 High	17	Intermediate	15 Intermediate
	3 Oct 2007	31	High			35	Intermediate			17	Intermediate	
	8 Jul 2008	25	Intermediate			36	Intermediate			15	Intermediate	
	12 Aug 2008	28	Intermediate			45	High			12	Limited	
TLE	9 May 2007	25	Intermediate	28 Intermediate	30 High	41	High	40 Intermediate	43 High	15	Intermediate	16 Intermediate
	3 Oct 2007	33	High			39	Intermediate			17	Intermediate	
	9 Jul 2008	26	Intermediate			39	Intermediate			15	Intermediate	
	13 Aug 2008	28	Intermediate			42	High			17	Intermediate	
Willis	8 May 2007	19	Limited	31 High	33 High	33	Limited	42 High	45 High	23	High	23 High
	4 Jun 2008	36	High			43	High			24	High	
	8 Jul 2008	38	Exceptional			45	High			23	High	
	12 Aug 2008	32	High			47	High			20	High	
Clear	23 May 2007	39	Exceptional	34 High	36 Exceptional	47	High	43 High	46 High	20	High	20 High
	5 Sep 2007	33	High			39	Intermediate			20	High	
	10 Jun 2008	32	High			44	High			22	High	
	5 Aug 2008	33	High			45	High			19	Intermediate	
Duck	23 May 2007	33	High	30 High	32 High	40	Intermediate	40 Intermediate	42 High	20	High	20 High
	6 Sep 2007	33	High			40	Intermediate			20	High	
	11 Jun 2008	28	Intermediate			40	Intermediate			19	Intermediate	
	6 Aug 2008	26	Intermediate			40	Intermediate			20	High	
Walnut	22 May 2007	37	Exceptional	32 High	34 High	42	High	41 Intermediate	44 High	20	High	21 High
	5 Sep 2007	33	High			41	Intermediate			22	High	
	10 Jun 2008	27	Intermediate			42	High			22	High	
	5 Aug 2008	32	High			40	Intermediate			21	High	

Measures of Nutrient Enrichment

One goal of this work is to add to the understanding of the effects of nutrient enrichment in small streams. To that end, it is important to understand ecological, and not just chemical, impacts of nutrients. Fish and benthic macroinvertebrate communities respond to differences in nutrients as one aspect of complex, interdependent, and dynamic environmental conditions, but their indices of biotic integrity were not designed with the intention of discerning effects of nutrient enrichment. These indices are able to detect the impact of extreme nutrient enrichment due to general declines in environmental conditions, but are insensitive to smaller changes in nutrient loading. Other, more sensitive measures are needed to detect ecological responses before catastrophic changes occur.

In an effort to stimulate nutrient criteria development, EPA prepared documents for lakes and reservoirs, rivers and streams, and wetlands. (For example, see EPA 2001a and 2001b.) These documents recommend criteria for both causative (phosphorus and nitrogen) and response (chlorophyll-a and turbidity) variables associated with the prevention and assessment of eutrophic conditions. Rather than adopt EPA's recommended criteria, Texas has pursued its own approach for reservoirs and TCEQ has initiated two studies to acquire data to use in establishing criteria for rivers and streams. Kiesling *et al*. (2006) looked at physicochemical parameters, water chemistry, fish and benthic macroinvertebrate communities, habitat and periphyton biomass in 33 East Texas streams. The authors focused on correlations among dissolved oxygen, nutrients, water column and benthic chlorophyll-*a*, and biological communities. Mabe (2007) looked at physicochemical parameters, water chemistry, fish and benthic macroinvertebrate communities, aquatic vegetation, and periphyton biomass in 13 Edwards Plateau streams. Streams were categorized as "least disturbed," "wastewater" and "not wastewater" for analysis, which included looking at correlations among stream types.

Brazos River Authority recently conducted a study of dissolved oxygen, nutrient level, and fish and benthic macroinvertebrate communities in four Brazos-basin streams (BRA 2005). The authors concluded that it was difficult to draw a clear connection between indicators of invertebrate and fish community health and the nutrient status of the streams, even though a range of nutrient conditions was documented across the four study streams. A visual survey was used to document excessive periphyton or aquatic macrophyte growth, but neither was observed during the sampling period.

Winemiller of Texas A&M University and King of Baylor University are currently conducting a study of Brazos Basin streams for the purpose of refining the Texas Habitat Quality Index (Winemiller 2009). King and Brooks are exploring nutrient dynamics in natural and simulated wadeable streams in Central Texas to determine critical levels of nutrients that cause harm to biological communities (King 2009). Both of these studies are large-scale, sampling dozens of Central Texas streams. As a consequence of their scope, these studies should provide statistically robust information regarding habitat and nutrients for the areas sampled.

In addition to characterizing the aquatic community and chemistry, this study used three methods to evaluate periphyton growth: aquatic vegetation surveys, periphyton biomass measurements and quantitative algal taxonomy. All three methods had comparable results and documented the presence of periphyton even though periphyton growth was not easily visible. Quantifying periphyton growth through one or more of these methods provides an opportunity to link elevated nutrient concentrations and habitat parameters to a direct response in the aquatic community, before extreme conditions occur.

Since datasets were small and non-normal, Spearman rank correlations were used to examine relationships among biotic and abiotic parameters. There was good agreement among most measures of algal growth (benthic algal chlorophyll-*a*, benthic algal AFDM, algal cell density, macroalgal thickness, macroalgal cover and microalgal thickness) (Table 28). Benthic algal chlorophyll-*a* and benthic algal AFDM were highly correlated ($\rho = 0.70$). Algal cell density was also highly correlated to both the benthic algal biomass measurements ($\rho = 0.75$ and 0.57, respectively). Measures of algal growth, macroalgal cover and thickness, were also correlated to biomass and cell density measurements with ρ values ranging from 0.45 to 0.55. Microalgal thickness was significantly correlated only to benthic algal chlorophyll-*a* ($\rho = 0.43$). Macroalgal cover is the easiest and most straightforward parameter to measure of the three aquatic vegetation variables. If the correlation between biomass and macroalgal cover is found to be valid for a broader range of streams, including both those receiving wastewater discharges and those without discharges, then habitat surveys could include macroalgal cover as a surrogate for benthic algal biomass, saving the time and expense of scraping substrate, and preparing and analyzing samples in the laboratory.

Some correlations were found between causal variables such as dissolved nutrient concentrations and algal response variables. Both benthic algal chlorophyll-*a* and AFDM were correlated with total phosphorus and orthophosphate, but not with nitrate. None of the aquatic vegetation measures or algal cell density was correlated with total phosphorus, orthophosphate, or nitrate. AFDM was the only measure of benthic algal growth correlated with either ammonia or total Kjeldahl nitrogen. Orthophosphate was significantly correlated with water column chlorophyll-*a* ($\rho = 0.45$), but other dissolved nutrients were not. Volatile suspended solids (VSS) was correlated with water column chlorophyll-*a* ($\rho = 0.53$), which is not surprising since algal cells suspended in the water column should contribute to both chlorophyll-*a* measurements and VSS measurements. VSS and total suspended solids were both correlated with benthic algae chlorophyll-a and AFDM, with ρ ranging from 0.52 to 0.62. VSS was correlated with numerous parameters including total dissolved solids, sulfate, total phosphorus, orthophosphate, and total Kjeldahl nitrogen. There was no correlation between water column chlorophyll-*a* and any measure of benthic algal growth.

Looking at environmental variables other than dissolved nutrients that might be expected to influence algal growth, flow severity was negatively correlated with macroalgae cover ($\rho = 0.55$) and macroalgae thickness ($\rho = 0.58$). Instantaneous flow was also negatively correlated with macroalgae cover and macroalgae thickness ($\rho = -0.49$ and -0.50, respectively). Departure from normal rainfall was negatively correlated to benthic algae chlorophyll-*a* ($\rho = -0.49$). Percent tree canopy was not significantly correlated with measures of algal growth, although such a relationship might be expected. Canopy cover is believed to be a major contributor to limiting algal growth in streams. An assessment of 225 minimally impacted streams in the western United States found that the probability of finding macroalgal growth decreased significantly when canopy cover exceeded 73.5% (Rollins *et. al*. 2002). The lack of correlation may be due in part to the relatively narrow range of percent tree canopy measured in the study streams. Canopy cover in this study ranged from 62% (only measurement below 75%) at the Tributary of Little Elm Creek to 92% at Willis Creek.

Table 28. Spearman rank correlation results for measures of algal growth.
Values are correlation coefficients (ρ). Significant correlations ($p < 0.05$) are noted in bold.

	Benthic algae chlorophyll-*a*	Ash free dry mass	Macroalgae thickness	Macroalgae cover	Microalgae thickness	Cell density	Water column chlorophyll-*a*
Benthic chlorophyll-*a*		**0.70**	**0.52**	**0.53**	**0.43**	**0.75**	0.02
Ash Free Dry Mass	**0.70**		**0.49**	**0.45**	-0.01	**0.57**	0.13
Macroalgae thickness	**0.52**	**0.49**		**0.99**	0.28	**0.52**	0.21
Macroalgae cover	**0.53**	**0.45**	**0.99**		0.31	**0.55**	0.17
Microalgae thickness	**0.43**	-0.01	0.28	0.31		0.37	0.08
Cell density	**0.75**	**0.57**	**0.52**	**0.55**	0.37		-0.09
Water column chlorophyll-*a*	0.02	0.13	0.21	0.17	0.08	-0.09	
Orthophosphate	**0.62**	**0.64**	0.44	0.39	0.19	0.31	**0.45**
Total phosphorus	**0.47**	**0.53**	0.26	0.20	0.05	0.13	0.31
Nitrate	0.19	0.26	0.09	0.05	0.06	0.28	0.12
Total Kjeldahl nitrogen	0.17	**0.59**	0.20	0.15	-0.12	0.16	0.38
Ammonia	0.10	0.37	0.05	0.06	-0.07	0.18	0.12
Specific conductance, diel mean	**0.57**	**0.58**	0.24	0.18	0.29	0.23	0.15
Total dissolved solids	**0.58**	**0.65**	0.38	0.32	0.24	0.29	0.38
Sulfate	**0.48**	**0.54**	0.27	0.21	0.15	0.16	0.32
Chloride	0.41	0.13	0.16	0.11	0.12	0.02	0.23
Total suspended solids	**0.52**	**0.55**	0.24	0.20	0.01	0.23	**0.56**
Volatile suspended solids	**0.62**	**0.59**	0.44	0.42	0.13	0.36	**0.53**
Dissolved oxygen, diel mean	0.12	0.08	-0.09	-0.07	-0.01	0.04	-0.03
pH, diel maximum	0.43	0.38	0.22	0.18	0.20	0.22	0.15
Temperature, diel mean	0.41	0.15	0.31	0.28	0.17	0.12	0.00
Secchi depth	-0.08	-0.35	-0.06	-0.02	0.19	0.04	**-0.49**
Mean stream depth	**-0.56**	-0.38	**-0.58**	**-0.57**	**-0.60**	**-0.45**	-0.16
Flow, instantaneous	-0.25	-0.12	**-0.50**	**-0.49**	-0.21	-0.30	-0.19
Flow severity	-0.23	-0.16	**-0.58**	**-0.55**	-0.16	-0.07	
Rainfall, departure from normal	**-0.49**	0.06	-0.27	-0.28	-0.37	-0.34	0.26
Mean percent tree canopy	-0.09	-0.30	0.22	0.20	-0.15	0.07	0.19
Mean percent gravel	-0.04	-0.21	0.16	0.15	0.05	0.13	0.06
Mean stream width	-0.32	-0.31	-0.22	-0.22	-0.23	-0.38	-0.03
Mean bank slope	0.08	0.14	-0.20	-0.22	-0.23	-0.18	-0.27
Mean percent bank erosion	0.03	-0.12	0.03	0.00	-0.05	-0.11	0.19
Watershed size	0.37	-0.06	0.39	**0.42**	0.41	**0.47**	**-0.43**

The USGS nutrient study conducted on small streams in the Edwards Plateau of central Texas (Mabe 2007) visually surveyed aquatic vegetation coverage in a manner similar to this study. The USGS macroalgae cover data suggested that, for streams receiving wastewater effluent, high levels of macroalgae are associated with increased total phosphorus concentrations. USGS found that the macroalgae survey is effective for identifying nuisance macroalgae growth associated with conditions of high nutrient enrichment. However, the macroalgae cover data were not as useful for streams that did not receive wastewater effluent. USGS concluded that the macroalgae survey by area cannot, in its present form, discriminate between nutrient concentrations under low nutrient conditions.

The USGS findings are consistent with the results of this work. The Tributary of Little Elm and Willis Creeks had total phosphorus concentrations that on occasion exceeded TCEQ screening levels, but high levels of macroalgae coverage were not observed at any of the creeks in this study. A number of factors could explain why high levels of macroalgae cover were not observed, including sampling soon after a scouring high flow event, high stream flows, canopy cover, stream width and depth, and shading by suspended solids.

Benthic algal biomass shows promise as an indicator of nutrient enrichment. Benthic algal biomass as estimated by chlorophyll-*a* was successful at distinguishing the steady, elevated levels of nutrients found in a wastewater-dominated stream, Tributary of Little Elm Creek, from the other streams (Figure 25). A trend or pattern was not easily observable in the other streams. All the streams except Tributary of Little Elm Creek started off with relatively low biomass in May 2007, perhaps due to recent scouring events. All the streams sampled in September and October 2007, with the exception of Tributary of Little Elm Creek (Clear, Duck, Walnut and Little Elm Creeks), had increased biomass relative to the first sample (Figure 25). Tributary of Little Elm Creek showed the opposite trend. In 2008 all sampling was conducted in June, July and August with a general trend of decreasing biomass observed.

In the USGS Edwards Plateau study, Mabe (2009) related instantaneous nutrient loads with benthic algae chlorophyll-*a* and found correlations with the sum of nitrite and nitrate, total nitrogen and total phosphorus. In the East Texas USGS study Kiesling *et al*. (2005) observed a weak negative correlation between benthic algae chlorophyll-*a* and fish IBI scores, weak positive correlations with dissolved oxygen maxima and ranges (maxima minus minima), and a weak positive correlation with dissolved nutrients. No correlation between fish or benthic IBI scores and any measure of nutrient enrichment or benthic algal growth was observed in this work.

Further study should be done to explore the feasibility and usefulness of sampling periphyton for biomass estimation. It would be useful to investigate the inherent range and variability of biomass estimates by sampling a greater range of streams in different ecoregions and sampling more intensively over time and space at a limited number of sites. Different patterns of biomass growth may occur in streams influenced by wastewater discharges, so this should be taken into account when interpreting biomass estimates.

As of 2001 about 20 states use benthic algae (periphyton) in addition to either macroinvertebrates or fish as indicators of biological condition (Figure 59) (EPA 2002a). As discussed in EPA's Consolidated Assessment and Listing Methodology Guidance (EPA 2002b), the periphyton assemblage serves as a good biological indicator in streams and shallow areas because of its naturally high number of species and rapid response to exposure and recovery. Most diatom taxa can be identified to species level by experienced taxonomists, and the tolerance or sensitivity to specific changes in environmental conditions is known for many species (Winsborough 2009). Because periphyton is attached to the substrate, this assemblage integrates physical and chemical disturbances to a stream reach.

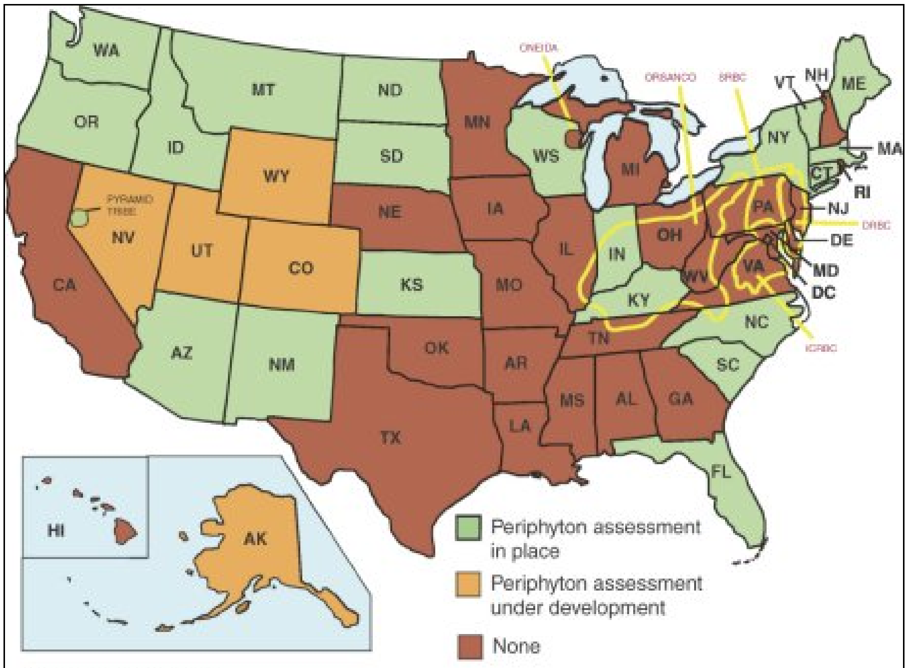

Figure 3c. Periphyton

Figure 59. Periphyton assessment programs by state.
(EPA 2002a, as referenced in Metzmeier 2009b).

As discussed by Metzmeier (2009b), neither sample methods nor interpretation of algal data are standardized among agencies at this point. Sample methods may be qualitative, quantitative or "semi–quantitative." Assessment may include biomass estimates (chlorophyll-*a* or ash-free dry mass), species composition, diatoms only, or rapid periphyton assessments (estimates of in-stream cover of aquatic vegetation, such as were done in this study and Mabe 2007). Some states have developed multi-metric indices; others use multivariate analyses, or a combination of both. Most states using periphyton assessment combine it with assessment of either fish or benthic macroinvertebrates, or use all three assemblages.

From a scientific point of view, algal taxonomy (qualitative or quantitative) is likely the most "finely-tuned" tool for providing information about the effects of nutrient enrichment on wadeable streams. However, since few agencies or entities in Texas currently have algal taxonomists on staff, the technique has the drawback of being relatively expensive compared to other biological sampling due to the need to contract with suitable experts, although others have noted that it is a relatively inexpensive and powerful tool for detecting nutrient enrichment (Stevenson and Pan 1999). In order to use periphyton assemblage information in assessment, it will be necessary to generate a body of data which will undoubtedly need to be specific to each ecoregion. To date, few studies in Texas have included algal assessment.

Benthic macroinvertebrates, fish and periphyton datasets were analyzed for correlations. The benthic macroinvertebrate IBI scores were correlated only with stream order ($\rho = 0.46$) and fish IBI scores ($\rho = 0.52$). For all study streams, the most abundant benthic functional feeding group was scrapers and the largest percentages of scrapers were found in Walnut, Clear and the Tributary to Little Elm Creeks. Spearman rank correlation revealed a significant correlation between percent scrapers and microalgae thickness ($\rho = 0.42$), but no correlation was found with other measures of periphyton biomass examined (macroalgae thickness, macroalgae cover, benthic algae chlorophyll-*a*).

The fish dataset contains one species that is considered herbivorous, the stoneroller. While stoneroller populations may be related to the periphyton community, those correlations were not explored since stonerollers are not an east Texas species, and were collected only in Ecoregion 32.

Biota and/or Environment matching (BIO-ENV) analysis revealed the environmental variables most related to the biological patterns were sulfate, mean dissolved oxygen, maximum pH, mean percent gravel and instantaneous flow. Sulfate acts as a variable affecting benthic macroinvertebrate data because the dissolved solids levels (sulfate, chloride, *etc*.) vary between ecoregions.

Next Steps / Suggestions for Future Work

Multivariate statistical techniques were useful in exploring differences among samples. MDS plots were useful in visualizing differences and natural groupings of samples, especially between ecoregions and between streams. ANOSIM allowed tests of statistical significance between groups identified *a priori* (ecoregions, streams) and SIMPER tests gave details about which species were responsible for significant differences identified by ANOSIM. LINKTREE highlighted which patterns of environmental variables matched patterns in the biological assemblages (soft algae and diatoms, in this case).

Study design considerations included sampling a number of streams with differing nutrient concentrations. The Tributary of Little Elm Creek was selected because of its constant input of nutrients from a domestic wastewater discharge upstream of the study reach. Little Elm Creek was selected in hopes that it would serve as a reference of sorts, since it is near Tributary of Little Elm Creek and yet the study reach is upstream of the point where Tributary of Little Elm Creek enters Little Elm Creek. As it turned out, Little Elm Creek had very low flow toward the end of the study, which had a large effect on sampling results that made it hard to distinguish nutrient impacts from other changes in the system. Also, while Little Elm Creek showed much lower levels of dissolved nutrients than the effluent-dominated Tributary of Little Elm Creek, there was strong evidence of nonpoint source impacts (trash, corn husks and other material in the stream) and habitat was poor (very few bends in the stream relative to Tributary of Little Elm Creek, which had the highest number of bends of any of the study streams). Walnut Creek receives wastewater from a mining operation, although that is further upstream from the study reach than the domestic wastewater discharge on Tributary of Little Elm Creek. All the streams in the study have some potential for nonpoint source nutrient input. For the streams in Ecoregion

32 this means cornfields; in Ecoregion 33 it means rangeland and possibly poultry operations (especially in the watershed of Duck Creek).

For purposes of this study it was difficult to draw direct correlations between different kinds and sources of nutrients, with the exception of the domestic wastewater in Tributary of Little Elm Creek. Clear effects of elevated nutrients were seen on the water chemistry, periphyton biomass, diatom community, and other data sets collected in Tributary of Little Elm Creek. Future data collection efforts for setting numeric nutrient criteria should consider that streams impacted by domestic wastewater probably have different responses to nutrients than those without wastewater discharge in their watersheds, as was suggested by Mabe (2007).

Selecting streams from two ecoregions was part of the study design because it was presumed that setting numeric nutrient criteria for streams must take ecoregional differences into account. Results of this study showed strong ecoregional differences in many data sets. As data collection efforts go forward for establishing nutrient criteria, ecoregional differences will have to be acknowledged. We recommend that standard protocols be followed among ecoregions, and that enough sampling be done within ecoregions to characterize the nutrient status of streams within ecoregions across a range of stream size. In retrospect it might have been better to confine sampling in this study to one ecoregion. This would have made it possible to collect samples more frequently, to better understand the temporal variability, or simply increase sample size overall to better understand variability between sites.

Flow strongly influenced the results of this study. It was hard to distinguish effects of nutrient enrichment from effects of flow in the small data set collected, especially when looking at periphyton biomass and algal communities. Standardization of procedures must include refraining from sampling algal communities that have recently been scoured. It is helpful to have good documentation of flow conditions for several weeks prior to sampling events. For purposes of developing numeric nutrient criteria, it would be good to avoid sampling streams that frequently become intermittent, since this changes the biological community and interferes with interpretation of more subtle nutrient impacts.

In this work, periphyton was sampled from woody debris, since it was available in all the streams and was the dominant hard substrate in most of the study streams. Protocols are available for sampling periphyton from rocks, sand and other substrates (USGS 2002). For this study, the decision was made to adhere to a single substrate to try to reduce variability, and we recommend future studies consider the benefits of standardizing to a single type of substrate, or analyzing data separately that are collected from different types of substrates. Another approach that is often used to reduce environmental variability is setting out artificial substrates for periphyton to colonize. This has the advantage of collecting periphyton samples that are related to the water quality of the streams but not constrained by any lack of available habitat, or habitat differences between study streams.

The aquatic vegetation survey was an effective tool for assessing the coverage of all available plant growth including macrophytes, macroalgae and microalgae. In its present form, it is thorough enough to allow an assessor to make a determination on whether benthic biomass laboratory analysis is warranted. Researchers from Auburn University and Utah State University designed a semi-quantitative method (Algal Cover Index, ACI) that can be used to rapidly estimate periphyton and algal biomass within clear-running streams in southwest Washington (Feminella and Hawkins 2000). The ACI is based on both visual and tactile assessments of periphyton. The modified methods used in this study are based on the methods used to develop the ACI, which in southwest Washington accounted for 85 percent of the variation in algal chlorophyll-*a*. There is potential for a similar index to be developed for Texas streams.

The aquatic vegetation assessment has limitations. Microalgae was difficult to identify in the field during the survey. Stream flow, sediment cover, depth and substrate were all factors that influenced the accuracy of the visual assessment. This method may prove to be best suited for shallow, clear-to-bottom streams, which are not often found in Ecoregions 32 and 33. Some of the aquatic vegetation survey measurement types were not identified in abundance, for example, sediment cover and macrophyte cover. These characteristics may, however, be important measures for other streams.

The aquatic vegetation survey is heavily tied to attributes of the stream bottom. In future assessments it may be important to pursue the collection and analysis of benthic algae for ash-free dry mass and chlorophyll-*a* from sediment in addition to woody debris in Ecoregions 32 and 33 to help strengthen the relationship between the aquatic vegetation survey and periphyton biomass.

All three techniques used to characterize levels of attached algal density, periphyton biomass measurements, quantitative algal taxonomic identification and aquatic vegetation surveys, show promise for use in assessing nutrient effects in wadeable streams and we recommend continued exploration with all three methods.

Conclusion

Water quality, fish, benthic macroinvertebrates, mussels, and periphyton were sampled four times at each of six sites in North Central Texas streams. Habitat and flow information were collected to characterize sites and aid in interpreting the other data. The study included three independent measurements of nutrient impacts on the benthic algae community: a rapid aquatic vegetation assessment technique, measurements of biomass (as ash-free dry mass and benthic algae chlorophyll-*a* density), and quantitative taxonomic identification of the soft algae and diatom benthic communities.

Fish were sampled using seine and electrofishing techniques. Data were analyzed using the regionalized index of biotic integrity (Linam *et al.* 2002). One collection effort, Willis Creek in May 2007, was rated at a limited aquatic life use. The other fish collections were rated intermediate or high. No fish collection events were rated exceptional during this study. When the four sampling events were averaged, Little Elm, Tributary of Little Elm, Duck and Walnut Creeks rated intermediate and Willis and Clear Creeks rated high.

Benthic macroinvertebrates were sampled with kick-nets or snag/woody debris collection and analyzed using the statewide benthic index of biotic integrity (Harrison 1996). Two collection efforts, Little Elm and Willis Creeks in May 2007, were rated as limited aquatic life use. Most benthic macroinvertebrates collections were rated intermediate or high. Collections at Clear Creek and Walnut Creek in May 2007 and Willis Creek in July 2008 were rated exceptional. When the four sampling events were averaged, Little Elm and Tributary of Little Elm Creeks rated intermediate and Willis, Clear, Duck and Walnut Creeks rated high. Scrapers were the dominant functional feeding group found in each stream.

Mussels were sampled using timed, random searches. No live mussels were collected during this study. Ages of shells ranged from relatively recently dead to very long dead. Willis Creek had the highest species richness (nine species), and Walnut Creek had six species. The other study streams had three species or fewer.

Physicochemical and water chemistry measurements were made. For most sampling events, mean dissolved oxygen levels for all streams exceeded 5.0 mg/L and minima exceeded 3.0 mg/L. Three exceptions occurred when streams were not flowing. Additionally, Duck Creek failed to meet mean or minimum dissolved oxygen criteria in June 2008. Pronounced diel cycling characteristic of algal photosynthesis and respiration was observed in the Tributary of Little Elm Creek. Average specific conductance values tended to increase from May 2007 – August 2008 for Ecoregion 32 streams and Ecoregion 33 average specific conductance values were variable.

Nitrate levels were higher in Ecoregion 32 streams than Ecoregion 33 streams, consistently exceeding TCEQ screening levels. Tributary of Little Elm Creek and Willis Creek had the highest total phosphorus levels in the study, consistently exceeding TCEQ screening levels. Water column chlorophyll-a levels, however, were not excessive and only exceeded TCEQ screening levels on two occasions in Willis Creek.

Habitat information was collected and analyzed using a Habitat Quality Index. All collection efforts were rated as intermediate or high. When the four sampling events were averaged, Little Elm and Tributary of Little Elm Creeks rated intermediate and Willis, Clear, Duck and Walnut Creeks rated high. All streams had a high percentage of canopy cover (62-92%), which is known to be a key limiting factor on algal and macrophyte growth.

The aquatic vegetation survey showed that aquatic vegetation cover and thickness were low throughout the study and all macro- and microalgae composite scores are below one-third the maximum possible score, which corresponds well with the absence of visual observations of nuisance algae growth. Sediment cover on algae was rarely observed at the sampling points. Macrophytes were not observed in any abundance.

Periphyton biomass was analyzed and reported in two ways: chlorophyll-*a* and ash-free dry mass (AFDM). Reported values were scaled to the original area of woody debris scraped to obtain a value representing periphyton biomass per area of substrate. Mean benthic algae chlorophyll-*a* values ranged from 8.4 to 39 mg/m^2 and ash-free dry mass values ranged from 0.72 to 1.6 mg/cm^2, which are well below threshold nuisance values of 70 mg/m^2 and 5 mg/cm^2, respectively. Wastewater-dominated Tributary of Little Elm Creek had the highest chlorophyll-*a* and ash-free dry mass levels.

Soft algae and diatom communities were identified and enumerated independently. Cyanobacteria dominated the soft algae samples, along with pennate diatoms and green algae (Chlorophyta). Diatoms were identified to species and ANOSIM revealed that diatom communities were significantly different between the two ecoregions. Community composition of the diatom samples was analyzed by applying known diatom attributes and looking for patterns among the streams. This analysis distinguished the Tributary of Little Elm Creek as having the highest percentage of tolerant and eutrophic taxa and the lowest percentage of sensitive taxa.

Stream flow influenced the biological communities in the study streams and differences between Ecoregions 32 and 33 are a dominant pattern in this study. Nutrient criteria for wadeable streams will need to acknowledge ecoregional differences. In the small data set collected, it is difficult to distinguish effects of nutrient enrichment from other effects.

All three techniques used to characterize levels of attached algal density, aquatic vegetation surveys, periphyton biomass measurements and quantitative algal taxonomic identification, show promise for use in assessing nutrient effects in wadeable streams. Effluent-dominated Tributary of Little Elm Creek stood out in both periphyton biomass and algal cell density measurements. It may be possible to refine easy, rapid aquatic vegetation survey methods to differentiate among streams by technique modifications or index development.

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Appendix A – Data

Weather

Table 29. NOAA NCDC rainfall and Palmer Drought Index (PDI) data summary.

Creek	Month	Rainfall departure from normal (in) [a]	Palmer Drought Index category [b]
		2007	
Little Elm	May	-1.29	Normal
	Oct	0.74	Extremely Moist
TLE	May	-1.29	Normal
	Oct	0.74	Extremely Moist
Willis	May	-1.39	Normal
Clear	May	3.46	Normal
	Sep	-1.63	Moderately Moist
Duck	May	3.46	Normal
	Sep	-1.63	Moderately Moist
Walnut	May	11.81	Normal
	Sep	-0.75	Moderately Moist
		2008	
Little Elm	Jul	-3.38	Normal
	Aug	-0.09	Normal
TLE	Jul	-3.38	Normal
	Aug	-0.09	Normal
Willis	Jun	-0.26	Normal
	Jul	-3.7	Normal
	Aug	-0.34	Normal
Clear	Jun	-1.95	Normal
	Aug	-1.22	Normal
Duck	Jun	-1.95	Normal
	Aug	-1.22	Normal
Walnut	Jun	-1.65	Normal
	Aug	-1.77	Normal

[a] Precipitation data source: NOAA/National Weather Service NCDC, http://www7.ncdc.noaa.gov/IPS/cd/cd.html

NCDC Weather Station Names: Stillhouse Hollow Dam, 16 miles from Little Elm Creek and the Tributary of Little Elm Creek; Granger (2007) and Granger Dam (2008), 2 and 4 miles from Willis Creek; Franklin, 16 miles from Clear Creek and 9.7 miles from Duck Creek; and Bremond, 9 miles from Walnut Creek.

If sample date is before the 15th of the month the previous month's departure from normal data is used.

[b] PDI data source: NOAA/National Weather Service - NCDC, http://www.ncdc.noaa.gov/oa/climate/monitoring/drought/mw/

Texas PDI Regions: East (Clear Creek, Duck Creek, and Walnut Creek); North Central (Little Elm Creek, Tributary of Little Elm Creek, and Willis Creek)

Table 30. NOAA NCDC rainfall and Palmer Drought Index (PDI) data for Ecoregion 32 creeks.

Sample date	NCDC date	Total monthly precip. (in) [a]	Departure from normal (in)	Normal precip. (in)	PDI - east region [b]
Little Elm Creek and Tributary of Little Elm Creek					
	30 Apr 2007	1.64	-1.29	2.93	Normal
7 May 2007	31 May 2007	11.34	6.4	4.94	Normal
	30 Jun 2007	10.99	7.12	3.87	Very Moist
	31 Jul 2007	7.44	5.56	1.88	Extremely Moist
	30 Aug 2007	0.53	-1.67	2.2	Extremely Moist
	30 Sep 2007	4.54	0.74	3.8	Extremely Moist
2 Oct 2007	31 Oct 2007	0.71	-3.14	3.85	Extremely Moist
	31 May 2008	6.51	1.57	4.94	Normal
	30 Jun 2008	0.49	-3.38	3.87	Normal
7 Jul 2008	31 Jul 2008	1.79	-0.09	1.88	Normal
11 Aug 2008	30 Aug 2008	Not Available	Not Available	2.2	Normal
Willis Creek					
	30 Apr 2007	1.66	-1.39	3.05	Normal
7 May 2007	31 May 2007	6.3	1.07	5.23	Normal
	30 Jun 2007	6.35	2.53	3.82	Very Moist
	31 Jul 2007	9.11	7.59	1.52	Extremely Moist
	30 Aug 2007	2.93	1.13	1.8	Extremely Moist
	30 Sep 2007	0.95	-2.08	3.03	Extremely Moist
	31 Oct 2007	2.11	-1.42	3.53	Extremely Moist
	31 May 2008	5.04	-0.26	5.3	Normal
3 Jun 2008	30 Jun 2008	0.12	-3.7	3.82	Normal
7 Jul 2008	31 Jul 2008	0.84	-0.34	1.18	Normal
11 Aug 2008	30 Aug 2008	Not Available	Not Available	1.8	Normal

[a] Precipitation data source: NOAA/National Weather Service NCDC, http://www7.ncdc.noaa.gov/IPS/cd/cd.html

NCDC Weather Station Names: Stillhouse Hollow Dam, 16 miles from Little Elm Creek and the Tributary of Little Elm Creek; Granger (2007) and Granger Dam (2008), 2 and 4 miles from Willis Creek.

If sample date is before the 15th of the month the previous month's departure from normal data is used.

[b] PDI data source: NOAA/National Weather Service - NCDC, http://www.ncdc.noaa.gov/oa/climate/monitoring/drought/mw/

Texas PDI Regions: East (Clear Creek, Duck Creek, and Walnut Creek); North Central (Little Elm Creek, Tributary of Little Elm Creek, and Willis Creek)

Table 31. NOAA NCDC rainfall and Palmer Drought Index (PDI) data for Ecoregion 33 creeks.

Sample date	NCDC date	Total monthly precip. (in) [a]	Departure from normal (in)	Normal precip. (in)	PDI - east region [b]
Clear Creek and Duck Creek					
	30 Apr 2007	2.5	-0.53	3.03	Normal
21 May 2007	31 May 2007	8.27	3.46	4.81	Normal
	30 Jun 2007	4.27	1.32	2.95	Normal
	31 Jul 2007	5.88	3.84	2.04	Moderately Moist
	30 Aug 2007	0.97	-1.63	2.6	Very Moist
4 Sep 2007	30 Sep 2007	1.45	-2.2	3.65	Moderately Moist
	31 Oct 2007	2.26	-2.12	4.38	Moderately Moist
	31 May 2008	2.86	-1.95	4.81	Normal
9 Jun 2008	30 Jun 2008	0.35	-2.6	2.95	Normal
	31 Jul 2008	0.82	-1.22	2.04	Normal
4 Aug 2008	30 Aug 2008	Not Available	Not Available	2.6	Normal
Walnut Creek					
	30 Apr 2007	2.37	-0.66	3.03	Normal
21 May 2007	31 May 2007	16.78	11.81	4.97	Normal
	30 Jun 2007	9.09	6	3.09	Normal
	31 Jul 2007	8.74	6.5	2.24	Moderately Moist
	30 Aug 2007	1.64	-0.75	2.39	Very Moist
4 Sep 2007	30 Sep 2007	1.15	-2.39	3.54	Moderately Moist
	31 Oct 2007	2.03	-2.36	4.39	Moderately Moist
	31 May 2008	3.32	-1.65	4.97	Normal
9 Jun 2008	30 Jun 2008	0.11	-2.98	3.09	Normal
	31 Jul 2008	0.47	-1.77	2.24	Normal
4 Aug 2008	30 Aug 2008	Not Available	Not Available	2.39	Normal

[a] Precipitation data source: NOAA/National Weather Service NCDC, http://www7.ncdc.noaa.gov/IPS/cd/cd.html

NCDC Weather Station Names: Franklin, 16 miles from Clear Creek and 9.7 miles from Duck Creek; and Bremond, 9 miles from Walnut Creek.

If sample date is before the 15th of the month the previous month's departure from normal data is used.

[b] PDI data source: NOAA/National Weather Service - NCDC, http://www.ncdc.noaa.gov/oa/climate/monitoring/drought/mw/

Texas PDI Regions: East (Clear Creek, Duck Creek, and Walnut Creek); North Central (Little Elm Creek, Tributary of Little Elm Creek, and Willis Creek)

Fish

Table 32. Numbers of fish collected in Little Elm Creek by gear type and effort for each event. Sampling effort in meters for seining and in seconds for electrofishing.

		9 May 2007		3 Oct 2007		8 Jul 2008		12 Aug 2008	
	Gear type:	Seine	Electrofisher	Seine	Electrofisher	Seine	Electrofisher	Seine	Electrofisher
	Sampling effort:	65	1047	60	967	86	1089	55	902
Taxon	Common name								
Ameiurus melas	Black bullhead				2				2
Ameiurus natalis	Yellow bullhead			1	2	3	1		21
Campostoma anomalum	Central stoneroller	9	3						
Cyprinella lutrensis	Red shiner	3							
Cyprinella venusta	Blacktail shiner	2				1		2	1
Etheostoma gracile	Slough darter			2					1
Gambusia affinis	Western mosquitofish					5		13	48
Hybrid sunfish	Hybrid sunfish							1	
Ictalurus punctatus	Channel catfish			1		1			1
Lepomis cyanellus	Green sunfish		8	6	15	1	37	10	82
Lepomis macrochirus	Bluegill	3		23	16	28	31	14	39
Lepomis megalotis	Longear sunfish		1	5		2	2	21	31
Micropterus salmoides	Largemouth bass		1	3	1	1		2	4
Moxostoma congestum	Gray redhorse					1			
Noturus gyrinus	Tadpole madtom								5
Pimephales vigilax	Bullhead minnow								4

Table 33. Numbers of fish collected in Tributary of Little Elm Creek by gear type and effort for each event. Sampling effort in meters for seining and in seconds for electrofishing.

		9 May 2007		3 Oct 2007		9 Jul 2008		13 Aug 2008	
	Gear type:	Seine	Electrofisher	Seine	Electrofisher	Seine	Electrofisher	Seine	Electrofisher
	Sampling effort:	75	1210	90	927	100	955	85	1046
Taxon	Common name								
Ameiurus natalis	Yellow bullhead					1	2		4
Campostoma anomalum	Central stoneroller	21	8	1					
Cyprinella lutrensis	Red shiner	85	28	19	6	20	2	11	1
Cyprinella venusta	Blacktail shiner			2	1	1			
Cyprinus carpio	Common carp				2				
Gambusia affinis	Western mosquitofish		3	11	17	15	7	19	17
Ictalurus punctatus	Channel catfish	8	1	1	3	3	2		1
Lepomis cyanellus	Green sunfish	3	16	2	15	4	29		22
Lepomis macrochirus	Bluegill		8	3	4		1		2
Lepomis megalotis	Longear sunfish		2			2	1	1	7
Micropterus salmoides	Largemouth bass					1			
Notropis volucellus	Mimic shiner	5							
Noturus gyrinus	Tadpole madtom	1					2		
Pimephales vigilax	Bullhead minnow	14	4	3	1	12		15	11
Pylodictis olivaris	Flathead catfish						1		1

Table 34. Numbers of fish collected in Willis Creek by gear type and effort for each event. Sampling effort in meters for seining and in seconds for electrofishing.

		8 May 2007		4 Jun 2008		8 Jul 2008		12 Aug 2008	
	Gear type:	Seine	Electrofisher	Seine	Electrofisher	Seine	Electrofisher	Seine	Electrofisher
	Sampling effort:	160	1128	160	938	123	909	130	979
Taxon	Common name								
Ameiurus natalis	Yellow bullhead				2		4	1	10
Campostoma anomalum	Central stoneroller	4		31		25	1		
Cyprinella lutrensis	Red shiner	65	1	232	22	69	2	38	2
Cyprinella venusta	Blacktail shiner	20	1	126	8	41		41	1
Cyprinus carpio	Common carp		3					1	
Dorosoma cepedianum	Gizzard shad			5		9	1	1	3
Gambusia affinis	Western mosquitofish			9	2	11		15	14
Ictalurus punctatus	Channel catfish	2		21	1		1	2	5
Lepisosteus oculatus	Spotted gar			1					
Lepomis cyanellus	Green sunfish	1	3	1	5	1	6	1	
Lepomis gulosus	Warmouth					1	1		4
Lepomis humilus	Orangespotted sunfish							1	
Lepomis macrochirus	Bluegill		1	17	8	4	7	9	4
Lepomis megalotis	Longear sunfish	6	1	48	13	73	11	256	22
Lepomis microlophus	Redear sunfish			1		2		1	
Micropterus salmoides	Largemouth bass	1		12	2	4	1	3	1
Morone chrysops	White bass			1					
Moxostoma congestum	Gray redhorse			5		2		1	
Notemigonus crysoleucas	Golden shiner	1							
Notropis volucellus	Mimic shiner			2					
Percina sciera	Dusky darter							2	
Pimephales vigilax	Bullhead minnow	79	1	13	1	30	1	19	1
Pylodictis olivaris	Flathead catfish					2	1		

Table 35. Numbers of fish collected in Clear Creek by gear type and effort for each event. Sampling effort in meters for seining and in seconds for electrofishing.

		22-23 May 2007		5 Sep 2007		10 Jun 2008		5 Aug 2008	
	Gear type:	Seine	Electrofisher	Seine	Electrofisher	Seine	Electrofisher	Seine	Electrofisher
	Sampling effort:	69	1453	90	945	80	968	75	929
Taxon	Common name								
Ameiurus natalis	Yellow bullhead			1	2		1	1	2
Amia calva	Bowfin	1							
Aphredoderus sayanus	Pirate perch								3
Cyprinella venusta	Blacktail shiner	30	2	26	1	4	14	7	8
Esox americanus	Redfin pickerel		3						
Etheostoma gracile	Slough darter		1			2			1
Etheostoma parvipinne	Goldstripe darter		1				1		
Fundulus olivaceus	Blackspotted topminnow	16	3	8	3	2	3	8	2
Gambusia affinis	Western mosquitofish				1	1			
Hybognathus nuchalis	Mississippi silvery minnow	5	5	23	2	22	1	1	6
Lepomis cyanellus	Green sunfish		7		1		2		6
Lepomis gulosus	Warmouth		1				1		3
Lepomis macrochirus	Bluegill		9	3		1	1	2	7
Lepomis megalotis	Longear sunfish			1	1	1			10
Lepomis microlophus	Redear sunfish		1		1				
Lythrurus fumeus	Ribbon shiner	2	27	100	1	25		13	1
Micropterus punctulatus	Spotted bass			2			3		1
Micropterus salmoides	Largemouth bass			1	1			2	2
Minytrema melanops	Spotted sucker	1					1		
Moxostoma congestum	Gray redhorse					3			
Notemigonus crysoleucas	Golden shiner		1						
Notropis texanus	Weed shiner								1
Noturus nocturnus	Freckled madtom						2		
Percina sciera	Dusky darter						1		1
Pimephales vigilax	Bullhead minnow		8	1		6	1	1	2
Pomoxis annularis	White crappie			1					

Table 36. Numbers of fish collected in Duck Creek by gear type and effort for each event. Sampling effort in meters for seining and in seconds for electrofishing.

		23 May 2007		6 Sep 2007		11 Jun 2008		6 Aug 2008	
	Gear type:	Seine	Electrofisher	Seine	Electrofisher	Seine	Electrofisher	Seine	Electrofisher
	Sampling effort:	27	1378	115	1093	55	928	87	974
Taxon	Common name								
Ameiurus melas	Black bullhead								1
Ameiurus natalis	Yellow bullhead		1		1		1		1
Aphredoderus sayanus	Pirate perch				3				2
Cyprinella venusta	Blacktail shiner	5	1	7		5			
Elassoma zonatum	Banded pygmy sunfish		1						1
Etheostoma gracile	Slough darter	1	1						1
Fundulus notatus	Blackstripe topminnow	3	3			4			1
Fundulus olivaceus	Blackspotted topminnow			4	2				
Hybognathus nuchalis	Mississippi silvery minnow		4	1	6				
Hybrid sunfish	Hybrid sunfish		1				1		
Ictalurus punctatus	Channel catfish							1	
Lepisosteus oculatus	Spotted gar		1						
Lepomis cyanellus	Green sunfish		11		6		1		3
Lepomis gulosus	Warmouth				1		2		2
Lepomis macrochirus	Bluegill	1	12	3	5	1	2	1	13
Lepomis megalotis	Longear sunfish		10		10		14		7
Lepomis sp.	Lepomis species			1					
Lythrurus fumeus	Ribbon shiner	23		68		10		10	1
Micropterus punctulatus	Spotted bass	1			1				1
Micropterus salmoides	Largemouth bass		4		1	1	1	1	3
Opsopoeodus emiliae	Pugnose minnow				1				
Percina sciera	Dusky darter	1							

Table 37. Numbers of fish collected in Walnut Creek by gear type and effort for each event. Sampling effort in meters for seining and in seconds for electrofishing.

		22 May 2007		5 Sep 2007		10 Jun 2008		5 Aug 2008	
	Gear type:	Seine	Electrofisher	Seine	Electrofisher	Seine	Electrofisher	Seine	Electrofisher
	Sampling effort:	75	1646	120	1054	105	990	85	1048
Taxon	Common name								
Ameiurus natalis	Yellow bullhead		2		2		1		1
Aphredoderus sayanus	Pirate perch		1						
Cyprinella lutrensis	Red shiner	3							
Cyprinella venusta	Blacktail shiner	24		38		51	5	71	2
Etheostoma chlorosoma	Bluntnose darter			1					
Etheostoma gracile	Slough darter		3	1					
Gambusia affinis	Western mosquitofish		5	32	1	1	1		
Ictalurus punctatus	Channel catfish			2	2		1	1	2
Lepisosteus oculatus	Spotted gar				1				1
Lepomis cyanellus	Green sunfish		3		3		10		1
Lepomis gulosus	Warmouth						1		
Lepomis macrochirus	Bluegill			2					
Lepomis megalotis	Longear sunfish		1		3		6		4
Lythrurus fumeus	Ribbon shiner			78		9			
Micropterus punctulatus	Spotted bass								4
Micropterus salmoides	Largemouth bass		1	1		5	3	3	
Notropis texanus	Weed shiner							1	
Notropis volucellus	Mimic shiner	8							
Noturus gyrinus	Tadpole madtom				1		1		
Percina sciera	Dusky darter								1
Pimephales vigilax	Bullhead minnow			2		2		3	
Pomoxis annularis	White crappie	3							

Benthic Macroinvertebrates

Table 38. Numbers of benthic macroinvertebrates collected in Ecoregion 32.

ORDER, Family	Taxon	Little Elm				Tributary of Little Elm				Willis				Total
		9 May 2007	3 Oct 2007	8 Jul 2008	12 Aug 2008	9 May 2007	3 Oct 2007	9 Jul 2008	13 Aug 2008	8 May 2007	4 Jun 2008	8 Jul 2008	12 Aug 2008	
ACARINA														
Sperchonidae	*Sperchon*		1				1							2
AMPHIPODA														
Gammaridae	*Gammarus*	31	4											35
Talitridae	*Hyalella*	7	2	17	18	3					1		41	89
ARCARINA														
Arrenuridae	*Arrenurus*		1		5						1			7
Hydrachnidae	*Hydrachna*			2	4								1	7
Torrenticolidae	*Torrenticola*				4									4
BASOMMATOPHORA														
Ancylidae	*Ferrissia*		1	1										2
Physidae	*Physella*			7	7				1		1		20	36
COLEOPTERA														
Carabidae	Carabidae	1											2	3
Curculionidae	Curculionidae					1								1
Dryopidae	*Helichus*						1	1					2	4
Dytiscidae	*Copelatus*	1												1
	Hydroporus	13	1											14
	Oreodytes	3												3
Elmidae	*Dubiraphia*				14									14
	Heterelmis						13	18	5					36
	Hexacylloepus											1	1	2
	Microcylloepus						6	6	1			2		15
	Neoelmis										1	1		2
	Stenelmis		7	2	1	4	16	56	3		6	2		97
Gyrinidae	*Gyretes*										1			1
Hydraenidae	*Hydraena*				1				1					2
Hydrochidae	*Hydrochus*								1				1	2
Hydrophilidae	*Berosus*												1	1

ORDER, Family	Taxon	Little Elm 9 May 2007	Little Elm 3 Oct 2007	Little Elm 8 Jul 2008	Little Elm 12 Aug 2008	Tributary of Little Elm 9 May 2007	Tributary of Little Elm 3 Oct 2007	Tributary of Little Elm 9 Jul 2008	Tributary of Little Elm 13 Aug 2008	Willis 8 May 2007	Willis 4 Jun 2008	Willis 8 Jul 2008	Willis 12 Aug 2008	Total
	Enochrus							3						3
	Tropisternus												1	1
Scirtidae	*Cyphon*			29	17				1				11	58
	Scirtes				7		2					1		10
Staphylinidae	Staphylinidae												1	1
DECAPODA														
Cambaridae	Cambaridae	1	1											2
DIPTERA														
Ceratopogonidae	*Bezzia*							1	1					2
Chironomidae	Chironomini	17	27	46	39	24	8	29	21	1	1		5	218
	Orthocladiinae	1				5		1			1	1		9
	Tanypodinae	1	3	9	9	5	3	3		3	2	1	2	41
	Tanytarsini						1			1				2
Culicidae	*Culex*				1									1
Dolichopodidae	Dolichopodidae				1									1
Simuliidae	*Simulium*		10			8	2				1			21
Tabanidae	*Chrysops*			2										2
	Tabanus							1				1		2
EPHEMEROPTERA														
Baetidae	*Baetis*		2											2
	Callibaetis			3									4	7
	Fallceon	1	11			10	50	13	140	2	18	6	1	252
	Paracloeodes							1	4					5
	Procloeon		1											1
Caenidae	*Caenis*		4	53	27	2		2		7	1		45	141
Heptageniidae	*Stenacron*		45	14	13			13	5				5	95
	Stenonema	1								10			2	13
Isonychiidae	*Isonychia*										5	10		15
Leptophlebiidae	*Farrodes*		6				8	3	3			19		39
	Neochoroterpes									2	45	19	3	69
	Thraulodes										10	16		26
Tricorythidae	*Leptohyphes*											50	4	54
	Tricorythodes		5				5	17	4		1	7	17	56

		Little Elm				Tributary of Little Elm				Willis				
ORDER, Family	Taxon	9 May 2007	3 Oct 2007	8 Jul 2008	12 Aug 2008	9 May 2007	3 Oct 2007	9 Jul 2008	13 Aug 2008	8 May 2007	4 Jun 2008	8 Jul 2008	12 Aug 2008	Total
HAPLOTAXIDA														
Lumbricidae	Lumbricidae									8	4			12
Tubificidae	*Branchiura*		1		2						2			5
HEMIPTERA														
Corixidae	*Trichocorixa*												1	1
Gerridae	*Rheumatobates*				1									1
Mesoveliidae	*Mesovelia*	1												1
Naucoridae	*Ambrysus*											1		1
Veliidae	*Rhagovelia*		1			1	2	2				2		8
LEPIDOPTERA														
Pyralidae	*Isonychia*							1						1
NEOTAENIOGLOSSA														
Hydrobiidae	Hydrobiidae				1			2						3
ODONATA														
Aeshnidae	*Boyeria*					1			1					2
	Nasiaeschna	2												2
Calopterygidae	*Hetaerina*		3			1	9							13
Coenagrionidae	*Argia*		20		3	1	5	4	1		3	9	23	69
	Enallagma	5			1					1			1	8
Corduliidae	*Didymops*		1											1
Gomphidae	*Erpetogomphus*		6				4				24	16		50
Libellulidae	*Brechmorhoga*										7	42		49
	Perithemis		1											1
Macromiinae	*Macromia*		6											6
PLECOPTERA														
Perlidae	*Perlesta*	13								46	1			60
RHYNCHOBDELLIDA														
Glossiphoniidae	*Placobdella*							5						5
TRICHOPTERA														
Hydropsychidae	*Cheumatopsyche*		3				4			18	60	35		120
	Hydropsyche					2	9							11
	Smicridea					3	43	12	7		4	6		75
Hydroptilidae	*Ochrotrichia*											1		1

		Little Elm				Tributary of Little Elm				Willis				
ORDER, Family	Taxon	9 May 2007	3 Oct 2007	8 Jul 2008	12 Aug 2008	9 May 2007	3 Oct 2007	9 Jul 2008	13 Aug 2008	8 May 2007	4 Jun 2008	8 Jul 2008	12 Aug 2008	Total
Leptoceridae	*Nectopsyche*						2				1	1		4
Philopotamidae	*Chimarra*		2								1	18		21
Polycentropodidae	*Polycentropus*												1	1
TRICLADIDA														
Planariidae	*Dugesia*							1				2	1	4
VENEROIDA														
Corbiculidae	*Corbicula*				1	1		2			5	4		13
Sphaeriidae	*Sphaerium*	1			1									2
NEMATOMORPHA	Nematomorpha												1	1
Total per Sampling Event		100	176	185	178	72	194	197	200	99	208	274	198	2081

Table 39. Numbers of benthic macroinvertebrates collected in Ecoregion 33.

Family	Taxon	Clear				Duck				Walnut				Total
		23 May 2007	5 Sep 2007	10 Jun 2008	5 Aug 2008	23 May 2007	6 Sep 2007	11 Jun 2008	6 Aug 2008	22 May 2007	5 Sep 2007	10 Jun 2008	5 Aug 2008	
AMPHIPODA														
Gammaridae	*Gammarus*	1												1
Talitridae	*Hyalella*	1				11		4	4					20
ARCARINA														
Lebertiidae	*Lebertia*		1		2		2		5					10
BASOMMATOPHORA														
Physidae	*Physella*				2	3				2				7
COLEOPTERA														
Dryopidae	*Helichus*				1								1	2
Dytiscidae	*Copelatus*									2				2
	Hydroporus					1		1						2
Elmidae	*Ancyronyx*	1	3	4	6		4	3	3					24
	Dubiraphia	1	1			12	5	5	4	2				30
	Heterelmis									12	2	9	11	34
	Macronychus	2	2	5	7									16
	Stenelmis	16	13	15	21	2	3		3	6	1	38	20	138
Gyrinidae	*Dineutus*	7	1	3		7				3				21
	Gyretes							2		2	1		1	6
	Gyrinus									1				1
Haliplidae	*Peltodytes*									2				2
Hydrochidae	*Hydrochus*								1					1
Hydrophilidae	*Berosus*									1				1
	Enochrus					1								1
Scirtidae	*Cyphon*			2				1						3
	Scirtes					12								12
COLLEMBOLA														
Isotomidae	*Isotomurus*				1									1
Sminthuridae	*Sminthurides*					1								1
DECAPODA														
Cambaridae	Cambaridae					1			1					2
DIPTERA														

Family	Taxon	Clear				Duck				Walnut				Total
		23 May 2007	5 Sep 2007	10 Jun 2008	5 Aug 2008	23 May 2007	6 Sep 2007	11 Jun 2008	6 Aug 2008	22 May 2007	5 Sep 2007	10 Jun 2008	5 Aug 2008	
Ceratopogonidae	*Bezzia*						2						1	3
	Probezzia					1								1
Chironomidae	Chironomini	15	13	28	20	34	13	52	130	24	6	4	7	346
	Orthocladiinae					6				3	1		2	12
	Tanypodinae		2	2	9	6	1	5	3	3	2			33
	Tanytarsini	4		3	2	15	1		1	1	1			28
Empididae	*Hemerodromia*										2			2
Simuliidae	*Simulium*	26	3	1						4				34
Tipulidae	*Geranomyia*												1	1
	Limnophila				1			1						2
EPHEMEROPTERA														
Baetidae	*Acentrella*	2	1											3
	Acerpenna		2			6	2			9		4		23
	Baetis	35	25	2	1	62	2			38	23	11	2	201
	Fallceon									16	16	27	30	89
	Labiobaetis	5								7	1	1		14
	Paracloeodes										4	5	3	12
	Procloeon			2	2	1								5
Caenidae	*Brachycercus*						1							1
	Caenis	6	4	1	1	8		8	3					31
Ephemerellidae	*Eurylophella*		1											1
Ephemeridae	*Hexagenia*												1	1
Heptageniidae	*Stenacron*	5	9	47	32	53	113	86	28	17	9	4	3	406
	Stenonema	47	50	68	19	13	17			2				216
Isonychiidae	*Isonychia*	49	15	3	2									69
Leptophlebiidae	*Farrodes*				1					34	70	35	70	210
Tricorythidae	*Tricorythodes*									19	18	23	28	88
HAPOLTAXIDA														
Lumbricidae	Lumbricidae	1	3	2		1				7				14
Naididae	*Dero*							1	5					6
	Pristina					2			1					3
	Slavina					5			2					7
Tubificidae	*Branchiura*							3	2			1		6

Family	Taxon	Clear				Duck				Walnut				Total
		23 May 2007	5 Sep 2007	10 Jun 2008	5 Aug 2008	23 May 2007	6 Sep 2007	11 Jun 2008	6 Aug 2008	22 May 2007	5 Sep 2007	10 Jun 2008	5 Aug 2008	
	Limnodrilus			2				1						3
HEMIPTERA														
Belostomatidae	*Belostoma*									3				3
Corixidae	*Trichocorixa*									3				3
Veliidae	*Rhagovelia*									16				16
ISOPODA														
Asellidae	*Asellus*	1												1
MEGALOPTERA														
Corydalidae	*Chauliodes*					4								4
	Corydalus	1	7	1	6		2					1		18
Sialidae	*Sialis*					3		2	4	2				11
ODONATA														
Aeshnidae	*Boyeria*	2			1		1			1			1	6
Calopterygidae	*Calopteryx*					1								1
	Hetaerina		2		1			1		11	3	1	1	20
Coenagrionidae	*Argia*			1	7	20	10	8	2	1			4	53
	Enallagma					3				1				4
	Ischnura					1								1
Gomphidae	*Arigomphus*					1								1
	Dromogomphus								3					3
	Erpetogomphus									3		1		4
	Hagenius	2		3										5
	Progomphus	6	3	1	1	5								16
Libellulidae	*Brechmorhoga*										1	1		2
Macromiinae	*Macromia*				2	11		1		1				15
PHARYNGOBDELLIDA														
Erpobdellidae	*Mooreobdella*						1							1
PLECOPTERA														
Perlidae	*Neoperla*	1												1
	Perlesta					13								13
RHYNCHOBDELLIDA														
Glossiphoniidae	*Placobdella*								2	2				4
TRICHOPTERA														

		Clear				Duck				Walnut				
Family	Taxon	23 May 2007	5 Sep 2007	10 Jun 2008	5 Aug 2008	23 May 2007	6 Sep 2007	11 Jun 2008	6 Aug 2008	22 May 2007	5 Sep 2007	10 Jun 2008	5 Aug 2008	Total
Hydropsychidae	*Cheumatopsyche*	6	9	2		15				14			1	47
	Hydropsyche	15	3			2				25	1	7	4	57
	Smicridea									68	19	17	8	112
Hydroptilidae	*Hydroptila*												1	1
Leptoceridae	*Nectopsyche*											1	1	2
	Oecetis	1	3	3	1						3			11
	Triaenodes												1	1
Limnephilidae	*Pycnopsyche*						1							1
Polycentropodidae	*Cyrnellus*							4				4		8
	Nyctiophylax	1		1	13		6		2	5	3		7	38
	Polycentropus			3	13	9		4		1			1	31
TRICLADIDA														
Planariidae	*Dugesia*				8									8
NEMATODA	Nematoda					1								1
Total per Sampling Event		260	176	205	183	353	187	193	209	374	187	195	211	2733

Soft Algae Community

Table 40. Number of soft algae units counted by taxon and total number for Ecoregion 32 streams.

	Little Elm				Tributary of Little Elm				Willis			
Taxon	9 May 2007	2 Oct 2007	8 Jul 2008	12 Aug 2008	9 May 2007	2 Oct 2007	8 Jul 2008	13 Aug 2008	8 May 2007	3 Jun 2008	7 Jul 2008	12 Aug 2008
Ankistrodesmus falcatus												1
Centric diatoms		4		1	5	1		10	1	4		
Characium sp.	1	2	1	6	2		2	2		4		
Chlamydomonas sp.				9		4		3	8	1		
Chlorococcum sp.	6								3			
Chroococcus sp.	54	18	9	13	25	18	16	17	123	27	8	5
Cladophora sp.	107	73			146				10	69	30	25
Closterium sp.						2						
Cosmarium sp.					1		1	1		1		1
Cryptomonadaceae		5				2						
Cryptomonas sp.									1			
Dinobryon sp.										3		
Euglena sp.	3	4	2	6	5	3	1	3		2	3	
Gloeoskene turfosa		59	11	4		16	17	11			2	1
Hormidium sp.		26			8							
Kirchneriella sp.		7	1							2	1	
Merismopedia glauca												1
Mougeotia sp.							40					
Oedogonium sp.							26				10	
Oocystis sp.					2							
Oscillatoria sp.			128	50		47	35	25	5	4	11	19
Pennate diatoms	70	96	58	55	72	139	93	54	98	148	136	156
Raphidiopsis curvata										2		1
Scenedesmus sp.						1	1			1		1
Schizothrix sp.	17	49	108	173	12	49	76	153	25	45	39	82
Schroderia setigera						1						
Spirogyra sp.											90	
Spirulina sp.						4						11
Synechococcus sp.		6	3	7	8	13	4	5	26	5	4	3

Taxon	Little Elm 9 May 2007	Little Elm 2 Oct 2007	Little Elm 8 Jul 2008	Little Elm 12 Aug 2008	Tributary of Little Elm 9 May 2007	Tributary of Little Elm 2 Oct 2007	Tributary of Little Elm 8 Jul 2008	Tributary of Little Elm 13 Aug 2008	Willis 8 May 2007	Willis 3 Jun 2008	Willis 7 Jul 2008	Willis 12 Aug 2008
Unknown alga	44	11		16	20		5	17		9	1	
Unknown dinoflagellate			2					1			1	
Total number of units	302	360	323	340	306	300	317	302	300	327	336	307

Table 41. Number of soft algae units counted by taxon and total number for Ecoregion 33 streams.

Taxon	Clear 23 May 2007	Clear 5 Sep 2007	Clear 10 Jun 2008	Clear 5 Aug 2008	Duck 24 May 2007	Duck 6 Sep 2007	Duck 11 Jun 2008	Duck 6 Aug 2008	Walnut 22 May 2007	Walnut 5 Sep 2007	Walnut 9 Jun 2008	Walnut 5 Aug 2008
Ankistrodesmus falcatus									4			
Audouinella hermannii	20				55							
Calothrix sp.						3						
Centric diatoms			2			4	13		7	18	5	16
Characium sp.		1	2	6	2		2	1	2		2	1
Chlamydomonas sp.			1				1					
Chroococcus sp.	3		5	6		1	10	11	1	6	7	4
Cladophora sp.			62	110			60	45		70		
Cosmarium sp.	1								2			
Cryptomonadaceae						4				4		
Cryptomonas sp.	1				1					1		
Euglena sp.			1	1		1		2			1	1
Lyngbya sp.		264										
Mallomonas sp.						1						
Nostoc sp.	15											
Oedogonium sp.	53				60							
Oscillatoria sp.	10			27		22	9	63	5		46	
Pennate diatoms	75	9	90	78	64	91	98	24	92	154	134	189
Phacus sp.									1			
Raphidiopsis curvata												3
Schizothrix sp.	125	7	110	75	121	188	97	148	184	21	94	76
Schroderia setigera									5			

Taxon	Clear 23 May 2007	Clear 5 Sep 2007	Clear 10 Jun 2008	Clear 5 Aug 2008	Duck 24 May 2007	Duck 6 Sep 2007	Duck 11 Jun 2008	Duck 6 Aug 2008	Walnut 22 May 2007	Walnut 5 Sep 2007	Walnut 9 Jun 2008	Walnut 5 Aug 2008
Sphaerocystis sp.							11					
Spirogyra sp.		44	23							25		
Spirulina sp.								3	1		30	5
Staurastrum sp.									1			
Synechococcus sp.	1		1		1	3	5		7	2		
Tetraedron regulare	1	1				1						
Trachelomonas sp.					1							
Trachelomonas volvocina										5		
Ulothrix zonata					3							
Unknown alga	2	1	7	10	2		5	10		3		8
Unknown dinoflagellate				1				1				
Total number of units	307	327	304	314	310	319	311	308	312	309	319	303

Diatoms

Table 42. Number of diatom valves counted by taxon for Ecoregion 32 streams.
500 valves total counted per sample.

Taxon	Little Elm				Tributary of Little Elm				Willis			
	9 May 2007	2 Oct 2007	8 Jul 2008	12 Aug 2008	9 May 2007	2 Oct 2007	8 Jul 2008	13 Aug 2008	8 May 2007	3 Jun 2008	7 Jul 2008	12 Aug 2008
Achnanthidium biassolettianum	3											
Achnanthidium minutissimum	120				2				106	14	43	30
Amphipleura pellucida									1			1
Amphora acutiuscula					1							
Amphora bullatoides								2				
Amphora coffeaeformis						3	1	1				
Amphora copulata		6	3	2								6
Amphora inariensis	2		8	21					2	1	6	
Amphora montana	1	6							2		6	1
Amphora pediculus	38	5							14	10	24	
Amphora veneta					4		116					
Aulacoseira granulata												2
Bacillaria paradoxa		34				1					5	10
Caloneis bacillum	4	4							4	2	2	
Caloneis schumanniana									1			
Campylodiscus clypeus			1									
Cocconeis pediculus	26			2	2	2			2		3	
Cocconeis placentula	7		17	51	240		72	52	35	99	114	2
Cocconeis placentula var euglypta		8				18						
Cocconeis placentula var pseudolineata				12								
Craticula (Navicula) minusculoides					1							
Craticula cuspidata	1			1		1	2				2	
Cyclotella meneghiniana	12	4							2			
Cymatopleura elliptica	2											
Cymbella hustedtii						2						
Denticula kuetzingii									12	1		
Diadesmis (Navicula) confervacea		6		14				2				
Diploneis elliptica				2				4				6

Taxon	Little Elm 9 May 2007	Little Elm 2 Oct 2007	Little Elm 8 Jul 2008	Little Elm 12 Aug 2008	Tributary of Little Elm 9 May 2007	Tributary of Little Elm 2 Oct 2007	Tributary of Little Elm 8 Jul 2008	Tributary of Little Elm 13 Aug 2008	Willis 8 May 2007	Willis 3 Jun 2008	Willis 7 Jul 2008	Willis 12 Aug 2008
Diploneis puella	4	6		2		20	2	2			5	
Encyonema (Encyonopsis) microcephala	2	2										
Encyonema silesiacum	5	2			23	4			26		1	
Encyonema triangulum					4							
Encyonopsis minuta										7		
Eunotia bilunaris		4										
Eunotia pectinalis	2		12	8								
Frustulia weinholdii		5										
Gomphonema affine		2		44							4	6
Gomphonema angustatum (micropus)				2								
Gomphonema angustum									1			
Gomphonema gracile			1				1				1	
Gomphonema mclaughlinii												2
Gomphonema parvulum		2				4					1	2
Gomphonema patrickii				6								
Gomphonema pumilum		2			5		4	4			35	3
Gomphosphenia (Gomphonema) lingulatiformis		115	201	65		4	2					
Gomphosphenia grovei			202	79			42	12				
Gyrosigma nodiferum		122	7	26			29	38		12	23	25
Gyrosigma obtusatum		7										
Gyrosigma scalproides	2				2							
Hantzschia amphioxys	2											
Luticola goeppertiana								12				
Luticola mutica		2	6			1	2					
Navicula (Eolimna) minima											2	
Navicula (Eolimna) subminuscula					30				2			
Navicula aikenensis												1
Navicula angusta				1				4				
Navicula antonii	4							1	3			
Navicula capitatoradiata									12			
Navicula cf. fauta						32						
Navicula cryptotenella	6			1	4	1		2	8			

	Little Elm				Tributary of Little Elm				Willis			
Taxon	9 May 2007	2 Oct 2007	8 Jul 2008	12 Aug 2008	9 May 2007	2 Oct 2007	8 Jul 2008	13 Aug 2008	8 May 2007	3 Jun 2008	7 Jul 2008	12 Aug 2008
Navicula erifuga					5							
Navicula incertata						16						
Navicula ingenua	1				2							
Navicula kotschii (texana)		9		4							21	16
Navicula libonensis					7							
Navicula radiosa	3									4		
Navicula recens		2	2	2	5	56	13	46	16	34	57	51
Navicula sanctaecrucis		55	1	16		15		12		3	25	118
Navicula schroeteri var escambia		20				12				45	10	42
Navicula symmetrica					2			4	2			4
Navicula tenelloides										6		
Navicula tripunctata								8				25
Navicula veneta	10	1			19	4		4	20	4		4
Navicula viridula var. rostellata		6			9	50		46		2		
Nitzschia (Tryb. apiculata) constricta				4		14		3				2
Nitzschia (Tryblionella) calida				15								
Nitzschia (Tryblionella) levidensis					2			12		1		6
Nitzschia amphibia	7	12		32		16	18	2	16	68	43	22
Nitzschia amphibioides		2										
Nitzschia angustata		2		9								
Nitzschia angustatula				2				2				11
Nitzschia brevissima								24				1
Nitzschia clausii					2							14
Nitzschia compressa var. balatonis				3								
Nitzschia dissipata	22					3		12	10	11		12
Nitzschia filiformis		6										
Nitzschia frustulum				2		81		12				
Nitzschia geitleri								10				
Nitzschia inconspicua	119				30				151	14	2	2
Nitzschia linearis	1			6			5	2			1	6
Nitzschia lorenziana						3						
Nitzschia microcephala									1			
Nitzschia palea					12			59	8			

Taxon	Little Elm 9 May 2007	Little Elm 2 Oct 2007	Little Elm 8 Jul 2008	Little Elm 12 Aug 2008	Tributary of Little Elm 9 May 2007	Tributary of Little Elm 2 Oct 2007	Tributary of Little Elm 8 Jul 2008	Tributary of Little Elm 13 Aug 2008	Willis 8 May 2007	Willis 3 Jun 2008	Willis 7 Jul 2008	Willis 12 Aug 2008
Nitzschia recta				11				4				10
Nitzschia sigma		4		8		1	6	6				
Nitzschia solita								4				2
Nitzschia vitrea										3		
Pinnularia gibba		6	6	14		2	1					4
Pinnularia microstauron		1	5	14	1				2			6
Pinnularia viridis			12									
Plagiotropis lepidoptera												2
Planothidium (Achnanthes) lanceolatum	6				1							
Pleurosigma salinarum		1										
Pleurosira (Ceratulina) laevis					27	15	2					
Pseudostaurosira brevistriata								6				
Reimeria sinuata	32	4	12		20	2	3	2	28	156	64	39
Rhoicosphenia abbreviata		4		6				2				
Sellaphora (Navicula) stroemii									6	2		2
Sellaphora pupula		1		2				1				
Sellaphora seminulum	52				30				3			
Seminavis (Amphora) strigosa						82		8				
Simonsenia delognei									3			
Stauroneis phoenicentron				2								
Stauroneis smithii	1											
Surirella angusta					1							
Surirella brebissonii	3				6	10	77	10				
Surirella tenera				7								2
Synedra (Fragilaria) ulna									1	1		
Terpsinoe musica			4	2		1	100	32				
Tryblionella (Nitzschia) acuminata					1		2	2				
Tryblionella debilis		20				24		29				

Table 43. Number of diatom valves counted by taxon for Ecoregion 33 streams.
500 valves total counted per sample.

	Clear				Duck				Walnut			
Taxon	23 May 2007	5 Sep 2007	10 Jun 2008	5 Aug 2008	24 May 2007	6 Sep 2007	11 Jun 2008	6 Aug 2008	22 May 2007	5 Sep 2007	9 Jun 2008	5 Aug 2008
Achnanthes inflata					1		4					
Achnanthidium biassolettianum				34								
Achnanthidium exiguum					6			1				
Achnanthidium minutissimum	3	2		28			1		2			
Adlafia bryophila	1	2							20			
Amphipleura pellucida		4	1									
Amphora bullatoides			2					2			7	8
Amphora coffeaeformis	1								2	17		
Amphora copulata			1		2	10	6	4	2	13	2	1
Amphora inariensis											1	
Amphora montana	4	4							5			
Amphora pediculus									2			
Amphora veneta	2											
Aulacoseira granulata								1		4	2	
Aulacoseira granulata var. angustissima									25			
Bacillaria paradoxa			73		1	47	18	22	8	3	35	6
Caloneis bacillum	6	2	2		4							4
Caloneis silicula						2	4				1	
Capartogramma crucicula			7					5				
Cocconeis placentula			1							26	28	38
Cocconeis placentula var euglypta	3	13				6			91	4		
Cocconeis placentula var pseudolineata							13	55				
Cocconeis scutellum	13				13							
Craticula (Navicula) halophila	5				21				17			
Craticula buderi		2										
Craticula cuspidata					4							
Cyclotella meneghiniana					1	1						
Cymatopleura elliptica							5	1				
Cymbella aspera	3											
Cymbella cistula				14								

Taxon	Clear 23 May 2007	Clear 5 Sep 2007	Clear 10 Jun 2008	Clear 5 Aug 2008	Duck 24 May 2007	Duck 6 Sep 2007	Duck 11 Jun 2008	Duck 6 Aug 2008	Walnut 22 May 2007	Walnut 5 Sep 2007	Walnut 9 Jun 2008	Walnut 5 Aug 2008
Cymbella excisa				80								
Denticula kuetzingii	2			5				1				
Denticula subtilis	2				2							
Diadesmis (Navicula) confervacea					1	8		8	1	2	14	6
Diadesmis (Navicula) contenta						4	8					
Diploneis elliptica		3	8			21		3		1	4	
Diploneis oblongella									1			
Diploneis ovalis	1				2							
Diploneis puella	2	7			6	18	6	10	4	22		4
Encyonema (Encyonopsis) evergladianum			1	24								
Encyonema (Encyonopsis) microcephala				12								
Encyonema delicatula				110								
Encyonema elginensis		9				2			2			
Encyonema silesiacum	6	16	20	4	2				6			
Encyonopsis minuta							1					
Eucocconeis (Achnanthes) flexella				21								
Eunotia bilunaris	10	19	16		2	2						
Eunotia formica	2				4							
Eunotia pectinalis	149		116	17	1	2	16	58		1	2	
Fallacia pygmaea									2			
Fallacia tenera						5	1	6	1			
Fragilaria capucina		14							4			
Fragilaria tenera				32	1				2			
Frustulia rhomboides		4	13									
Frustulia vulgaris	33		3		6	2		6				
Geissleria decussis		7	1			2						
Gomphonema affine				1						2		
Gomphonema angustatum (micropus)			67					10		1	2	
Gomphonema gracile					2	2						
Gomphonema intricatum var vibrio				8								
Gomphonema mclaughlinii	3		9		4				2			
Gomphonema parvulum		33	18			4			6	2		
Gomphonema patrickii			28					16				

Taxon	Clear 23 May 2007	Clear 5 Sep 2007	Clear 10 Jun 2008	Clear 5 Aug 2008	Duck 24 May 2007	Duck 6 Sep 2007	Duck 11 Jun 2008	Duck 6 Aug 2008	Walnut 22 May 2007	Walnut 5 Sep 2007	Walnut 9 Jun 2008	Walnut 5 Aug 2008
Gomphonema pumilum	11	16	23		20	2	55	58	6	10	18	8
Gomphonema rhombicum				2								
Gomphosphenia (Gomphonema) lingulatiformis	10	52			3			16			28	2
Gomphosphenia grovei	31	8			167		76	40			68	6
Gyrosigma nodiferum	4	70	12		53	191	212	8	5	116	94	27
Gyrosigma obtusatum						6				9		
Gyrosigma scalproides	2				2							
Gyrosigma spencerii					1							
Hantzschia amphioxys	2	1			4					9	1	
Hippodonta (Navicula) hungarica	2	3	4		14	3	2	2	12	3		6
Hippodonta capitata		8	2		2	1		8		2		2
Luticola goeppertiana					3					1	2	2
Luticola mutica			1		1	1				1	2	
Mastogloia smithii				16								
Melosira varians		4							4			
Navicula (Eolimna) minima	2	1							10			
Navicula (Eolimna) subminuscula					2							
Navicula aikenensis			6									
Navicula cf. fauta										6		
Navicula cf. pseudanglica	3				2					2		
Navicula cincta					1							
Navicula constans									3		2	
Navicula cryptocephala		1							7			
Navicula cryptotenella	2			2		3			16			
Navicula erifuga	2	4	2				9		1			
Navicula exigua var capitata								13				
Navicula incertata	2				13			2	4			
Navicula ingenua					4			2	2			
Navicula kotschii (texana)		2				4		14	2		2	
Navicula leptostriata	2	8										
Navicula libonensis		8			2							
Navicula margalithii											2	2

Taxon	Clear 23 May 2007	Clear 5 Sep 2007	Clear 10 Jun 2008	Clear 5 Aug 2008	Duck 24 May 2007	Duck 6 Sep 2007	Duck 11 Jun 2008	Duck 6 Aug 2008	Walnut 22 May 2007	Walnut 5 Sep 2007	Walnut 9 Jun 2008	Walnut 5 Aug 2008
Navicula orangiana		7							2	2		
Navicula peregrina											4	
Navicula radiosa				4		1			2			
Navicula recens			4			25	4	16	44	111	6	4
Navicula sanctaecrucis					2	24		4	6	77	38	10
Navicula schadei									2			
Navicula schroeteri var escambia	11	50			6	4						
Navicula soehrensis (hassiaca)					8							
Navicula symmetrica	6				3			3	23			
Navicula tenelloides		2										
Navicula tridentula									3			
Navicula trivialis									2			
Navicula veneta	5	22			4	2			10			
Navicula viridula								2				
Navicula viridula var. rostellata	17		2		5	6	2	8	5	3		
Neidium ampliatum	2											
Nitzschia (Tryb. apiculata) constricta			2				2		3		8	4
Nitzschia (Tryblionella) calida			2			2			1			
Nitzschia (Tryblionella) coarctata						13						
Nitzschia (Tryblionella) levidensis	2	4			2		3	2	10		6	3
Nitzschia (Tryblionella) littoralis		8										
Nitzschia acicularioides	1								1			
Nitzschia amphibia		1					4	2	12	1	10	
Nitzschia angustata						2			1			
Nitzschia angustatula						4	2	6				
Nitzschia brevissima		7							4			
Nitzschia clausii	6		6									
Nitzschia dissipata		6			1	7	2			2		
Nitzschia filiformis					2							
Nitzschia frustulum		3	4		2	1		6				
Nitzschia homburgiensis					1							
Nitzschia inconspicua			1						5			
Nitzschia linearis	9		5		6		1	17	2			

	Clear				Duck				Walnut			
Taxon	23 May 2007	5 Sep 2007	10 Jun 2008	5 Aug 2008	24 May 2007	6 Sep 2007	11 Jun 2008	6 Aug 2008	22 May 2007	5 Sep 2007	9 Jun 2008	5 Aug 2008
Nitzschia lorenziana	4	9				6		6		2	5	
Nitzschia nana	4	2			2							
Nitzschia obtusa					2			2	3			
Nitzschia palea	38				10		2		14			
Nitzschia panduriformis					2							
Nitzschia recta									4			
Nitzschia scalpelliformis	6					3		3				
Nitzschia sigma	2	1	1		5	23	5		1	4		
Nitzschia solita	1	2	5		3							
Nitzschia tropica	6	1	4		1			3				
Nitzschia vermicularis		6										
Pinnularia acrosphaeria		8				2						
Pinnularia appendiculata								4				
Pinnularia borealis		1	3			1	1			1		3
Pinnularia braunii						1						
Pinnularia gibba	1	6			2	6			1			
Pinnularia hemiptera								1				
Pinnularia interrupta		2	1									
Pinnularia microstauron	28		12		6	9		2		2		
Pinnularia obscura							2					
Pinnularia subcapitata						2						
Pinnularia viridis	4	2				2			1	2		
Placoneis clementis			6									
Placoneis elginensis											1	
Plagiotropis lepidoptera								2				
Planothidium (Achnanthes) biporomum									2			
Planothidium (Achnanthes) delicatulum									2	1	6	6
Planothidium (Achnanthes) lanceolatum		4	2		2			4	14		5	
Planothidium apiculatum		7										
Pleurosira (Ceratulina) laevis							4		7	2	6	42
Pseudostaurosira brevistriata											2	3
Reimeria sinuata					2							
Rhoicosphenia abbreviata							2	2		2	33	8

	Clear				Duck				Walnut			
Taxon	23 May 2007	5 Sep 2007	10 Jun 2008	5 Aug 2008	24 May 2007	6 Sep 2007	11 Jun 2008	6 Aug 2008	22 May 2007	5 Sep 2007	9 Jun 2008	5 Aug 2008
Rhopalodia gibba				2						7		
Rhopalodia gibberula	1											
Sellaphora (Navicula) stroemii				4				2			2	
Sellaphora pupula	2							6				
Sellaphora seminulum					10				12			
Seminavis (Amphora) strigosa										3		14
Stauroneis phoenicentron										2		
Stauroneis smithii					2	1						
Stauroneis smithii var sagitta	2											
Surirella angusta	8				9							
Surirella brebissonii	2				8	4	2	4	1			
Surirella minuta					2		1					
Surirella splendida										1		
Surirella tenera								1				
Synedra (Fragilaria) acus									2			
Synedra (Fragilaria) ulna	4	12	3	80	3		3	4	12	17	38	203
Terpsinoe musica					3		19	10	4		13	76
Tryblionella (Nit. tryb.) gracilis									5			
Tryblionella (Nitzschia) acuminata							2	4		1		
Tryblionella debilis	2				4			2				2

Table 44. Diatom classification following Winsborough (2009a).

Classification	R1	R2	R3	R4a	R4b	R4c	R4d	R4e	R4f	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14
Alkaliphilic				4,5											al	alk			
Eutrophic	1	2				4	5	5	5,6		1		eu	5	eu, sp, nh	eu			
Halophilic					3,4								hal			sal			
Motile																			M
Nitrogen heterotrophs						3,4									nh	nit			
Polysaprobic								4,5							sp	sap			
Sensitive	3	4									4								
Tolerant	1	1									1								

Aquatic Vegetation

Table 45. Macroalgae cover from aquatic vegetation surveys.
Tabulated values are percent of points from a 25 point transect assigned to each category and composite scores.

		Percent in category						
Creek	Month	0%	< 5%	5 to 25%	25 to 50%	50 to 75%	75 to 100%	Composite score
2007								
Little Elm	May	100	0	0	0	0	0	0
	Oct	88	0	8	0	0	4	9
TLE	May	100	0	0	0	0	0	0
	Oct	100	0	0	0	0	0	0
Willis	May	100	0	0	0	0	0	0
Clear	Apr	100	0	0	0	0	0	0
	May	100	0	0	0	0	0	0
	Sep	92	0	0	0	4	4	9
Duck	May	100	0	0	0	0	0	0
	Sep	100	0	0	0	0	0	0
Walnut	May	100	0	0	0	0	0	0
	Sep	100	0	0	0	0	0	0
2008								
Little Elm	Jul	76	0	0	4	8	12	26
	Aug	96	0	0	0	0	4	5
TLE	Jul	92	0	8	0	0	0	4
	Aug	92	0	8	0	0	0	4
Willis	Jun	100	0	0	0	0	0	0
	Jul	92	0	0	4	4	0	7
	Aug	64	0	16	4	4	12	30
Clear	Jun	100	0	0	0	0	0	0
	Aug	100	0	0	0	0	0	0
Duck	Jun	100	0	0	0	0	0	0
	Aug	96	0	0	4	0	0	3
Walnut	Jun	96	0	0	0	4	0	4
	Aug	68	0	20	8	0	4	21

Table 46. Microalgae thickness from aquatic vegetation surveys.
Tabulated values are percent of points from a 25 point transect assigned to each category and composite scores.

Creek	Month	Percent in category: Rough	Slimy	Thin layer	0.5 - 1 mm	1 - 5 mm	5 - 20 mm	> 2 cm	Composite score
2007									
Little Elm	May	100	0	0	0	0	0	0	0
	Oct	100	0	0	0	0	0	0	0
TLE	May	100	0	0	0	0	0	0	0
	Oct	72	4	24	0	0	0	0	6.5
Willis	May	96	0	4	0	0	0	0	1
Clear	Apr	100	0	0	0	0	0	0	0
	May	84	0	8	0	8	0	0	8
	Sep	100	0	0	0	0	0	0	0
Duck	May	96	0	4	0	0	0	0	1
	Sep	100	0	0	0	0	0	0	0
Walnut	May	100	0	0	0	0	0	0	0
	Sep	80	0	20	0	0	0	0	5
2008									
Little Elm	Aug	92	0	0	8	0	0	0	4
	Jul	88	0	4	4	0	4	0	7
TLE	Jul	84	0	16	0	0	0	0	4
	Aug	88	0	0	12	0	0	0	6
Willis	Aug	100	0	0	0	0	0	0	0
	Jun	80	8	12	0	0	0	0	4
	Jul	68	12	20	0	0	0	0	6.5
Clear	Aug	100	0	0	0	0	0	0	0
	Jun	64	0	36	0	0	0	0	9
Duck	Jun	100	0	0	0	0	0	0	0
	Aug	96	0	4	0	0	0	0	1
Walnut	Aug	88	0	12	0	0	0	0	3
	Jun	72	8	20	0	0	0	0	6

Table 47. Macroalgae thickness from aquatic vegetation surveys.
Tabulated values are percent of points from a 25 point transect assigned to each category and composite scores.

		Percent in category							
Creek	Month	0%	< 5%	5 to 25%	25 to 50%	50 to 75%	75 to 100%	~100% and thick	Composite score
2007									
Little Elm	May	100	0	0	0	0	0	0	0
	Oct	88	4	4	0	0	0	4	9
TLE	May	100	0	0	0	0	0	0	0
	Oct	100	0	0	0	0	0	0	0
Willis	May	100	0	0	0	0	0	0	0
Clear	Apr	100	0	0	0	0	0	0	0
	May	100	0	0	0	0	0	0	0
	Sep	96	0	0	0	4	0	0	4
Duck	May	100	0	0	0	0	0	0	0
	Sep	100	0	0	0	0	0	0	0
Walnut	May	100	0	0	0	0	0	0	0
	Sep	100	0	0	0	0	0	0	0
2008									
Little Elm	Jul	80	0	0	4	16	0	0	19
	Aug	96	0	0	0	0	4	0	5
TLE	Jul	92	0	8	0	0	0	0	4
	Aug	92	0	8	0	0	0	0	4
Willis	Jun	100	0	0	0	0	0	0	0
	Jul	92	0	0	8	0	0	0	6
	Aug	64	0	20	0	8	8	0	28
Clear	Jun	100	0	0	0	0	0	0	0
	Aug	100	0	0	0	0	0	0	0
Duck	Jun	100	0	0	0	0	0	0	0
	Aug	96	0	4	0	0	0	0	2
Walnut	Jun	96	0	0	0	4	0	0	4
	Aug	68	0	20	12	0	0	0	19

Table 48. Macrophyte cover from aquatic vegetation surveys.
Tabulated values are percent of points from a 25 point transect assigned to each category and composite scores.

Creek	Month	Percent in category: 0% cover	< 5% cover	5 to 25% cover	25 to 50% cover	50 to 75% cover	75 to 100% cover	~100% cover and thick	Composite score
2007									
Little Elm	May	100	0	0	0	0	0	0	0
	Oct	100	0	0	0	0	0	0	0
TLE	May	100	0	0	0	0	0	0	0
	Oct	100	0	0	0	0	0	0	0
Willis	May	100	0	0	0	0	0	0	0
Clear	Apr	100	0	0	0	0	0	0	0
	May	100	0	0	0	0	0	0	0
	Sep	100	0	0	0	0	0	0	0
Duck	May	100	0	0	0	0	0	0	0
	Sep	100	0	0	0	0	0	0	0
Walnut	May	100	0	0	0	0	0	0	0
	Sep	100	0	0	0	0	0	0	0
2008									
Little Elm	Jul	100	0	0	0	0	0	0	0
	Aug	100	0	0	0	0	0	0	0
TLE	Jul	100	0	0	0	0	0	0	0
	Aug	100	0	0	0	0	0	0	0
Willis	Jun	100	0	0	0	0	0	0	0
	Jul	100	0	0	0	0	0	0	0
	Aug	100	0	0	0	0	0	0	0
Clear	Jun	100	0	0	0	0	0	0	0
	Aug	100	0	0	0	0	0	0	0
Duck	Jun	100	0	0	0	0	0	0	0
	Aug	100	0	0	0	0	0	0	0
Walnut	Jun	100	0	0	0	0	0	0	0
	Aug	100	0	0	0	0	0	0	0

Table 49. Sediment cover on algae from aquatic vegetation surveys.
Tabulated values are percent of points from a 25 point transect assigned to each category and composite scores.

Creek	Month	Percent in category: No sediment cover	Minimal film	Film on all algal surfaces	Heavy, obscures color of algae	Heavy, algal growth limited	Composite score
2007							
Little Elm	May	100	0	0	0	0	0
	Oct	92	0	4	4	0	5
TLE	May	100	0	0	0	0	0
	Oct	100	0	0	0	0	0
Willis	May	100	0	0	0	0	0
Clear	Apr	100	0	0	0	0	0
	May	100	0	0	0	0	0
	Sep	100	0	0	0	0	0
Duck	May	92	8	0	0	0	2
	Sep	100	0	0	0	0	0
Walnut	May	100	0	0	0	0	0
	Sep	100	0	0	0	0	0
2008							
Little Elm	Jul	84	4	4	8	0	9
	Aug	96	4	0	0	0	1
TLE	Jul	100	0	0	0	0	0
	Aug	100	0	0	0	0	0
Willis	Jun	100	0	0	0	0	0
	Jul	88	4	8	0	0	5
	Aug	100	0	0	0	0	0
Clear	Jun	100	0	0	0	0	0
	Aug	100	0	0	0	0	0
Duck	Jun	100	0	0	0	0	0
	Aug	100	0	0	0	0	0
Walnut	Jun	100	0	0	0	0	0
	Aug	100	0	0	0	0	0

Habitat

Table 50. Study site attributes for habitat assessment.

Creek	Date	Aesthetic category	Bed slope (m/km)	Drainage area (km^2)	Flow (cfs)	Flow category	Inlets	Stream order	Study reach length (km)	Total bends
Little Elm	9 May 2007	Common	1.87	49	13	High	1	3	0.20	3
	3 Oct 2007	Common	1.87	49	1.5	Moderate	1	3	0.20	3
	9 Jul 2008	Common	1.87	49	0	Low	1	3	0.20	3
	12 Aug 2008	Common	1.87	49	0	No flow	1	3	0.20	3
TLE	7 May 2007	Common	2.54	20	8	Moderate	0	3	0.24	11
	4 Oct 2007	Common	2.54	20	1.4	Moderate	0	3	0.24	11
	9 Jul 2008	Common	2.54	20	1.7	Low	0	3	0.24	11
	13 Aug 2008	Common	2.54	20	2.2	Moderate	0	3	0.24	11
Willis	8 May 2007	Natural	1.4	164	43	High	1	5	0.26	9
	3 Jun 2008	Natural	1.4	164	6.7	Moderate	1	5	0.26	9
	8 Jul 2008	Natural	1.4	164	0.47	Low	1	5	0.26	9
	12 Aug 2008	Natural	1.4	164	0.08	Low	1	5	0.26	9
Clear	23 May 2007	Natural	2.7	78	5.9	Moderate	4	4	0.18	6
	6 Sep 2007	Natural	2.7	78	3.9	Moderate	2	4	0.18	6
	10 Jun 2008	Natural	2.7	78	1.6	Moderate	3	4	0.18	6
	5 Aug 2008	Natural	2.7	78	0.52	Low	3	4	0.18	6
Duck	23 May 2007	Natural	0.54	342	10	Moderate	1	5	0.30	5
	6 Sep 2007	Natural	0.54	342	4.5	Moderate	1	5	0.30	5
	11 Jun 2008	Natural	0.54	342	1.7	Low	1	5	0.30	5
	5 Aug 2008	Natural	0.54	342	0	Moderate	1	5	0.30	5
Walnut	22 May 2007	Natural	1.09	320	37	Moderate	0	5	0.28	4
	5 Sep 2007	Natural	1.09	320	14	Moderate	0	5	0.28	4
	10 Jun 2008	Natural	1.09	320	11.5	Moderate	0	5	0.28	4
	5 Aug 2008	Natural	1.09	320	9.8	Moderate	0	5	0.28	4

Table 51. Riparian habitat measurements for each sampling event.
Means are based on five transects for each study reach.

						Riparian vegetation				
Creek	Date	Mean bank slope (degrees)	Mean percent bank erosion	Mean percent tree canopy	Mean width riparian (m)	Mean percent trees	Mean percent shrubs	Mean percent grasses	Mean percent cultivated fields	Mean percent pasture
Little Elm	9 May 2007	51	47	87	7	21	42	37	0	0
	3 Oct 2007	49	51	90	5	36	23	40	1	0
	9 Jul 2008	49	54	89	5	32	17	50	1	0
	12 Aug 2008	48	52	83	7	36	16	48	0	0
TLE	7 May 2007	52	46	62	1	6	8	86	0	0
	4 Oct 2007	54	54	75	2	38	4	7	0	51
	9 Jul 2008	55	50	75	3	21	1	23	0	56
	13 Aug 2008	57	58	85	2	16	0	9	0	75
Willis	8 May 2007	44	56	92	20	35	38	28	0	0
	3 Jun 2008	35	60	88	19	72	13	16	0	0
	8 Jul 2008	35	60	92	20	67	15	18	0	0
	12 Aug 2008	34	62	90	20	65	18	18	0	0
Clear	23 May 2007	43	49	79	11	25	52	23	0	0
	6 Sep 2007	38	49	83	11	44	26	20	0	11
	10 Jun 2008	35	48	85	13	49	25	22	0	5
	5 Aug 2008	42	57	88	12	53	33	15	0	0
Duck	23 May 2007	54	61	88	10	33	28	40	0	0
	6 Sep 2007	69	65	91	12	42	23	27	0	11
	11 Jun 2008	63	62	89	16	56	20	22	0	2
	5 Aug 2008	68	51	89	12	55	22	23	0	0
Walnut	22 May 2007	49	60	81	13	30	27	43	0	0
	5 Sep 2007	52	65	88	15	34	23	42	0	0
	10 Jun 2008	46	63	84	14	35	25	32	0	8
	5 Aug 2008	51	60	88	13	57	21	23	0	0

Table 52. Instream habitat measurements for each sampling event.
Means are based on five transects for each study reach.

Creek	Date	Mean stream width (m)	Mean stream depth (m)	Mean thalweg depth (m)	Largest pool			Mean percent gravel	Riffles (number)	Mean percent instream cover
					Percent of channel	Depth (m)	Width (m)			
Little Elm	9 May 2007	5.5	0.60	0.95	50	1.3	1	1	1	21
	3 Oct 2007	4.9	0.37	0.70	100	0.9	3	41	1	24
	9 Jul 2008	4.3	0.22	0.45	80	1.2	2	1	1	32
	12 Aug 2008	3.1	0.02	0.05	100	1.5	4	2	0	2
TLE	7 May 2007	2.5	0.37	0.54	50	0.8	1	0	4	5
	4 Oct 2007	2.1	0.18	0.29	50	0.95	1	2	7	20
	9 Jul 2008	2.0	0.18	0.36	95	0.5	1	5	3	21
	13 Aug 2008	2.1	0.22	0.38	80	0.7	1.5	9	2	30
Willis	8 May 2007	6.7	0.46	0.94	50	1.5	1	44	6	11
	3 Jun 2008	5.4	0.37	0.82	100	2	4	54	7	14
	8 Jul 2008	3.7	0.33	0.64	100	1.5	3	62	7	20
	12 Aug 2008	3.1	0.24	0.48	100	1.5	3	41	1	18
Clear	23 May 2007	4.2	0.39	0.75	80	1.1	1	0	4	28
	6 Sep 2007	3.4	0.25	0.43	90	0.94	5	5	2	28
	10 Jun 2008	3.5	0.30	0.50	95	0.97	3.8	6	5	30
	5 Aug 2008	3.3	0.25	0.54	95	0.8	2	4	4	36
Duck	23 May 2007	6.2	0.51	0.89	50	1.3	2	14	2	34
	6 Sep 2007	6.7	0.58	0.99	70	1.5	3	12	1	40
	11 Jun 2008	6.8	0.62	1.06	100	2	6	16	1	38
	5 Aug 2008	6.2	0.42	0.78	90	1.5	4	22	1	39
Walnut	22 May 2007	9.0	0.51	0.83	50	1.1	1	0	10	27
	5 Sep 2007	8.2	0.30	0.61	80	1.3	9.3	0	5	30
	10 Jun 2008	7.2	0.24	0.45	80	1.1	3	10	4	33
	5 Aug 2008	7.0	0.22	0.50	90	1.8	5	0	4	32

Water Quality

Table 53. Comparison of instantaneous and diel temperature, pH, dissolved oxygen and specific conductance measurements. Italicized cells indicate instantaneous values greater than the diel maximum or less than the diel minimum.

		Dissolved oxygen (mg/L)				pH			Temperature (°C)				Specific conductance (µS/cm)			
Creek	Date	Avg	Min	Max	Instant	Min	Max	Instant	Avg	Min	Max	Instant	Avg	Min	Max	Instant
Little Elm	10 Apr 2007	8.6	8.2	9.3	*9.7*	7.9	7.9	7.9	15.2	13.6	16.3	*13.1*	522	507	532	509
	7 May 2007	7.5	7.4	7.7	*7.9*	7.8	8.0	*7.6*	22.9	22.7	23.0	*22.6*	575	574	577	*581*
	2 Oct 2007	5.8	5.4	6.7	5.9	7.6	7.7	*7.1*	24.3	23.0	25.4	23.8	564	559	568	562
	7 Jul 2008	0.7	0.5	0.8	*0.9*	7.1	7.3	7.1	23.6	22.9	24.0	*24.3*	618	611	628	611
	11 Aug 2008	0.5	0.4	0.9	0.8	7.1	7.2	*7.5*	24.8	24.5	25.1	*25.4*	615	609	621	*645*
TLE	7 May 2007	7.1	6.9	7.4	*7.5*	7.9	8.0	*7.6*	23.6	22.3	24.9	23.0	817	806	827	*831*
	2 Oct 2007	7.4	6.5	9.2	9.0	7.9	8.3	*7.8*	25.3	23.5	27.6	25.8	960	943	972	947
	7 Jul 2008	7.9	7.6	9.0	*7.5*	7.8	8.1	*7.7*	25.8	24.6	27.9	26.1	992	968	1007	999
	11 Aug 2008	6.7	6.1	8.3	7.1	7.8	8.2	7.9	27.1	26.3	28.7	26.6	1075	1058	1084	*1092*
Willis	7 May 2007	7.8	7.6	8.0	*8.1*	8.0	8.0	*7.5*	23.6	23.0	24.2	23.4	561	555	565	*579*
	3 Jun 2008				7.5	7.6	7.8	*7.9*	25.7	24.8	26.8	25.5	608	605	616	*647*
	7 Jul 2008	6.7	6.1	7.7	7.5	7.6	7.9	*8.0*	25.3	24.7	26.0	26.0	710	678	724	*1850*
	11 Aug 2008	7.8	5.5	10.0	6.7	7.6	8.0	*8.3*	26.3	25.8	26.7	*28.1*	543	539	549	*3151*
Clear[a]	22 May 2007	7.8	7.5	8.0	*8.1*	7.0	7.0	*6.8*	21.1	20.6	21.4	*20.5*	185	164	210	195
	4 Sep 2007	7.0	6.8	7.2	*7.3*	6.9	7.2	*7.6*	24.3	24.0	24.5	*23.9*	141	139	143	143
	9 Jun 2008				6.6	6.7	6.9	*7.5*	25.3	24.9	25.8	25.3	166	164	179	168
	4 Aug 2008	6.0	5.6	6.2	*6.4*	6.5	6.6	*6.7*	25.4	24.5	26.3	*24.3*	148	140	155	142
Duck[a]	22 May 2007	5.8	5.5	6.2	*6.4*	7.1	7.2	*6.9*	20.9	20.7	21.2	20.9	607	587	616	*620*
	4 Sep 2007	5.6	5.2	5.8	*4.3*	7.0	7.1	7.1	24.7	24.2	25.2	*24.0*	481	437	508	*419*
	9 Jun 2008	2.3	2.0	2.6	*2.9*	6.7	6.9	*7.2*	26.3	26.0	26.6	26.2	533	527	540	*518*
	4 Aug 2008	2.6	2.3	2.8	*1.3*	6.7	6.8	*6.6*	25.8	25.6	26.0	25.6	262	257	268	280
Walnut[a]	22 May 2007	6.4	6.3	6.6	6.6	7.4	7.5	7.4	23.3	23.0	23.5	*23.6*	543	532	561	539
	4 Sep 2007	6.6	6.3	6.7	*6.9*	7.7	7.8	*7.6*	24.8	24.7	25.1	24.8	798	782	810	786
	9 Jun 2008	6.6	6.2	7.2	7.2	7.9	8.0	7.9	26.0	25.7	26.4	26.2	815	695	878	871
	4 Aug 2008	7.1	6.7	7.4	7.1	7.9	8.0	8.0	26.0	25.9	26.3	26.1	771	742	799	766

a. Instantaneous measurement made 5/21/2007

Table 54. Comparison of specific conductance and total dissolved solids (TDS) measurements. Specific conductance was converted to TDS using [Specific conductance (µS/cm) * 0.67] = TDS (mg/L). Italicized cells indicate calculated values greater or less than the water chemistry measurement.

		Specific conductance (µS/cm)		TDS (mg/L)		
Creek	Date	Average	Instant	Water chemistry	Calculated from average	Calculated from instantaneous measurement
Little Elm	10 Apr 2007	522	509	279	*350*	*341*
	7 May 2007	575	581	334	*386*	*389*
	2 Oct 2007	564	562	321	*378*	*377*
	7 Jul 2008	618	611	351	*414*	*409*
	11 Aug 2008	615	645	369	*412*	*432*
TLE	7 May 2007	817	831	479	*547*	*557*
	2 Oct 2007	960	947	574	*643*	*634*
	7 Jul 2008	992	999	581	*665*	*669*
	11 Aug 2008	1075	1092	617	*721*	*732*
Willis	7 May 2007	561	579	322	*376*	*388*
	3 Jun 2008	608	647	398	*408*	*433*
	7 Jul 2008	710	1850	806	*476*	*1240*
	11 Aug 2008	543	3151	1900	*364*	*2111*
Clear[a]	22 May 2007	185	195	141	*124*	*131*
	4 Sep 2007	141	143	121	*94*	*96*
	9 Jun 2008	166	168	124	*111*	*113*
	4 Aug 2008	148	142	113	*99*	*95*
Duck[a]	22 May 2007	607	620	375	*407*	*415*
	4 Sep 2007	481	419	249	*322*	*281*
	9 Jun 2008	533	518	306	*357*	*347*
	4 Aug 2008	262	280	163	*175*	*188*
Walnut[a]	22 May 2007	543	539	330	*364*	*361*
	4 Sep 2007	798	786	481	*535*	*527*
	9 Jun 2008	815	871	550	*546*	*584*
	4 Aug 2008	771	766	454	*517*	*513*

a. Instantaneous measurement made 5/21/2007

Appendix B – Report: Algal Community Interpretation for Nutrient Effects on Small Brazos River Basin Streams

Algal Community Interpretation

for

Nutrient Effects on Small Brazos River Basin Streams

From

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May 2009

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Acronyms

FRP	Filterable Reactive Phosphorus
N	Nitrogen

NAWQA	National Water-Quality Assessment
P	Phosphorus
PTI	Pollution Tolerance Index
RDI	River Diatom Index
TN	Total Nitrogen
TP	Total Phosphorus
TSS	Total Suspended Solids
USGS	U.S. Geological Survey

Diatom Metrics

Algae (particularly diatoms since they often dominate a stream assemblage) are critically important to stream ecology as they stabilize the substrate, are primary producers and converters of inorganic nutrients into organic forms useable by other organisms. Although the usefulness of diatoms in monitoring the effects of nutrients on many aquatic systems, particularly large lakes and rivers, has been well established, less information is available about the responses of diatoms to nutrient effects in smaller streams. Analyses at the national scale of 2735 benthic algal samples from the U. S. Geological Survey's National Water-Quality Assessment (NAWQA) program (Potapova and Charles 2002) have shown that there are three major ecological gradients affecting diatom distribution, (not correlated with measured environmental characteristics), that explain up to one-third of the total variation in species data. These gradients are: (1) the downstream gradient from highland rivers with fast flowing, mostly oligotrophic water, to eutrophic rivers of high and low elevation plains, (2) the gradient from soft, more acidic waters in the humid eastern parts of the United States to the alkaline waters of arid western regions, and (3) latitudinal and altitudinal variation of temperature. For this reason Potapova and Charles (2002) advocate the development and calibration of metrics based on data sets collected from more limited geographical areas and having relatively narrow ranges of environmental characteristics other than those which the metrics being used are designed to indicate.

Metrics and attributes that have been used historically to assess biotic integrity were tabulated for the diatom taxa found in the 2007-2008 collections (Table 55). The various metrics that were tabulated are described below. In Table 55, "R#" indicates the reference used, and the numbers and letters refer to specific columns, corresponding to different values within that reference. The key to the fields in Table 55 is given in Table 56, and authorship for diatom names is given in Table 57. As many diatom names have been revised in the last few years some of the names used by the various authors of the metrics were older synonyms for the names used in this study, and that was taken into account when tabulating the various metrics.

Six streams, selected because they represent a gradient of conditions from highly impacted to relatively unimpacted, were sampled four times during 2007 and 2008. The area has fluctuated between flood and drought. In spring 2007 streams experienced high flows and in 2008 flow was sometimes reduced due to limited rainfall. In some instances water was limited to unconnected pools. This has several effects. There is an increase in the residence time of the water, allowing any phytoplankton washed down from a lake or pond upstream to grow, for nutrients to become depleted, and for salts to accumulate as water evaporates. Stream habitats are connected during high flow, but during low flow the stream becomes a patchy mosaic of discrete and overlapping habitats. Wood was the substrate sampled because that was what was available. Although most periphyton metrics were developed using data from rock scrapings it has been noted that if the purpose of an investigation is to determine the impact of perturbations on the indigenous benthic algal community, then the indigenous community should be sampled on the substrate present in the stream (Lowe and Pan 1996).

The purpose of this portion of the study was to analyze the algal composition of the streams under investigation and to provide information regarding previous investigations aimed at understanding the relationship of algal (particularly diatom) metrics and attributes to stream biotic integrity. A comparison of these historic data with the information collected during the present study can then be used to determine how well the various diatom-based metrics and indices, developed for use in evaluating the effect of nutrient enrichment in larger water bodies or in other parts of the country, are applicable to small, wadeable streams of the Brazos River Basin in ecoregions 32 and 33. These results will contribute to the development of science-based numeric nutrient criteria for conservation management of rivers and streams.

Autecological (individual) attributes of diatom taxa have been composited into various community level pollution metrics called trophic diatom indices that combine the responses of all taxa into a new set of metrics such as diversity. Attributes are any features of the assemblage that are tolerant of particular conditions. Trophic state refers to the presence of inorganic nutrients such as nitrogen, phosphorus, silica and carbon (fertilizers); in contrast, saprobity refers to the presence of biodegradable organic matter and low oxygen concentrations (Van Dam *et al.* 1994). Autecological indices use the relative abundance of species in assemblages and their ecological preferences, sensitivities, and tolerances to infer specific or general environmental conditions in an ecosystem (Stevenson and Pan 1999). An index or metric is an attribute that correlates diatom assemblages with water quality variables and types of land use, and thus demonstrates a significant correlation with human disturbance. These indices link algal assemblages, primarily diatoms, with biological and physico-chemical parameters, such as pH, temperature, instream or riparian vegetation and cover, catchment land cover, land use, flow regime, habitat, substrate type and sediment size, conductivity, salinity, total dissolved solids, dissolved oxygen, and phosphorus and nitrogen concentrations. A data file called Algal Attributes, with metrics indicating physiological optima or tolerances to various water quality parameters, was created at the Academy of Natural Sciences of Philadelphia to help with the analysis or trophic conditions etc. in U.S. streams and rivers (http:/diatom.acnatsci.org/Algae Image/).

Many diatoms are cosmopolitan and their autecological characteristics have been well documented, particularly for the indicator species. There is a geographical component, however, to the relationship between diatoms and environmental characteristics (Potapova and Charles 2007) due to floristic and environmental differences among regions. In a recent and comprehensive study, Porter *et al.*, (2008) used periphyton data collected between 1993-2001 from 976 streams and rivers by the U.S. Geological Survey's NAWQA program to evaluate national and regional relations of periphyton with water chemistry. They explored the efficacy of algal metrics for assessing nutrient and organic enrichment in flowing waters and determined whether algal-metric values differ significantly among undeveloped and developed land-use classifications. The results of their study were that algal metrics having significant positive correlations with nutrient concentrations included indicators of trophic condition, organic enrichment, salinity, motility and taxa richness. Another result of their study was that the abundance of diatoms associated with high concentrations of dissolved oxygen was negatively correlated with both nitrogen and phosphorus concentrations. Their data set most relevant to this study comes from the Southern Plains Region that includes the Lower Mississippi, Arkansas-White-Red, and Texas-Gulf basins.

Nitrogen (N) and phosphorus (P) are the most commonly measured nutrients because they are the ones most likely to be limiting in aquatic environments, and because in excessive amounts they produce nuisance blooms of algae, such as *Cladophora*, and macrophytes that interfere with the uses of a stream. Nitrogen and phosphorus are essential nutrients for living organisms and may come from natural sources such as decomposition of plants and animals and dissolution of sediments. However, much of the phosphorus and nitrogen that enters streams is of human origin or related to human activities, such as wastewater treatment plant discharges, wastes from poultry and livestock facilities, and runoff of fertilizers. Most algae use inorganic forms of phosphorous or nitrogen (such as nitrate, nitrite and ammonia), but some algae are able to use various forms of organic phosphorus of nitrogen (phosphorus or nitrogen that is bound to carbon-based molecules) such as urea.

Because studies of this nature are just being started for this part of Texas, and a comprehensive regional set of metrics has yet to be developed and calibrated, the first step is to provide background information concerning algal attributes and nutrient-related numeric criteria defined in other areas, by tabulating biological integrity metrics (based on relative abundance of species and their environmental sensitivities), that have been devised for other regions or countries, and assess how well they apply to the diatoms found in this study.

Metrics and attributes that are tabulated to provide information for the development of numeric nutrient criteria include the pollution classes of Bahls 1993; the Kentucky 2002 pollution tolerance index (PTI); the growth forms of Wang *et al*. 2005, used to determine siltation, and a modified version of the motile growth forms of the author; the ecological indicator values of Van Dam *et al.* 1994; total nitrogen and phosphorus values of Potapova and Charles 2007; the Muscio (2002) pollution tolerance values calculated for Austin, Texas; the Lange-Bertalot and Metzeltin (1996) indicators of oligotrophy in three kinds of lakes; the Lange-Bertalot and Genkal (1999) autecological characteristics of diatoms; the trophic diatom index of Kelly and Whitton (1995); the multimetric disturbance index of Idaho streams by Fore and Grafe (2002); a multimetric disturbance index for the Mid-Atlantic Region by Fore (2002); and the Potapova *et al.* 2004 index for total phosphorus. Incorporated in some of these various metrics are the saprobic system of Lange-Bertalot (1979), and the ecological tabulation of Lowe (1974).

R1: Bahls, 1993. Pollution Classes

Bahls modified the designations of Lange-Bertalot (1979) and Lowe (1974) to reflect the response of diatoms to pollution in wadeable streams of Montana. His metrics are based on hundreds of collections over 20 years as well as ecological information from other workers. He calculated diversity index, pollution index, and siltation index to generate a score of overall impairment and biological integrity.

Pollution classes. 1: most tolerant, 2: less tolerant, 3: sensitive (based on Lange-Bertalot 1979)

R1a: Default values for genera whose species are not listed in Bahls 1993

R2: Kentucky Department for Environmental Protection, Kentucky PTI Value, 2002.

A multiple metric index (Diatom Bioassessment Index) was designed (Wang, Stevenson and Metzmeier 2005) to assess biological integrity by categorizing the water quality as excellent, good, fair or poor. It combines total number of taxa, Shannon diversity, pollution tolerance index, *Cymbella* group richness, *Fragilaria* group richness and % *Navicula*, *Nitzschia* and *Surirella*. It is an adaptation of Lange-Bertalot's list, along with several others, expanded to 4 categories ranging from one (most tolerant) to four (most sensitive), with a value of zero given in no autoecological information is known. Lange-Bertalot (1979) developed the saprobic system to include the effects of inorganic nutrients in the absence of significant organic pollution.

R3: Wang et al., 2005. Wang Growth Form

The type of substrate in a stream determines the kinds of diatoms that can live there. Those that live on a firm substrate include those that are attached, either prostrately or with a pad, stalk, or tube, and those that are motile and can move around. Loose sediment is an unstable substrate and selects for those diatoms that can crawl up to the surface if they are buried. Diatoms with two raphes are considered motile. This includes the genera *Navicula* (and the many new genera that have been separated from *Navicula sensu stricto)*, *Nitzschia*, *Tryblionella* and *Surirella*.
Appendix 2. Classifications of growth form and motility for diatom genera. P = prostrate, E = erect, S = stalked, U = unattached, V = variable, M = motile. Since many of the biraphid forms are classified as other than motile by Wang, another motility classification scheme is included for comparison (R14).

R4: Van Dam et al., 1994. Ecological Indicator Values

This report is a comprehensive checklist of the ecological values of diatoms in fresh and weakly brackish water in the Netherlands. Each of these ecological indicators is represented by a number that represents a classification of values for that parameter.

R4a= R: pH
- 1: acidobiontic (optimal occurrence at pH<5.5)
- 2: acidophilous (mainly occurring at pH <7)
- 3: circumneutral (mainly occurring at pH-values about 7)
- 4: alkaliphilous (mainly occurring at pH >7) (alkaliphilic)
- 5: alkalibiontic (exclusively occurring at pH >7)
- 6: indifferent (no apparent optimum)

R4b= H: Salinity

	Cl^- (mg/L)	Salinity (%)
1: fresh	<100	<0.2
2: fresh brackish	<500	<0.9
3: brackish fresh	500-1000	0.9-1.8
4: brackish	1000-5000	1.8-9.0

R4c= N: Nitrogen uptake metabolism
- 1: nitrogen-autotrophic taxa, tolerating very small concentrations of organically bound nitrogen
- 2: nitrogen-autotrophic taxa, tolerating elevated concentrations of organically bound nitrogen
- 3: facultatively nitrogen-heterotrophic taxa, needing periodically elevated concentrations of bound nitrogen

4: obligately nitrogen-heterotrophic taxa, needing continuously elevated concentrations of organically bound nitrogen

R4d= O: Oxygen requirements
1: continuously high (about 100% saturation)
2: fairly high (above 75% saturation)
3: moderate (above 50% saturation)
4: low (above 30% saturation)
5: very low (about 10% saturation)

R4e= S: Saprobity

	Water quality class	Oxygen saturation (%)	BOD_5^{20} (mg/L)
1: oligosaprobous	I	>85	<2
2: β-mesosaprobous	II	70-85	2-4
3: α-mesosaprobous	III	25-70	4-13
4: α-meso-/polysaprobous	III-IV	10-25	13-22
5: polysaprobous	IV	<10	>22

R4f= T: Trophic state
1: oligotraphentic (oligotrophic)
2: oligo-mesotraphentic (oligo-mesotrophic)
3: mesotraphentic
4: meso-eutraphentic
5: eutraphentic (eutrophic)
6: hypereutraphentic
7: oligo- to eutraphentic (no apparent optimum)

R4g= M: Moisture
1: never, or only rarely, occurring outside water bodies
2: mainly occurring in water bodies, sometimes on wet places
3: mainly occurring in water bodies, also rather regularly on wet and moist places
4: mainly occurring on wet and moist or temporarily dry places
5: nearly exclusively occurring outside water bodies

R5: Potapova and Charles, 2007.

These authors used NAWQA diatom and water quality data from U.S. rivers to create diatom metrics for monitoring eutrophication, and showed that regional-scale studies are more refined than continental-scale studies. They provided information about total nitrogen and total phosphorus. Diatoms indicating low (≤ 10 µg/L) total phosphorus are indicated by (-), high (≥ 100 µg/L) total phosphorus (TP) by (+); low (≤ 0.2 mg/L) total nitrogen (TN) by (-), and high (≥ 3 mg/L) total nitrogen by (+). Diatoms with indicator values greater than 5 ($|P|<0.05$) are shown. A second analysis was based on calculation of species abundance-weighted means. Diatoms with TP and TN abundance-weighted means above the 75^{th} percentile (+*) or below the 25^{th} percentile (-*) of all values are listed here and marked by asterisks.

R5a= total nitrogen (TN) (mg/L)

R5b= total phosphorus (TP) (µg/L)

R6: Muscio, 2002. PTI Values for Austin, Texas

Austin PTI numbers: These values have been determined for diatoms recorded from streams in the City of Austin. They are scaled from 1 to 4 with low numbers indicating most pollution tolerant and 4 representing the most pollution sensitive. This set of values includes the Kentucky PTI plus indicator scores for the Austin area taxa generated through literature survey and calculation methods.

R7: Lange-Bertalot and Metzeltin, 1996. Indicators of Oligotrophy

This book contains a description of 800 diatom taxa representative of three ecologically distinct lake systems, carbonate buffered, oligodystrophic and weakly buffered soft water. Upon examination of the results of applying this information to our data, it appears that this reference is not very relevant in this part of the world, since the majority of the diatoms in this study are mesotrophic or eutrophic. This paper does show that some eutrophic diatoms occur in low nutrient water as well.

R7a= 1: electrolyte poor, humic acid rich lake
R7b= 2: carbonate buffered, electrolyte rich lake
R7c= 3: electrolyte rich clear, humic acid free lake

R8: Lange-Bertalot and Genkal, 1999. Autoecology of Diatoms

This is a book about the diatoms from Siberia, in which the authors looked at freshwater and slightly brackish water habitats and found that of the 345 of the 490 taxa they found in Siberia about 70% occur in Central Europe. Their tabulation is based on “reliably known” autecological characteristics.

- ae (aerophilic)
- alk alkaliphilic
- oc (oligotrophic predominately carbonate buffered waters)
- od (oligotrophic or dystrophic electrolyte poor waters)
- o (oligotrophic waters of different quality)
- hal (halophilic)
- eu (highest vitality in stronger mesotrophic to eutrophic waters)
- tol (tolerant to a wide range from oligo- to eutrophic waters without discernible preference)

R9: Kelly and Whitton, 1995. Sensitivity values for Trophic Diatom Index (TDI)

This index, based on a suite of 86 diatom taxa selected for their indicator value and ease of identification, was developed to monitor the trophic status of rivers in England and Wales. They used the concentration of molybdate-reactive phosphate (orthophosphate) as a proxy for organic pollution. There was good correlation with aqueous phosphate in sites without significant pollution but where there was heavy organic pollution it was difficult to separate the effects of eutrophication from other effects. Their index is based on epilithic periphyton from 70 clean sites and 10 sites subject to organic pollution. The authors also tested their index on a river, above and below a major sewage discharge and found that the effect of inorganic nutrients on the river downstream of the discharge was slight if the river was already nutrient rich, but there was a big increase in the proportion of organic-pollution-tolerant taxa. Their taxon sensitivity index is based on the concentration of filterable reactive phosphorus (FRP) at which each taxon was most abundant. Pollution sensitivity (s) values between 1 and 5 were assigned to each taxon depending upon the FRP concentration at which taxa were most abundant. Indicator values (v) (1-3) depended on the spread of values around this peak. These taxon weightings (s and v), were used with the abundance of a species in a sample to calculate the trophic diatom index (TDI).

Values of “s” are as follows, no further definition for the values of “v” were provided by the authors.

1: <0.01 mg/L
2: ≥0.01, <0.035 mg/L
3: ≥0.035, <0.1 mg/L
4: ≥0.1, <0.3 mg/L
5: ≥0.3 mg/L

R10: Fore and Grafe, 2002. River Diatom Index

These authors describe a multimetric, nine attribute, river diatom index (RDI), developed as a monitoring tool to assess the biological condition of fourth order or greater, wadeable Idaho streams, wider than 30 meters and at least 0.4 meters deep. Using data from rock scrapings they determined which metrics demonstrated a significant correlation with human disturbance. The results are tabulated according to the number and kinds of attributes that are considered significant.

ox: species that require high oxygen
mo: species that are motile or sediment tolerant
al: species that prefer alkaline water
eu: species that prefer eutrophic conditions
sp: species that prefer saprobic conditions
nh: species that are nitrogen heterotrophs

R11: Fore, 2002. Multimetric Index for the Mid-Atlantic Region

Fore used a diatom data set from the Mid-Atlantic region to select and develop a set of regional diatom metrics that were consistently associated with human disturbance. The author tabulated the data alphabetically and included three more categories than Fore and Grafe, 2002. These columns include a tabulation of taxa listed as very tolerant by Bahls, 1993, a column indicating salt tolerant taxa, and a column indicating the taxa that were not listed by Van Dam *et al.* 1994. Salt tolerances are tabulated because of the potential impact of salts on the ecology of a system. Sources of salt include salt used to melt ice on roads and bridges, salts from evaporation of irrigation water and salts from treated wastewater. These data represent periphyton samples collected from riffles in wadeable streams. This metric set is included because although it is very similar to Fore and Grafe, 2002, the samples come from a different part of the country (Mid-Atlantic region) and therefore some of the species are different.

tol: species classified as very tolerant of pollution by Bahls (1993)
sal: species listed as tolerant to salt by Van Dam (1994)
ox: species that require high oxygen
eu: species that prefer eutrophic conditions
nit: species that are nitrogen heterotrophs

sap: species that prefer polysaprobic conditions
alk: species that prefer alkaline water
vd: species not included in Van Dam (1994)
mo: species that are motile or sediment tolerant

R12: Winter and Duthie, 2000a. Total Nitrogen and Phosphorus

These authors examined patterns of diatom distribution in relation to total nitrogen and phosphorus in southern Ontario lowland streams and developed a model for inferring stream water concentrations of nitrogen and phosphorus. Using the data from 126 samples, they concluded that their model for indicating eutrophication predicted 76% of the mesotrophic and 57% of the eutrophic samples correctly, but only 20% of oligotrophic and hypereutrophic samples. In their analysis they excluded rare diatom taxa, outlier samples, and planktonic diatoms and used only epilithic species.
R12a: optimal total nitrogen (TN mg/L)
R12b: optimal total phosphorus (TP μg/L)

R13: Potapova et al., 2004. Diatom Indices using Total Phosphorus

These authors used NAWQA data from 155 benthic diatom samples from 118 sites in the Northern Piedmont Ecoregion of the northeastern U.S. to look at the response curves of individual diatom species to total phosphorus. They compared two approaches: their first approach is based on simple weighted averaging of species indicator values, the other approach was to use multiple indicator values (ranges of total phosphorus (TP) values) based on ranges of phosphorus concentration. They concluded that both were useful as there were only a few diatoms that displayed a unimodal response to phosphorus and that the single simple weighted average provided the best total phosphorus predictions in the real-life situation when species responses vary in shape and several environmental gradients determine community composition.

Total phosphorus data from Potapova *et al.* 2004 were included in these tabulations as they complement Winter and Duthie, 2000a and include total phosphorus values for species Winter and Duthie do not include. It should be noted however that these authors used diatom data from four different studies with somewhat different protocols, and there is no clear relationship about the closeness of the phosphorus data and the diatom data: “Water chemistry samples were collected either simultaneously with algal sample collections or within one month preceding or following algal sampling” (Potapova *et al.* 2004, p. 26). There is an underlying assumption here that phosphorus values in a stream do not change and that statistical manipulations such as averaging, smoothing etc. are adequately robust to generate repeatable, reliable results from this type of data. Other researchers have also included the standard deviation of phosphorus values in their reports. The concern is that some of the non-linear results reported by Potapova *et al.* 2004 may be artifacts of this lag time between chemistry and algae collecting efforts. Causes of fluctuation in total phosphorus include seasonal fertilization of crops and accumulated manure that are washed into a stream after heavy rains. The result of these activities can be an increase (bloom) in algal growth within days, rapidly using up available nutrients.
R 13: optimal total phosphorus (TP μg/L) (weighted average)

R 14: Winsborough, 2009. Motile Diatoms

Motility in diatoms is restricted to those with two raphes (slits), and many of these taxa are found living principally on the surface of sand and mud. These diatoms can migrate downward in response to disturbance by tides, wind and current, and upward in response to light, air, gravity and sediment deposition. The complications of assigning motility derive from the fact that diatoms move only about two-thirds of the time (Harper 1977), some diatoms are much more motile than others: some are very sluggish, others move rapidly, some are motile only during part of their life, some move around only within their mucilage tube. All leave a sticky slime trail. This tabulation includes the genera *Navicula* (and all new names that have been separated from *Navicula*: *Adlafia, Biremis, Capartogramma, Craticula, Diadesmis, Fallacia, Geissleria, Hippodonta, Luticola, Mayamaea,* and *Sellaphora*), *Pinnularia, Pleurosigma, Gyrosigma, Nitzschia, Tryblionella, and Surirella.* Also included are *Amphora copulata, Amphora montana, Cymatopleura solea, Campylodiscus clypeus, Hantzschia amphioxys,* and *Cymbella cistula*. These data were derived, in part, from personal experience. Additional motility data was found in a multiaccess key to the common freshwater diatoms of Britain and Ireland (EADiatom key), a list of motile diatoms found in Hill *et al*. (2003), and those species specifically mentioned in Harper (1977).
R14: M = motile

Additional Metrics That Have Been Used to Investigate Community Attributes

Taxa Richness

Taxa richness is the number of species in a sample. Species composition is often described by taxa richness, by evenness of their abundances, and by diversity indices that include both.

Diversity (Shannon diversity index)

This index incorporates both dominance and species richness. The theory is that environmental disturbances reduce or eliminate sensitive species and populations of tolerant individuals expand leading eventually to a decrease in species diversity, although minor disturbances can increase diversity. Diversity has been used traditionally as a measure of stream health or ecological integrity. It is suggested (Stevenson and Pan 1999) that the best use of diversity-related indices in stream assessments is as a change in species composition when comparing impacted and reference assemblages, as diversity can increase or decrease with increased pollution depending on the type and severity of pollution. Clustering, ordination, and community similarity are indices that can be used to assess variation in species composition among communities in different streams (Stevenson and Pan 1999). Diversity data can be misleading because very clean water and very polluted water can both have low diversities. It can also be a function of timing. Colonization after a scour depends in part on the availability of diatom inoculants and the nature of the substrate.

Percent dominant taxon

As a system is stressed, those taxa adapted to unfavorable conditions often become more abundant and sensitive taxa disappear, making an assemblage uneven in the distribution of the diatoms. For example, eutraphentic (eutrophic) species generally increase in nutrient impacted sites and halophilic diatoms increase in irrigation return water.

Percent *Achnanthidium minutissimum*

The abundance of this diatom is sometimes used as a disturbance index because this taxon is often the first species to colonize a bare surface. Reports of various authors differ on the reliability of this attribute. Fore (2002) reported that *A. minutissimum* was not significantly correlated with disturbance. *A. minutissimum* is well represented in many waters with pH above 5 but is rare in more acid waters (Van Dam *et al.* 1994). *A. minutissimum* is reported as "often the dominant diatom in upland oligo/mesotrophic rivers and streams, whereas *Planothidium lanceolatum* tends to be more common in more nutrient-rich conditions" (Kelly and Whitton 1995). In central Texas, *Achnanthidium minutissimum* is one of the most common diatoms to colonize seasonal streams at the beginning of the wet season. It thrives on bare rock, in full sun, with only the nutrients found in local rain and groundwater. It also thrives in a film of flowing spring water, such as found on an active travertine slope. *Cocconeis placentula* often replaces *Achnanthidium minutissimum* in habitats with relatively lower light levels and possibly higher nutrient concentrations.

Siltation Index

Also called the algal status index, this is a measure of the percent of motile diatoms in a population. Increased siltation favors motile forms (that can move over unstable substrates) over attached taxa and as siltation increases the number of attached diatoms decreases. This includes the epipelic diatoms (living in mud), and episammic species (found in silt and sand). Human activities that increase sedimentation often reduce habitat complexity that may lead to decline of diversity and dominance by a few tolerant taxa. There are some limitations to this index, such as the natural prevalence of fine sediments in an area, but, particularly in epilithic habitats, a change in the proportion of motile taxa can indicate nutrient and/or organic enrichment. Siltation can also increase as a result of clearing an area of timber, urbanization, mining, and other land uses.

Salinity

Diatoms have variable responses to elevated ion concentrations. This attribute is typically expressed as salinity when the ion is chloride and as conductivity when there are mixed anion concentrations such as carbonate and sulfate. Some diatoms are sensitive to salts and others thrive on elevated concentrations. Some diatoms favor one particular ion such as carbonate, sulfate, or chloride. Diatom salinity classification schemes (Denys and De Wolf 1999, Fritz *et al.* 1999, Admiraal 1984) show that diatoms replace each other with increasing salinity and this series of species replacements along the salinity gradient makes diatoms powerful indicators of chemical change driven by changes in hydrology and climate

Indicator taxa

Certain diatoms are consistently found under particular environmental conditions and can be considered indicator species for those conditions. *Achnanthidium minutissimum*, *Gomphonema parvulum*, and other taxa have proven to be particularly useful. Kelly and Whitton (1995) report that there are a number of large forms of *Cymbella* that are characteristic of eutrophic water, whereas most of the genus is more frequent at lower nutrient concentrations, and similarly, many small forms (they used an arbitrary 12 µm length) of *Navicula* (including *Sellaphora*) were extremely abundant in highly eutrophic (usually organically-polluted) water. The total number of diatoms belonging to the *Cymbella* group of genera (including *Cymbella*, *Encyonema*, *Encyonopsis*, and *Reimeria* in our data) is sometimes used as an estimate of good water quality. These taxa all live attached to a substrate. The total number of diatoms belonging to the *Fragilaria* group (represented in our data by *Fragilaria*, *Pseudostaurosira*, *Staurosira*, and *Synedra*) is also used as an indicator of clean water.

Winter and Duthie (2000a) found that *Navicula lanceolata*, *Navicula schroeteri*, and *Nitzschia inconspicua* were good indicators of high phosphorus conditions; *Nitzschia amphibia*, *Nitzschia constricta (Tryblionella apiculata)*, and *Nitzschia solita* were also good indicators of high phosphorus but also indicated low nitrogen conditions; *Cymbella affinis* was a good indicator of low phosphorus, and *Navicula (Sellaphora) pupula* was a good indicator of low nitrogen.

Porter *et al.*, (2008) used periphyton data collected between 1993-2001 from 976 streams and rivers by the U.S. Geological Survey's NAWQA program to evaluate national and regional relations of periphyton with water chemistry. They explored the efficacy of algal metrics for assessing nutrient and organic enrichment in flowing waters and determined whether algal-metric values differ significantly among undeveloped and developed land-use classifications. The results of their study were that algal metrics having significant positive correlations with nutrient concentrations included indicators of trophic condition, organic enrichment, salinity, motility and taxa richness. Another result of their study was that the abundance of diatoms associated with high concentrations of dissolved oxygen was negatively correlated with both nitrogen and phosphorus concentrations. Their data set most relevant to this study comes from the Southern Plains Region that includes the Lower Mississippi, Arkansas-White-Red, and Texas-Gulf basins.

Discussion

An examination of the various tabulations of attributes and metrics used to characterize diatom communities shows that the science has evolved gradually from tabulations of diatom natural history and general autecological characteristics to groups of ecological guilds, combining the various aspects of a diatom's biology into community metrics relevant to specific ecoregions. The reason for developing a multimetric index is that diatoms are influenced by, sensitive to, and respond differently to more than water chemistry alone, such as increased sedimentation, nutrients or salinity associated with different types of human disturbance (Fore 2003). The overall goal is to be able to distinguish between natural variability and the various kinds of changes caused by humans.

Stream diatom communities are constrained at the regional level by physiography, climate, geology, geochemistry, stream order, land cover, and general land use. These background factors determine the baseline characteristics of the communities. Within an ecoregion, streams can be further grouped or ranked according to the type and intensity of human disturbance. Those characteristics that have been shown to correlate positively with human disturbance (including agriculture and urbanization) include percent eutrophic species, percent nitrogen heterotrophs, percent polysaprobic species and percent alkaliphilic species.

According to Potapova *et al.* (2004) total phosphorus is thought to be the most important nutrient responsible for river eutrophication in the densely populated regions of the U.S. One of the conclusions of Porter *et al.*, (2008) was that median algal-metric values and nutrient concentrations were significantly lower at undeveloped sites that those draining agricultural or urban catchments. An example of the need for regionally calibrated metrics was demonstrated by Stevenson and Wang (2001) when developing and testing algal indicators of nutrient (trophic) status in Florida streams. They compared indices developed in other regions with the data from Florida streams and found that species indices developed with data from Florida were better correlated with multimetric physicochemical indicators of trophic status than indices developed with data from other regions. For example, their results showed that weighted average total phosphorus indicators developed in other regions, and the van Dam indicator of trophic status, were not well correlated to nutrient conditions in Florida. When they evaluated nutrient indicators they found that diatom taxa richness and diversity indices were not as reliable as species-level autecological indicators based on diatoms. They also report that in their Florida data set, weighted average indicators for nutrient conditions could be improved significantly by reducing importance of common species that have a broad tolerance for a range of nutrient conditions, although down weighting for tolerances in studies from other regions has not shown to be important. These findings illustrate the need for establishment of region-specific metrics.

The autecological and community characteristics listed in the various studies show that there is some redundancy and a certain degree of disagreement among the investigations due to differences in sampling and analyzing protocols, but for the most part there is reasonable agreement. Differences can often be related to the methods of collection, taxonomic precision, purpose of the investigation and available funding. Potapova *et al.* (2004, p. 25-26) make the important point that “the underlying assumption of inference models or indices based on weighted averaging of species indicator values is that the shapes of species response curves along the environmental gradient are unimodal and symmetrical.” This is not necessarily the case.

In Great Britain, the effects of seasonality on the composition of diatom assemblages were investigated by The Environment Agency (2005), the leading public body protecting and improving the environment in England and Wales, who did a literature review on sampling littoral diatoms in lakes for ecological status assessments. They found that seasonal changes in species composition were influenced by seasonal succession of individual species, geography, the variability in physico-chemical conditions, nutrient status, grazer activity (especially chironomid larvae that affects diatom species differentially), and shading by macrophytes.

The physical and chemical properties of the substratum influence colonization and the composition of attached communities. The boundary layer that surrounds the substrate and the microtopography are important features of the substratum during initial colonization when microcrevices offer refugia for the settlement of cells with a reduced risk of dislodgment. Substrates with complex surfaces such as certain leaves can filter and slow water down enabling high settling, attachment, and accumulation rates compared with substrates of simple construction such as twigs. The stability and permanence of the substrate also influences algal colonizers in flowing water. The growth of a periphyton biofilm matrix takes on the order of several weeks to maturity after a disturbance, depending in large part on the rate of colonization, (time of year, availability of inoculants) and quantity and quality of invertebrate grazers. Blinn and Herbst (2003) found that factors that define characteristic stream assemblages were elevation, gradient, discharge rate, fineness of substrate, amount of canopy cover and conductivity.

Some taxa have preferences for a particular substrate such as rock, sand, mud, or vegetation (including host macrophytes), but the extent of this specificity is unclear and varies across studies. Substrate specificity is also related to the fact that algae obtain nutrients from their host substrate. *Achnanthidium minutissimum* for example obtains phosphorus from macrophytes. Winter and Duthie (2000b) compared the use of epilithic, epiphytic and epipelic diatom communities in stream biomonitoring by looking at the species composition and water quality variables of these three substrates and found out that the community structures of the three habitats were not consistently different and the best relationships are obtained using the sum of the diatom data from all three habitats. They reported that the relationships between epiphytic diatom community structure and water chemistry were similar to epipelic and epilithic communities. Their conclusion recommends sampling a single substrate as often as possible and using a second substrate if the first one is not available.

These observations agree with the results of diatom analyses in central Texas, where rock scrapings and plant scrapings, both stable, firm substrates, contain a mixture of epilithic (rock), epipelic (mud), episammic (sand) and epiphytic (plant) diatoms. The epiphytes can attach to any available stable substrate (although some may have a preference for a particular substrate), and the motile diatoms crawl through sand, silt, and mud, according to their abilities. Small diatoms attach to large ones and many attach to macroalgae or rooted vegetation. Length of time since colonization following disturbance determines the complexity of the microbial mat architecture, number of microhabitats available, and the degree to which the diatoms have sorted themselves out according to competition for resources. Attached diatoms, especially *Achnanthidium minutissimum* and *Cocconeis placentula* are among the first diatoms to colonize a site, along with *Gomphonema*, *Gomphoneis*, *Amphora*, *Achnanthes*, and *Reimeria*. The exact species is determined in part by availability of inoculants (who gets there first and manages to move in). In streams that fluctuate in volume seasonally, the ability of a diatom to tolerate fluctuations in osmotic pressure such as at the beginning of a season when flow is low or intermittent, or at the end of the rainy season when flows are reduced, can outweigh other considerations. Some diatoms thrive in a thin film of flowing water.

Diatom Communities in Each Stream

Overall, there were 201 diatom taxa recorded in counts of 500 cells per sample from the six streams. The most abundant species were somewhat different in their relative abundances from one stream to another and also from one sampling period to another, as would be expected. However, there is consistency in the kinds of species, meaning that there was no indication of major variations in physico-chemical characteristics, such as a change in the proportion of alkaliphilic forms to acidophilic forms, or from benthic to planktonic taxa indicating major depth or turbidity changes. There were a few centric diatoms but they are species that are found typically associated with the benthos. The greatest differences within a stream system appear to be in the proportion of diatoms with attached life forms versus motile species. This does not seem to correlate with trophic changes, but rather may be associated with accumulated sediment normally associated with the development of a more complex algal community. The presence of sediment is to some extent related to the amount of extracellular mucopolysacharides (mucilage) produced by soft algae and diatoms, allowing sediment to adhere to the microbial mat. As the mat thickens some fine sediment particles will adhere and with time a thick, porous mat is produced, allowing an assortment of algae with a variety of life forms to fill all the new niches in the three-dimensional mat. This includes prostrately attached and short-stalked forms as the understory, stalked forms with many long branches as the overstory and motile and unattached freely drifting forms moving among the different layers. Some streams flow through areas with little topographic relief and are more likely to accumulate fine sediment during periods of low flow velocity, which can smother all but the non-motile forms.

Some of the algae found in this study are classified as nitrogen heterotrophs, meaning that they have the ability to use simple organic compounds such as amino acids (nitrogen bound to carbon-based molecules) for nutrition and as an energy source to supplement photosynthesis, therefore their relative abundance can be used as an indicator of organic nitrogen compounds and (or) reduced light availability (Porter 2008). Attributes of diatoms making up at least 4% of the population of any sample are listed in Table 58.

Species richness ranged from a low of 17 taxa in Little Elm Creek to a high of 69 taxa in Duck Creek with an overall mean of 39 species per sample. For comparison, there was an average of 34 species per Mid-Appalachian stream, based on a study of 199 streams (Hill *et al.* 2001). Within the Brazos River basin, for a local, more relevant data set, a comparison can be made of the number of taxa recorded from 73 diatom samples collected from the middle Brazos drainage basin in June and July 2008 by Baylor University and Texas A&M University, with the same protocols except that the substrate was rock or sand (Winsborough, analyst). The number of taxa ranged from a low of 12 to a high of 80, with an average of 42 taxa per sample.

Tributary of Little Elm Creek

This site is downstream of the city of Temple and a sewage treatment plant. Nutrient levels tend to be higher downstream of treatment plants and the diatom assemblage reflects this nutrient enrichment. The diatom assemblages varied from 21 taxa in June 2008 to 41 in August 2008. The most abundant taxa were different in each sampling period. Looking at the most abundant species each time (at least 20 individuals, 4% of the population), the species composition changed substantially with each sampling period but the kinds of species remained the same, although the sample was relatively depauperate (low diversity) in June 2008. The pH was at or above 7 as the diatoms are all alkaliphils.

Of the diatoms species representing an abundance of at least 4% of the population (Table 59) there is a combination of attached and motile taxa, but there were more motile species than attached forms, except in one data set. Of the seven dominant taxa in the May 2007 data set, three species were attached. These attached forms represent 56% of the population due to *Cocconeis placentula*, an early colonizer that went from 240 cells in May 2007, to 18 cells in October, to 0 the following June and 52 in August of 2008. In October 2007, of the seven species that dominated the assemblage only one was attached and represented only 16% of the total. In June 2008, of the five dominants two were attached, for a total of 32%; in August 2008, of the eight dominant species one was attached, representing only 10% of the total number present.

The other dominant taxa showed similar ranges in their abundance. *Seminavis strigosa* (attached) went from 0-82-0-8, *Amphora veneta* (attached) went from 4-0-116-0. This could be an effect of seasonality with one attached form replacing another and (or) competition for space or some other variable. *Nitzschia palea* (motile), historically considered one of the most pollution tolerant species, went from 12-0-0-59. Over all, the species are characteristic of eutrophic conditions. The autecological characteristics suggest that there may be a slight increase in pollution due to the impacts of treatment plant discharge but the sample appears to be downstream far enough to have recovered from any point source degradation and does not reflect seriously impaired conditions. The number of species varied from 21 to 41 with an average of 31.2 which is not substantially lower than the overall average of 39.

Little Elm Creek

The dominant taxa in Little Elm Creek indicate low to moderate nutrients (Table 60). The most abundant taxa are sensitive to pollution. A few taxa are tolerant to pollution but that is to be expected. Pollution sensitive species cannot thrive in eutrophic conditions but diatoms found typically in eutrophic water can also live under less eutrophic conditions. Competition for substrate was probably particularly important in this stream, especially in the July 2008 sample where all of the dominant species were attached forms. *Gomphosphenia lingulatiformis* and the variety *grovei* (now elevated to its own species) were rather consistently dominant except for the May 2007 sample. These diatoms form long, branching stalks with many individuals that are held above the substrate, in contrast to *Achnanthidium minutissimum* and *Nitzschia inconspicua* (the dominants in May 2007) that make up the understory and fill the crevices. There were three motile taxa representing 39% of the flora in May 2007. They are all small species that are frequently found in large numbers, especially *Nitzschia inconspicua*. It and *Achnanthidium minutissimum* are early colonizers found commonly in seasonal streams in central Texas. The niche occupied by *Achnanthidium minutissimum* and *Nitzschia inconspicua* in May 2007 is filled by *Gomphonema grovei* and *Gomphonema lingulatiformis* the rest of the time.

The number of species in the samples was similar from one sampling period to another except the July 2008 sample that had the least number of different species of any single sample in the entire study (17) probably due to reduced flow conditions. The four most abundant diatoms in May 2007 were very small, mostly attached, early colonizing species that are moderately sensitive to pollution. All but one of the abundant diatoms in the October 2007 sample was motile but the motile species are classified as sensitive to pollution (not forms that indicate eutrophic conditions), although there may have been an increase in siltation. All of the abundant diatoms in the July 2008 sample are attached species, adnate in the case of *Cocconeis placentula* and stalked as are the *Gomphonema* spp. The August 2008 was very similar in composition to the other samples. There does not seem to be a seasonal increase in chemical load.

Willis Creek

Willis Creek was particularly consistent in diatom composition. Many of the dominants are early colonizers of new habitats suggesting that biological succession and development of a mature microbial mat was frequently arrested by some form of disturbance or scouring. The number of species varied from 23-38 taxa, with a somewhat low average of 29 species per sample (Table 61). Overall a dozen diatom taxa accounted for all the species representing 4 % or more of any one of the four samples, suggesting that the kinds of available habitat may have been limited or that some other stressor was operative in restricting population structure. The only difference from one sampling period to another is the relative abundance of each species. The Willis Creek May 2007 sample is very similar in composition to the May 2007 sample from Little Elm Creek. There were two motile taxa, *Nitzschia inconspicua* and *Navicula veneta*. *Navicula veneta* is the only diatom in the sample classified as tolerant and it is tolerant to practically anything. It is common in seasonal carbonate-rich streams in central Texas. There seems to be relatively less impact due to reduced flow in this creek as compared to Little Elm Creek. The 8/12/2008 sample was composed of 57% motile forms among the abundant species suggesting that there was an increase in sediment accumulation but there was a mixture of pollution tolerant and sensitive taxa, at the site indicating only moderate degradation. Increased sedimentation may, in this case, be a function of low stream flow and a low stream gradient.

Clear Creek

The diatom assemblage found in Clear Creek was different than the previous three creeks. The dominant taxa are, in general, more pollution sensitive and indicative of a more circumneutral pH. The number of species in the Clear Creek samples averages 44 taxa, with the 8/5/2008 sample much less taxa rich (Table 62). The number of species decreased with each sampling period, possibly related to declining rainfall. The May 2007 and June 2008 samples were dominated by *Eunotia pectinalis*, which is classified as acidophilous by the U.S. Geological Survey USGS). It is common in clear carbonate streams in central Texas, however, and found commonly in circumneutral settings. It may be associated with moss, accounting for the lower pH. In the entire sample set from Clear Creek there were only seven motile species, one of which, *Nitzschia palea*, is a pollution indicator when it is a significant component of the population, which it was not. The 8/5/2008 sample was well aerated, with no evidence of increasing pollution so the limited numbers of species may be a function of available substrate.

Walnut Creek

The number of species in Walnut Creek, 68, 43, 37, 28 declined with each collecting event (Table 63). The 5/22/2007 sample was very diverse, considering that *Cocconeis placentula* accounted for 91 of the 500 cells. Only 5 diatoms were very abundant, representing at least 20 cells or 4% of the population. One of these is a phytoplanktonic form, three are motile but one of these is an aerophil growing commonly on moss or other moist substrate. There are three centric diatoms in this sample suggesting that there was little current in the stream, even though these taxa are found associated with the benthos. In the 9/5/2007 sample, four of the five species present at least 4% were motile forms and they account for 65% of the total diatoms counted in the sample. This abundance of motile forms may be a function of the sandy and gravelly nature of the substrate at this site. Only three of the eight dominants in the 6/9/2008 sample were motile, and most of the abundant taxa are pollution sensitive. The 8/5/2008 sample contains diatoms that are tolerant to or prefer elevated salt concentrations.

Duck Creek

Duck Creek had a relatively high diversity at each sampling event with 69, 49, 36, and 55 species Table 64.). The large number of taxa, in this case suggests that there are abundant nutrients but not enough, in most cases, to limit the kinds of diatoms present to those that are particularly pollution tolerant. There is the suggestion of an elevated salt concentration in the 5/24/2007 sample by the presence of *Craticula halophila*, and in general the diatoms indicate a well-aerated stream with at least moderate concentrations of pollutants. Porter (2008) observed that the abundance of halophilic diatoms increases significantly with concentrations of nutrients and suspended sediment. All of the abundant taxa in the 9/6/2007 are motile and at least somewhat pollution tolerant. The 6/11/2008 sample had only three taxa that occurred over 20 times. This is in part caused by the motile sediment inhabiting diatom *Gyrosigma nodiferum* accounting for 212 of the 500 cells. The other two common species are stalked *Gomphonema* species that are somewhat pollution sensitive. Four of the five dominant diatoms in the 8/6/2008 sample are attached forms that are somewhat pollution sensitive. The other diatom, *Bacillaria paradoxa* is colonial, not attached and can drift with the current.

Soft Algae

The soft algae include cyanobacteria and all classes of algae except the Bacillariophyceae. In many cases these taxa can only be distinguished to the genus level as they have several life cycle stages, need to have special reproductive structures to be distinguished, or cannot be distinguished without culturing. Most of the classes of algae are represented in the overall assemblage. A good discussion of nitrogen and phosphorus nutrient limitation can be found in Borchardt (1996), who noted that phosphorus and nitrogen are the two nutrients most likely to be growth limiting, although light, disturbance and grazing may be the primary determinates of biomass and growth, with nutrients as secondarily limiting and masked by the effects of grazing.

The autecological attributes of the non-diatom algae found in the six streams are summarized in Table 65. These observations were extracted from the following references. Palmer (1969) compiled information on the pollution tolerance of algae from 165 authors. His composite rating of algae tolerating organic pollution rates the genera from 1-60 with 1 being the most tolerant. He rates the top 80 species also from most to least tolerant, believing that organic pollution tended to influence the algal flora more than any other factor in the aquatic environment.

Porter *et al.* (2008) examined candidate metrics for soft algae in streams and rivers and found that the relative abundance of nitrogen-fixing algae was negatively correlated with nitrogen concentrations. Thus the metric they suggested for soft algae is nitrogen fixation by certain cyanobacteria. Excessive amounts of nitrogen and phosphorus in streams with relatively clear water can produce nuisance growths of benthic algae, particularly in exposed stream reaches with little riparian shading (Porter *et al.* 2008). These nuisance growths can impair water quality and stream habitat, and provide visual evidence of eutrophication and water quality degradation. Porter (2008) provided USGS algal attribute data for some of the taxa discussed in this study. These attributes are tabulated below. Five of the taxa found in this study are classified by Porter as nuisance algae: *Cladophora* sp., *Dinobryon* sp., *Mougeotea* sp., *Spirogyra* sp., and *Ulothrix zonata*.

A reference text by Stevenson and others (1996) on algal ecology of freshwater benthic ecosystems discusses many aspects of lake and stream algae. Particular citations from this book are included in this report. Wehr and Sheath (2003) wrote an ecology and classification of the freshwater algae of North America that mentions some of the algae found in Central Texas.

Bahls (1993) recommended three metrics for soft-bodied algae: dominant phylum, indicator taxa, and number of genera, but suggested using these metrics only in a supporting role to the diatom metrics and not as definitive accounts of biological integrity and aquatic life impairment. Bahls (*ibid*) also notes that dominance by cyanobacteria (blue-green algae) may be a function of relatively small inorganic nitrogen values in streams as cyanobacteria have a competitive advantage over other algae by being able to fix atmospheric or molecular nitrogen; in contrast, dominance by green algae could be favored by nitrogen enrichment. With regard to indicator taxa, one observation by Bahls (*ibid*) of significance to this analysis is that red algae are common only in relatively pristine waters, and *Audouinella* is a genus of red algae that occurs frequently in western Montana streams. There were 20 cells of *Audouinella hermannnii* in the May 2007 Clear Creek sample, and 55 cells in the May 2007 sample from Duck Creek.

According to Bahls (*ibid*) the number of non-diatom genera in a periphyton community is inversely proportional to the degree of pollution, except possibly in cases where harsh conditions may increase competition for resources and limit the number of niches available. Thirty-seven genera of algae were recorded during this study. For comparison, 38 genera were collected from 199 streams in the entire Mid-Appalachian Region, which includes about 9 ecoregions, one of which is the Coastal Plains Ecoregion (Hill *et al*. 2000).

Blinn and Herbst (2003) looked at the efficacy of using diatoms and soft algae as indicators of environmental determinants in 38 streams of the Lahontan Basin of California. They identified "over 30 soft algal taxa" and found that diatoms were better indicators of stream conditions than soft algal communities.

Potapova (2005) calculated optima and tolerances for soft algae from 6,455 NAWQA samples nationwide. This analysis of the NAQWA data is a very large file containing relationships of soft-bodied algae to water quality and habitat characteristics in U.S. rivers.

Soft Algae Communities in Each Stream

The abundant or dominant (at least 4% or 12 cells) soft algae for each stream are listed in Table 67 - Table 72. At least 300 cells from each sample were counted. The number is usually higher than 300 because all of the algal cells in each scanned field, including the last one, were enumerated. Pennate and centric diatom counts, where significant, are listed in the tables along with soft algae. Because the dilutions or concentrations necessary to enumerate the soft algae vary with each sample, the abundances of each taxon can only be considered in terms of its relative abundance in counts of 300 or slightly more cells. Counts are given to illustrate the influence of each dominant taxon in the overall composition of the microbial mat or film that has been sampled.

Tributary of Little Elm Creek

The abundant or dominant soft algae in the Tributary of Little Elm Creek in May 2007 were *Cladophora* sp. (146 cells) and *Chroococcus* sp. (25 cells). *Chroococcus* is a very small, round cell about 1-3 micrometers (µm) in diameter. *Cladophora* is a large, sometimes macroscopic filamentous green alga that is counted in 10 micrometer long segments. *Cladophora* becomes abundant when nitrate and phosphate levels are relatively high and there is sufficient sunlight. It is listed as somewhat pollution tolerant with a value of 42^{nd} on the Palmer list of pollution tolerant algae. The diatom flora indicates a circumneutral to alkaline pH. Dominant soft algae in alkaline water include *Cladophora*, *Ulothrix*, and *Oedogonium* (Lowe 1996). In the October 2007 sample *Cladophora* was gone, replaced by two small cyanobacteria, *Oscillatoria* sp. (35 cells) and *Schizothrix* sp. (76 cells) *Oscillatoria* was number 2 on the Palmer list suggesting that there might have been an increase in organic pollutants. In July 2008 the dominants were all filamentous forms: *Schizothrix* sp. (76 cells), *Mougeotea* sp. (40 cells), *Oscillatoria* sp. (35 cells), and *Oedogonium* sp. (26 cells). The last sample, July 2008, was dominated by the filamentous cyanobacteria *Schizothrix* sp. (153 cells) and *Oscillatoria* sp. (25 cells).

Little Elm Creek

The composition of the soft algae in Little Elm Creek was similar to that found in the Tributary of Little Elm Creek, but less taxa rich. *Cladophora* sp. (107 cells) was the overwhelming dominant in May 2007. In October 2007 *Cladophora* sp. was still the dominant taxon followed by a very small alga called *Gloeoskene turfosa* (59 cells) and then *Schizothrix* sp. (49 cells). In July 2008 the dominants were *Oscillatoria* sp. (128 cells) and *Schizothrix* sp. (108 cells). By August 2008, about a month later, *Schizothrix* sp. (173 cells) was the clear dominant, followed by *Oscillatoria* (50 cells). *Cladophora* and *Oscillatoria* are listed by Palmer (1969) as tolerant of organic pollution. There were many pennate diatoms in the samples as well so any interpretation of the water quality weighs heavily on the diatom flora.

Willis Creek

The abundant soft algae in Willis Creek are similar to the other streams. The most abundant algae in May 2007 were three very small cyanobacteria: *Chroococcus* sp. (123 cells) followed by *Synechococcus* sp. (26 cells) and *Schizothrix* sp. (25 cells). These are all very small forms less than 3 µm in diameter. In June 2008 *Cladophora* sp. (69 cells) dominated the soft algae, followed by *Schizothrix* sp. (45 cells) and *Chroococcus* sp. (27 cells). By July 2008 the dominants were *Spirogyra* sp. (90 cells) followed by *Schizothrix* sp. (39 cells) and *Cladophora* sp. (30 cells). One month later, by August 2008, *Schizothrix* sp. was the dominant (82 cells) followed by *Cladophora* sp. (25 cells).

Clear Creek

The soft algae dominating the Clear Creek assemblage in May 2007 were *Schizothrix* sp. (125 cells) and *Oedogonium* sp. (53 cells). There were also 20 cells of *Audouinella hermannii,* a red alga reported by Palmer (1969) as an indicator of clean water, but by Walker (2006) as one of the species tolerant of high total phosphorus. In September 2007 the overwhelming dominant was *Lyngbya* sp. (264 cells), followed by *Spirogyra* sp. (44 cells), both considered to be tolerant to organic pollution. By June 2008 the dominants shifted to *Schizothrix* sp. (110 cells), followed by *Cladophora* sp. (62 cells) and then *Spirogyra* sp. (23 cells). In August 2008 *Cladophora* sp.

(110 cells) was the most abundant soft alga followed by *Schizothrix* sp. (75 cells) and *Oscillatoria* sp. (27 cells).

Walnut Creek

The only dominant or even common soft alga in Walnut Creek in May 2007 was *Schizothrix* sp. (184 cells). The rest of the count consisted of pennate diatoms. By September 2007 the dominance had shifted to *Cladophora* sp. (70 cells) followed by *Spirogyra* sp. (25 cells) and *Schizothrix* sp. (21 cells). In June 2008 the dominants were *Schizothrix* sp. (94 cells), *Oscillatoria* sp. (46 cells) and *Spirulina* (30 cells). By August 2008 the pattern had again shifted to dominance by diatoms and *Schizothrix* sp. (76 cells) alone. The low numbers of soft algae in proportion to diatoms in these samples may indicate either early or slow colonization, lack of adequate substrate, relatively low nutrient levels, deep shade or high grazing impacts.

Duck Creek

The soft algae dominating the Duck Creek assemblage in May 2007 was *Schizothrix* sp. (121 cells), *Oedogonium* (60 cells) and the red alga *Audouinella hermannii* (55 cells), an indicator of clean water. In September 2007 Schizothrix sp. (188 cells) was the clear dominant, followed by *Oscillatoria* sp. (22 cells). The June 2008 sample was dominated by *Schizothrix* sp. (97 cells) and *Cladophora* sp. (60 cells) only. By August 2008 the dominants were *Schizothrix* sp. (148 cells) and *Cladophora* sp. (45 cells).

Conclusions

Overall, historically, diatom and soft algae species richness and diversity decrease under seriously elevated organic enrichment. Since the streams investigated in this study are both species rich and display a variety of life forms, it can be concluded that these streams show only a moderately high degree of pollution at most and a resilience to shift the algal composition to adapt to disturbance. The abundant or dominant (at least 4% or 12 cells) soft algae investigated in this study are similar in all of the streams. *Cladophora* sp., *Schizothrix* sp., *Oscillatoria* sp., *Chroococcus* sp., *Synechococcus* sp., *Audouinella hermannii*, *Lyngbya* sp., *Spirogyra* sp., *Gloeoskene turfosa, Oedogonium* sp., and *Mougeotea* sp. are taxa that can be considered characteristic of the regional stream assemblages as a whole, with each stream containing various proportions of these taxa. Of these, *Cladophora, Oscillatoria, Lyngbya, and Spirogyra* are listed among the top 60 genera tolerant to organic pollution at numbers 42, 2, 34 and 21 respectively.

The diatom periphyton that characterizes the streams includes sensitive taxa and species tolerant of various kinds of pollution. Overall the assemblage indicates moderate concentrations of nutrients (mesotrophic), a circumneutral to definitely alkaline pH and possibly slightly elevated salinity or high conductivity. Interpretation is complicated since there are similar and overlapping responses to sustained increases in pollutant loads and no evidence that any of the streams were brackish. Other factors may influence more control over growth and composition than nutrient levels, such as pollutant loads from road salt, irrigation return water and frequent heavy fertilization, light availability, stream flow velocity and substrate. Shading and turbidity or excessive sedimentation limits the growth of algae. Stagnant streams do not provide a steady supply of nutrients, allowing certain taxa to bloom at the expense of others. Rapid velocities can dislodge the benthic mat from its substrate causing a scour disturbance.

With regard to substrate, Walker et al. (2006) found that in general, periphyton grew poorly on sand, clay, and highly organic substrates; cobbles had the highest biomass of periphyton, while gravels had the lowest biomass and sand and boulders were intermediate. They also report that grazing by snails, various larvae and other organisms can control and substantially reduce the growth of periphyton, particularly in low velocity streams even when nutrient levels are high. Differences among pool, run, and riffle habitats can also be significant. Long-term patterns of periphyton biomass often observed within a stream reach include constantly low periphyton biomass, cycles of accrual and sloughing of periphyton, and seasonal cycles of the growth of periphyton (Watson & Gestring 1996).

Many of the dominant diatom taxa are forms that produce mucilaginous stalks (*Gomphonema* spp., *Gomphoneis* spp., *Amphora* spp., *Reimeria sinuata*) or are chain formers (*Pleurosira laevis*) and thus have the ability to extend outward from their substrate and access light and nutrients. Size is also an important characteristic especially in the calculation of biomass and biovolume. Some soft algae such as *Chroococcus* sp., *Schizothrix* sp. and *Synechococcus* are very small (1 or 2 μm in diameter) whereas other taxa, particularly the filamentous algae *Cladophora, Spirogyra, Oedogonium etc*. are orders of magnitude larger, and are more significant photosynthesizers.

The results from this study contribute to the establishment of background benthic algal community conditions for the region. This information can then be used to detect and interpret changes in stream conditions due to anthropogenic impacts. Any restoration efforts require that a predisturbance or reference condition be established, where water quality, soil and vegetation best approximate historical conditions. From the reference condition a multimetric periphyton index of biotic integrity can be developed. Identification of reliable candidate indicator species (both sensitive and tolerant), of low and high nitrogen and phosphorus, calibrated for a specific region, kind of water body, topography, flow gradient, and geological province, is one aspect to be considered in future protocol design. Targeted sampling times that identify and take into account local groundwater chemistry, sediment composition, contributions from various point and non point sources of pollution and that accommodate the lag time necessary for microbial mat recovery and return to baseline conditions for each particular ecoregion, will provide the best material for reference samples. Changes in aquatic ecology due to long-term drought may have to be calculated into future projects.

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Table 55. Diatom attributes.

Diatom Final ID	Diatom Short Taxon Name	R1	R1a	R2	R3	R4a	R4b	R4c	R4d	R4e	R4f	R4g	R5a TN mg/L	R5b TP µg/L	R6	R7a	R7b	R7c	R8	R9s	R9v	R10	R11	R12a TN mg/L	R12b TP µg/L	R13 TP µg/L	R14
Achnanthes brevipes	ACbrevip		3		P															3	1						
Achnanthes inflata	ACinflat		3	0	P	-	-	2	-	-	-	-								3	1						
Achnanthidium biassolettianum	ACbiasso	3			P	4	2	-	-	-	3	-			3		2			3	1	al	alk				
Achnanthidium exiguum	AHexigum	3			P	4	2	2	1	2	7	3		+*	3			3		3	1					40	
Achnanthidium minutissimum	AHminuti	3		3	P	3	2	2	1	2	7	3	-71		3	1	2	3	tol	2	2	ox	alk	3.5	35	33	
Adlafia bryophila	ADbryoph		2			3	1	1	1	1	3	5	-*	+*					tol								M
Amphipleura pellucida	ALpelluc	2			P	4	2	2	2	4	2	2	-11*	-*	3		2	3		1	3	al, sp	sap, alk				
Amphora acutiuscula	AMactscl	1			P															5	1						
Amphora bullatoides	AMbullat		2	0	P															5	1						
Amphora coffeaeformis	AMcoffea	1			P	4	2	2	3	3	5	3		+*	2				hal	5	1						
Amphora copulata	AMcopula	3		3	P	4	2	2	2	2	5	1		+*	3		2	3	tol	5	1		eu, alk				
Amphora granulata	AMgranul		2		P															5	1						
Amphora inariensis	AMinarie	3			P	-	2	-	-	-	1	-					2	3	o	5	1					54	
Amphora montana	AMmontan	3		3	P	4	2	2	1	2	5	4			3			3	ae	5	1		eu, alk			51	M
Amphora pediculus	AMpedcls	3		3	P	4	2	2	2	2	5	3			3					5	2	eu, al	eu, alk	3.1	47	67	
Amphora sabiniana	AMsabina		2		P															5	1						

Diatom Final ID	Diatom Short Taxon Name	R1	R1a	R2	R3	R4a	R4b	R4c	R4d	R4e	R4f	R4g	R5a TN mg/ L	R5b TP µg/ L	R6	R7a	R7b	R7c	R8	R9s	R9v	R10	R11	R12 a TN mg/ L	R12 b TP µg/ L	R13 TP µg/ L	R14
Amphora veneta	AMveneta	1		1	P	5	3	2	3	4	5	3			2					5	1	eu, al, sp	sal, eu, sap, alk			50	
Anomoeoneis costata	ANcostat	1			P	-	4	-	-	-	-	-								1	2						
Anomoeoneis sphaerophora	ANsphaer	2			P	5	3	2	4	3	5	3			2					1	2						
Aulacoseira ambigua	AUambig	3				4	2	2	3	2	5	1			3					2	1						
Aulacoseira granulata	AUgranlt	3		3		4	2	2	3	2	5	1	+15		3					2	1	eu, al	eu, alk			92	
Aulacoseira granulata var. angustissima	AUgrnang	3				4	2	2	3	2	5	1			3					2	1						
Bacillaria paradoxa	BApardxa	2		2		5	4	2	4	3	5	3	+*		2								sal, ox, eu, alk			56	M
Biremis circumtexta	BMcircum	1			P															4	1						M
Brachyseira neoexilis (Navicula exilis)	NAexilis		2			-	-	-	-	-	-	-			2	1		3	o	1	3						
Brachyseira vitrea	BRvitrea	2		2		4	2	1	2	1	2	2			3		2			1	3	al	alk				
Caloneis bacillum	CAbacill	2		3	P	4	2	1	2	2	4	2			3				eu	3	1	al	alk	3.6	36	53	
Caloneis oregonica	CAoregon		3		P															3	1						
Caloneis schumanniana	CAschuma		3	0	P	5	2	1	2	1	3	2			3				o	3	1		alk				
Caloneis silicula	CAsilicu	2		3	P	4	2	1	2	1	4	1			3	1		3		3	1						
Campylodiscus clypeus	CAclypeu		2		M	5	4	-	-	2	5	3			2				ak l								M
Capartogramma crucicula	CPcrucic			2	P																						M

Diatom Final ID	Diatom Short Taxon Name	R1	R1a	R2	R3	R4a	R4b	R4c	R4d	R4e	R4f	R4g	R5a TN mg/L	R5b TP µg/L	R6	R7a	R7b	R7c	R8	R9s	R9v	R10	R11	R12a TN mg/L	R12b TP µg/L	R13 TP µg/L	R14
Cocconeis pediculus	CCpedcls	3		3	P	4	3	2	2	2	5	1			3					4	2	eu, al	sal, eu, alk	3	51	74	
Cocconeis placentula	CCplacen	3		3	P	4	2	2	3	2	5	2			3					3	2		eu, alk	1.9	43		
Cocconeis placentula var euglypta	CCplaeug	3		3	P	4	2	2	3	2	5	2								2	2	eu, al	eu, alk			109	
Cocconeis placentula var pseudolineata	CCplapse		3		P															2	2						
Cocconeis scutellum	CCscutel		3		P	5	-	-	-	-	-	-								2	2						
Craticula (Navicula) halophila	KChaloph	2		2	P	4	4	2	2	3	5	2		+*	2								sal, eu, alk				M
Craticula (Navicula) minusculoides	KCminusc		2		P	-	2	4	4	4	5	2															M
Craticula buderi	KCbuderi		2		P																						M
Craticula cuspidata	KCcuspid	2		2	P	4	2	2	3	3	5	1			2								eu, alk				M
Cyclostephanos tholiformis	CStholis	2			U															5	1						
Cyclotella cf. stelligera	CYcfstel	3		3	U	-	2	-	-	-	-	1			3	1		3		5	1					74	
Cyclotella meneghiniana	CYmenegh	2		1	U	4	3	3	5	4	5	2	+48		2					5	1	eu, al, nh, sp	sal, ox, eu, nit, sap, alk	1.7	38	84	
Cymatopleura elliptica	CTellipt	2			P, M	4	3	2	2	2	5	1			3					4	1						M
Cymbella aspera	CMaera	3		4	S	4	2	1	1	1	7	-			4	1	2			4	2		alk				
Cymbella cistula	CMcistul	3		4	S	4	2	1	2	2	5	1			3		2	3		4	2		eu, alk				M

Diatom Final ID	Diatom Short Taxon Name	R1	R1a	R2	R3	R4a	R4b	R4c	R4d	R4e	R4f	R4g	R5a TN mg/L	R5b TP µg/L	R6	R7a	R7b	R7c	R8	R9s	R9v	R10	R11	R12a TN mg/L	R12b TP µg/L	R13 TP µg/L	R14
Cymbella cymbiformis	CMcymbis	3		4	S	3	2	1	1	1	2	2			4	1	2			2	1	ox					
Cymbella excisa	CMexcisa		3		S															2	1						
Cymbella hustedtii	CMheusted		3	0	S	4	2	1	1	1	2	3			4		2	3		2	1		alk				
Cymbella kolbei	CMkolbei		3		S															2	1						
Cymbella laevis	CMlaevis		3	0	S								-11*	-*	3		2			2	1						
Cymbella tumida	CMtumida	3		4	S	4	2	1	1	1	4	1		-24						2	1		alk			38	
Denticula kuetzingii	DEkuetzi		3	3	P	4	2	1	1	2	3	3	-9		3		2			2	2						
Denticula subtilis	DEsubtil		3		P	-	3	1	1	1	-	4			3					2	2						
Diadesmis (Navicula) confervacea	DIconfer		2	2	P	3	3	3	3	3	5	3	+*	+*	2								sal, eu, nit			100	M
Diadesmis (Navicula) contenta	DIcontent	2		2	P	4	2	2	1	2	7	4				1		3					alk				M
Diploneis elliptica	DPellipt	3		3	P	4	2	1	1	1	3	3			3	1	2	3		1	1		alk				
Diploneis oblongella	DPoblong	3		3	P	4	2	1	1	1	-	4	-*	-32	4		2			1	1		alk				
Diploneis ovalis	DPovalis		3		P	4	2	1	1	1	-	4			4		2	3	oc	1	1						
Diploneis pseudovalis	DPpsudov	2			P								-10		2				hal	1	1						
Diploneis puella	DPpuella	2		0	P	4	2	1	1	1	3	3			3					1	1		alk				
Encyonema (Encyonopsis) evergladianum	ECevergl		3		S								-24*	-*	3					2	1						
Encyonema (Encyonopsis) microcephala	EYmicroc	2		4	S	4	2	1	1	1	4	3	-58*	-21	3		2	3	tol	1	2		alk				
Encyonema carina	ECcarina		3		S										3					2	1						
Encyonema delicatula	CMdelcat	3		4	S	4	1	1	1	1	1	3	-35*	-*	4		2			1	3						

Diatom Final ID	Diatom Short Taxon Name	R1	R1a	R2	R3	R4a	R4b	R4c	R4d	R4e	R4f	R4g	R5a TN mg/L	R5b TP µg/L	R6	R7a	R7b	R7c	R8	R9s	R9v	R10	R11	R12a TN mg/L	R12b TP µg/L	R13 TP µg/L	R14
Encyonema elginensis	CMelgine		3		S											1		3	od	2	1						
Encyonema silesiacum	ECsilesi	3		4	S	3	2	2	3	3	7	1			3	1	2	3		3	2			6.1	37	13	
Encyonema triangulum	ECtriang	3		4	S										3					4	2						
Encyonopsis minuta	EYminuta	2		3	S	3	2	-	-	-	-	-			2	1	2	3		3	2						
Eolimna subminuscula	EOsubmin	1		1	P	4	2	4	4	4	3	3	+52	+53	2					5	1	eu, al, nh, sp					M
Epithemia adnata	EPadnata	2		2	P	5	2	1	2	2	4	2			3		2	3	eu	1	2		alk				
Epithemia sorex	EPsorex	3		3	P	5	2	1	2	2	5	2	-*	-20*	3		2	3	eu	1	2	eu, al	eu, alk				
Epithemia turgida	EPturgid	3		3	P	5	2	1	2	2	4	3			3					1	2	al	alk				
Eucocconeis (Achnanthes) flexella	ESflexel	3			P	3	1	1	1	1	1	3			4	1	2	3	o	3	1						
Eunotia arcus	EUarcus		3	2	E	3	1	1	-	1	2	3			4	1			od	1	3						
Eunotia bilunaris	EUbilun		3	3	E	6	2	2	2	2	7	3			3	1	2	3	tol	1	3						
Eunotia formica	EUformic		3	0	E	2	2	1	1	1	3	2			4	1				1	3						
Eunotia pectinalis	EUpectin		3	3	E	2	1	2	1	2	3	3			3	1			o	1	3						
Fallacia litoricola	FAlitori		3		P															5	1						M
Fallacia monoculata	FAmonoc	1			P	4	2	3	2	3	5	3			2				eu	5	1						M
Fallacia pygmaea	FApygmae	2		3	P	5	2	3	3	3	5	2			2				eu	5	1						M
Fallicia (Navicula) lenzii	FAlenzii		2		P	4	2	-	-	1	-	-	-*				2			5	1						M
Fallicia tenera	FAtener2	1		2	P	5	-	-	-	-	-	3								5	1		tol, alk				M
Fragilaria capucina	FRcapuci	2	2	2	V	3	2	-	-	2	3	-			3	1		3	eu	2	2		eu, alk	4.2	42	36	

Diatom Final ID	Diatom Short Taxon Name	R1	R1a	R2	R3	R4a	R4b	R4c	R4d	R4e	R4f	R4g	R5a TN mg/ L	R5b TP µg/ L	R6	R7a	R7b	R7c	R8	R9s	R9v	R10	R11	R12 a TN mg/ L	R12 b TP µg/ L	R13 TP µg/ L	R14
Fragilaria famelica	FRfameli	2			V	4	2	1	1	1	3	3						3	eu	2	1						
Fragilaria nanana	FRnanana	3		3	V	3	1	1	1	1	2	2				1	2	3		2	1						
Fragilaria tenera	FRterera		3		V	2	1	1	1	1	2	2			4	1	2			2	1			2.6	54		
Frustulia rhomboides	FSrhombo	3		3	P	2	1	1	1	1	1	2		-*						1	2					77	
Frustulia vulgaris	FSvulgar	2		3	P	4	2	2	1	2	4	3			3	1		3	tol	1	2		alk			34	
Frustulia weinholdii	FSwein	3		3	P	3	2	-	-	1	2	2			4					1	2						
Geissleria decussis	GEdecu	3		3	P	4	2	1	-	1	4	3			3			3		4	1	al	alk			35	M
Gomphonema acuminatum	GOacumin		3	4	S	4	2	1	2	2	5	2			3	1	2		tol	3	1		eu, alk				
Gomphonema affine	GOaffine		3	3	S	4	2	1	1	2	3	3	-23		3					3	1		alk				
Gomphonema angustatum (micropus)	GOangstt	2		2	S	4	2	2	2	2	5	3		+19	2		2			1	2		alk			66	
Gomphonema angustum	GOangust	3		1	S	4	2	1	1	1	1	-			3					3	1		alk				
Gomphonema clavatum	GOclavat	2			S	3	1	1	1	1	4	2	-*	-11	3	1			o	3	1	ox					
Gomphonema gracile	GOgracil	2		3	S	3	2	1	1	1	3	3	-29	-18	3	1	2	3		3	1					123	
Gomphonema intricatum	GOintric	3		3	S								-5	-22						3	1						
Gomphonema intricatum var vibrio	GOintvib		3		S	4	2	1	1	2	4	3	-17		3		2			3	1		alk				
Gomphonema mclaughlinii	GOmaclau		3		S															3	1						
Gomphonema parvulum	GOparvul	1		1	S	3	2	3	4	4	5	3			1			3	tol	5	3	eu, nh, sp	tol, ox, eu, nit, sap	2.6	57	50	

Diatom Final ID	Diatom Short Taxon Name	R1	R1a	R2	R3	R4a	R4b	R4c	R4d	R4e	R4f	R4g	R5a TN mg/L	R5b TP µg/L	R6	R7a	R7b	R7c	R8	R9s	R9v	R10	R11	R12a TN mg/L	R12b TP µg/L	R13 TP µg/L	R14
Gomphonema patrickii	GOpatric		3		S															3	1						
Gomphonema pumilum	GOpumilu	3			S	-	2	-	-	-	7	-		-69				3		3	1						
Gomphonema rhombicum	GOrhombi		3	4	S								+*	+*	3					3	1						
Gomphonema vibrioides	GOvibdes		3		S															3	1						
Gomphosphenia (Gomphonema) lingulatiformis	GMlinfor		3		S	-	-	-	-	-	-	-															
Gomphosphenia grovei	GMgrovei		3		S																						
Gomphosphenia reicheltii	GMreicht		3		S																						
Gyrosigma nodiferum	GYnodfrm		2	4	P, M										3					5	2		vd, mo				M
Gyrosigma obscurum	GYobscur		2	0	P, M										2					5	2						M
Gyrosigma obtusatum	GYobtusa		2	0	P, M	4	2	2	1	2	5	3		+*						5	2		eu, alk, mo				M
Gyrosigma scalproides	GYscalpd		2	3	P, M										2					5	2		vd, mo				M
Gyrosigma spencerii	GYspence	2		3	P, M										2					5	2					87	M
Hantzschia amphioxys	HAamphio	2		3	P, M	3	2	2	2	3	7	4			3	1	2	3	ae	5	1		mo				M
Hippodonta (Navicula) hungarica	HIhunga		2		P									+*	3				eu	4	1						M
Hippodonta capitata	HIcapita	2		3	P	4	2	2	3	3	4	3			2				eu	4	1	al	alk	2.7	66	44	M
Lemnicola (Achnanthes) hungarica	LEhungar	2		4	P	4	2	2	4	3	6	1								3	1						

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Luticola goeppertiana	LUgoept2		2		P										2					4	1					106	M
Luticola mutica	LUmutica	2		2	P	3	3	2	1	3	5	4			2			3	tol	5	1	ox, eu	sal, eu			61	M
Mastogloia elliptica	MSellipt	2			P	4	4	-	-	-	-	3	-12*	-*	2												
Mastogloia smithii	MSsmithi	2		0	P	4	4	-	-	2	-	3	-22*	-*	2								sal, alk				
Mayamaea (Navicula) atomus	MYatomus	1		1	P	4	2	4	2	4	6	4		+35 *	2					5	1					59	M
Melosira varians	MEvarian	2		2	U	4	2	3	3	3	5	2			2					4	2	eu, al, nh	eu, nit, alk	3.3	17	60	
Navicula (Eolimna) minima	NAminima	1		1	P	4	2	3	4	4	5	3		+45	1				tol	5	1	eu, al, nh, sp	tol, ox, eu, nit, sap, alk				M
Navicula (Eolimna) subminuscula	NAsubmin	1		1	P	4	2	4	4	4	5	3	+52	+53	2					5	1						M
Navicula aikenensis	NAaiken		2		P															5	1						M
Navicula angusta	NAangust		2	0	P	2	1	1	1	1	1	2			3	1		3		5	1						M
Navicula antonii	NAantoni		2		P															5	1					37	M
Navicula capitatoradiata	NAcaprad	2		2	P	4	2	2	3	3	5	3								4	1	eu, al	eu, alk	3	33	57	M
Navicula cf. fauta	NAcffaut		2		P															5	1						M
Navicula cf. pseudanglica	NAcfpsan		2		P	4	2	2	1	2	4	2			2		2			4	1						M
Navicula cincta	NAcincta	2			P	4	2	2	3	3	5	4	+11		2				eu	4	1						M
Navicula constans	NAconstn		2		P										4	1				4	1						M

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Navicula cryptocephala	NAcrypto	3		3	P	3	2	2	3	3	7	2			3	1		3	eu	4	1			3.2	31	31	M
Navicula cryptotenella	NAcryten	2		2	P	4	2	-	-	2	7	2			3		2	3	tol	5	2	al	alk	4.3	36	54	M
Navicula erifuga	NAerifga	2			P	4	3	-	-	-	5	2			2					4	1		sal, eu, alk			87	M
Navicula exigua var capitata	NAexicap		2	3	P	4	1	1	1	2	5	2								4	1						M
Navicula gregaria	NAgregar	2		2	P	4	3	2	4	3	5	3			2				hal	5	1	eu, al		3.4	54	55	M
Navicula incertata	NAincrtt	1			P										1				hal	4	1						M
Navicula ingenua	NAingua		2	0	P	-	-	-	-	-	-	-	+*	+*	2					4	1					84	M
Navicula integra	NAintgra		2	0	P	3	3	2	3	3	5	2								4	1						M
Navicula kotschii (texana)	NAkotsch		2		P	4	2	-	1	1	-	4	-21		3					4	1						M
Navicula leptostriata	NAleptos		2		P	2	1	1	1	1	2	3								4	1						M
Navicula libonensis	NAlibone	2			P										2				eu	4	1						M
Navicula margalithii	NAmargal		2		P	-	2	-	-	-	-	1								4	1						M
Navicula oblonga	NAoblong	2			P	4	2	2	2	2	5	1			3		2		tol	4	1						M
Navicula orangiana	NAorangi		2		P															4	1						M
Navicula peregrina	NAperegr	2			P	4	4	-	-	-	5	-							hal	4	1					48	M
Navicula perminuta	NApermnt		2		P									-*					hal	5	1					86	M
Navicula phyllepta	NAphylpt	2			P														hal	5	1						M
Navicula radiosa	NAradios	3		3	P	3	2	2	2	2	4	3	-27*		3	1	2	3	tol	4	1						M
Navicula recens	NArecens	2			P	4	3	-	-	3	5	3			2					4	1		sal, eu, alk			142	M

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Navicula reichardtiana	NAreichd	2			P	4	2	-	-	3	-	-			3			3	eu	5	2	al		4.7	34	34	M
Navicula rhynchocephala	NArhynch	3		3	P	4	2	2	4	2	7	2			3	1		3		4	1		ox, alk			65	M
Navicula rostellata	NArostel	2		2	P	4	2	2	2	2	5	2			3					4	1	eu, al				52	M
Navicula sanctaecrucis	NAsancru		2		P										2	1				4	1						M
Navicula savannahiana	NAsavana		2	0	P															4	1						M
Navicula schadei	NAschdei		2		P	3	2	1	1	1	3	-								5	1						M
Navicula schroeteri var escambia	NAschesc	2		3	P	4	3	-	1	2	5	3			2					4	1		sal, eu, alk	2.1	102	83	M
Navicula soehrensis (hassiaca)	NAhasaca		2		P	2	1	1	1	1	1	4			4	1	2		o	5	1						M
Navicula subrhynchocephala	NAsubrhy		2		P	-	-	-	-	-	-	-								4	1						M
Navicula symmetrica	NAsymtrc	2		2	P										2					4	1					59	M
Navicula tenelloides	NAtenell	1		3	P	4	2	1	1	1	5	4	+18		2			3		5	1		tol, eu, alk			39	M
Navicula texana (Grimmei)	NAtexana		2		P															4	1						M
Navicula tridentula	NAtriden	3		0	P	2	1	-	-	-	-	4			3	1				5	1						M
Navicula tripunctata	NAtripun	3		3	P	4	2	2	2	2	5	3			3			3		4	2	eu, al	eu, alk	5.8	39	72	M
Navicula trivialis	NAtrivls	2		2	P	4	3	2	3	3	5	3		+28	2					4	1		sal, eu, alk	2.4	50	55	M

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Navicula veneta	NAveneta	1			P	4	3	2	4	4	5	3	+27		2			3	eu	4	1		tol, sal, ox, eu, sap, alk	2.6	48	58	M
Navicula viridula	NAvirdia	2		2	P	4	2	2	2	3	5	1			2		2		tol	4	1		eu, alk	4.7	56		M
Navicula viridula var. rostellata	NAvirdla	2		2	P	4	2	2	2	2	5	2			3					4	1		eu, alk				M
Neidium ampliatum	NEamplia				P	3	2	-	-	-	2	3			4		2			2	3						
Neidium iridis	NEiridis			0	P	3	2	1	1	2	3	1								2	3						
Nitzschia (Tryb. apiculata) constricta	TYapicul	2		3	P, M	4	4	2	3	3	5	2			2					4	1		sal, eu, alk, mo	1.8	70	80	M
Nitzschia (Tryblionella) calida	TYcaldid		2		P, M	-	3	-	-	-	5	-			2					4	1						M
Nitzschia (Tryblionella) coarctata	TYcoarc	1		3	P, M															4	1						M
Nitzschia (Tryblionella) levidensis	TYlevid		2	3	P, M	4	3	2	3	3	5	1	+*		2				hal	4	1		sal, eu, alk, mo				M
Nitzschia (Tryblionella) littoralis	TYlittor		2	3	P, M	4	4	-	3	-	5	3			2					4	1						M
Nitzschia acicularioides	NIacides		2	2	P, M															4	1						M
Nitzschia amphibia	NIamphib	2		1	P, M	4	2	3	3	3	5	3	+55	+61*	2		2	3	tol	4	3	mo, eu, al, nh	eu, nit, alk, mo	1.6	70	63	M
Nitzschia amphibioides	NIampoid		2		P, M										2					4	1						M

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Nitzschia angustata	NIangust	2		2	P, M	3	2	1	1	1	3	1	-22		3	1	2		tol	4	1						M
Nitzschia angustatula	NIangtu		2	2	P, M	4	3	-	-	-	5	1								4	1						M
Nitzschia brevissima	NIbrevis		2	0	P, M	3	3	-	3	2	5	3								4	1						M
Nitzschia clausii	NIclausi	2		2	P, M	4	4	2	2	3	5	3			2				eu	4	1		sal, eu, alk, mo				M
Nitzschia compressa var. balatonis	NIcombal	1			P, M										1					4	1						M
Nitzschia dissipata	NIdissip	3		3	P, M	4	2	2	2	2	4	3		+39	3			3	eu	4	2	mo, al	alk, mo	4.1	50	35	M
Nitzschia filiformis	NIfilifr	2		1	P, M	4	4	3	3	3	5	3			2					4	1	mo, eu, al, nh	sal, eu, nit, alk, mo				M
Nitzschia frustulum	NIfrustu	2		1	P, M	4	3	4	3	2	5	3			2				eu	4	1	mo, eu, al, nh	sal, eu, nit, alk, mo			71	M
Nitzschia geitleri	NIgeitlr		2		P, M															4	1						M
Nitzschia homburgiensis	NIhombur		2		P, M	3	2	1	1	1	3	-							od	4	1						M
Nitzschia inconspicua	NIincons	2		2	P, M	4	3	3	3	3	5	3	+42	+42	2					4	1	mo, eu, al, nh	sal, eu, nit, alk, mo	2.1	115	68	M
Nitzschia linearis	NIlinear	2		3	P, M	4	2	2	2	2	4	3		+19	3				eu	4	1	mo, al	alk, mo	5.3	31	47	M
Nitzschia lorenziana	NIlorenz		2	3	P, M	-	4	-	-	-	-	-								4	1		sal, vd, mo				M

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Nitzschia microcephala	NImicroc	1		1	P, M	4	2	4	3	3	5	1			2				ha l	4	1		tol, eu, nit, alk, mo				M
Nitzschia nana	NInana		2	3	P, M	3	2	-	1	2	3	3			3				eu	4	1		mo				M
Nitzschia obtusa	NIobtusa	1		0	P, M									+*						4	1		tol, vd, mo				M
Nitzschia palea	NIpalea		2	1	P, M	3	2	4	4	5	6	3	+54	+48 *	1			3	eu	4	1	mo, eu, nh, sp	tol, ox, eu, nit, sap, mo	3.7	34	58	M
Nitzschia panduriformis	NIpandur		2		P, M															4	1						M
Nitzschia recta	NIrecta		2	3	P, M	4	2	2	2	2	7	1			3		2	3	tol	4	1		alk, mo	3.2	33	54	M
Nitzschia scalpelliformis	NIscalpe		2		P, M										1					4	1		tol, vd, mo				M
Nitzschia serpentiraphe	NIserpen		2		P, M										2					4	1						M
Nitzschia sigma	NIsigma		2	1	P, M	4	4	2	3	3	5	2			2					4	1		sal, eu, alk, mo				M
Nitzschia sinuata v delognei	NIsinde		2		P, M	4	2	1	1	2	4	4	-*		3			3		4	1						M
Nitzschia solita	NIsolita		2		P, M	-	3	-	-	-	5	-	+16	+20 *	1					4	1		sal, eu, vd, mo	1.9	119		M
Nitzschia subacicularis	NIsubaci		2	0	P, M	4	2	1	1	2	7	2								4	1						M
Nitzschia tropica	NItropic		2	2	P, M										2					4	1		vd, mo				M
Nitzschia vermicularis	NIvermcl		2	2	P, M	4	2	-	1	2	7	2			3					4	1		alk, mo				M

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Nitzschia vitrea	NIvitrea		2	0	P, M	4	4	-	-	-	5	2	-18*		1				hal	4	1						M
Pinnularia acrosphaeria	PIacro		3	0	P	3	1	-	3	1	2	3			4					1	3						M
Pinnularia appendiculata	PIappend		3	2	P	2	1	1	1	1	2	4			4					1	3						M
Pinnularia borealis	PIboreal	2		2	P	3	2	2	1	2	2	4			3	1		3	ae	1	3						M
Pinnularia braunii	PIbrauni		3	3	P	1	-	-	-	-	-	-			4					1	3						M
Pinnularia gibba	PIgibba		3	3	P	3	2	2	3	3	7	2			3	1		3		1	3						M
Pinnularia hemiptera	PIhemipt		3		P	3	1	-	1	1	1	3				1				1	3						M
Pinnularia interrupta	PIinterr		3	3	P	3	1	1	1	1	2	3								1	3						M
Pinnularia microstauron	PImicros	2		0	P	3	2	2	3	2	7	3	-11		3	1	2	3	od	1	3					79	M
Pinnularia obscura	PIobscur		3	3	P	3	2	1	1	1	-	4						3		1	3						M
Pinnularia streptoraphe	PIstrept		3	0	P	2	1	1	1	1	2	3				1				1	3						M
Pinnularia subcapitata	PIsubcap		3	3	P	2	2	2	3	2	2	3				1				1	3						M
Pinnularia viridis	PIviridi		3	0	P	3	2	2	3	2	7	3			3	1		3		1	3						M
Placoneis clementis	PCclemen	2		0	P	4	3	2	1	2	4	3							eu	4	1						M
Placoneis elginensis	PCelgine	3		3	P	4	2	2	2	2	5	3			3	1	2			4	1	eu, al	eu, alk	2.4	96		M
Plagiotropis lepidoptera	PGlepidp	2		3	M										2												M
Planothidium (Achnanthes) biporomum	PTbipo		3		P												2			3	1						
Planothidium (Achnanthes) delicatulum	PTdeli	2			P	5	4	-	-	-	-	-			2				hal	3	1			4.5	50		

Diatom Final ID	Diatom Short Taxon Name	R1	R1a	R2	R3	R4a	R4b	R4c	R4d	R4e	R4f	R4g	R5a TN mg/L	R5b TP µg/L	R6	R7a	R7b	R7c	R8	R9s	R9v	R10	R11	R12a TN mg/L	R12b TP µg/L	R13 TP µg/L	R14
Planothidium (Achnanthes) lanceolatum	PTlanceo	2		3	P	4	2	2	3	3	5	3			2			3	tol	3	1	eu, al	eu, alk	2.4	32	58	
Planothidium apiculatum	PTapic		3		P															3	1						
Pleurosigma delicatulum	PLdelica	2		0	P, M	-	4	-	-	-	-	-			2												M
Pleurosigma salinarum			2		P, M	4	4	-	-	1	-	-	+*	+*	4								sal, alk				M
Pleurosira (Ceratulina) laevis	PRlaevis	2			P, M	5	4	-	-	1	5	3			2								sal, eu, alk				
Pseudostaurosira brevistriata	PDbrevis	3		0	V	4	2	1	1	1	7	2		-30	4	1	2	3	tol	2	2	ox, al	alk	5.1	25	51	
Pseudostaurosira parasitica var. subconstricta	PDparsub		3	4	V	4	2	1	1	2	4	2		-*	4			3		2	1						
Reimeria sinuata	REsinuta	3		4	S	3	2	2	1	2	3	3		-58	3	1	2		tol	4	3	ox		2.3	57	51	
Rhoicosphenia abbreviata		3		3	S	4	2	2	2	2	5	2			3				eu	4	1	eu, al	eu, alk	2.8	58	63	
Rhopalodia brebissonii	RPbrebsn		2		P	4	3	-	-	-	-	-	-*	-*	1					1	1						
Rhopalodia gibba	RPgibba	2		3	P	5	2	1	3	2	5	3	+*	-14	3				o	1	1	eu, al					
Rhopalodia gibberula	RPgibbrl		2	0	P	4	3	-	1	-	-	3	+*		2					1	1		sal, alk				
Rhopalodia musculus	RPmuscul		2		P	-	4	-	-	1	-	3								1	1						
Sellaphora (Navicula) stroemii	NAstroem		2		P	4	2	-	1	-	-	4	-29*	-*	3		2			5	1		alk				M
Sellaphora laevissima	SFlaevis	3		0	P	3	1	1	1	1	3	2	-35		2	1	2			4	1						M
Sellaphora pupula	SFpupula	2		3	P	3	2	2	3	3	4	2			2	1	2	3	eu	4	1			1.9	48	69	M

Diatom Final ID	Diatom Short Taxon Name	R1	R1a	R2	R3	R4a	R4b	R4c	R4d	R4e	R4f	R4g	R5a TN mg/L	R5b TP µg/L	R6	R7a	R7b	R7c	R8	R9s	R9v	R10	R11	R12a TN mg/L	R12b TP µg/L	R13 TP µg/L	R14
Sellaphora seminulum	SFseminu	1		1	P	3	2	3	4	4	5	3	+25*	+29*	1	1		3		5	1		tol, sal, ox, eu, nit, sap			71	M
Seminavis (Amphora) strigosa	AMstrg		2		P															5	1						
Simonsenia delognei	SIdelog	2		3	P	-	3	-	1	3	5	3			2					4	1						
Stauroneis phoenicentron		2		0	P	3	2	2	3	2	4	2			3	1	2	3		5	2						
Stauroneis smithii	SSsmithi		3	4	P	4	2	2	1	2	7	3			3		2	3		5	2		alk				
Stauroneis smithii var sagitta	SSsmisag		3	4	P															5	2						
Staurosira (Fragilaria) construens	SRconstr	3		0	V	4	2	1	1	2	4	1			3			3		2	1	ox, al	alk	3.1	44	99	
Staurosira (Fragilaria) construens var. venter	SRconven	3		0	V	4	2	2	1	2	4	1			3		2			2	1	ox, al	alk			68	
Surirella angusta	SUangust	1			P, M	4	2	2	2	2	5	3			2			3	eu	3	1		tol, eu, alk, mo			38	M
Surirella brebissonii	SUbreb	2		0	P, M	4	-	-	-	-	-	-	+*	+*	2				eu	3	1	mo, al	sal, alk, mo	4.5	51	64	M
Surirella minuta	SUminuta	2		2	P, M	4	2	-	3	3	5	3		+21	2					3	1	mo, eu, al	eu, alk, mo			44	M
Surirella splendida	SUsplen		2	0	P, M	4	2	-	2	2	4	2				1		3		3	1		alk, mo				M

Diatom Final ID	Diatom Short Taxon Name	R1	R1a	R2	R3	R4a	R4b	R4c	R4d	R4e	R4f	R4g	R5a TN mg/L	R5b TP µg/L	R6	R7a	R7b	R7c	R8	R9s	R9v	R10	R11	R12a TN mg/L	R12b TP µg/L	R13 TP µg/L	R14
Surirella tenera	SUtenera		2	3	P, M	4	2	-	2	2	5	1			3					3	1		eu, alk, mo				M
Synedra (Fragilaria) acus	SYacus	2		3	E								-*	-*						4	1					36	
Synedra (Fragilaria) ulna	SYulna	2		3	E	4	2	2	3	4	7	2	-62		3			3		3	1			5.7	42	59	
Tabularia (Fragilaria) fasciculata	TBfascic		3		V	4	4	2	3	3	5	3			3		2		hal	2	1						
Terpsinoe musica	TEmusica				V	-	3	-	-	-	-	3															
Thalassiosira sp.	THsp		2		U															4	1						
Thalassiosira weissflogii	THweiss		2	2	U	4	3	3	3	3	6	1			2					4	1		sal, eu, nit, alk,			47	
Tryblionella (Nit. tryb.) gracilis	TYgracil		2	3	P, M	4	3	2	3	3	5	3	+12	+11*					tol	4	1						M
Tryblionella (Nitzschia) acuminata	TYacum		2		P, M										2				hal	4	1		sal, eu, alk, mo				M
Tryblionella debilis	TYdebili		2	0	P, M	4	2	2	1	3	-	4			3			3	ae	4	1		alk, mo				M

Table 56. Key to Table 1.

R1. Pollution classes of Bahls, 1993. Bahls, L.L., 1993. Periphyton Bioassessment Methods for Montana Streams. Water Quality Bureau, Department of Health and Environmental Sciences, Helena, Montana:1- 22.
Pollution classes
1: most tolerant 2: less tolerant 3: sensitive (based on Lange-Bertalot 1979)
R1a. Default values for genera whose species are not listed
R2. Kentucky PTI Value. Kentucky Pollution Tolerance Index Value, 2002. Kentucky Division of Water, Methods for Assessing Biological Integrity of Surface Waters in Kentucky. 2002. C-5 Diatom Master Taxa List: 112-118.
Pollution classes
0: no autoecological information is known 1: most tolerant 2: less tolerant 3: sensitive 4: most sensitive
R3. Wang Growth Form, Wang *et al.*, 1995. Wang, Yi-K., R.J. Stevenson and L. Metzmeier, 2005. Development and evaluation of a diatom-based index of biotic integrity for the Interior Plateau Ecoregion, USA. J. N. Am. Benthol. Soc. 24(4):990-1008.
Appendix 2. Classifications of growth form and motility for diatom genera. P = prostrate E = erect S = stalked U = unattached V = variable M = motile
R4. Ecological indicator values of Van Dam *et al.*, 1994. Van Dam, H., A. Mertens and J. Sinkeldam, 1994. A Coded checklist and ecological indicator values of freshwater diatoms from the Netherlands. Netherlands Journal of Aquatic Ecology 28(1) 117-133.
Classification of ecological indicator values.
R4a= R: pH
1: acidobiontic (optimal occurrence at pH<5.5) 2: acidophilous (mainly occurring at pH <7) 3: circumneutral (mainly occurring at pH-values about 7) 4: alkaliphilous (mainly occurring at pH >7) (alkaliphilic) 5: alkalibiontic (exclusively occurring at pH >7) 6: indifferent (no apparent optimum)
R4b= H: Salinity

	Cl- (mg/L)	Salinity (%)
1: fresh	<100	<0.2
2: fresh brackish	<500	<0.9
3: brackish fresh	500-1000	0.9-1.8
4: brackish	1000-5000	1.8-9.0

R4c= N: Nitrogen uptake metabolism

1: nitrogen-autotrophic taxa, tolerating very small concentrations of organically bound nitrogen
2: nitrogen-autotrophic taxa, tolerating elevated concentrations of organically bound nitrogen
3: facultatively nitrogen-heterotrophic taxa, needing periodically elevated concentrations of organically bound nitrogen
4: obligately nitrogen-heterotrophic taxa, needing continuously elevated concentrations of organically bound nitrogen

R4d= O: Oxygen requirements

1: continuously high (about 100% saturation)
2: fairly high (above 75% saturation)
3: moderate (above 50% saturation)
4: low (above 30% saturation)
5: very low (about 10% saturation)

R4e= S: Saprobity

	Water quality class	Oxygen saturation (%)	BOD_5^{20} (mg/L)
1: oligosaprobous	I	>85	<2
2: β-mesosaprobous	II	70-85	2-4
3: α-mesosaprobous	III	25-70	4-13
4: α-meso-/polysaprobous	III-IV	10-25	13-22
5: polysaprobous	IV	<10	>22

R4f= T: Trophic state

1: oligotraphentic (oligotrophic)
2: oligo-mesotraphentic (oligo-mesotrophic)
3: mesotraphentic
4: meso-eutraphentic
5: eutraphentic (eutrophic)
6: hypereutraphentic
7: oligo- to eutraphentic (no apparent optimum)

R4g= M: Moisture

1: never, or only rarely, occurring outside water bodies
2: mainly occurring in water bodies, sometimes on wet places
3: mainly occurring in water bodies, also rather regularly on wet and moist places
4: mainly occurring on wet and moist or temporarily dry places
5: nearly exclusively occurring outside water bodies

- = missing value

R5. Potapova, M. and D.F. Charles, 2007. Diatom metrics for monitoring eutrophication in rivers of the United States. Ecological Indicators 7:48-70. Diatoms indicating low (≤ 10 µg/L)

total phosphorus are indicated by (-), high (≥ 100 µg/L) total phosphorus (TP) by (+); low (≤ 0.2 mg/L) total nitrogen (TN) by (-), and high (≥ 3 mg/L) total nitrogen by (+). Diatoms with indicator values greater than 5 are shown. A second analysis was based on calculation of species abundance-weighted means. Diatoms with TP and TN abundance-weighted means above the 75th percentile (+*) or below the 25th percentile (-*) of all values are listed here and marked by asterisks.
R5a= total nitrogen (TN) (mg/L)
R5b= total phosphorus (TP) (µg/L)
R6. City of Austin Pollution Tolerance Index values. Muscio, C., 2002. The diatom pollution tolerance index. City of Austin Watershed Protection and Development Review Department, Environmental Resource Management Division. SR-02-02: 1-17. Published online at City of Austin website http://www:ci.austin.tx.us/watershed/downloads/.
Values are scaled from 1 to 4 with low numbers indicating most pollution tolerant and 4 is pollution sensitive.
R7. Indicators of Oligotrophy. Lange-Bertalot, H. and D. Metzeltin. 1996, Indicators of Oligotrophy. 800 taxa representative of three ecologically distinct lake types. Carbonate buffered - oligodystrophic - weakly buffered soft water. Iconographia Diatomologica, Vol 2. Koeltz Scientific Books, Königstein, 371-390.
R7a= 1: electrolyte poor, humic acid rich lake
R7b= 2: carbonate buffered, electrolyte rich lake
R7c= 3: electrolyte rich clear, humic acid free lake
R8. Autoecology of Diatoms. Lange-Bertalot, H and S.I. Genkal, 1999, Iconographia Diatomologica. Annotated diatom monographs Vol. 6. Diatoms from Siberia 1, Koeltz Scientific Books, Königstein. 18-25.
ae (aerophilic) alk (alkaliphilic)
oc (oligotrophic predominately carbonate buffered waters)
od (oligotrophic or dystrophic electrolyte poor waters)
o (oligotrophic waters of different quality)
hal (halophilic)
eu (highest vitality in stronger mesotrophic to eutrophic waters)
tol (tolerant to a wide range from oligo- to eutrophic waters without discernible preference)
R9. Sensitivity values for Trophic Diatom Index. Kelly, M.G. and B.A. Whitton, 1995. The Trophic Diatom Index: a new index for monitoring eutrophication in rivers, Journal of Applied Phycology 7: 433-444. The taxon sensitivity range (s) and indicator value (v) are used
Taxon Sensitivity (s) range 1-5; concentration of phosphorus as filterable reactive phosphorus (FRP) derived from a graph summarizing percent count versus FRP for each taxon
1. <0.01 mg/l 2. ≥0.01, <0.035 mg/l 3 ≥0.035, <0.1 mg/l 4. ≥0.1, <0.3mg/l

5. ≥0.3mg/l Indicator values (v) range 1-3 represent the spread of values around the peak for FRP.
R10. River Diatom Index. Fore, L.S. and C. Grafe, 2002. Using diatoms to assess the biological condition of large rivers in Idaho (U.S.A.). Freshwater Biology 47: 2015-2037.
ox: species that require high oxygen
mo: species that are motile or sediment tolerant
al: species that prefer alkaline water
Eu: species that prefer eutrophic conditions
sp: species that prefer saprobic conditions
nh: species that are nitrogen heterotrophs
R11. Fore, 2003. Response of diatom assemblages to human disturbance: development and testing of a multimetric index for the Mid-Atlantic Region (USA). in: Simon, T.P., Biological Response Signatures: Indicator Patterns Using Aquatic Communities. CRC Press, Hoboken: 445-471.
tol: species classified as very tolerant of pollution by Bahls (1993)
sal: species listed as tolerant to salt by Van Dam (1994)
ox: species that require low oxygen
eu: species that prefer eutrophic conditions
nit: species that are nitrogen heterotrophs
sap: species that prefer polysaprobic conditions
alk: species that prefer alkaline water
vd: species not included in Van Dam (1994)
mo: species that are motile or sediment tolerant
R12: Winter, J.G. and H.C. Duthie, 2000. Epilithic diatoms as indicators of stream total nitrogen and total phosphorus concentration. J. N. Am. Benthol. Soc. 19 (1): 32-49.
R12a: optimal total nitrogen (TN) (mg/L)
R12b: optimal total phosphorus (TP) (µg/L)
tolerance = standard deviation of the optima (Lowe and Pan 1996, p 729.)
R13: Potapova, M.G., D.F. Charles, K.C. Ponader and D.M. Winter, 2004. Quantifying species indicator values for trophic diatom indices: a comparison of approaches. Hydrobiologia 517: 24-41.
Weighted average total phosphorus (TP) (µg/L)
R14: Motile forms: M. Barbara Winsborough, personal communication.

Table 57. Diatom authorship.

Diatom	Diatom Short Taxon Name	Authorship
Achnanthes brevipes	ACbrevip	Agardh 1824
Achnanthes inflata	ACinflat	(Kützing) Grunow
Achnanthidium biassolettianum	ACbiasso	(Grunow) Round & Bukhtiyarova 1996
Achnanthidium exiguum	AHexigum	(Grunow) Czarnecki 1990
Achnanthidium minutissimum	AHminuti	(Kützing) Czarnecki 1994
Adlafia bryophila	ADbryoph	(Petersen) Lange-Bertalot
Amphipleura pellucida	ALpelluc	(Petersen) Lange-Bertalot
Amphora acutiuscula	AMactscl	Kützing 1844
Amphora bullatoides	AMbullat	Hohn & Hellerman 1963
Amphora coffeaeformis	AMcoffea	(Agardh) Kützing 1844
Amphora copulata	AMcopula	(Kützing) Schoeman et Archibald
Amphora granulata	AMgranul	Gregory 1857
Amphora inariensis	AMinarie	Krammer 1980
Amphora montana	AMmontan	Krasske 1932
Amphora pediculus	AMpedcls	(Kützing) Grunow 1880
Amphora sabiniana	AMsabina	Reimer 1975
Amphora veneta	AMveneta	Kützing 1844
Anomoeoneis costata	ANcostat	(Kützing) Hustedt 1959
Anomoeoneis sphaerophora	ANsphaer	(Ehrenberg) Pfitzer 1871
Aulacoseira ambigua	AUambig	(Grunow) Simonsen 1979
Aulacoseira granulata	AUgranlt	(Ehrenberg) Simonsen 1979
Aulacoseira granulata var. angustissima	AUgrnang	(Müller) Simonsen
Bacillaria paradoxa	BApardxa	Gmelin 1791
Biremis circumtexta	BMcircum	(Meister ex Hustedt) Lange-B. & Witkowski 2000
Brachyseira neoexilis (Navicula exilis)	NAexilis	Lange-Bertalot 1994
Brachyseira vitrea	BRvitrea	(Grunow) Ross 1986
Caloneis bacillum	CAbacill	(Grunow) Cleve 1894
Caloneis oregonica	CAoregon	(Ehrenberg) Patrick 1966
Caloneis schumanniana	CAschuma	(Grunow) Cleve 1894
Caloneis silicula	CAsilicu	(Ehrenberg) Cleve 1894
Campylodiscus clypeus	CAclypeu	Ehrenberg) Ehrenberg ex Kützing 1844
Capartogramma crucicula	CPcrucic	(Grunow ex Cleve) Ross

Diatom	Diatom Short Taxon Name	Authorship
Cocconeis pediculus	CCpedcls	Ehrenberg 1838
Cocconeis placentula	CCplacen	Ehrenberg 1838
Cocconeis placentula var euglypta	CCplaeug	(Ehrenberg) Grunow 1884
Cocconeis placentula var pseudolineata	CCplapse	Geitler 1927
Cocconeis scutellum	CCscutel	Ehrenberg 1838
Craticula (Navicula) halophila	KChaloph	(Grunow) Mann 1990
Craticula (Navicula) minusculoides	KCminusc	(Hustedt) Lange-Bertalot 2001
Craticula buderi	KCbuderi	(Hustedt) Lange-Bertalot 2000
Craticula cuspidata	KCcuspid	(Kützing) Mann 1990
Cyclostephanos tholiformis	CStholis	Stoermer et al. 1987
Cyclotella cf. stelligera	CYcfstel	(Cleve et Grunow) Van Heurck 1882
Cyclotella meneghiniana	CYmenegh	Kützing 1844
Cymatopleura elliptica	CTellipt	(Brebisson) W. Smith 1851
Cymbella aspera	CMaera	(Ehrenberg) H. Peragallo 1849
Cymbella cistula	CMcistul	(Ehrenberg) Kirchner 1878
Cymbella cymbiformis	CMcymbis	Agardh 1830
Cymbella excisa	CMexcisa	Kützing 1844
Cymbella hustedtii	CMheusted	Krasske 1923
Cymbella kolbei	CMkolbei	Hustedt 1949
Cymbella laevis	CMlaevis	Naegeli 1849
Cymbella tumida	CMtumida	(Brebisson) Van Heurck 1880
Denticula kuetzingii	DEkuetzi	Grunow 1862
Denticula subtilis	DEsubtil	Grunow 1862
Diadesmis (Navicula) confervacea	DIconfer	Kützing 1844
Diadesmis (Navicula) contenta	DIcontent	(Grunow) Mann 1990
Diploneis elliptica	DPellipt	(Kützing) Cleve 1891
Diploneis oblongella	DPoblong	(Naegeli) A. Cleve-Euler 1922
Diploneis ovalis	DPovalis	(Hilse) Cleve 1891
Diploneis pseudovalis	DPpsudov	Hustedt 1930
Diploneis puella	DPpuella	(Schumann) Cleve 1894
Encyonema (Encyonopsis) evergladianum	ECevergl	Krammer 1997
Encyonema (Encyonopsis) microcephala	EYmicroc	(Grunow) Krammer 1997

Diatom	Diatom Short Taxon Name	Authorship
Encyonema carina	ECcarina	Lange-Bertalot et Krammer 1997
Encyonema delicatula	CMdelcat	Kützing 1849
Encyonema elginensis	CMelgine	(Krammer) D.G. Mann in Round et al. 1990
Encyonema silesiacum	ECsilesi	(Bleisch ex Rabenhorst) D. G. Mann 1990
Encyonema triangulum	ECtriang	(Ehrenberg) Kützing 1849
Encyonopsis minuta	EYminuta	Krammer & Reichardt 1997
Eolimna subminuscula	EOsubmin	(Manguin 1941) G. Moser, H. Lange-Bertalot
Epithemia adnata	EPadnata	(Kützing) Brebisson 1838
Epithemia sorex	EPsorex	Kützing 1844
Epithemia turgida	EPturgid	(Ehrenberg) Kützing 1844
Eucocconeis (Achnanthes) flexella	ESflexel	(Kützing) Cleve 1895
Eunotia arcus	EUarcus	Ehrenberg 1837
Eunotia bilunaris	EUbilun	(Ehrenberg) Mills 1934
Eunotia formica	EUformic	Ehrenberg 1843
Eunotia pectinalis	EUpectin	(Kützing) Rabenhorst 1864
Fallacia (Navicula) lenzii	FAlenzii	(Hustedt) Lange-Bertalot 2004
Fallacia litoricola	FAlitori	(Hustedt) D.G.Mann 1990
Fallacia monoculata	FAmonoc	(Hustedt) Mann 1990
Fallacia pygmaea	FApygmae	(Kützing) Stickle & Mann 1990
Fallacia tenera	FAtener2	(Hustedt) Mann 1990
Fragilaria capucina	FRcapuci	Desmazieres 1825
Fragilaria famelica	FRfameli	(Kützing) Lange-Bertalot 1980
Fragilaria nanana	FRnanana	Lange-Bertalot 1991
Fragilaria tenera	FRterera	(W. Smith) Lange-Bertalot 1980
Frustulia rhomboides	FSrhombo	(Ehrenberg) DeToni 1891
Frustulia vulgaris	FSvulgar	(Thwaites) DeToni 1891
Frustulia weinholdii	FSwein	Hustedt 1937
Geissleria decussis	GEdecu	(Hustedt) Lange-Bertalot & Metzeltin 1996
Gomphonema acuminatum	GOacumin	Ehrenberg 1832
Gomphonema affine	GOaffine	Kützing 1844
Gomphonema angustatum (micropus)	GOangstt	(Kützing) Rabenhorst 1864
Gomphonema angustum	GOangust	Agardh 1831

Diatom	Diatom Short Taxon Name	Authorship
Gomphonema clavatum	GOclavat	Reichardt 1999
Gomphonema gracile	GOgracil	Ehrenberg 1838
Gomphonema intricatum	GOintric	Kützing 1844
Gomphonema intricatum var vibrio	GOintvib	(Ehrenberg) Cleve 1894
Gomphonema mclaughlinii	GOmaclau	Reichardt 1999
Gomphonema parvulum	GOparvul	(Kützing) Kützing 1849
Gomphonema patrickii	GOpatric	Kociolek , Stoermer & Edlund 1995
Gomphonema pumilum	GOpumilu	(Grunow) Reichardt et Lange-Bertalot 1991
Gomphonema rhombicum	GOrhombi	Fricke 1904
Gomphonema vibrioides	GOvibdes	Reichardt et Lange-Bertalot 1991
Gomphosphenia (Gomphonema) lingulatiformis	GMlinfor	(Lange-Bertalot & Reichardt) Lange-Bertalot 1995
Gomphosphenia grovei	GMgrovei	(Schmid) Lange-Bertalot 1995
Gomphosphenia reicheltii	GMreicht	(M. Schmidt) Lange-Bertalot 1995
Gyrosigma nodiferum	GYnodfrm	(Grunow) Reimer 1966
Gyrosigma obscurum	GYobscur	(W. Smith) Griffith et Henfrey 1856
Gyrosigma obtusatum	GYobtusa	(Sullivant et Wormley) Boyer 1922
Gyrosigma scalproides	GYscalpd	(Rabenhorst) Cleve 1894
Gyrosigma spencerii	GYspence	(W. Smith) Griffith et Henfrey 1856
Hantzschia amphioxys	HAamphio	(Ehrenberg) Grunow 1880
Hippodonta (Navicula) hungarica	HIhunga	(Grunow) Lange-Bertalot, Metzeltin et Witkowski
Hippodonta capitata	HIcapita	(Ehrenberg) Lange-Bertalot et al. 1996
Lemnicola (Achnanthes) hungarica	LEhungar	(Grunow) Lange-Bertalot et al. 1996
Luticola goeppertiana	LUgoept2	(Bleisch) Mann in Round, Crawford & Mann 1990
Luticola mutica	LUmutica	(Kützing) Mann 1990
Mastogloia elliptica	MSellipt	(Agardh) Cleve 1893
Mastogloia smithii	MSsmithi	Thwaites ex W. Smith 1856
Mayamaea (Navicula) atomus	MYatomus	(Kützing) Lange-Bertalot 1997
Melosira varians	MEvarian	Agardh 1827
Navicula (Eolimna) minima	NAminima	(Grunow) Lange-Bertalot 1998
Navicula (Eolimna) subminuscula	NAsubmin	(Manguin) Moser, Lange-Bertalot & Metzeltin 1998
Navicula aikenensis	NAaiken	Patrick 1959

Diatom	Diatom Short Taxon Name	Authorship
Navicula angusta	NAangust	Grunow 1860
Navicula antonii	NAantoni	Lange-Bertalot 2000
Navicula capitatoradiata	NAcaprad	Germain 1981
Navicula cf. fauta	NAcffaut	Hustedt 1954
Navicula cf. pseudanglica	NAcfpsan	Lange-Bertalot 1985
Navicula cincta	NAcincta	(Ehrenberg) Ralfs 1861
Navicula constans	NAconstn	Hustedt 1944
Navicula cryptocephala	NAcrypto	Kützing 1844
Navicula cryptotenella	NAcryten	Lange-Bertalot 1985
Navicula erifuga	NAerifga	Lange-Bertalot 1985
Navicula exigua var capitata	NAexicap	Patrick 1945
Navicula gregaria	NAgregar	Donkin 1861
Navicula incertata	NAincrtt	Lange-Bertalot 1985
Navicula ingenua	NAingua	Hustedt 1957
Navicula integra	NAintgra	(W. Smith) Ralfs 1861
Navicula kotschii (texana)	NAkotsch	Grunow 1860
Navicula leptostriata	NAleptos	Jorgensen 1948
Navicula libonensis	NAlibone	Schoemann 1970
Navicula margalithii	NAmargal	Lange-Bertalot 1985
Navicula oblonga	NAoblong	(Kützing) Kützing 1844
Navicula orangiana	NAorangi	Patrick 1959
Navicula peregrina	NAperegr	(Ehrenberg) Kützing 1844
Navicula perminuta	NApermnt	Grunow 1880
Navicula phyllepta	NAphylpt	Kützing 1844
Navicula radiosa	NAradios	Kützing 1844
Navicula recens	NArecens	(Lange-Bertalot) Lange-Bertalot 1985
Navicula reichardtiana	NAreichd	Lange-Bertalot 1989
Navicula rhynchocephala	NArhynch	Kützing 1844
Navicula rostellata	NArostel	Kützing 1844
Navicula sanctaecrucis	NAsancru	Østrup 1913
Navicula savannahiana	NAsavana	Patrick 1959
Navicula schadei	NAschdei	Krasske 1929
Navicula schroeteri var escambia	NAschesc	Patrick 1959
Navicula soehrensis (hassiaca)	NAhasaca	Krasske 1923
Navicula subrhynchocephala	NAsubrhy	Hustedt 1935
Navicula symmetrica	NAsymtrc	Patrick 1944
Navicula tenelloides	NAtenell	Hustedt 1937

Diatom	Diatom Short Taxon Name	Authorship
Navicula texana (Grimmei)	NAtexana	Patrick 1959
Navicula tridentula	NAtriden	Krasske 1923
Navicula tripunctata	NAtripun	(O.F. Muller) Bory 1822
Navicula trivialis	NAtrivls	Lange-Bertalot 1980
Navicula veneta	NAveneta	Kützing 1844
Navicula viridula	NAvirdia	(Kützing) Ehrenberg 1838
Navicula viridula var. rostellata	NAvirdla	(Kützing) Cleve 1895
Neidium ampliatum	NEamplia	(Ehrenberg) Krammer 1985
Neidium iridis	NEiridis	(Ehrenberg) Cleve 1894
Nitzschia (Tryb. apiculata) constricta	TYapicul	(Gregory) Grunow
Nitzschia (Tryblionella) calida	TYcaldid	Grunow 1880
Nitzschia (Tryblionella) coarctata	TYcoarc	(Grunow) D.G. Mann 1990
Nitzschia (Tryblionella) levidensis	TYlevid	W. Smith 1856
Nitzschia (Tryblionella) littoralis	TYlittor	(Grunow) D.G. Mann 1990
Nitzschia acicularioides	NIacides	Hustedt 1959
Nitzschia amphibia	NIamphib	Grunow 1862
Nitzschia amphibioides	NIampoid	Hustedt 1942
Nitzschia angustata	NIangust	(W. Smith) Grunow 1880
Nitzschia angustatula	NIangtu	Lange-Bertalot 1987
Nitzschia brevissima	NIbrevis	Grunow ex Van Heurck 1881
Nitzschia clausii	NIclausi	Hantzsch 1860
Nitzschia compressa var. balatonis	NIcombal	(Grunow) Lange-Bertalot 1987
Nitzschia dissipata	NIdissip	(Kützing) Grunow 1862
Nitzschia filiformis	NIfilifr	(W. Smith) Van Heurck 1896
Nitzschia frustulum	NIfrustu	(Kützing) Grunow 1880
Nitzschia geitleri	NIgeitlr	Hustedt 1959
Nitzschia homburgiensis	NIhombur	Lange-Bertalot 1978
Nitzschia inconspicua	NIincons	Grunow 1862
Nitzschia linearis	NIlinear	(Agardh) W. Smith 1853
Nitzschia lorenziana	NIlorenz	Grunow 1880
Nitzschia microcephala	NImicroc	Grunow 1878
Nitzschia nana	NInana	Grunow 1881
Nitzschia obtusa	NIobtusa	W. Smith 1853

Diatom	Diatom Short Taxon Name	Authorship
Nitzschia palea	NIpalea	(Kützing) W. Smith 1856
Nitzschia panduriformis	NIpandur	W. Gregory 1857
Nitzschia recta	NIrecta	Hantzsch 1861-1879
Nitzschia scalpelliformis	NIscalpe	(Grunow) Grunow in Cleve & Grunow 1880
Nitzschia serpentiraphe	NIserpen	Lange-Bertalot 1993
Nitzschia sigma	NIsigma	(Kützing) W. Smith 1853
Nitzschia sinuata v delognii	NIsinde	(Grunow) Lange-Bertalot 1980
Nitzschia solita	NIsolita	Hustedt 1953
Nitzschia subacicularis	NIsubaci	Hustedt 1922
Nitzschia tropica	NItropic	Hustedt 1949
Nitzschia vermicularis	NIvermcl	(Kützing) Hantzsch 1860
Nitzschia vitrea	NIvitrea	Norman 1861
Pinnularia acrosphaeria	PIacro	Rabenhorst 1853
Pinnularia appendiculata	PIappend	(Agardh) Cleve 1895
Pinnularia borealis	PIboreal	Ehrenberg 1841
Pinnularia braunii	PIbrauni	(Grunow) Cleve 1895
Pinnularia gibba	PIgibba	Ehrenberg 1841
Pinnularia hemiptera	PIhemipt	(Kützing) Rabenhorst 1853
Pinnularia interrupta	PIinterr	W. Smith 1853
Pinnularia microstauron	PImicros	(Ehrenberg) Cleve 1891
Pinnularia obscura	PIobscur	Krasske 1932
Pinnularia streptoraphe	PIstrept	Cleve 1891
Pinnularia subcapitata	PIsubcap	Gregory 1856
Pinnularia viridis	PIviridi	(Nitzsch) Ehrenberg 1841
Placoneis clementis	PCclemen	(Grunow) Cox 1987
Placoneis elginensis	PCelgine	(Gregory) Cox 1987
Plagiotropis lepidoptera	PGlepidp	(Gregory) Kuntze in Cleve 1894
Planothidium (Achnanthes) biporomum	PTbipo	(Hohn et Hellerman) Lange-Bertalot 1999
Planothidium (Achnanthes) delicatulum	PTdeli	(Kützing) Round & Bukhtiyarova 1996
Planothidium (Achnanthes) lanceolatum	PTlanceo	(Brebisson ex Kützing) Lange-Bertalot 1999
Planothidium apiculatum	PTapic	(Patrick) Lange-Bertalot 1999
Pleurosigma delicatulum	PLdelica	W. Smith 1852
Pleurosigma salinarum	PLsalinm	(Grunow) Grunow in Cleve & Grunow 1880

Diatom	Diatom Short Taxon Name	Authorship
Pleurosira (Ceratulina) laevis	PRlaevis	(Ehrenberg) Compere 1982
Pseudostaurosira brevistriata	PDbrevis	(Grunow) Williams & Round 1987
Pseudostaurosira parasitica var. subconstricta	PDparsub	(Grunow) Morales 2003
Reimeria sinuata	REsinuta	(Gregory) Kociolek & Stoermer 1987
Rhoicosphenia abbreviata	ROabbre	(Agardh) Lange-Bertalot 1980
Rhopalodia brebissonii	RPbrebsn	Krammer 1987
Rhopalodia gibba	RPgibba	(Ehrenberg) O. Muller 1895
Rhopalodia gibberula	RPgibbrl	(Ehrenberg) O. Muller 1899
Rhopalodia musculus	RPmuscul	(Kützing) O. Muller 1899
Sellaphora (Navicula) stroemii	NAstroem	(Hustedt) Mann in Round, Crawford & Mann 1990
Sellaphora laevissima	SFlaevis	(Kützing) Mann 1989
Sellaphora pupula	SFpupula	(Kützing) Mereschkowsky 1902
Sellaphora seminulum	SFseminu	(Grunow) Mann 1989
Seminavis (Amphora) strigosa	AMstrg	(Hustedt) Danieledis & Economou-Amilli in D.B. Danielidis & D. G. Mann 2003
Simonsenia delognei	SIdelog	(Grunow) Lange-Bertalot 1979
Stauroneis phoenicentron	SSphoeni	(Nitzsch) Ehrenberg 1843
Stauroneis smithii	SSsmithi	Grunow 1860
Stauroneis smithii var sagitta	SSsmisag	(Cleve) Hustedt 1959
Staurosira (Fragilaria) construens	SRconstr	(Ehrenberg) Williams & Round 1987
Staurosira (Fragilaria) construens var. venter	SRconven	(Ehrenberg) Hamilton 1992
Surirella angusta	SUangust	Kützing 1844
Surirella brebissonii	SUbreb	Krammer & Lange-Bertalot 1987
Surirella minuta	SUminuta	Brebisson in Kützing 1849
Surirella splendida	SUsplen	(Ehrenberg) Kützing 1844
Surirella tenera	SUtenera	Gregory 1856
Synedra (Fragilaria) acus	SYacus	Kützing 1844
Synedra (Fragilaria) ulna	SYulna	(Nitzsch) Ehrenberg 1836
Tabularia (Fragilaria) fasciculata	TBfascic	(Agardh) Williams et Round
Terpsinoe musica	TEmusica	Ehrenberg 1843
Thalassiosira sp.	THsp	Cleve 1873
Thalassiosira weissflogii	THweiss	(Grunow) Fryxell & Hasle 1977

Diatom	Diatom Short Taxon Name	Authorship
Tryblionella (Nit. tryb.) gracilis	TYgracil	W. Smith 1853
Tryblionella (Nitzschia) acuminata	TYacum	W. Smith 1853
Tryblionella debilis	TYdebili	Arnott 1873

Table 58. Attributes of observed diatoms.

Diatom	Attributes
Achnanthidium biassolettianum	pollution sensitive, alkaliphilic, fresh brackish salinity, mesotrophic, mainly aquatic, also occurs regularly in wet places
Achnanthidium minutissimum	stalked, circumneutral pH, alkaliphilic, fresh brackish salinity, tolerant to elevated organic nitrogen, oligotrophic to hypereutrophic, moderately pollution sensitive, needs high oxygen (near saturation), beta-mesosaprobous, mainly aquatic, also occurs regularly in wet places, low and high conductivity and humate rich or poor water
Adlafia bryophila	moderately pollution tolerant, circumneutral pH, fresh water, needs high oxygen (near saturation), oligosaprobous, mesotrophic, mostly occurs outside water bodies
Amphora inariensis	pollution sensitive, fresh brackish salinity, oligotrophic
Amphora pediculus	pollution sensitive to tolerant, alkaliphilic, fresh brackish salinity, tolerant to elevated organic nitrogen, needs 75% oxygen saturation, beta-mesosaprobous, eutrophic, mainly aquatic, also occurs regularly in wet places
Amphora veneta	prostrate, most pollution tolerant, alkalibiontic, brackish fresh salinity, tolerant to elevated organic nitrogen, above 50% oxygen saturation, alpha-meso-polysaprobous, eutrophic, in water and moist-wet places, prefers high conductivity, subaerial (occurs out of water)
Aulacoseira granulata var. angustissima	centric diatom, pollution sensitive, alkaliphilic, fresh brackish salinity, tolerant of elevated organic nitrogen, needs 50% oxygen saturation, beta-mesosaprobous, eutrophic, only aquatic
Bacillaria paradoxa	moderately pollution tolerant, alkaliphilic to alkalibiontic (obligately alkaline pH), brackish salinity, tolerant to elevated nitrogen, low oxygen - 30% saturation, alpha-mesosaprobous, mainly aquatic, also occurs regularly in wet places, eutrophic, tolerant of salts, low oxygen
Cocconeis pediculus	
Cocconeis placentula	prostrate, sensitive to pollution, alkaliphilic, fresh brackish salinity, tolerant to elevated nitrogen, above 50% oxygen saturation, beta meso-saprobic, eutrophic, mainly aquatic
Cocconeis placentula var euglypta	pollution sensitive, alkaliphilic, fresh brackish salinity, tolerant to elevated organic nitrogen, needs 50% oxygen saturation, beta-mesosaprobous, eutrophic, mainly aquatic, sometimes wet places
Cocconeis placentula var pseudoline	attached, somewhat pollution sensitive

Diatom	Attributes
Craticula halophila	somewhat tolerant to pollution, alkaliphilic, brackish salinity, tolerant of elevated organic nitrogen, needs 75% oxygen saturation, alpha-mesosaprobous, eutrophic, mainly aquatic, sometimes in wet places, salt tolerant
Cymbella excisa	pollution sensitive, stalked, somewhat sensitive to organic pollution
Diploneis elliptica	pollution sensitive, alkaliphilic, fresh brackish salinity, tolerant of very small concentration of organic nitrogen, needs high oxygen (near saturation), oligosaprobous, mesotrophic, mainly aquatic, also occurs regularly in wet places
Diploneis puella	moderately tolerant to pollution, alkaliphilic, fresh brackish salinity, tolerant of very small concentration of organic nitrogen,, needs high oxygen (near saturation), oligosaprobic, mesotrophic to eutrophic, mainly aquatic, also regularly in wet places
Encyonema delicatula	pollution sensitive, stalked, alkaliphilic, fresh water salinity, tolerant of very small concentration of organic nitrogen, needs high oxygen (near saturation), oligosaprobous, oligotrophic, mainly aquatic, also regularly occurs in wet places, carbonate buffered, high conductivity water
Encyonema evergladianum	somewhat tolerant to pollution , stalked, fresh brackish salinity, tolerant of very small concentration of organic nitrogen, needs high oxygen (near saturation), oligotrophic, mainly aquatic, also regularly in wet places, high conductivity water
Encyonema silesiacum	somewhat pollution sensitive, alkaliphilic, stalked, circumneutral pH, fresh brackish salinity, tolerant to elevated organic nitrogen, needs 50% oxygen saturation, alpha-mesosaprobous, broad trophic tolerance, aquatic only, in high and low conductivity water
Navicula (Eolimna) subminuscula	pollution tolerant, alkaliphilic, fresh brackish salinity, obligate nitrogen heterotroph (needing continuously elevated concentrations of organically bound nitrogen), needs 30% oxygen saturation, alpha-meso-polysaprobous, eutrophic, , mainly aquatic, also regularly occurs in wet places
Eucocconeis flexella	circumneutral pH, fresh water salinity, pollution sensitive, attached, tolerant of very small concentration of organic nitrogen, needs high oxygen (near saturation),oligotrophic, oligosaprobous, mainly aquatic, also regularly occurs in wet places
Eunotia pectinalis	somewhat pollution sensitive, attached, acidophilous (mainly pH<7), fresh water salinity, tolerant to elevated organic nitrogen, needs high oxygen (near saturation), beta-mesosaprobous, mesotrophic, mainly aquatic, also regularly occurs in wet places, electrolyte poor, humic acid rich, oligotrophic waters of different quality
Fragilaria tenera	pollution sensitive, variable form, acidophilous (mainly pH<7), fresh water, tolerant of very small concentration of organic nitrogen, needs high oxygen (near saturation), oligosaprobous, oligo-mesotrophic, mainly aquatic, also sometimes occurs in wet places

Diatom	Attributes
Frustulia vulgaris	somewhat sensitive to somewhat pollution tolerant, alkaliphilic, fresh brackish salinity, tolerant to elevated organic nitrogen, needs high oxygen (near saturation),, beta-mesosaprobous, mesotrophic, mainly aquatic, also regularly occurs in wet places, low and high conductivity, wide environmental tolerance, sensitive to organic pollution
Gomphonema affine	pollution sensitive, stalked, alkaliphilic, fresh brackish salinity, tolerant of very small concentration of organic nitrogen, needs high oxygen (near saturation), beta-mesosaprobous, mesotrophic, mainly aquatic, also regularly occurs in wet places
Gomphonema angustatum	somewhat pollution tolerant, stalked, alkaliphilic, fresh brackish salinity, tolerant of elevated organic nitrogen, needs 75% oxygen saturation, beta-mesosaprobous, eutrophic, mainly aquatic, also regularly occurs in wet places, in carbonate buffered waters, high conductivity water, sensitive to organic pollutants
Gomphonema patrickii	somewhat pollution sensitive, stalked
Gomphonema pumilum	somewhat pollution sensitive, stalked, fresh brackish salinity, oligo-eutrophic, high conductivity water
Gomphosphenia grovei	pollution sensitive, stalked, attached
Gomphosphenia lingulatiformis	pollution sensitive, stalked, attached
Gyrosigma nodiferum	somewhat sensitive to moderately pollution tolerant, motile
Navicula kotschii	somewhat pollution tolerant, alkaliphilic, fresh brackish salinity, needs high O (near saturation), oligosaprobous, mainly occurring on wet and moist or temporarily dry places
Navicula recens	moderately tolerant to pollution, alkaliphilic, brackish fresh salinity, alpha-mesosaprobous, meso-eutrophic, mainly aquatic, also regularly occurs in wet places, tolerant of organic pollution, salt tolerant, eutrophic
Navicula(viridula var.) rostellata	moderately pollution tolerant, alkaliphilic, fresh brackish salinity, tolerant to elevated organic N, needs 75% O saturation, beta-mesosaprobous, eutrophic, mainly aquatic, also sometimes occurs in wet places
Navicula sanctaecrucis	somewhat sensitive to moderately pollution tolerant
Navicula schroeteri (probably variety escambia)	moderately tolerant to pollution, alkaliphilic, brackish fresh salinity, needs high oxygen (near saturation), beta-mesosaprobic, eutrophic, mainly aquatic, also regularly occurs in wet places, salt tolerant
Navicula symmetrica	motile, somewhat pollution tolerant

Diatom	Attributes
Navicula tripunctata	pollution sensitive to tolerant, alkaliphilic, fresh brackish salinity, tolerant to elevated organic nitrogen, requires 75% oxygen saturation, beta-mesosaprobous, eutrophic, mainly aquatic, also regularly occurs in wet places, high conductivity water, motile
Navicula veneta	pollution tolerant, motile, alkaliphilic, brackish fresh salinity, tolerant to elevated organic nitrogen, low oxygen requirements, alpha-meso-polysaprobous, eutrophic, mainly aquatic, also regularly occurs in wet places, high conductivity, very tolerant of pollution, salt tolerant
Nitzschia amphibia	moderately to very pollution tolerant, motile, alkaliphilic, fresh brackish salinity, facultative nitrogen heterotroph (needs periodically elevated organic nitrogen), needs 50% O saturation, alpha-mesosaprobous, eutrophic, mainly aquatic, also regularly occurs in wet places
Nitzschia brevissima	moderately tolerant to pollution, motile, circumneutral pH, brackish fresh salinity, needs 50% oxygen saturation, beta-mesosaprobous, eutrophic, mainly aquatic, also regularly occurs in wet places
Nitzschia dissipata	rather pollution sensitive, motile, alkaliphilic, fresh brackish salinity, tolerant to elevated organic nitrogen, needs 75% oxygen saturation, beta-mesosaprobous, meso-eutrophic, mainly aquatic, also regularly occurs in wet places
Nitzschia frustulum	moderately tolerant to pollution, brackish fresh salinity, motile, eutrophic, alkaliphilic, obligate nitrogen heterotroph (needs continuously elevated organic nitrogen),, needs 50% oxygen saturation, beta-mesosaprobous, mainly aquatic, also regularly occurs in wet places, tolerates elevated salts
Nitzschia inconspicua	moderately tolerant to pollution, motile, alkaliphilic, brackish fresh salinity, facultative nitrogen heterotroph (needs periodically elevated organic nitrogen), needs 50% oxygen saturation, alpha-mesosaprobous, eutrophic, mainly aquatic, also regularly occurs in wet places, tolerant to elevated salts
Nitzschia palea	moderately to very tolerant to pollution, motile, circumneutral pH, fresh brackish salinity, obligate nitrogen heterotroph (needs continuously elevated organic nitrogen),, requires 30% oxygen saturation , polysaprobous, hypereutrophic, mainly aquatic, also regularly occurs in wet places, high conductivity clear water
Nitzschia sigma	somewhat to very pollution tolerant, alkaliphilic, brackish salinity, tolerant of elevated organic nitrogen, needs 50% oxygen saturation, alpha-mesosaprobous, eutrophic, mainly aquatic, also regularly occurs in wet places, tolerant of salts, motile
Pinnularia microstauron	moderately tolerant of pollution, circumneutral pH, fresh brackish salinity, tolerant of elevated organic nitrogen, requires 50% oxygen saturation, beta-mesosaprobous, oligo-eutrophic, mainly aquatic, also regularly occurs in wet places

Diatom	Attributes
Pleurosira laevis	moderately tolerant of pollution, motile, alkalibiontic, brackish, oligosaprobous, eutrophic, mainly aquatic, also regularly occurs in wet places, tolerates elevated salts, centric, benthic
Reimeria sinuata	stalked, sensitive to pollution, circumneutral pH, fresh brackish salinity, tolerant to elevated organic nitrogen, needs high oxygen (near saturation), beta-mesosaprobous, mesotrophic, mainly aquatic, also regularly occurs in wet places, low to moderate conductivity, tolerates a wide trophic range
Rhoicosphenia abbreviata	pollution sensitive, stalked, alkaliphilic, fresh brackish salinity, tolerant to elevated organic N, requires 75% O saturation, beta-mesosaprobous, eutrophic, mainly aquatic, also sometimes occurs in wet places
Sellaphora seminulum	pollution tolerant, salt tolerant, circumneutral pH, fresh brackish salinity, requires 30% oxygen saturation, eutrophic, facultative nitrogen heterotroph (needs periodically elevated organic nitrogen), alpha-meso-polysaprobous
Seminavis strigosa	prostrate, moderately tolerant to pollution, tolerant of organic pollution
Surirella brebissonii	moderately tolerant to pollution, motile, eutrophic, alkaliphilic, tolerates elevated salts
Synedra ulna	somewhat sensitive to pollution, attached, alkaliphilic, fresh brackish salinity, tolerant of elevated organic nitrogen, needs 50% oxygen saturation, alpha-meso-polysaprobous, very wide trophic tolerances, mainly aquatic, also sometimes occurs in wet places
Terpsinoe musica	variable life form, brackish fresh salinity, mainly aquatic, also regularly occurs in wet places
Tryblionella debilis	moderately tolerant to pollution, motile, alkaliphilic, fresh brackish salinity, tolerant to elevated organic nitrogen, needs high oxygen (near saturation), alpha-mesosaprobous, mainly on wet or moist surfaces, high conductivity water, aerophilic

Table 59. Predominant diatom species observed in the Tributary of Little Elm Creek.

Date	5/9/2007	10/2/2007	7/8/2008	8/13/2008
Total number of species observed	31	32	21	41
Predominant species, Cell count / percent of total	*Cocconeis placentula* 240 / 48%	*Seminavis strigosa* 82 / 16%	*Amphora veneta* 116 / 23%	*Nitzschia palea* 59 / 12%
	Sellaphora seminulum 30 / 6%	*Nitzschia frustulum* 81 / 16%	*Terpsinoe musica* 100 / 20%	*Cocconeis placentula* 52 / 10%
	Nitzschia inconspicua 30 / 6%	*Navicula recens* 56 / 11%	*Surirella brebissonii* 77 / 15%	*Navicula recens* 46 / 9%
	Navicula (Eolimna) subminuscula 30 / 6%	*Navicula viridula var rostellata* 50 / 10%	*Cocconeis placentula* 72 / 14%	*Navicula viridula var rostellata* 46 / 9%
	Pleurosira laevis 27 / 5%	*Navicula cf fauta* 32 / 6%	*Gomphosphenia grovei* 42 / 8%	*Gyrosigma nodiferum* 38 / 8%
	Encyonema silesiacum 23 / 5%	*Tryblionella debilis* 24 / 5%	*Gyrosigma nodiferum* 29 / 6%	*Terpsinoe musica* 32 / 6%
	Reimeria sinuata 20 / 4%	*Diploneis puella* 20 / 4%		*Tryblionella debilis* 29 / 6%
				Nitzschia brevissima 24 / 5%

Table 60. Predominant diatom species observed in Little Elm Creek.

Date	5/9/2007	10/2/2007	7/8/2008	8/12/2008
Total number of species observed	31	38	17	38
Predominant species, Cell count / percent of total	*Achnanthidium minutissimum* 120 / 24%	*Gyrosigma nodiferum* 122 / 24%	*Gomphosphenia grovei* 202 / 40%	*Gomphosphenia grovei* 79 / 16%
	Nitzschia inconspicua 119 / 24%	*Gomphosphenia lingulatiformis* 115 / 23%	*Gomphosphenia lingulatiformis* 201 / 40%	*Gomphosphenia lingulatiformis* 65 / 13%
	Selaphora seminnulum 52 / 10%	*Navicula sanctaecrucis* 55 / 11%		*Cocconeis placentula* 51 / 10%
	Amphora pediculus 38 / 8%	*Bacillaria paradoxa* 34 / 7%		*Gomphonema affine* 44 / 9%
	Reimeria sinuata 32 / 6%	*Tryblionella debilis* 20 / 4%		*Nitzschia amphibia* 32 / 6%
	Cocconeis pediculus 26 / 5%	*Navicula schroeteri var escambia* 20 / 4%		*Gyrosigma nodiferum* 26 / 5%
	Nitzschia dissipata 22 / 4%			*Amphora inariensis* 21 / 4%

Table 61. Predominant diatom species observed in Willis Creek.

Date	5/8/2007	6/3/2008	7/7/2008	8/12/2008
Total number of species observed	31	23	25	38
Predominant species, Cell count / percent of total	*Nitzschia inconspicua* 151 / 30%	*Reimeria sinuata* 156 / 31%	*Cocconeis placentula* 114 / 23%	*Navicula sanctaecrucis* 118 / 24%
	Achnanthidium minutissimum 106 / 21%	*Cocconeis placentula* 99 / 20%	*Reimeria sinuata* 64 / 13%	*Navicula recens* 51 / 10%
	Cocconeis placentula 35 / 7%	*Nitzschia amphibia* 68 / 14%	*Navicula recens* 57 / 11%	*Navicula schroeteri var escambia* 42 / 8%
	Reimeria sinuata 28 / 6%	*Navicula schroeteri var escambia* 45 / 9%	*Nitzschia amphibia* 43 / 9%	*Reimeria sinuata* 39 / 8%
	Encyonema silesiacum 26 / 5%	*Navicula recens* 34 / 7%	*Achnanthidium minutissimum* 43 / 9%	*Achnanthidium minutissimum* 30 / 6%
	Navicula veneta 20 / 4%		*Gomphonema pumilum* 35 / 7%	*Navicula tripunctata* 25 / 5%
			Navicula sanctaecrucis 25 / 5%	*Gyrosigma nodiferum* 25 / 5%
			Amphora pediculus 24 / 5%	*Nitzschia amphibia* 22 / 4%

Date	5/8/2007	6/3/2008	7/7/2008	8/12/2008
			Gyrosigma nodiferum 23 / 5%	
			Navicula kotschii 21 / 4%	

Table 62. Predominant diatom species observed in Clear Creek.

Date	5/23/2007	9/5/2007	6/10/2008	8/5/2008
Total number of species observed	59	54	43	21
Predominant species, Cell count / percent of total	*Eunotia pectinalis* 149 / 30%	*Gyrosigma nodiferum* 70 / 14%	*Eunotia pectinalis* 116 / 23%	*Encyonema delicatula* 110 / 22%
	Nitzschia palea 38 / 8%	*Gomphosphenia lingulatiformis* 52 / 10%	*Bacillaria paradoxa* 73 / 15%	*Synedra ulna* 80 / 16%
	Frustulia vulgaris 33 / 7%	*Navicula schroeteri var escambia* 50 / 10%	*Gomphonema angustatum* 67 / 13%	*Cymbella excisa* 80 / 16%
	Gomphosphenia grovei 31 / 6%	*Gomphonema parvulum* 33 / 7%	*Gomphonema patrickii* 28 / 6%	*Achnanthidium biassolettianum* 34 / 7%
	Pinnularia microstauron 28 / 6%	*Navicula veneta* 22 / 4%	*Gomphonema pumilum* 23 / 5%	*Fragilaria tenera* 32 / 6%
			Encyonema silesiacum 20 / 4%	*Achnanthidium minutissimum* 28 / 6%
				Encyonema evergladianum 24 / 5%
				Eucocconeis flexella 21 / 4%

Table 63. Predominant diatom species observed in Walnut Creek.

Date	5/22/2007	9/5/2007	6/9/2008	8/5/2008
Total number of species observed	68	43	37	28
Predominant species, Cell count / percent of total	*Cocconeis placentula var euglypta* 91 / 18%	*Gyrosigma nodiferum* 116 / 23%	*Gyrosigma nodiferum* 116 / 19%	*Synedra ulna* 203 / 41%
	Navicula recens 44 / 9%	*Navicula recens* 111 / 22%	*Gomphosphenia grovei* 68 / 14%	*Terpsinoe musica* 76 / 15%
	Aulacoseira granulata var. angustissima 25 / 5%	*Navicula sanctaecrucis* 77 15%	*Synedra ulna* 38 / 8%	*Pleurosira laevis* 42 / 8%
	Navicula symmetrica 23 / 5%	*Cocconeis placentula* 26 / 5%	*Navicula sanctaecrucis* 38 / 8%	*Cocconeis placentula* 38 / 8%
	Adlafia bryophila 20 / 4%	*Diploneis puella* 22 / 4%	*Bacillaria paradoxa* 35 / 7%	*Gyrosigma nodiferum* 27 / 5%
			Rhoicosphenia abbreviata 33 / 7%	
			Gomphosphenia lingulatiformis 28 / 6%	
			Cocconeis placentula 28 / 6%	

Table 64. Predominant diatom species observed in Duck Creek.

Date	5/24/2007	9/6/2007	6/11/2008	8/6/2008
Total number of species observed	69	49	36	55
Predominant species, Cell count / percent of total	*Gomphosphenia grovei* 167 / 33%	*Gyrosigma nodiferum* 191 / 38%	*Gyrosigma nodiferum* 212 / 42%	*Gomphonema pumilum* 58 / 12%
	Gyrosigma nodiferum 53 / 11%	*Bacillaria paradoxa* 47 / 9%	*Gomphosphenia grovei* 76 / 15%	*Eunotia pectinalis* 58 / 12%
	Craticula halophila 21 / 4%	*Navicula recens* 25 / 5%	*Gomphonema pumilum* 55 / 11%	*Cocconeis placentula var pseudolineata* 55 / 11%
	Gomphonema pumilum 20 / 4%	*Navicula sanctaecrucis* 24 / 5%		*Gomphosphenia grovei* 40 / 8%
		Nitzschia sigma 23 / 5%		*Bacillaria paradoxa* 22 / 4%
		Diploneis elliptica 21 / 4%		

Table 65. Soft algae attributes.

Soft Algae Name	Autecological Observations (numbers in parentheses following attribute refer to authors listed below on Table 12)
Ankistrodesmus falcatus	Palmer rating of 8 (1), eutrophic, high total phosphorus, alkaliphilic, high conductivity, non-motile, sestonic (2)
Audouinella hermannii	benthic, non-motile (2), favored under low resource supplies, prefers substrates without large crevices (4)
Calothrix sp.	fixes nitrogen, low total phosphorus, alkaliphilic, low chlorides, benthic, non-motile, low optimal total suspended solids (TSS) (2), favored in water with high calcium levels; can grow under artificial and reduced light; attached to substrate, epilithic and epiphytic (4)
Characium sp.	benthic, non-motile (2)
Chlamydomonas sp.	Palmer rating of 3 (1), eutrophic, high TP, alkaliphilic, high conductivity, high chlorides, sestonic, motile, high TSS (2), also aerophilic (4)
Chlorococcum sp.	Palmer rating of 60 (1), eutrophic, benthic, non-motile (2), also aerophilic (4)
Chroococcus sp.	eutrophic (2), can grow under artificial and reduced light; also phytoplanktonic (4)
Cladophora sp. (probably *C. glomerata*)	Palmer rating of 42 (1), eutrophic, high TP, sestonic, nuisance algal bloomer, alkaliphilic, high conductivity, low TSS, non-motile (2). This is probably *C. glomerata*, reported as abundant when nitrogen and phosphorus levels are relatively high and there is sufficient sunlight (3), favored under elevated nutrient supply, adaptable to high or low current velocity; found in nutrient-rich wetlands (4)
Closterium sp.	Palmer rating of 16 (1), non-motile (2)
Cosmarium sp.	Palmer rating of 53 (1), low TN, low TP, alkaliphilic, sestonic, non-motile (2)
Cryptomonas sp.	Palmer rating of 23 (1), high TP, somewhat tolerant to nutrients and organics, alkaliphilic, low conductivity, sestonic, motile (2)
Dinobryon sp.	nuisance algal bloomer, sestonic, motile (2)
Euglena sp.	Palmer rating of 1 (1), eutrophic, high TN, high TP, alkaliphilic, high conductivity high chlorides, sestonic, motile (2)
Gloeoskene turfosa	euplanktonic, epiphytic and metaphytic in dystrophic, mesotrophic, and eutrophic ponds, pools and seeps (4)
Hormidium sp.	
Kirchneriella sp.	Eutrophic, high TN, high TP, alkaliphilic, high conductivity, high chlorides, sestonic, motile (2)
Lyngbya sp.	Palmer rating of 34 (1), alkalibiontic, high conductivity, benthic, motile (2), found in nutrient-rich wetlands; forms thick mats during floods that protect algal cells during dry phases; also aerophilic (4)

Mallomonas sp.	sestonic nuisance bloomer, motile (2)
Merismopedia glauca	low TP, eutrophic, alkaliphilic, high conductivity, high chlorides (2), also phytoplanktonic (4)
Mougeotea sp.	fixes nitrogen, low TP, sestonic nuisance algal blooms, alkaliphilic, high conductivity, sestonic, non-motile (2), found in oligotrophic systems (4)
Nostoc sp.	fixes nitrogen, benthic, non-motile (2), found in nutrient-rich wetlands; also aerophilic (4)
Oedogonium sp.	alkalibiontic, high conductivity, high chlorides, benthic, non-motile (2), reduced by high current velocities, found in nutrient-rich wetlands; forms thick mats during floods that protect algal cells during dry phases; found in sewage treatment outflows (4)
Oocystis sp.	Palmer rating of 35 (1), eutrophic, alkaliphilic, high chlorides, sestonic, non-motile (2)
Oscillatoria sp.	Palmer rating of 2 (1), alkaliphilic, benthic, motile (2), found in nutrient-rich wetlands; forms thick mats during floods that protect algal cells during dry phases; found in sewage treatment outflows; more abundant in warm water; also aerophilic; can form floating mats; motile, gliding or oscillating; planktonic (floating mats) and benthic (mud, plants, stones and sand) depending on the species (4)
Phacus sp.	Palmer rating of 11 (1), eutrophic, high TP, circumneutral pH, low chloride, sestonic, motile (2)
Raphidiopsis curvata	fixes N, eutrophic, high TN, high TP, alkaliphilic, high conductivity, high chlorides, benthic, non-motile (2)
Scenedesmus sp.	eutrophic, alkalibiontic, sestonic, non-motile, low TSS (2)
Schizothrix sp. (probably *S. calcicola*)	non-motile (2), favored under low resource supplies; can grow under artificial and reduced light; also found in soil; free living and attached to substrate (4)
Schroederia setigera	eutrophic, high TP, alkaliphilic, high conductivity, sestonic, non-motile (2)
Sphaerocystis sp.	eutrophic, sestonic, non-motile (2)
Spirogyra sp.	Palmer rating of 21 (1), eutrophic, sestonic nuisance algal bloomer, alkaliphilic, high chlorides, benthic, low TSS, non-motile (2), found in oligotrophic systems (4)
Spirulina sp.	Palmer rating of 37 (1), eutrophic, sestonic, non-motile (2), "*Spirulina* is intensely motile; trichomes glide with rapid clockwise or counterclockwise rotation" p. 132; sometimes found in heavily polluted habitats (4)
Staurastrum sp.	non-motile (2)
Synechococcus sp.	eutrophic, sestonic, non-motile (2), also commonly found in soil and in the phytoplankton (4)
Tetraedron regulare	eutrophic, sestonic, non-motile (2)
Trachelomonas sp.	Palmer rating of 26 (1), sestonic, motile (2)
Trachelomonas volvocina	Palmer rating of 72 (1), acidophilous (pH 6.5-7), sestonic, motile, high TSS (2)
Ulothrix zonata	Palmer rating of 30 (1), sestonic nuisance algal bloomer, alkaliphilic, low conductivity, low chlorides benthic, non-motile (2), favored under elevated nutrient supplies (4)

Table 66. Key to Table 65.

(1) Palmer, C.M, 1969. A composite rating of algae tolerating organic pollution. J. Phycology 5: 78-82. The pollution-tolerant genera are assigned a value from 1 to 60 in order of decreasing emphasis by 165 authorities with 1 being the most pollution tolerant. The pollution-tolerant species are assigned a value from 1 to 80 in decreasing order by 165 authorities with 1 being the most pollution tolerant. These numbers are listed as the Palmer rating in Table 10.
(2) Porter, S.D., 2008. Algal attributes: an autecological classification of algal taxa collected by the National Water-Quality Assessment Program. U.S. Geological Survey Data Series 329, (http://pubs.usgs.gov/ds/ds329/).
TN = total nitrogen high TN means TN optima >3 mg/L low TN means TN optima <=0.65 mg/L
TP = total phosphorus high TP means TP optima>=0.10 mg/L low TP means TP optima <=0.04 mg/L
Trophic terms used oligotrophic (oligotraphentic): found typically in water with low concentrations of nutrients mesotrophic (mesotraphentic): found typically in water with moderate concentrations of nutrients eutrophic (eutraphentic): found typically in water with high concentrations of nutrients
Benthic means primarily associated with benthic substrates
Sestonic means primarily planktonic (not attached and can drift with the current)
Total suspended solids (TSS) low TSS= optimum <15 mg/L high TSS= optimum >70 mg/L
(3) Borchardt, M., 1996. Nutrients. In: R.J. Stevenson, M.L. Bothwell and R.L. Lowe eds., Algal Ecology, Freshwater Benthic Ecosystems. Academic Press, San Diego, 183-227.
(4) Wehr, J.D. & R.G. Sheath, 2003. Freshwater Algae of North America, Ecology and Classification. Academic Press, 918 pp.

Table 67. Predominant soft algae observed in the Tributary of Little Elm Creek.

Date	5/9/2007		10/2/2007		7/8/2008		8/13/2008	
Total soft algae species counted	10	Cell Count	12	Cell Count	12	Cell Count	11	Cell Count
Total cells counted	306		300		317		302	
	Cladophora sp.	146	Pennate diatoms	139	Pennate diatoms	93	*Schizothrix* sp.	153
	Pennate diatoms	72	*Schizothrix* sp.	49	*Schizothrix* sp.	76	Pennate diatoms	54
	Chroococcus sp.	25	*Oscillatoria* sp.	47	*Mougeotia* sp.	40	*Oscillatoria* sp.	25
	Unknown alga	20	*Chroococcus* sp.	18	*Oscillatoria* sp.	35	*Chroococcus* sp.	17
	Schizothrix sp.	12	*Gloeoskene turfosa*	16	*Oedogonium* sp.	26	Unknown alga	17
			Synechococcus sp.	13	*Gloeoskene turfosa*	17		
					Chroococcus sp.	16		

Table 68. Predominant soft algae observed in Little Elm Creek.

Date	5/9/2007		10/2/2007		7/8/2008		8/12/2008	
Total soft algae species counted	7	Cell Count	11	Cell Count	9	Cell Count	9	Cell Count
Total cells counted	302		360		323		340	
	Cladophora sp.	107	Pennate diatoms	96	*Oscillatoria* sp.	128	*Schizothrix* sp.	173
	Pennate diatoms	70	*Cladophora* sp.	73	*Schizothrix* sp.	108	Pennate diatoms	55
	Chroococcus sp.	54	*Gloeoskene turfosa*	59	Pennate diatoms	58	*Oscillatoria* sp.	50
	Unknown alga	44	*Schizothrix* sp.	49			Unknown alga	16
	Schizothrix sp.	17	*Hormidium* sp.	26			*Chroococcus* sp.	13
			Chroococcus sp.	18				

Table 69. Predominant soft algae observed in Willis Creek.

Date	5/8/2007		6/3/2008		7/7/2008		8/12/2008	
Total soft algae species counted	8	Cell Count	14	Cell Count	12	Cell Count	12	Cell Count
Total cells counted	300		327		336		307	
	Chroococcus sp.	123	Pennate diatoms	148	Pennate diatoms	136	Pennate diatoms	156
	Pennate diatoms	98	*Cladophora* sp.	69	*Spirogyra* sp.	90	*Schizothrix* sp.	82
	Synechococcus sp.	26	*Schizothrix* sp.	45	*Schizothrix* sp.	39	*Cladophora* sp.	25
	Schizothrix sp.	25	*Chroococcus* sp.	27	*Cladophora* sp.	30	*Oscillatoria* sp.	19

Table 70. Predominant soft algae observed in Clear Creek.

Date	5/23/2007		9/5/2007		6/10/2008		8/5/2008	
Total soft algae species counted	11	Cell Count	6	Cell Count	9	Cell Count	8	Cell Count
Total cells counted	307		327		304		314	
	Schizothrix sp.	125	*Lyngbya* sp.	264	*Schizothrix* sp.	110	*Cladophora* sp.	110
	Pennate diatoms	75	*Spirogyra* sp.	44	Pennate diatoms	90	Pennate diatoms	78
	Oedogonium sp.	53			*Cladophora* sp.	62	*Schizothrix* sp.	75
	Audouinella hermannii	20			*Spirogyra* sp.	23	*Oscillatoria* sp.	27
	Nostoc sp.	15						

Table 71. Predominant soft algae observed in Walnut Creek.

Date	5/22/2007		9/5/2007		6/9/2008		8/5/2008	
Total soft algae species counted	11	Cell Count	9	Cell Count	6	Cell Count	7	Cell Count
Total cells counted	312		309		319		303	
	Schizothrix sp.	184	Pennate diatoms	154	Pennate diatoms	134	Pennate diatoms	189
	Pennate diatoms	92	*Cladophora* sp.	70	*Schizothrix* sp.	94	*Schizothrix* sp.	76
			Spirogyra sp.	25	*Oscillatoria* sp.	46	Centric diatoms	16
			Schizothrix sp.	21	*Spirulina* sp.	30		
			Centric diatoms	18				

Table 72. Predominant soft algae observed in Duck Creek.

Duck Creek								
Date	5/24/2007		9/6/2007		6/11/2008		8/6/2008	
Total soft algae species counted	9	Cell Count	9	Cell Count	9	Cell Count	9	Cell Count
Total cells counted	310		319		311		308	
	Schizothrix sp.	121	*Schizothrix* sp.	188	Pennate diatoms	98	*Schizothrix* sp.	148
	Pennate diatoms	64	Pennate diatoms	91	*Schizothrix* sp.	97	*Oscillatoria* sp.	63
	Oedogonium sp.	60	*Oscillatoria* sp.	22	*Cladophora* sp.	60	*Cladophora* sp.	45
	Audouinella hermannii	55			Centric diatoms	13	Pennate diatoms	24

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