EFFECTS OF RECYCLED WASTEWATER EFFLUENT AS AUGMENTED BASEFLOW ON BENTHIC MACROINVERTEBRATE ASSEMBLAGES IN SALADO CREEK, BEXAR COUNTY, TEXAS

THESIS

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"Be zealous for the better gifts. And I show unto you a yet more excellent way." (*1 Cor.* 12:31).

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INTRODUCTION

In the late 1960s several environmental disasters occurred in the United States, including the Cuyahoga River in Ohio catching fire and a 946 million-L oil spill off the coast of California (Kubasek and Silverman 1994). The disasters prompted the passage of several federal environmental acts such as the Federal Water Pollution Control Act (FWPCA) of 1972 and the Clean Water Act (CWA) of 1977. One result of these acts was a permitting program to restrict pollution discharge and regulate water quality (Buchholz 1993). In 1986, the United States Environmental Protection Agency (U. S. EPA) initiated a major study of the Agency's surface water monitoring activities, resulting in a report entitled "Surface Water Monitoring: A Framework for Change" (U. S. EPA 1987). This report urged cost effective approaches to problem identification and trend assessment and the development of biological monitoring techniques. In 1989 use of the original Rapid Bioassessment Protocols began and was refined into the current document, "Rapid Bioassessment Protocols for Use in Wadeable Streams and Rivers" (Plafkin et al. 1989, Barbour et al. 1999). By using an array of indicators in simple indices, research in the field of biological assessment (bioassessment) has improved water resource programs (Karr 1991).

Rapid Biological Protocols (rapid bioassessments, RBAs) use a multi-metric approach to establish a qualitative scoring gradient of various animal populations in the stream. Multi-metric indices are used to identify many aspects of the structure and function of stream ecosystems (Karr and Chu 1999). For example, a multi-metric study by the Ohio EPA found that fish respond more quickly to restorative efforts than benthic macroinvertebrates (Barbour et al. 1999). Multi-metric indices integrate data on physical habitat, seasonal flow of water, food bases, interactions within stream biota, and water chemistry, to evaluate human impacts on water quality (Fausch et al. 1984).

Negative biological responses are generally associated with point and non-point source pollution (Bartsch and Ingram 1959, Herricks 1984, Kerans and Karr 1994, Lyons et al. 1995, Barbour et al. 1996, El-Nagger et al. 1997, Bailey et al. 1998, Barbour et al. 1999). However, several investigations report only modest detrimental effects of untreated wastewater on biological indicators (Alabaster 1959, Hamilton et al. 1970, Marcus 1980). Chemical and biological assessments have also indicated improved environments where treated wastewater has replaced untreated wastewater (Schults et al. 1976, Headstream et al. 1977, Iranpour et al. 2000). The use of treated wastewater to augment depleted water supplies in natural systems is increasing around the world and in the United States (Angelakis et al. 1999, Barnett et al. 2000, Newby and Hough 1994, Milliken and Trumbly 1979, Drewes and Jekel 1998, Marcucci and Tognotti 2001). In Dimmit, Texas, treated wastewater is used by local farmers for irrigation and an Amarillo wastewater treatment plant provides reclaimed sewage water for industrial reuse (Ehly 1971, Scherer 1971).

As a result of over pumping, decreased water levels in the Edwards Aquifer have reduced annual flow in springs and streams throughout Bexar County, Texas (Bowles and Arsuffi 1993, Vottler 1998). Specifically, lower water tables affect Salado Springs and Salado Creek by intermittent loss of spring discharge. An historic artesian well that augmented natural spring flow into Salado Creek (San Antonio River Authority 'SARA' 1988) was capped in 1992. This exacerbated low flows and left standing pools of water with low dissolved oxygen (SARA 1994, SARA 1996). In 1998, Salado Creek was added to the EPA's 303(d) list of water bodies not supporting water quality standards (Texas Natural Resource Conservation Commission 'TNRCC' 1999). Salado Creek exceeds the standard for Total Maximum Daily Loads (TMDLs), the amount of nutrients allowed by regulation and does not meet dissolved oxygen standards (Miertschin et al. 1999). In March of 2001, treated wastewater began flowing into Salado Creek to supplement dwindling baseflow (Pape-Dawson 2001).

The purpose of this study was to examine the effects of augmented baseflow of treated effluent on Salado Creek benthic macroinvertebrate communities. Flow and precipitation for the study year, as well as eight years of temperature, oxygen and pH data were examined. Habitat assessments were also done to evaluate habitats in and around the river. Macroinvertebrates were collected nine times, counted and identified. Fish were surveyed one time, counted and identified. As a result of a large flood, macroinvertebrate densities and recolonization sources were determined to assess recovery. Rapid bioassessments were used to discern disturbance between sites. RBAs use metrics based on community attributes and tolerance values, such as taxa richness, % Chironomidae and ratio of intolerant to tolerant taxa. I tested family and genus tolerance levels for significant differences. An Index of Biotic Integrity (IBI) was applied to the fish survey. IBIs use metrics based on fish community attributes such as taxa richness, % omnivores and number of individuals sampled. Two historic biological surveys were compared to this study, Buzan's (1982) report titled: "Intensive Survey of Salado Creek Segment 1910" and Webb's (1988) study titled: "Application of the Index of Biotic Integrity to Selected Sites Along Salado Creek." A study done concurrently to this study was also examined for comparison purposes: "Use and Attainability Analysis of Salado Creek, Segment 1910" (Davis et al. 2003). Individual metric scores for Cibolo Creek, Leon Creek, Medina Creek and the upper San Antonio River are compared to data from this study to evaluate metrics and determine regional and watershed patterns

DESCRIPTION AND LOCATION OF STUDY AREA

Salado Creek is 71km long and drains a watershed of about 518km^2 (Fig. 1). The headwaters are located on the southeastern portion of the Edwards Plateau (29°40'09"N 98°08'69"W), and after crossing the Balcones Escarpment meanders across Blackland Prairie with riparian forest community dominated by *Carya illinoensis* (pecan), *Salix babylonica* (willow), and *Ulmus crassifolia* (cedar elm) trees (Lynch 1981, Vines 1984). From the headwaters to Loop 410, Salado Creek is ephemeral, only flowing during periods of heavy rainfall. Upon entering San Antonio city limits, the stream is channelized for storm water runoff. A few natural springs on Fort Sam Houston in northeast San Antonio occasionally supply flow for the lower half of the creek. In many parts of the stream, heavy canopy allows little sunlight to penetrate to the water. After flowing through San Antonio, Salado Creek flows through rural farm and ranch land where *Prosopis glandulosa* (mesquite), *Parkinson aculeata* (retama) and *Opuntia lindheimeri* (prickly pear) are the dominant plant species (Lynch 1981, Vines 1984). Salado Creek discharges into the San Antonio River south of San Antonio (29°17'04"N 98°26'10"W). There are three ephemeral tributaries into Salado Creek. The confluence of Beitel Creek and Salado Creek is just south of Loop 410. Walzem Creek meets Salado near Rittiman Road at the John James

Park where the treated wastewater effluent site is located. Rosillo Creek flows into Salado just north of Goliad Road.

There are six permitted wastewater facilities in the Salado Creek watershed, three of which are authorized to discharge. Effluents from two of the discharge facilities enter Salado Creek 1.6km upstream from NE Loop 410, via an unnamed tributary. One, a steam electric plant operated by City Public Service of San Antonio, is authorized to discharge an average of 2650m^3/day of cooling tower blowdown and stormwater. The other, a cement plant operated by Capital Aggregates, Ltd., is authorized to discharge a maximum of 37900m^3/day of quarry water and unspecified amounts of plant washdown water, process wastewater and stormwater. The third discharge consists of effluent from the City of San Antonio Salado Creek Wastewater Treatment Plant, which enters Salado Creek at John James Park near Winans Road, where it supplements flow into Salado Creek (Fig. 1, Davis et al. 2003, Pape-Dawson 2001). The permitted maximum volume for the Salado Creek Wastewater Treatment Plant is 11370 m^3/day (Davis et al. 2003). The recycled water is treated with sulfur dioxide to remove the chlorine and improve dissolved oxygen and pH levels, the effluent permit allows up to 10mg/l CBOD 5, 2mg/l ammonia, 5mg/l dissolved oxygen (Yrle 2002, personal communication). This treated wastewater is not potable and contains nutrients, yet meets TCEQ standards for reusable treated wastewater (Yrle 2002, personal communication). The San Antonio River Authority (SARA) reports that recent analysis of dissolved oxygen by the Clean Rivers Program indicates that Salado Creek has potential for partial de-listing from the 303(d) list (SARA 2001).

Four sampling sites on Salado Creek were used for this study. The sites from North to South are: Austin Highway (N29°30.095'/W98°25.239') 1.6km upstream of the effluent discharge site (Fig. 2), Gembler Road (N29°25.983'/W98°25.248') 6km downstream from the effluent discharge (Fig. 3), the Pecan Valley Golf Course (N29°22.43'/W98°25.502') 16km downstream from the discharge point (Fig. 4), and Goliad Road (Old Corpus Christi Road, N29°19.201'/W98°24.454') 22.8km downstream of the discharge site (Fig. 5).

MATERIALS AND METHODS

Discharge, Temperature, Oxygen and pH

Discharge data was taken from the Untied State Geological Survey (USGS) station #08178700 Salado Creek at Loop 410 for the site upstream to augmentation and USGS station #08178800 Salado Creek at Loop 13 for the downstream augmented baseflow site (USGS 2005). Temperature, oxygen and pH data were considered for January 1996 through July 2003 (SARA 2005).

Recolonization Sources

While investigating colonization sources I made observations at the Beitel Creek, Walzem Creek, and Rosillo Creek tributaries as well as the San Antonio River. I measured hyporheic depths in Salado Creek and mapped out distances over land and to confluences.

Habitat Assessment

Habitat Assessments were conducted according to the EPA's Rapid Bioassessment Protocols (Appendix 1, Barbour et al. 1999). On scales from 0-20 (0 being poor and 20 being optimal) the observer ranks each of the 10 habitat structural components that function to dissipate flow energy, such as sinuosity, roughness of bed and bank materials and presence of point bars. The scores are added together to create a total score (up to 200) that is then compared to a reference site. Deviation to the reference expectations would indicate habitat alteration.

Macroinvertebrates and Fish

Benthic macroinvertebrate and fish sampling was conducted according to EPA standards for Rapid Bioassessment Protocols (Karr 1981, Lenat 1988, Barbour et al. 1999). Benthic macroinvertebrate sampling took place from June 26, 2002 through June 30, 2003. The fish survey took place on October 12, 2002. For benthics, the 100m-reach sites at Gembler Road and Pecan Valley Road were sampled nine times each, while the Austin Highway and Goliad sites were sampled eight times each for benthic macroinvertebrates. During sample period 1 (June 26- July 1), the Austin Highway site was dry and no samples were collected. On July 1, 2002, a major flood event took place in Bexar and surrounding counties. Thus the scheduled July 1st sampling at Goliad Road was cancelled. The Gembler Road and the Pecan Valley sites were both sampled in June 2002, just prior to the flood. After flood, sample dates were July 30, 31, August 1 & 6 (Sample Period 2), August 30-31 (Sample Period 3), September 27 (Sample Period 4), November 22 (sample Period 5), January 11 & 24 (sample period 6), March 9, 11 & 12 (Sample Period 7), May 7 & 8 (Sample Period 8), and June 29 & 30 (Sample Period 9).

All benthic samples were collected using the multihabitat approach described in the EPA's Rapid Bioassessment Protocols (Barbour et al. 1999). Riffles dominate this shallow urban stream except during flood events. Most of the macroinvertebrates were taken from riffle habitat and those few samples found in pool areas appeared to be riffle inhabitants that were washed there from riffles, similar to Brown and Brussock (1991). Parsons and Norris (1996) found that the strength of the riffle habitat model and environmental predictability suggests that emphasis can be placed on riffle habitat. Snags were sampled occasionally. Because pools and snags were few (Table 1), samples were combined. Twenty jabs (or kicks) were taken at each site during each sampling period. Benthic macroinvertebrates were collected using a standard 500-µ opening mesh Triangle-frame dip net. Dip nets are widely considered a qualitative sampling device, however, when used consistently throughout a study can take on a quantitative value. For example the Surber sampler (a sack-like net, framed at the mouth and having an additional frame in front of the mouth at a right angle) is considered a quantitative sampler, but that relies on how deep the user digs in the substrate. Throughout this study a kick sample consisted of a meter long disturbance (no more than 10cm deep) starting downstream moving upstream with the dip-net catching specimens on the downstream side of the disturbance. Dip net samples were washed into a 500-µ opening mesh sieve bucket. Samples were then washed with 95% alcohol into field containers before removal to the laboratory.

Fish sampling methods included a backpack electrofisher with two catch nets and a seine net. Block nets were placed at each end of the reach to prevent loss of samples. Fish were caught by moving upstream along the length of each 100m reach. Most fish were counted and identified in the field and returned to the river, 2 of each species were preserved in 100% formalin for taxonomic verification.

A dissecting microscope was used to count and identify macroinvertebrates. Benthic macroinvertebrates were identified to genus level of identification using taxonomic keys (Merrit and Cummins 1996, Thorp and Covich 1991) except Chironomidae, Oligochaeta, Hirudinea, Ostracoda and Cambaridae, for time and consistency as suggested by Texas Commission on Environmental Quality (TCEQ, formerly TNRCC) guidelines (TNRCC 1999).

Taxonomic Recovery

To discover trends and identify patterns in recovery, I examined the most abundant taxa that comprised the majority of macroinvertebrates. Densities of macroinvertebrates and dates of recolonization were used in this analysis.

Rapid Bioassessment Metrics

Although collection techniques followed EPA Rapid Bioassessment Protocols, summary analysis followed the San Antonio River Authority Benthic Worksheet Protocol II (Appendix 2). This worksheet was used to summarize taxa richness, Ephemeroptera, Plecoptera and Trichoptera (EPT), taxa abundance, Hilsenhoff Biotic Index, % Chironomidae, % dominant taxon, % dominant functional feeding group, % predators, ratio of intolerant/tolerant taxa, % of total Trichoptera as Hydropsychidae, # of non-insecta taxa, % collector-gatherers, and % of total number as Elmidae. The results of these metrics were used to develop Aquatic Life Use Point Scores (Appendix 3). For a list of metrics and responses to disturbance see Table 2. Student t-tests were used to discern differences between tolerance levels assigned to family and genus levels of taxonomic identification.

Index of Biotic Integrity Metrics

Although collection techniques followed EPA Rapid Bioassessment Protocols for fish, I applied a regionalized IBI to the fish survey done for this study (Appendix 4, Gonzalez 1988). This IBI is based on numerical scores for twelve metrics, # fish, # darter species, # sunfish species, # sucker species, # intolerant species, % green sunfish, % omnivores, % insectivores, % piscivores, # individuals per sample, % hybrids and % diseased fish.

Historic Studies

Historic studies were used to evaluate the macroinvertebrate and fish assemblages as well as stream conditions over time. Webb (1988) performed a fish survey using a bag seine and a riffle net and applied the Index of Biotic Integrity (Karr 1981). Buzan (1982) collected both benthic macroinvertebrates and fish in 1981. Buzan (1982) collected fish using gill nets, rotenone, minnow seine, trawl, backpack-electrofisher, and an electrofishing boat. To collect macroinvertebrates, Buzan (1982) used a Surber sampler in riffles and an Ekman dredge in pools. A concurrent RBA was done by the TCEQ from August 2001 to September 2002 (Davis et al. 2003). ALU scores from the concurrent study were compared to ALU scores from this study. San Antonio River Authority Benthic Worksheets for Cibolo Creek, Leon Creek, Medina Creek and the upper San Antonio River for year 2003 were used to compare metrics from this study (SARA 2002).

RESULTS

Discharge Temperature, Oxygen and pH

Discharge continued at sites in Salado Creek downstream of the augmented baseflow even during periods of low precipitation when upstream areas ceased flowing (Fig. 6). On July 1, 2002, a major flood occurred. A peak discharge of 1,240m^3/sec was observed at U.S. Geological Survey gauge 08178700 Salado Creek at Loop 410, which was the second largest flood at that gauge since 1961 (USGS 2005). Numerous precipitation events occurred during the months of July and September, resulting in frequent and prolonged periods of elevated discharge (Fig. 6). Peak flows were 3-4 times greater than any other storm flows during the study and 410 times greater than the average stream flow during the entire study year. In April and May flow stopped at the upstream gage site. Precipitation events in June resulted in elevated flows through the end of the study period (National Oceanic and Atmospheric Administration 'NOAA' 2005).

Water temperature, oxygen and pH were graphed eight years from January 1996 to July 2003 (Fig. 7, SARA 2005). The primary feature of annual variation in temperature was the abrupt increase in temperature associated with summer conditions. For all eight years (1996-2003) water temperatures peaked at the end of July at about 28°C. Oxygen levels ranged from 3mg/l to 14mg/l. From January 1996 to January 2001 pH ranged from 6.93-8.04. After augmentation started in March of 2001 pH ranged from 7.5-7.8.04.

Recolonization Sources

Recolonization sources such as the hyporheic zone, upstream migration, drift and aerial pathways were examined to determine possible recolonization pathways. The hyporheic zone was shallow, about 10-20cm deep and bedrock was exposed after the flood. Beitel Creek is upstream of the study segment. The distance to the confluence of Salado Creek and the San Antonio River from the Goliad site is 11.6km, the Walzem Creek confluence is 2.4km downstream from the Austin Highway site, and the Rosillo Creek confluence is at the Goliad Road site, providing an upstream migration and drift sources. The distance over land from the Salado Creek study segment to the San Antonio River averages about 5km, the distance to the Walzem tributary over land averages about 2km and distance over land to the Rosillo tributary averages about 4km, and the Beitel Creek tributary are aerial sources.

Habitat Assessment

Habitat assessment scores did not distinguish between upstream and downstream sites (Fig. 8). Habitat assessment scores ranged between 60 and

140. The June 2002 assessment, with a score of 66, indicates that the Austin Highway site was the most disturbed of the four, with no water. With the return of water to the upstream site, the Austin Highway site score improved and remained comparable to the downstream sites through the end of the study.

Macroinvertebrates and Fish

In this study I collected 20 macroinvertebrate orders (Amphipoda, Cladoceran, Colembola, Coleoptera, Decapoda, Diptera, Ephemeroptera, Gastropoda, Hemiptera, Heterodonta, Hirudinea, Lepidoptera, Limnophila, Megaloptera, Mesogastropoda, Odonata, Ostracoda, Trichoptera, and Turbellaria). Of the 49,157 macroinvertebrates collected, 35,494 were identified to genus (Thorp and Covich 1991, Merritt and Cummins 1996). While a large number of macroinvertebrates were collected, few abundant taxa made up the majority of the total (Appendix 5). Abundant taxa were: Elmidae (11.2%), Chironomidae (24.0%), Simuliidae (3.7%), Baetidae (9.8%), Caenidae (2.2%), Tricorythidae (6.2%), Corbiculidae (1.3%), Coenagrionidae (2.9%), Hydropsychidae (17.1%), and Planariidae (14.0%) for a total of over 92.4% of all organisms.

I collected 6 families of fish (Charicidae, Ciclidae, Cyprinidae, Poediliidae, Centrarchidae and Ictaluridae). Of the 449 fish collected, all were identified to genus, and 326 were identified to species (Appendix 6, Eddy et al. 1978, Hubbs et al. 1991). Taxa included: Notropis (15.4%), *Campostoma anomalum* (15.1%), *Astyanax mexicanus* (13.8%), Gambusia (12.0%), *Lepomis cyanallus* (12.0%), *Poecilia latipinna* (9.4%), *Cichlasoma cyanoguttatum* (6.7%), *Lepomis auritus* (3.8%), *Ictalurus punctatus* (3.3%), *Lepomis macrochrius* (2.7%), *Lepomis gulosus* (2.2%), *Notropis amabilis* (1.8%), *Lepomis megalotis* (.7%), *Micropterus salmoides* (.7%), and *Ameiurus natalus* (.4%).

Taxonomic Recovery

Macroinvertebrate densities were examined in relation to recovery dates and times. Elmidae (riffle beetles) recolonized Pecan Valley with greater than $60/m^2$ in August. From September through March Elmidae populations at both Pecan Valley and Goliad were between $20\text{-}80/m^2$. In May there was a brief increase in density at all downstream sites (Fig. 9). Austin Highway had no Elmidae throughout the study. Chironomids (midges) Baetidae (mayflies) and Tricorythidae (mayflies) densities had similar timings in peaks and decreases throughout the study (Fig. 10). While midges peaked in January with about $350/m^2$, the baetids peaked in November with $160/m^2$ and Tricorythidae reached densities above $60/m^2$ in May and June. Simuliidae (black flies) recolonization reached densities over $136/m^2$ in September at Goliad Road then decreased to less than 11 per m^2 for all sites in November (Fig. 11). Blackfly densities decreased to 0 in May for all sites. Caenidae (mayflies) densities remained low, less than $5/m^2$, for most sites throughout the study (Fig 12). Austin Highway densities of Caenidae peaked twice to about 30 insects/m^2 in July and May, and to over $75/m^2$ in August. Corbiculidae (*Corbicula*) and Coenagrionidae (damselflies) densities were similar at all sites (Fig. 13). Both *Corbicula* and damselflies peaked in August then decreased in September, densities remained low (about 5-10/m^2) through March. In May, both *Corbicula* and damselfly densities peaked above 35/m^2. The Hydropsychidae (caddisflies) and Planariidae (flat worms) densities were similar throughout the study (Fig. 14). Hydropsychidae had low or 0 densities until May, when densities peaked above 600/m^2. Flatworm densities remained near 0 until March then peaked in May. Both caddisfly and flatworm densities decreased in June. Total densities of macroinvertebrates, on average, increased from July through May at all sites (Fig. 15). Pecan Valley had the greatest density of total macroinvertebrates in May with greater than 1085/m^2. As only Pecan Valley and Gembler Road were sampled before the flood, only these densities were used to compare before and after flood population densities. Population densities decreased at Pecan Valley by 87% and Gembler Road by 95%.

Rapid Bioassessment Metrics

Taxa richness and Ephemeroptera Plecoptera Trichoptera (EPT) taxa indicate greater disturbance at the Austin Highway site. Taxonomic richness ranged from 10 at Austin Highway in January to 37 at Pecan Valley in August (Fig. 16). On all but three sampling periods Austin Highway had the lowest diversity, especially during January and March. Generally there were fewer taxa during winter than other months. EPT taxa ranged from 2 at Austin Highway in

January to 9 at Gembler Road in August (Fig. 17). Austin Highway had the lowest number of EPT taxa ranging from 2-5 fewer taxa than other sites.

Percent Trichoptera, percent Elmidae and percent Chironomidae indicate greater disturbance upstream than downstream from augmentation. The percent of Trichoptera as Hydropsychidae ranged from 0% at three different sites to 100% at all four sites throughout the study period (Fig. 18). All sites had high percentages of Trichoptera in September, then decreasing through January and finally returning to preflood percentages in June 2003. Austin Highway had very high percentages of Trichoptera as Hydropsychidae in July, but dropped and remained at 0 from January through May. Percent Elmidae ranged from 0% at Austin Highway most of the study year to greater than 40% at Pecan Valley in January (Fig. 19). Percent chironomids ranged from 0% in June 2002, July 2002 and May 2003 at the Pecan Valley site to greater than 90% at Austin Highway in January (Fig. 20). Austin Highway had the highest percentages of Chironomidae 6 out of 8 sampling periods. Austin Highway had scores at both ends of the scales for Trichoptera, Elmidae and Chironomidae throughout the winter months and in the case of Elmidae throughout the year.

Metrics that measure tolerance to pollution include the Hilsenhoff Biotic Index, ratio of intolerant to tolerant taxa, non-insect taxa and dominant taxa. These metrics distinguished between upstream and downstream sites. HBI scores ranged from 3.38 at Gembler Road in June 2002 to 8.06 at Pecan Valley in September 2002 (Fig. 21, Table 3). The Austin Highway site ran in the "Fair" to "Fairly Poor" HBI ranges from 5.00-7.08. The ratio of intolerant to tolerant taxa remained low (below 6) from June 2002 to March 2003 for all sites (Fig. 22). In May, the ratio of intolerant to tolerant taxa at Pecan Valley and Goliad Road increased above 30. The Austin Highway ratio remained at or near 0 throughout the entire study. After the July 1st flood, non-insect taxa increased at all sites (Fig. 23). Non-insect taxa abundance was lowest during the winter months then returned to preflood abundances in June 2003. I examined the single dominant taxa for each site and sampling period (Fig. 24 and Table 4). Gembler Road, Pecan Valley and Goliad Road had 2 to 4 out of 8 sampling periods with greater than 40% of any one taxon. The Austin Highway site had greater than 40% of any one taxon for 6 sampling periods. Student t-tests were used to determine whether differences between family and genus level of taxonomic identification altered tolerance values for four sample periods. I found no significant difference between family and genus level tolerance determinations for; June 28, 2002, Pecan Valley- $t_{crit\ 0.05,\ 23=2.069} > t_{calc\ 0.05,\ 23=0.52983}$, July 31, 2002, Gembler Road- $t_{crit\ 0.05,\ 11=2.201} > t_{calc\ 0.05=.6465}$, August 31, 2002, Pecan Valley- $t_{crit\ 0.05,\ 40=2.0} > t_{calc\ 0.05,\ 35=0.69555}$, and January 11, 2003, Austin Highway- $t_{crit\ 0.05,\ 5=2.571} > t_{calc\ 0.05,\ 5=0.25355}$. All critical values were greater than calculated values.

For collector/gatherers and percent predators, Austin Highway had the most extreme scores 6 out of 8 sampling periods. In June 2002, Gembler Road had a 52% dominance of grazers. All other sampling periods at all sites showed collector/gatherers to be the dominant functional feeding group (Fig. 25). Collector/gatherer relative abundance ranged from nearly 100% at Austin Highway in January to less than 40% in June at Gembler Road. Percent Predators ranged from greater than 25% at Austin Highway in August to 0% at Austin Highway in January (Fig. 26). Predators at all sites decreased through January then returned to preflood percentages in June.

Aquatic Life Use point scores were lowest for all sites in winter months (Fig. 27). Goliad Road ranged from 20-29, reaching the "High" range only twice in August and January. Pecan Valley was in the "High" range 4 times, while Goliad was only in the "High" range once and this was the only site to reach the "Exceptional Range." Austin Highway never ranked higher than "Intermediate" on the ALU point score range. The ALU multi-metric had Austin Highway with the most extreme scores (highest or lowest) 7 out of 8 sampling periods.

Index of Biotic Integrity Metrics

Values of the metrics are assigned are 1, 3, or 5, depending on the criteria being considered. As five is the high score, the nearer the particular criteria is to the maximum expectation compared to an undisturbed stream, the higher the score (Appendix 4). Individual regionalized scores and categories for each site include, Austin Highway 32-poor, Gembler Road 40-fair, Pecan Valley 40-fair, Goliad Road 32-poor.

Historic Studies

Webb's (1988) study titled: "Application of the Index of Biotic Integrity to Selected Sites Along Salado Creek" was used in comparison with this study to determine if fish populations have changed over time. Of Webb's (1988) five sites, three were similar to sites in this study, Webb's Rittiman Road site is within 1-2 km of my Austin Highway site, both Gembler Road and Goliad Road sites are the same (Appendix 7). At Rittiman Road Webb (1988) reported a fair (38) IBI score while I reported a poor (32) score at Austin Highway, both studies at Gembler Road reported fair (40) scores. Webb's (1988) Goliad Road score was poor-fair (36) while I reported Goliad Road with a poor (32) score.

Buzan's (1982) study, "Intensive Survey of Salado Creek Segment 1910," was compared to this study to determine if macroinvertebrate populations have changed over time. Buzan (1982) used three sites that were similar to sites in this study, Buzan's (1982) site II is close (within 1 km) to my Austin Highway site, Buzan's site B is my Goliad Road site and Buzan's Site D is close (within 1 km) to the Pecan Valley site. Buzan (1982) reported macroinvertebrate densities. I applied RBA metrics and developed Aquatic Life Use point scores for Buzan's (1982) densities to compare to ALU scores in this study (Appendix 7). Buzan's (1982) Site II scored intermediate (24), while my Austin Highway site scored limited (19.4). Buzan (1982) scored Pecan Valley high (31), while I gave Pecan Valley an intermediate score (27.8). Both studies gave Goliad Road an intermediate score (25).

Buzan (1982) also reported 13 taxa of fish, eight of the fish taxa were in common with my fish survey. As Buzan (1982) only reported presence or absence of fish taxa in Salado Creek (Appendix 8), no further fish comparisons were made between Buzan's study and this study.

The "Use and Attainability Analysis of Salado Creek, Segment 1910" (Davis et al. 2003) study was used to determine if a concurrent study is similar to my study. Davis et al.'s (2003), station 1, 2 and 3 were very close geographically to my Austin Highway, Gembler Road and Pecan valley sites (respectively, within 1-2 km) and his station 4 was my Goliad Road site. I used ALU scores from Davis et al. (2003) to compare to ALU scores to this study. Davis et al. (2003) reported an intermediate-high score (28.3) at his site 1, while I calculated a limited score (19.4) at Austin Highway (Appendix 9). Sites 2, 3 and 4 were ranked high (29.3, 30.3 and 33.7, respectively). I found Gembler Road, Pecan Valley and Goliad Road in the intermediate ranges (27.7, 27.8 and 25, respectively). Davis et al. (2003) reported macroinvertebrate abundances for each taxon. To determine why there were differences in ALU scores I used Davis et al's (2003) most abundant taxa that made up 75% of the total macroinvertebrate population and found an averaged tolerance value of 5.3. The averaged tolerance value for the most abundant taxa that made up 75% of the total macroinvertebrate population in this study is 6.2.

Salado Creek metrics from this study were compared to Medina Creek, Leon Creek, Cibolo Creek and the San Antonio River metrics (Fig. 28, SARA

2003), to determine watershed trends and conditions. I used the March 9, 2003, Gembler Road sample from this study for comparison purposes. The Medina Creek samples were taken on March 29, 2003. Leon Creek was sampled on May 13, 2003. Cibolo Creek was sampled on August 18, 2003 and the San Antonio River was sampled on June 3, 2003. The San Antonio River Authority uses EPA Rapid Bioassessment Protocols, except samples are only taken from riffles. Taxa richness was similar in all water bodies, and Salado Creek had the highest score with 25, EPT taxa was less than 9 for all streams, predator abundances were low for all streams, chironomid abundances were high for Salado Creek and Leon Creek, and non-insect taxa was highest in Salado Creek by 44%.

DISCUSSION

Study Design

In this study I used the classic design of upstream/downstream to perturbation, where the upstream site is the control and the downstream sites are treatments (Stewart-Oaten et al. 1992). Hurlbert (1984) argues that the objection to upstream/downstream studies is that macroinvertebrate populations receiving the treatment are not a representative sample of the entire population. Stewart-Oaten et al. (1986) found that the populations, before and after (or upstream and downstream) the actual impact are the *only* populations of interest, time and place of impact cannot be unrepresentative in this sense. However, in this study, the "control" has problems other than the absence of point-source pollution. This upstream site has low or no flow conditions for some periods. Therefore, the goal here was to determine whether the state of Salado Creek differs from what would have been in the absence of augmented baseflow with treated wastewater.

Flow

I found that the increased flow downstream of the augmented baseflow improved the biological condition of that segment of Salado Creek. Differences between reference and test sites in the invertebrate fauna of Salado Creek are likely the result of augmented baseflow. Flow is widely recognized as important to the recruitment and supply of particulate food for deposit and suspension feeders in rivers and streams (Nowel and Jumars 1984). Schlosser and Ebel (1989) found that frequent and prolonged periods of elevated discharge caused increases in colonization and abundance of invertebrates and cyprinids. Inferrera (1989) suggests using pumping and recharge wells to stabilize aquifers and raise water tables to prevent the drying of springs. Orange and Nassau Counties use recycled wastewater to recharge aquifers (Millikin and Trumbly 1979).

Disturbance and Biotic Response

The mode of action of hydrologic disturbances on stream communities are by erosion (e g. storms) when habitats are scoured by floods, or by desiccation (e.g. during droughts) when aquatic habitats decrease gradually and organisms become stranded above the water surface (Collier and Quinn 2003, Resh et al. 1988, Siegfried and Knight 1977). Three weeks after the flood, I found new bar formation, new deposition and exposed bedrock, demonstrating habitat alteration. Summer drying appeared to be a factor structuring the intermittent riffle assemblages at the Austin Highway site. Some taxa (e.g. Elmidae) which were common at the downstream sites were rarely collected from Austin Highway. Thus riffle assemblages consisted mainly of taxa capable of rapid recolonization upon rewetting (e.g. Coenagrionidae), or those able to survive in intermittent pools (e.g. *Caenis*, mayflies). *Caenis* have specialized gills, such as thickened opercula and interlacing fringes, which protect underlying gills from siltation and improve oxygen uptake in stagnant water (Needham et al. 1945).

Recolonization Sources

Recolonization sources such as the hyporheic zone, upstream migration, drift and aerial pathways are examined to determine possible recolonization pathways. Underlain by bedrock which is frequently exposed, Salado Creek has almost no hyporheic zone. Thus, this habitat is an unlikely source of recolonization following events that scour and reduce surface macroinvertebrate abundance. Drift to all sites from the Beitel Creek tributary is possible. The Walzem tributary may provide drift colonizers to the downstream sites and the Rosillo Creek tributary may provide drift colonizers to the Goliad Road site. Walzem, and Rosillo Creeks and the San Antonio River may provide upstream migration sources. Distances over land make the tributaries and the San Antonio River likely sources of aerial colonization. However, the three tributaries, like Salado Creek, dry in the summer months, reducing their ability to provide colonizers (personal observation). It is likely that streams such as Salado Creek, that suffer from scour are recolonized primarily by aerial adults (Gray and Fisher 1981).

Habitat Assessment

The habitat assessment for Salado Creek does not discriminate between sites, but does establish that the entire segment is stressed. In performing habitat assessments over the study year, I found one parameter would decrease while others would increase leading to ambiguous scoring. For example, during the first sampling period Austin Highway scores were low due to drying. After the July 1, 2002 flood, scores increased simply because water flowed and filled the stream bed, produced new tree fall, new snag habitat, and increased the number and size of pools. A variety and abundance of submerged structures in a stream provide macroinvertebrates with a high number of niches, thus encouraging habitat diversity (Plafkin et al. 1989, Wallace 1996). Snags and submerged logs are among the most productive habitat structures in low gradient steams while riffles, runs and embeddedness are equally important to high gradient streams (Benke et al. 1984). As the flood improved some scores, other scores decreased due to bank erosion, exposed roots, and increased bar formation. Sediment accumulation is associated with major storms and deforestation and may result in the formation of islands, point bars or shoals, and may result in the filling of pools and runs (Barbour et al. 1999, Brush 1989). While the flood, in general, improved the habitat at the Austin Highway site, it is important to remember that urbanized streams are subject to increasing frequencies and varieties of disturbances such as, erosion from housing developments, runoff from paved areas and direct alteration of stream beds that will continue to affect the Salado Creek habitat.

r/K Strategists

The ecological strategy of a species is determined by its environment (MacArthur 1960). High frequencies of disturbances, especially run off due to impervious ground cover, create an unstable habitat for the benthic macroinvertebrates of Salado Creek. As organisms are exposed to environmental fluctuations, strategies such as high reproductive rates, diapause, aestivation, or migration may have developed to promote population stability (Jones 1976). Species that are opportunistic (r-selected) are fugitives with a high rate of per-capita population growth, but poor competitive ability, while equilibrium (K-selected) species compete well, but reach carrying capacity at a much slower rate (MacArthur 1960). Pianka (1970) suggests that, whereas most vertebrates have been K-selected, insects represent r-selection. However, within specific habitats insects also range from r to K strategists. Southwood et al. (1974) proposes that it is the stability of the habitat in relation to the generation time that is the source of selection pressure. The stochastic nature of Salado Creek would then select against K-strategists favoring the short generation times of r-strategists. Examples of this are the simuliids and *Corbicula*. Simuliids have high fecundity and will lay eggs in a variety of lotic environments from large rivers to a small trickle, can be parthenogenic, sometimes have up to 16 generations per year and have the capacity for downstream dispersal (Merritt and Cummins 1996). *Corbicula* have a relatively short life span, early maturity, high fecundity, high growth rates and capacity for downstream dispersal making it well adapted for life in unstable lotic habitats (Thorp and Covich 1991). However, Salado

Creek may also be stable enough to support K-strategist macroinvertebrates. For example, Elmidae deposit eggs singularly or in small groups, larvae undergo 6-8 instars which may take three or more years, adult life spans are uncertain but suspected to be about one year (Thorp and Covich 1991, Merritt and Cummins 1996).

Metrics and Macroinvertebrates

In this study the taxa richness metric was a strong indicator, distinguishing between upstream and downstream sites. High taxa richness is generally thought to indicate undisturbed or unpolluted conditions (Plafkin et al. 1989, Resh 1995). In Salado Creek taxa richness decreased at all sites during the winter months. I suggest that taxa richness is lower in winter due to seasonality. However, the overall lower taxa richness at Austin Highway may be due to distance to upstream migration from the San Antonio River. Of the ten taxa that make up the majority of macroinvertebrate abundance, nine can be found at all downstream sites (Caenidae is at one downstream site). However, only five of the major taxa inhabit the Austin Highway site. Four taxa colonized through aerial migration, Caenidae, Coenagrionidae, Chironomidae, Baetidae (Merritt and Cummins 1996), and one taxa, Planariidae, most likely drifted downstream from the Beitel tributary (Thorp and Covich 1991, Merritt and Cummins 1996). The distance to the San Antonio River confluence is over 48km, indicating upstream migration is unlikely and that aerial and downstream drift are the most likely sources of colonizers. In the island biogeography theory, MacArthur and Wilson

(1967) recognized that species arrived on islands at different rates because some organisms are more mobile than others. Whitehead and Jones (1969) found that the rate of colonization depends on an island's size as well as distance from a source of potential colonists. Therefore, aerial colonization and drift are the most likely sources of recolonization.

Another factor affecting taxa richness at the Austin Highway site is drying before flooding. Drying is a disturbance to the macroinvertebrate population in the stream, possibly causing low taxa richness. Adding the flood creates a higher disturbance, causing lower taxa richness. The intermediate disturbance hypotheses suggests habitats that experience frequent or intense disturbances are expected to exhibit low species richness because few species are able to colonize (Wilson 1994). Richness should be highest at intermediate levels of disturbance because both rapid colonizers and more competitive species co-occur (Wilson 1994). In this study, it is likely that low taxa richness at high frequencies and intensities of disturbance reflects the poor ability of some stream invertebrates to colonize or persist in such situations. Townsend et al. (1997) found greater richness at the intermediate disturbance levels, although it is unknown if competition or ability to colonize were factors in taxa richness. Death and Winterbourne (1995) found the greatest richness in the most stable habitats and they found the greatest eveness at sites of intermediate stability. In a study of fish and their response to flooding, Ross and Baker (1983) found higher abundances of *Notropis texanis* in three years of flood than in three years of lower discharge.

Whether the lower taxa richness at Austin Highway is due to distances of recolonization sources or higher disturbance levels is uncertain. However, there is some preliminary evidence that drying and flooding are both acting on the benthic population of this upstream site.

The EPT taxa metric, using the family level of taxonomy, discerned differences between upstream and downstream sites. Resh et al. (1995) found the number of EPT taxa among the most widely used and recommended metrics in rapid assessment programs because of the sensitivity of Ephemeroptera, Plecoptera and Trichoptera to pollution. In the development of a Stream Condition Index (SCI) for Florida streams, the number of EPT taxa was among the strongest discriminators between reference and impaired sites (Barbour et al. 1996). The use of Ephemeroptera, Plecoptera and Trichoptera taxa to measure impairment in Florida streams and in Salado Creek is of special interest because there are no Plecoptera in either area. The EPT metric measures the richness of three specific taxa that require high dissolved oxygen. Possible reasons for the lack of Plecoptera in Salado Creek include: restrictive habitats requiring specific water temperature, substrate type, stream and hyphoreic size requirements and high oxygen demands (Merritt and Cummins 1996). I believe the EPT metric discriminates between levels of disturbance where there are no Plecoptera because Trichoptera and Ephemeroptera complete the metric requirement.

The lack of Elmidae and low percent of non-insect taxa are strong indicators that the Austin Highway site is more disturbed when compared to the three downstream sites. The Texas Commission on Environmental Quality (TCEQ) found riffle beetles and non-insect taxa in reference streams, while impaired streams had reduced numbers of macroinvertebrates (TNRCC 1999). Ransom and Prophet (1974) found that the presence of Elmidae among the dominating taxa indicated that the Cedar Creek basin in east-central Kansas is relatively free from environmental stresses. Riffle beetles have plastron, a gas film that serves as a physical gill that allows continuous diffusion of oxygen inward (Merritt and Cummins 1996). Oxygen consumption is determined by the limited surface area of the plastron, consequently, most insects with plastrons require high dissolved oxygen (Merritt and Cummins 1996). The Non-insect taxa metric discerned differences between upstream and downstream sites. Barbour et al. (1996) found crustacean + mollusca taxa is a measure of calcium-dependant taxa that are generally most diverse in healthy macrophyte beds. Among non-insect taxa, respiratory adaptations have occurred determining their sensitivity to disturbance. For example, prosobranch Gastropods have a single ctenidium or gill where gaseous exchange occurs from oxygen rich water currents (Thorp and Covich 1991). However, the low numbers of non-insect taxa at Austin Highway may have more to do with the dispersal ability (as discussed above) than with disturbance.

On many dates and sites chironomids dominated Salado Creek. High percentages of chironomids are often associated with disturbance due to higher tolerance to low oxygen levels (Merritt and Cummins 1996). Anoxic conditions may favor insects that use hemoglobin in low oxygen conditions. Certain Chironomidae possess high-affinity hemoglobin, which means oxygen is released when low external oxygen pressures are found in water and mud (Merritt and Cummins 1996). Many of the chironomids found in Salado Creek had the characteristic red color of the hemoglobin rich taxa.

In this study I used the family level tolerance values in the Hilsenhoff Biotic Index (HBI) to distinguish between upstream and downstream sites. HBIs are oriented to detect organic pollution according to tolerance (to pollution) levels of macroinvertebrates and abundance per taxa, therefore, high scores indicate greater disturbance (Barbour et al. 1999, Hilsenhoff 1988). There is some disagreement in the literature concerning the appropriate level of macroinvertebrate identification. Resh and Unzicker (1975) found that 89 macroinvertebrate genera tolerance values were different than the associated species specific tolerance values. Furse et al. (1984) analyzed data from 268 unpolluted sites in Great Britain and found that the added cost of species level identification was so great that they recommended family-based classifications where species information is not essential. Hilsenhoff (1988) altered his Biotic Index of Organic Pollution (BI, species level of tolerance) to a Family Biotic Index (FBI) and found the overall FBI usually overestimated pollution in clean streams and underestimated pollution in polluted streams. Even with these results Hilsenhoff (1988) found the FBI advantageous for evaluating the general status of organic pollution in streams. I tested the family vs. generic level of tolerance values for this study. Using student t-tests to analyze four samples, I did not find a significant difference between family and genus-level determination of tolerance values. Resh and Unzicker (1975) found notable differences between generic and species-level tolerance levels. This study suggests that there is not as great a difference between family and genus as genus and species levels in use of tolerance values as indices of organic pollution.

Historic Studies

When Webb's (1988) IBI and Buzan's (1982) RBA were compared to my study, I found greater impairment. One challenge in temporal assessments of different studies is reconciling differences in sampling protocols between historic and recent surveys. It is occasionally possible to duplicate sampling methods between surveys. For example, Anderson et al. (1995) in a study of the fish fauna of Texas duplicated sampling locations, sampling gear and effort, and even one original investigator. In another case, comparisons between recent and historic surveys did not address differences in sampling efficiencies. Reinthal and Stiassly (1991) used various techniques to gather fish species in

Madagascar lakes, including a trip to the local market. For Reinthal and Stiassly (1991) it was not possible to duplicate sampling techniques as they were comparing their data to museum collections and literature with few collection technique records. When improved or standardized sampling protocols prevent using historic methodologies, trend interpretations are confounded by sampling protocols. Even so, comparisons between surveys provide minimum estimates of species declines when sampling efficiency in the recent survey exceeds that of the historic survey, especially when species are collected in fewer locations or densities despite greater gear efficiency (Patton et al. 1988).

Using a regionalized Index of Biotic Integrity, Webb's (1988) fish study and the fish survey in this study were compared to determine if fish populations have changed over time. The IBI was developed to assess the habitat quality of streams in the Midwest and was designed to be flexible enough to vary each category for different geographical areas (Karr 1981). The IBI applied to fish in this study and Webb's (1988) study was adjusted by Gonzalez (1988) in 1987 for use in an assessment of the upper San Antonio River and was assumed appropriate for the watershed. My study showed that IBI scores at two sites, Austin Highway and Goliad Road dropped indicating that habitats in this segment of Salado Creek are more disturbed in 2002 than in 1988.

In his survey of benthic macroinvertebrates, Buzan (1982) attributed differences, in diversity and community composition between stations in Salado

Creek, to slight habitat differences and subjectively determined the stream under "healthy environmental conditions." This term is difficult to quantify for comparison to my study, therefore I applied rapid bioassessment metrics to Buzan's (1982) macroinvertebrate data set. I then compared ALU ranges for Buzan's (1982) study sites and my study sites and found Buzan's (1982) site II scored "Intermediate" while Austin Highway was "Limited" and Buzan's site D scored "High" compared to Pecan Valley's "Intermediate" score (Appendix 3). Buzan (1982) sampled the macroinvertebrate population at the end of April, 1982. Compared to my May 2003 sample period Buzan had 68% greater macroinvertebrate density. It is possible the 20 years between studies has seen a 68% drop in density due to increased urbanization or the decrease could be due to natural variation in community composition.

The Webb (1988) and Buzan (1982) studies when compared to this study indicate increased historical degradation in at least two sites in Salado Creek. Another issue that can confound comparative studies is the examination of the smallest spatial scale (sites) which may lead to erroneous interpretations. Local stochastic and deterministic events lead to natural population fluctuations that effect survey interpretations (Yant et al. 1984). Patten et al. (1998) found silvery and brassy minnows appeared stable at the site spatial scale, but silvery minnows showed evidence of decline while brassy minnows showed evidence of expansion at a larger spatial scale. Webb's (1988), Buzan's (1982) and this study indicate there is increased perturbation after twenty years of increased urbanization.

I used Aquatic Life Use point scores to compare and contrast Davis et al.'s (2003) "Use and Attainability Analysis of Salado Creek, Segment 1910" study to this study. The Aquatic Life Use multimetric uses a combination of metrics to develop a single score to describe stream condition for use by non-scientists such as managers and politicians. Harrison (1996) developed this multimetric for the Texas Commission on Environmental Quality, a state water resources agency. Although Davis et al. (2003) found the upstream site more impaired than the downstream sites, I found my the upstream site more impaired than Davis' upstream site. My evaluations never ranked Austin Highway above intermediate, while Davis et al. (2003) ranked station 1 intermediate-high. To determine why Davis et al.'s (2003) ALU scores ranked higher at each site, I compared Davis et al's (2003) averaged tolerance value to the averaged tolerance value in this study. Davis et al.'s (2003) averaged score is valued as intolerant to pollution while the averaged score for this study is valued as tolerant to pollution. As five of the metrics are directly affected by tolerance, I believe the averaged tolerance values explain the differences in ranges. It is possible that Davis et al.'s (2003) three samples over eighteen months may be insufficient to account for normal seasonal patterns or this study may be overemphasizing flood effects.

Regional or watershed patterns may be discerned from metric score comparisons of Salado Creek, Medina Creek, Leon Creek, Cibolo Creek and the San Antonio River (SARA 2003) as well as streams outside the San Antonio watershed. When I compared the EPT metric scores from this study to streams outside the San Antonio watershed, I found Salado Creek had 2-9 EPT taxa, while Florida streams (without Plecoptera, Barbour et al. 1996), had 29-36 EPT taxa and in a study of North Carolina streams (with Plecoptera), had up to 49 EPT taxa (Lenat 1988). However, when Salado Creek EPT scores are compared to scores from Medina Creek with 3 EPT taxa, Leon Creek with 4 EPT taxa, Cibolo Creek with 8 EPT taxa and the San Antonio River with 5 EPT taxa, the metric score ranges are comparative. This indicates low EPT scores are regional to the watershed, or possibly to south-central Texas. The extremely low metric of percent predators for the all five streams may reflect an imbalanced trophic structure, and may be the condition for the entire watershed. The metric scores found in Salado Creek are similar to the scores from Medina Creek, Leon Creek, Cibolo Creek and the San Antonio River, indicating that Salado Creek is no more disturbed than other streams in the watershed.

CONCLUSIONS

Flow in Salado Creek slows or stops entirely without augmentation, limiting the benthic fauna of the river. The drying that occurs upstream of the baseflow is an added disturbance when coupled with flooding, affecting benthic macroinvertebrate recolonization. Austin Highway riffle assemblages are dominated by species that have adapted to low oxygen levels, while the downstream sites maintain populations requiring higher oxygen levels.

I found macroinvertebrate metrics from this study as well as a concurrent study evidence of improved habitat conditions downstream of augmentation. Of the 13 metrics and 1 Habitat Assessment investigated in this study, all but one metric (% predators) and the Habitat Assessment did not distinguish between the upstream site and downstream sites. This is strong evidence of improved habitat conditions at the downstream to augmentation sites. The ALU scores further support the evidence of improved habitat conditions downstream to augmentation. The TCEQ study also reported improved habitat conditions at downstream sites (Davis et al. 2003).

Trends in habitat disturbances can be identified through comparisons with historic studies. Webb's (1988) 17 year old IBI and Buzan's (1982) 22 year old survey, when compared to this study indicate increased disturbance, probably due to increased urbanization.

Future studies of the San Antonio River watershed may answer questions concerning the effect of treated effluent in Salado Creek on the San Antonio River. Sampling the Beitel, Walzem and Rosillo tributaries could provide insight to potential colonization sources. This year long study produced extensive macroinvertebrate and fish taxonomic lists that may be useful to future studies.

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TABLE 1. Sample dates, location and habitat composition of Salado Creek from June 2002 through June 2003.

Date	Sampling Period	River segment	% Riffle	% Pool	% Snag
26-Jun	1	Austin Hwy	Dry		
26-Jun	1	Gembler Rd	90	10	
28-Jun	1	Pecan Valley	80	20	
1-Jul	1	Goliad	Flood		
30-Jul	2	Austin Hwy	80	20	
31-Jul	2	Gembler Rd	80	10	10
1-Aug	2	Pecan Valley	80	10	10
8-Aug	2	Goliad	90	10	
30-Aug	3	Austin Hwy	100		
30-Aug	3	Gembler Rd	90	10	
31-Aug	3	Pecan Valley	80	15	5
31-Aug	3	Goliad	90	10	
27-Sep	4	Austin Hwy	85	15	
27-Sep	4	Gembler Rd	90	10	
27-Sep	4	Pecan Valley	85	10	5
27-Sep	4	Goliad	90	10	
22-Nov	5	Austin Hwy	100		
22-Nov	5	Gembler Rd	90	10	
22-Nov	5	Pecan Valley	95		5
22-Nov	5	Goliad	80	20	
11-Jan	6	Austin Hwy	90	10	
11-Jan	6	Gembler Rd	90	10	
11-Jan	6	Pecan Valley	90	5	5
11-Jan	6	Goliad	90	10	
9-Mar	7	Austin Hwy	100		
9-Mar	7	Gembler Rd	95	5	
9-Mar	7	Pecan Valley	100		
12-Mar	7	Goliad	80	20	
7-May	8	Austin Hwy	95	5	
7-May	8	Gembler Rd	95	5	
7-May	8	Pecan Valley	100		
8-May	8	Goliad	95	5	
29-Jun	9	Austin Hwy	90	10	
29-Jun	9	Gembler Rd	90	10	
30-Jun	9	Pecan Valley	100		
29-Jun	9	Goliad	90	10	

TABLE 2. Macroinvertebrate metrics, description, response to pollution and source agency (Barbour et al. 1999, TNRCC 1999).

Metric	Definition	Predicted Response to Increasing Perturbation	Agency
Taxa Richness	total number of benthic macroinvertebrate taxa	decrease	EPA/TCEQ
No. EPT Taxa	total number of families within the orders of Ephemeroptera	decrease	EPA/TCEQ
Hilsenhoff Biotic Index	calculated $\Sigma n_i t_i / N$	increase	EPA/TCEQ
% Chironomidae	ratio of the number of individuals in the family Chironomidae to the total number of individuals in the sample	disproportionate representation	EPA/TCEQ
% Dominant Taxa	ratio of the number of individuals in the numerically dominant taxon	high percentage	EPA/TCEQ
% Dominant Functional Feeding Group	ratio of the number of individuals in the numerically dominant functional feeding group to the total number of individuals	exceptionally high or low percentages	TCEQ
% Predators	metric consists of the number of individuals in the predator functional group to the total number of individuals	exceptionally high or low percentages	EPA/TCEQ
Ratio of Intolerant to Tolerant Taxa	ratio of the number of individuals in taxa with tolerance values <6 to the number of individuals in taxa with tolerance values $\geq$6	increase	TCEQ
% of Total Trichoptera as Hydropsychidae	ratio of the number of individuals in the family Hydropsychidae to the total number of individuals in the order Trichoptera	exceptionally high or low percentages	EPA/TCEQ
# of Non-insecta Taxa	total number of non-insecta taxa collected	decrease	EPA/TCEQ
% Collector-Gatherers	ratio of the number of individuals in the collector-gatherer functional feeding group to the total number of individuals in the sample	increase	EPA/TCEQ
% of Total Number as Elmidae	ratio of the number of individuals from the family Elmidae to the total number in individuals	exceptionally high or low percentages	TCEQ
Aquatic Life Use Scores	a combination of metrics to gauge the condition of a river	decrease	TCEQ
Habitat Assessments	approach used for evaluating habitat structure is visual-based and was developed to describe the overall quality of physical habitat	decrease	EPA/TCEQ

TABLE 3. The Hilsenhoff Biotic Index showing scores in relation to levels of organic pollution (Barbour et al. 1999, Hilsenhoff 1988).

Score	Level	Description
0.00-3.75	Excellent	Organic pollution not likely
3.76-4.25	Very Good	Possible slight organic pollution
4.26-5.00	Good	Some organic pollution
5.01-5.75	Fair	Fairly substantial pollution likely
5.76-6.50	Fairly Poor	Substantial pollution likely
6.51-7.25	Poor	Very substantial pollution likely

TABLE 4. Percent and specific dominant taxon for all sites and periods

	AUSTIN HWY	% Dominanat Taxon	GEMBLER RD	% Dominanat Taxon	PECAN VALLEY	% Dominanat Taxon	GOLIAD RD	% Dominanat Taxon
JUN			Tricladid	35.40%	Elmidae	31.10%		
JUL	Caenidae	31.77%	Caenidae	30.77%	Tricorythidae	17.04%	Hydropsychidiae	27.96%
AUG	Caenidae	56.26%	Tricorythidae	23.30%	Elmidae	21.91%	Tricorythidae	29.32%
SEP	Chironomidae	16.84%	Elmidae	24.37%	Chironomidae	32.54%	Chironomidae	11.57%
NOV	Chironomidae	85.61%	Baetidae	60.22%	Baetidae	48.87%	Baetidae	43.92%
JAN	Chironomidae	96.33%	Chironomidae	55.91%	Elmidae	43.07%	Chironomidae	54 90%
MAR	Chironomidae	60.71%	Chironomidae	34.52%	Baetidae	21.11%	Chironomidae	57 99%
MAY	Planaridae	49.43%	Planaridae	29.42%	Hydropsychidae	63.24%	Hydropsychidiae	47 31%
JUN	Chironomidae	44.14%	Tricorythidae	22.28%	Hydropsychidae	25.38%	Hydropsychidiae	24.93%

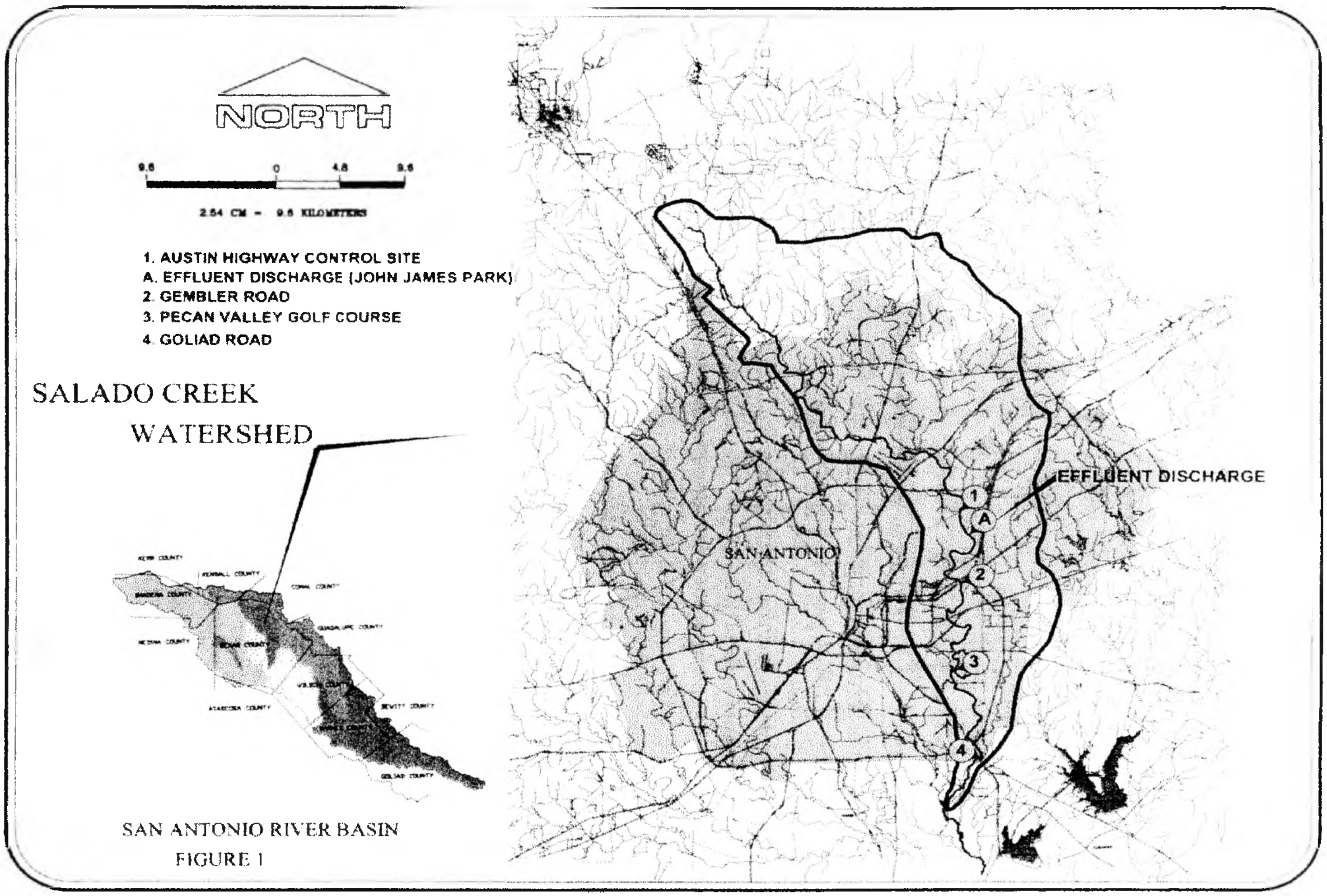
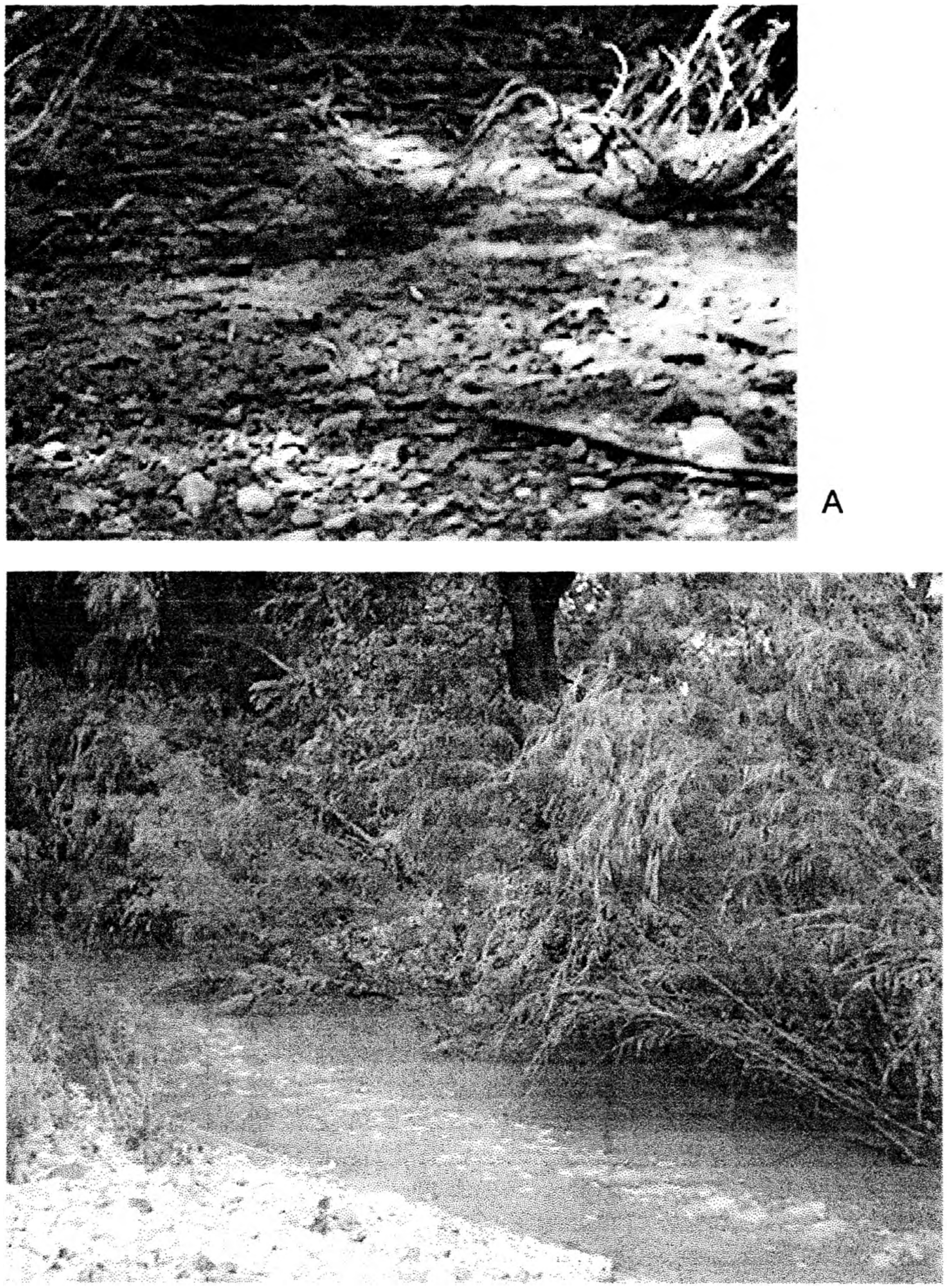


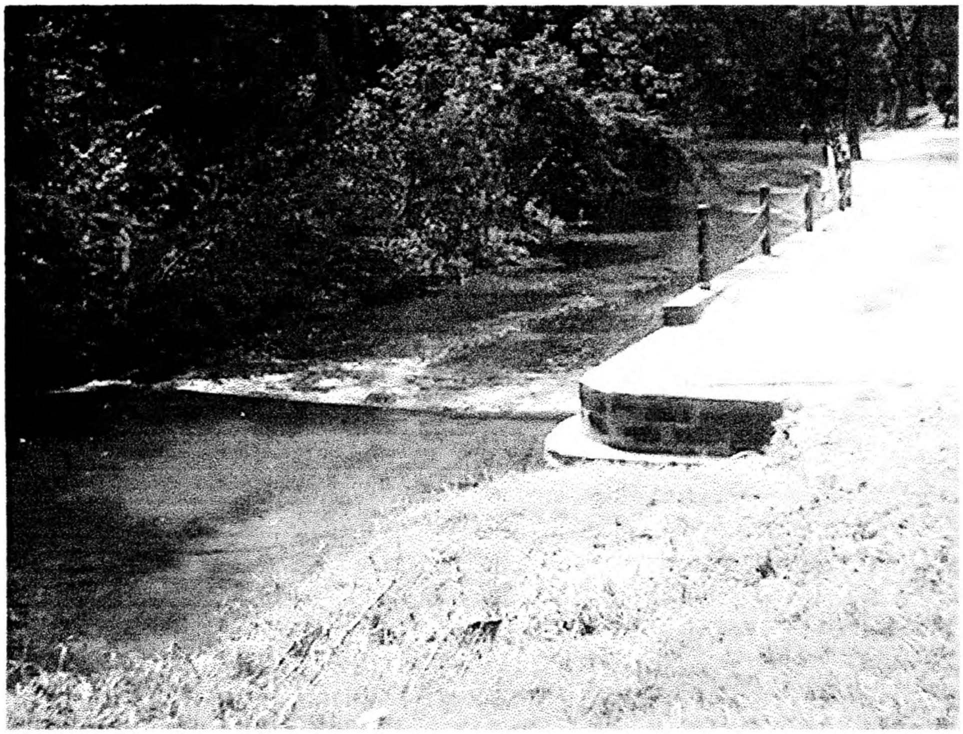
FIGURE 1. San Antonio River basin showing study sites on Salado Creek.



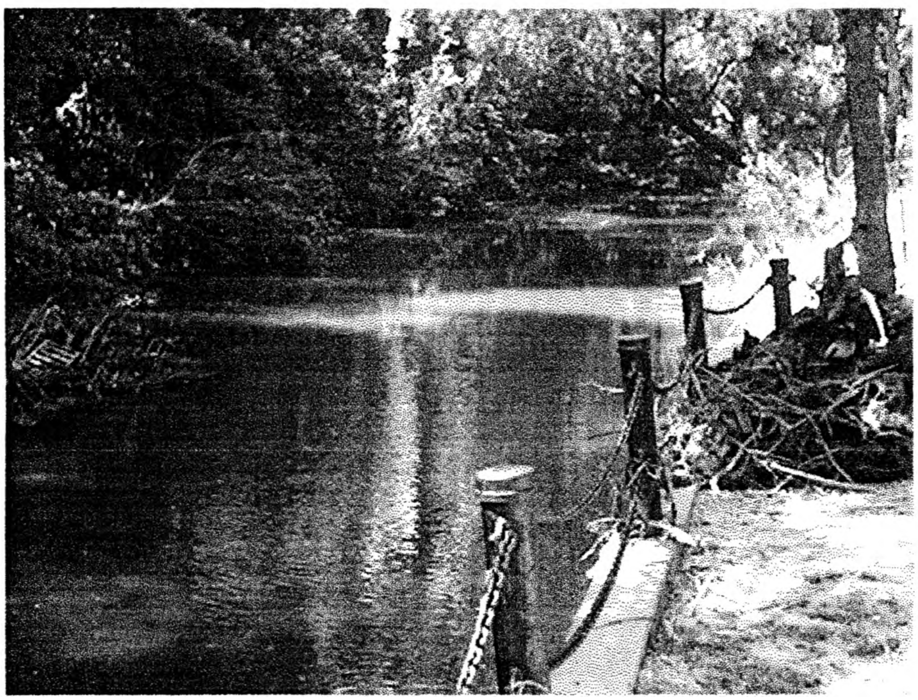
A

B

FIGURE 2. A. Austin Highway Site (June 2002) before flood, no flow and standing pools of water. B. Austin Highway (July 2002) after flood, bent over trees and new deposition from the July 1st 2002 flood.



A



B

FIGURE 3. A. Gembler Road Site (Camp Ground, June 2002) before flood. B. Gembler Road (July 2002) after flood, debris and bent over trees from the July 1st 2002 flood.

A

B

FIGURE 4. A. Pecan Valley Golf Course (June 2002). B. Pecan Valley Golf Course (March 2003) fallen tree and debris from the July 1st 2002 flood.

FIGURE 5. Goliad Road site (July 2002), severe bank damage from the July 1st 2002 flood. No preflood photo.

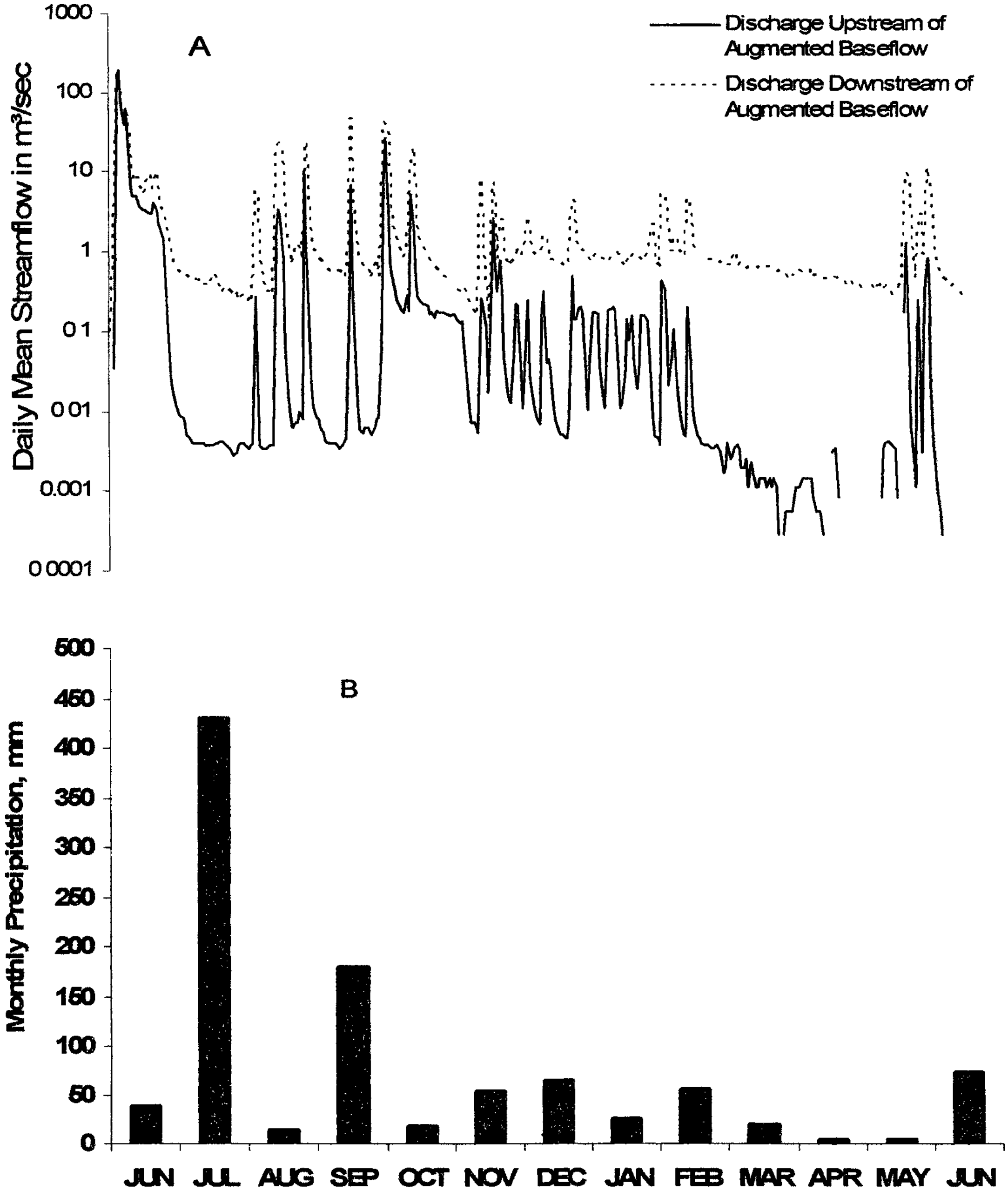


FIGURE 6. Discharge in Salado Creek upstream and downstream of augmentation from June 2002 to June 2003. Monthly precipitation for Bexar County from June 2002 to June 2003.

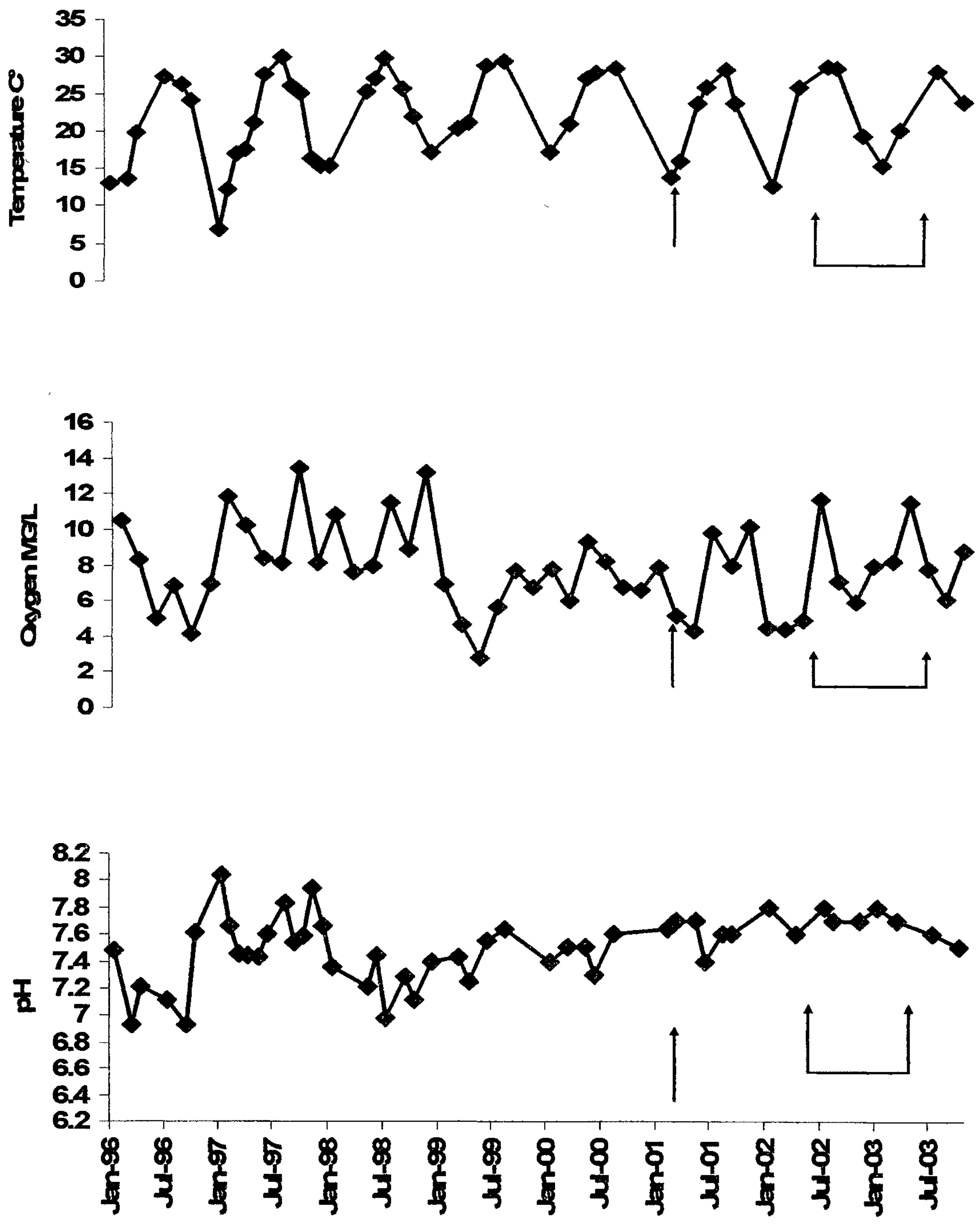


FIGURE 7. Temperature, oxygen and pH of Salado Creek data at Gembler Road, from January 1996 through September 2003. Supplemental recycled wastewater began flowing upstream of this site in March 2001 (single arrows), boxed arrows indicate this study period (SARA, 2005).

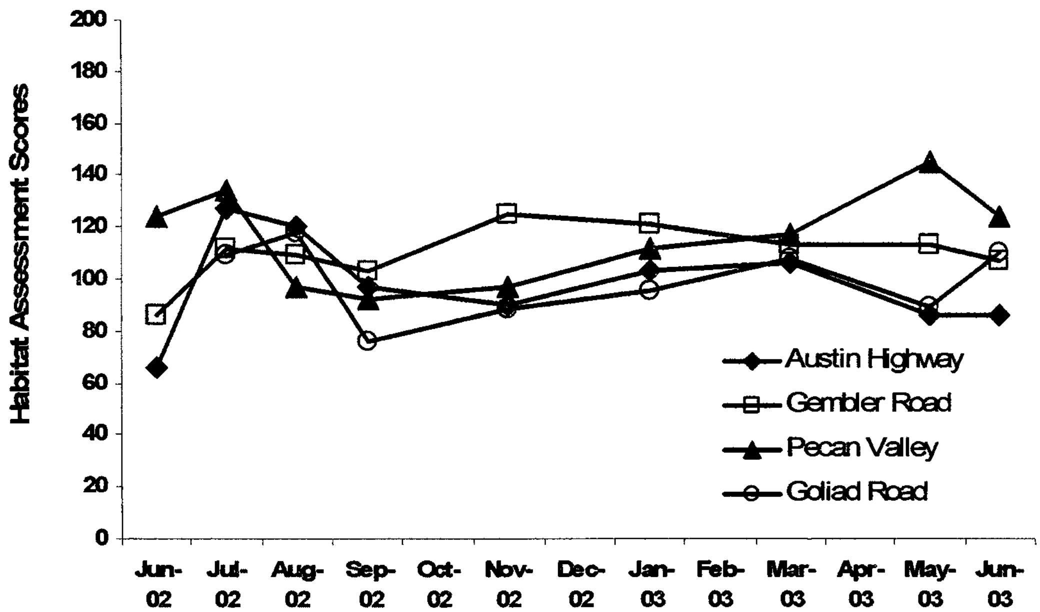


FIGURE 8. Habitat assessment scores for all sites and periods.

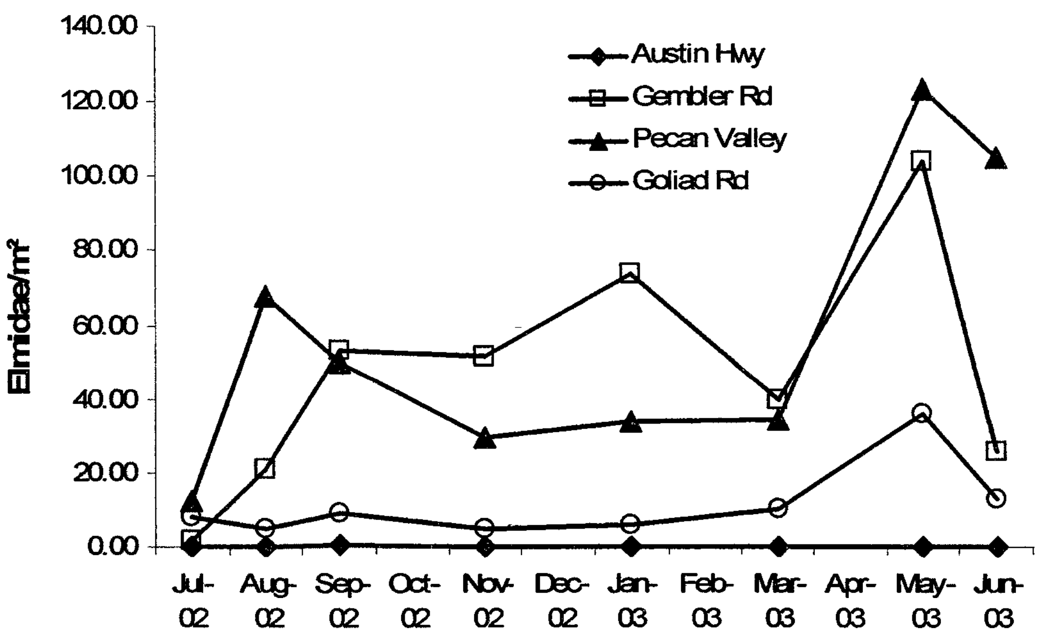


FIGURE 9. Elmidae densities for all sites and periods.

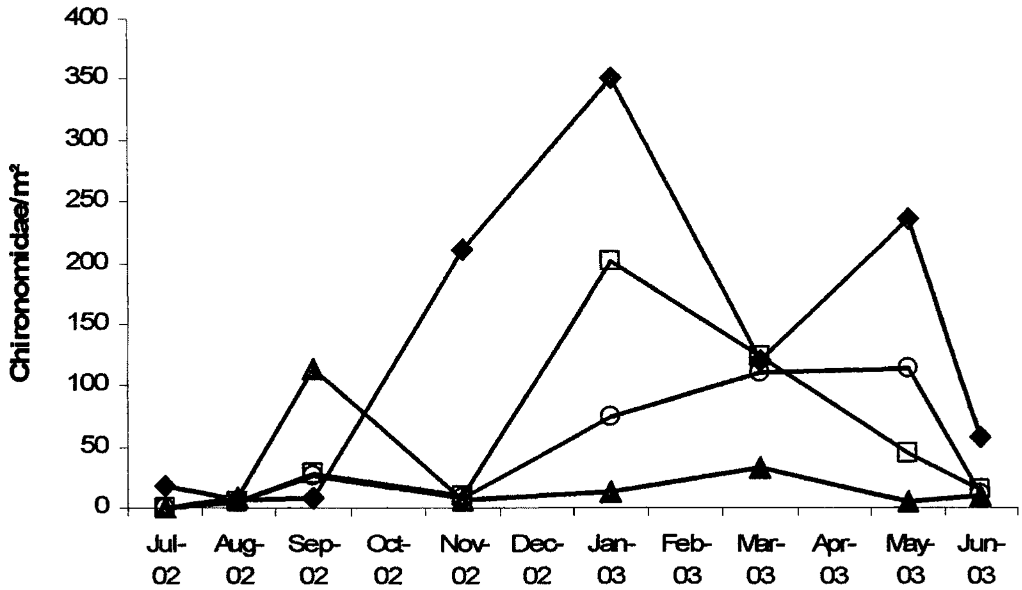


FIGURE 10. Chironomidae densities for all sites and periods.

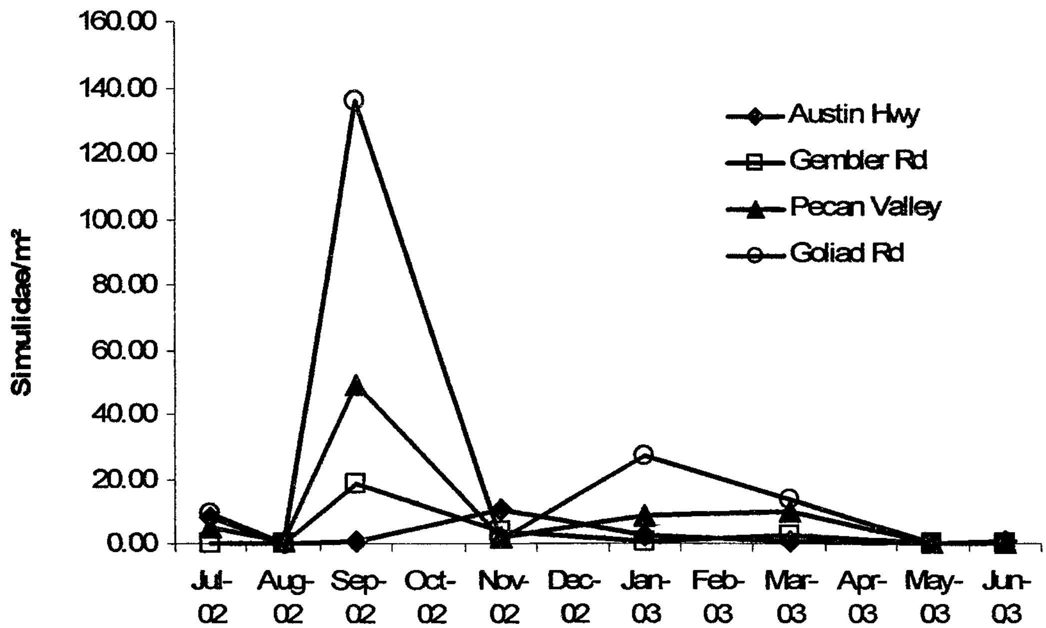


FIGURE 11. Simuliidae densities for all sites and periods.

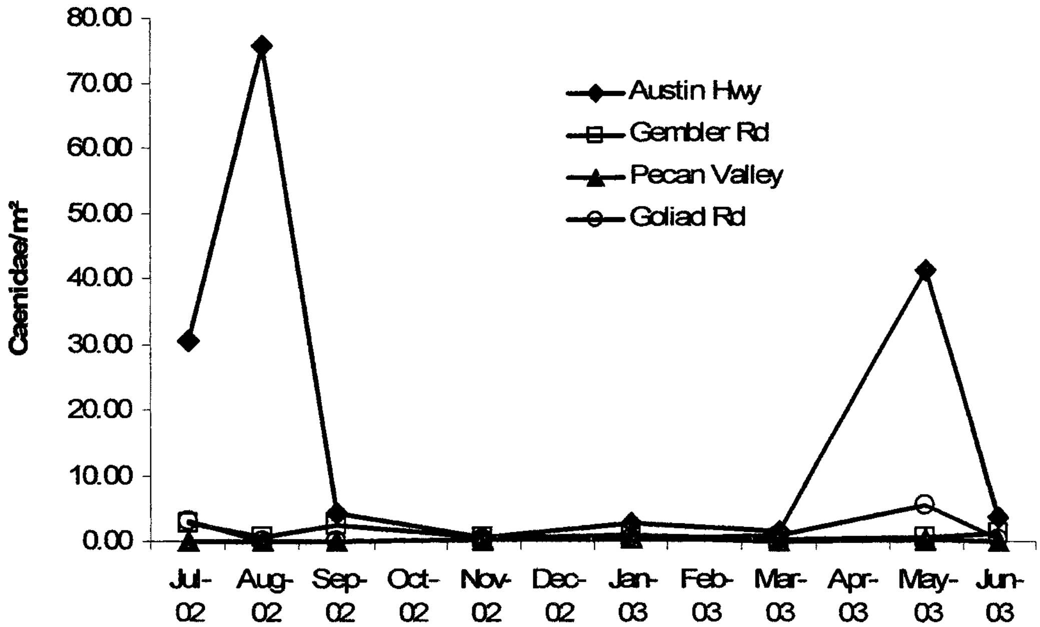


FIGURE 12. Caenidae densities for all sites and periods.

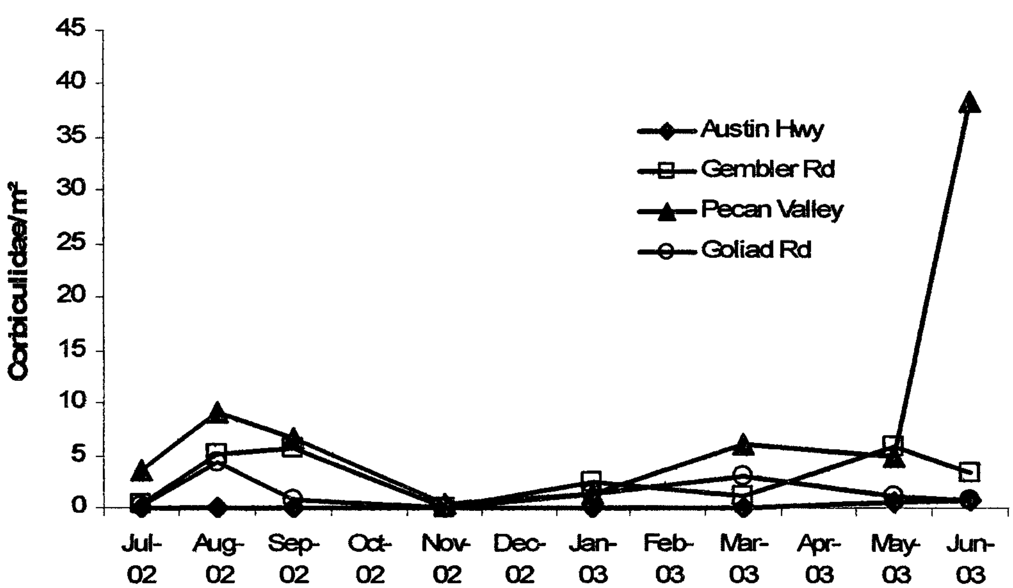


FIGURE 13. Corbiculidae densities for all sites and periods.

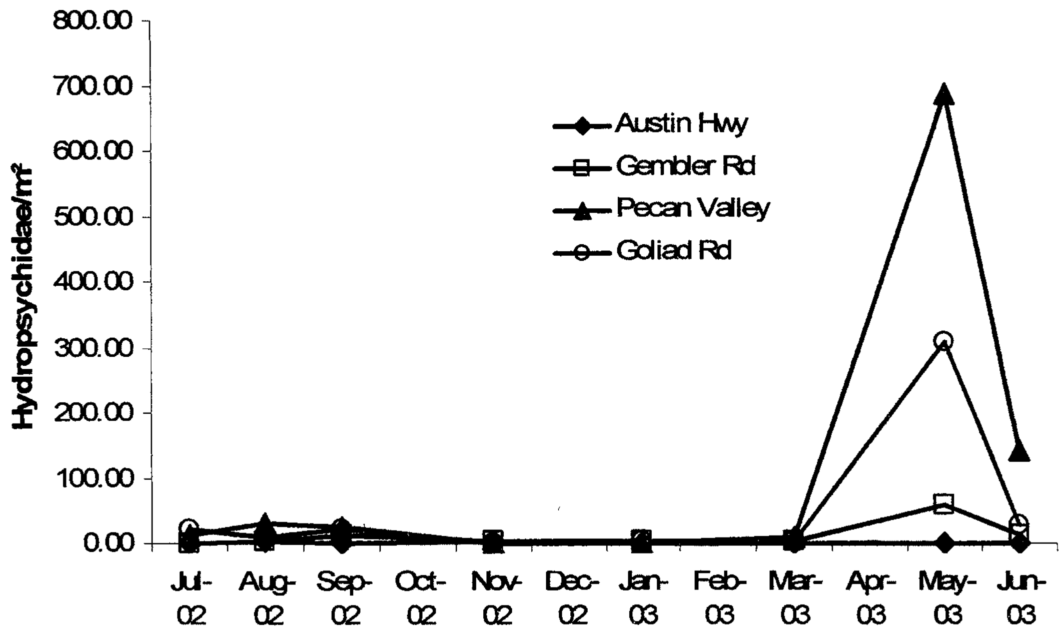


FIGURE 14. Hydropsychidae densities for all sites and periods.

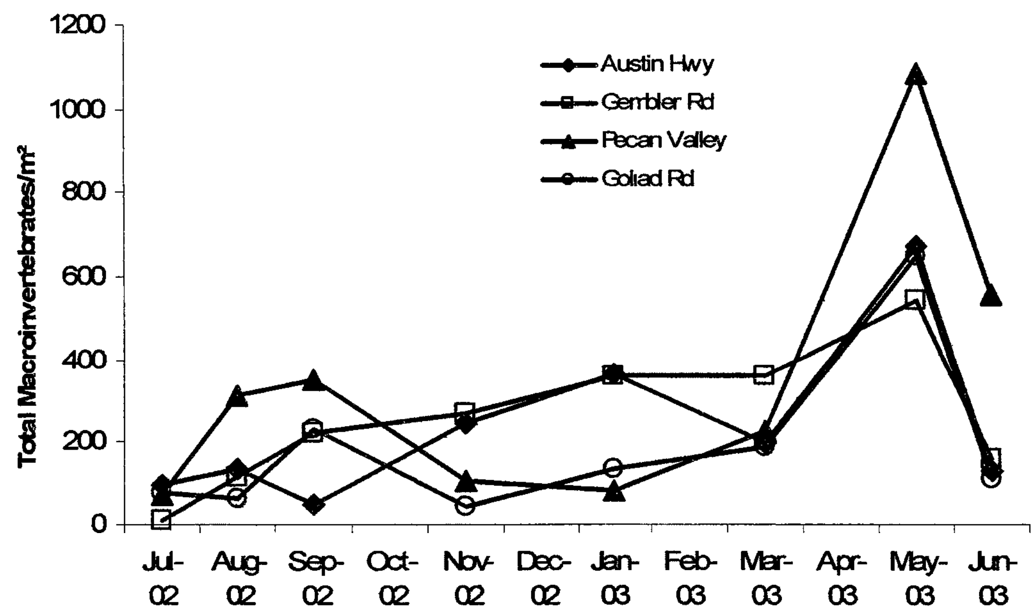


FIGURE 15. Total densities of macroinvertebrates for all sites and periods.

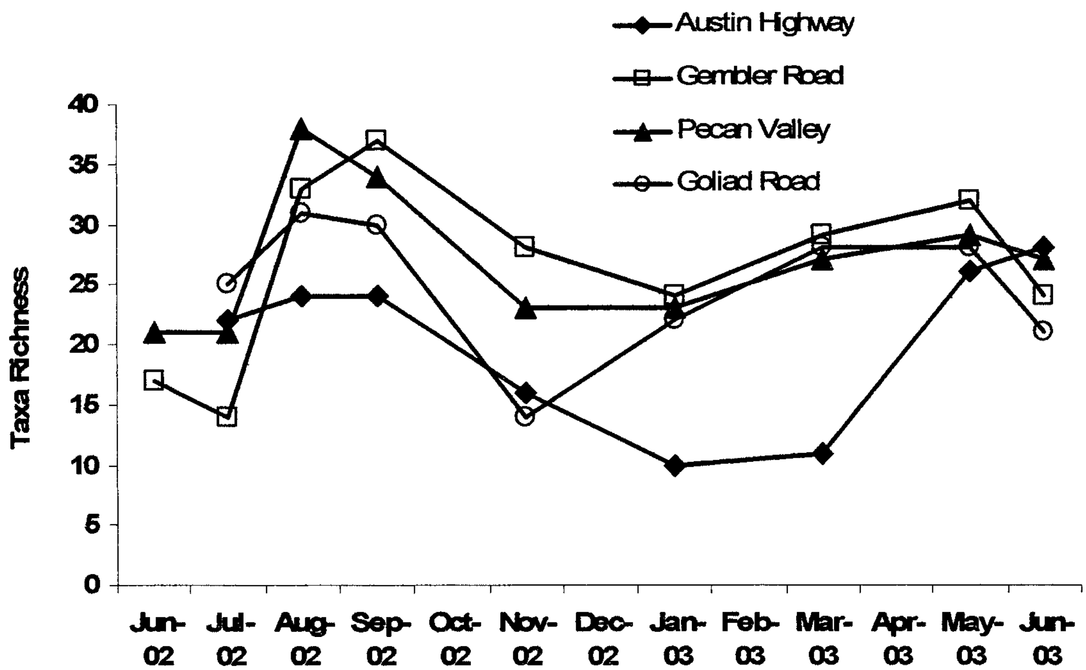


FIGURE 16. Taxa richness for all sites and periods.

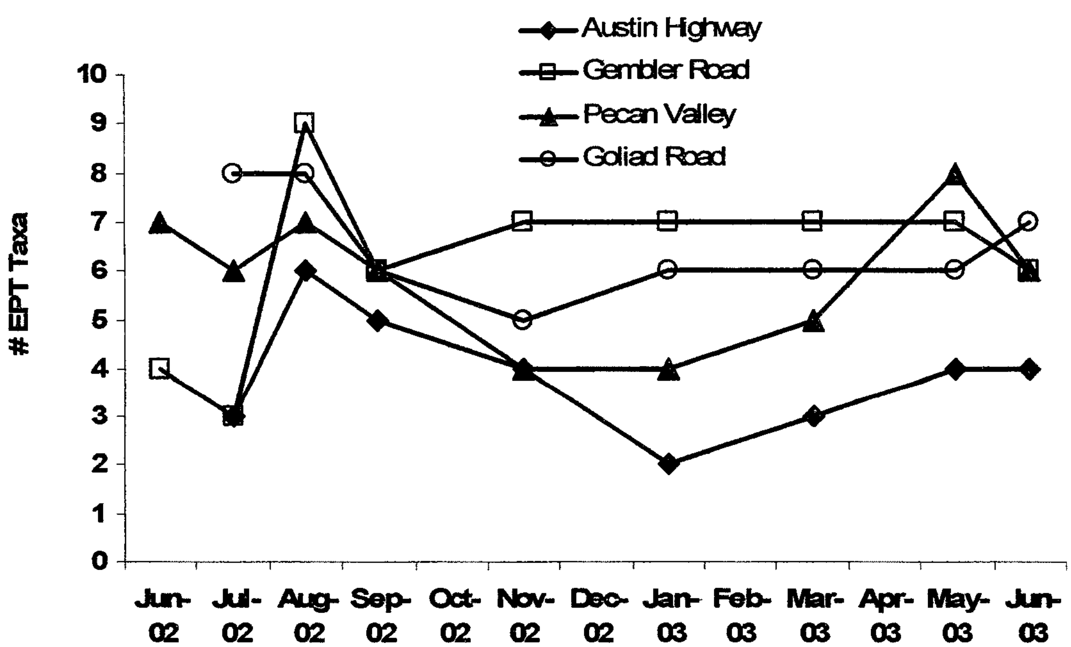


FIGURE 17. Number of EPT taxa for all sites and periods.

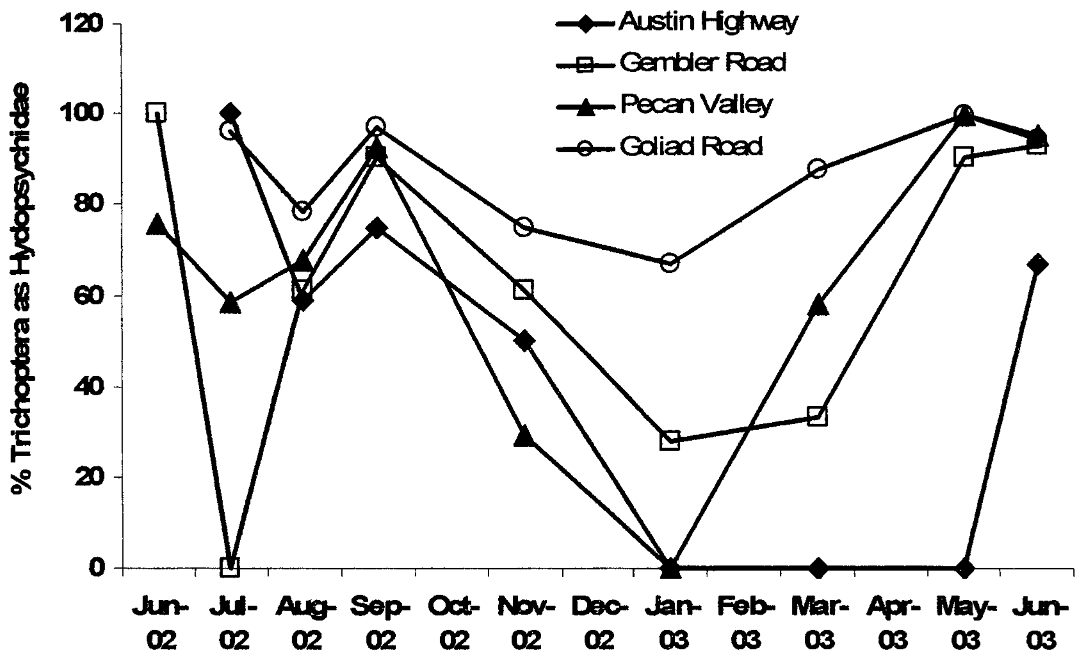


FIGURE 18. Percent of total Trichoptera as Hydropsychidae for all sites and periods.

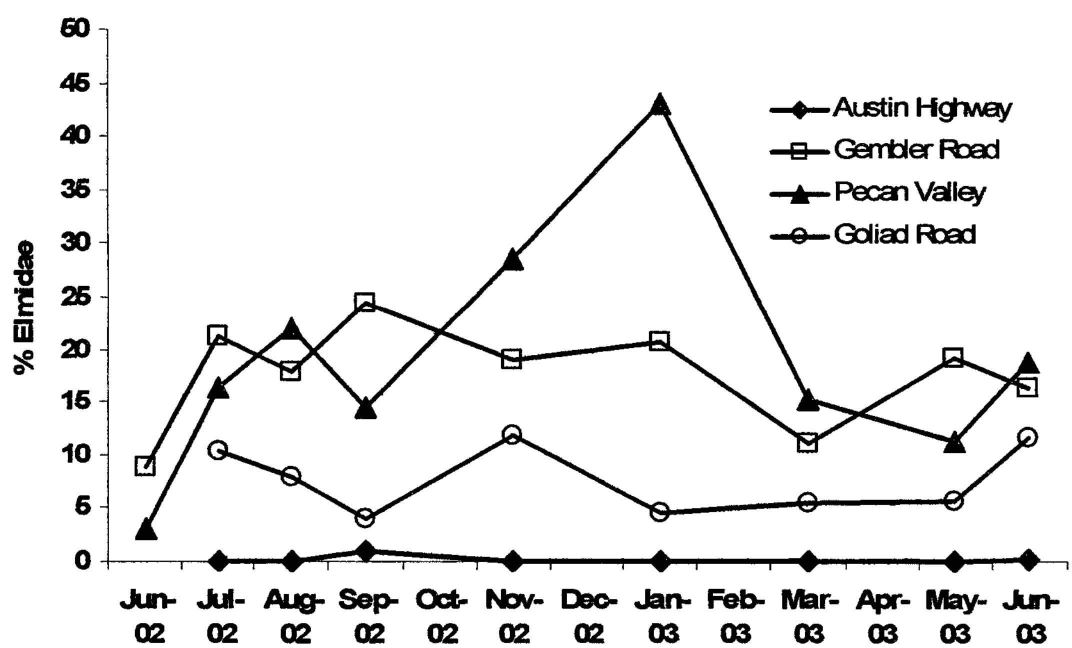


FIGURE 19. Percent Elmidae for all sites and periods.

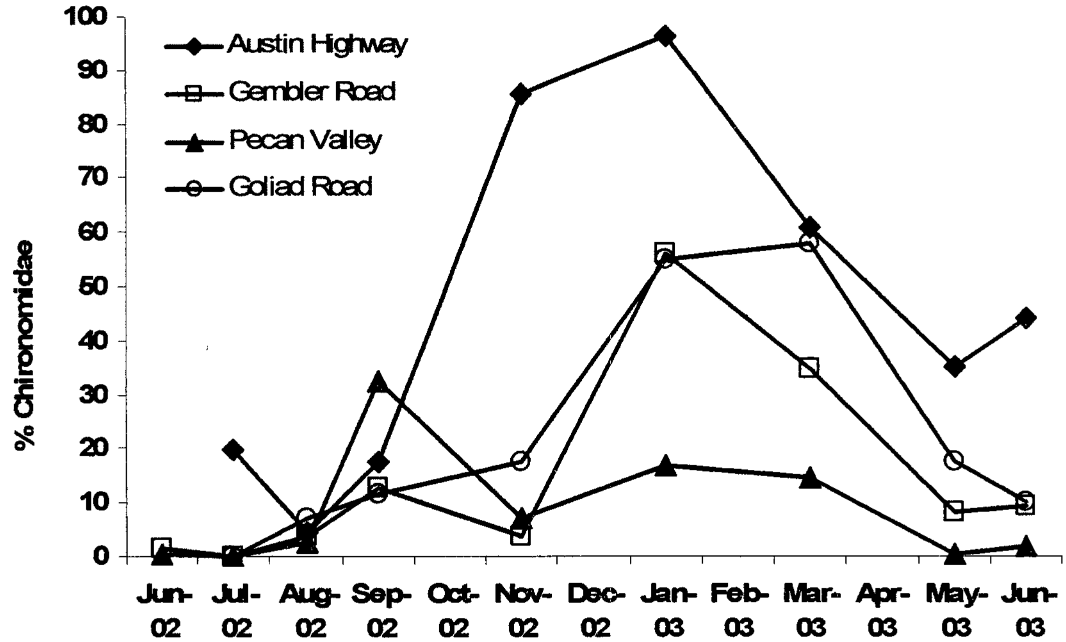


FIGURE 20. Percent Chironomidae for all sites and periods.

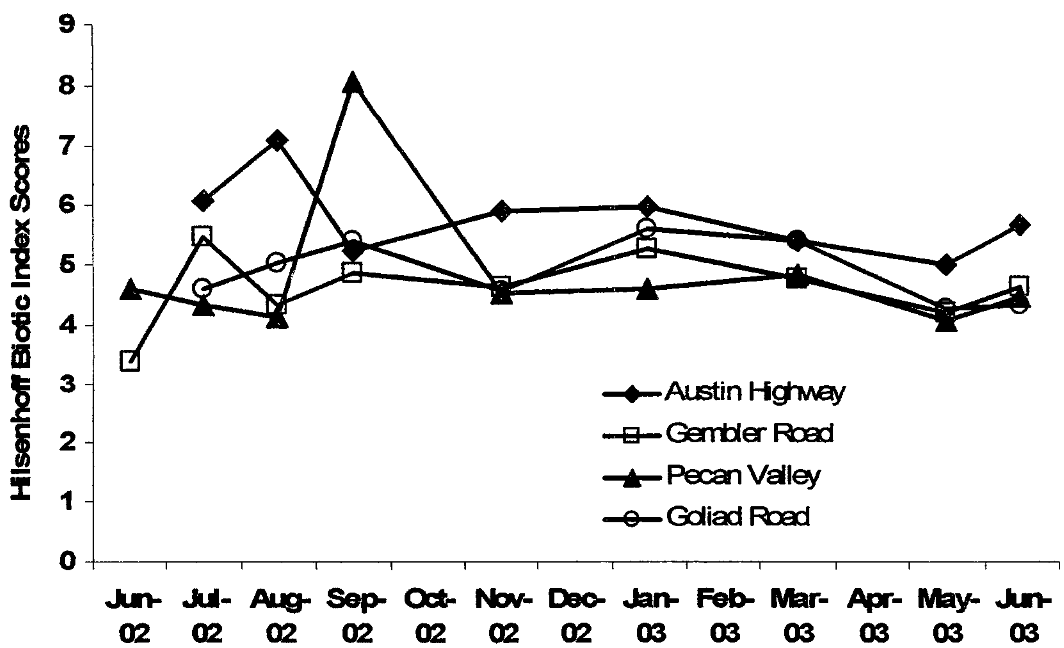


FIGURE 21. Hilsenhoff Biotic Index scores for all sites and periods.

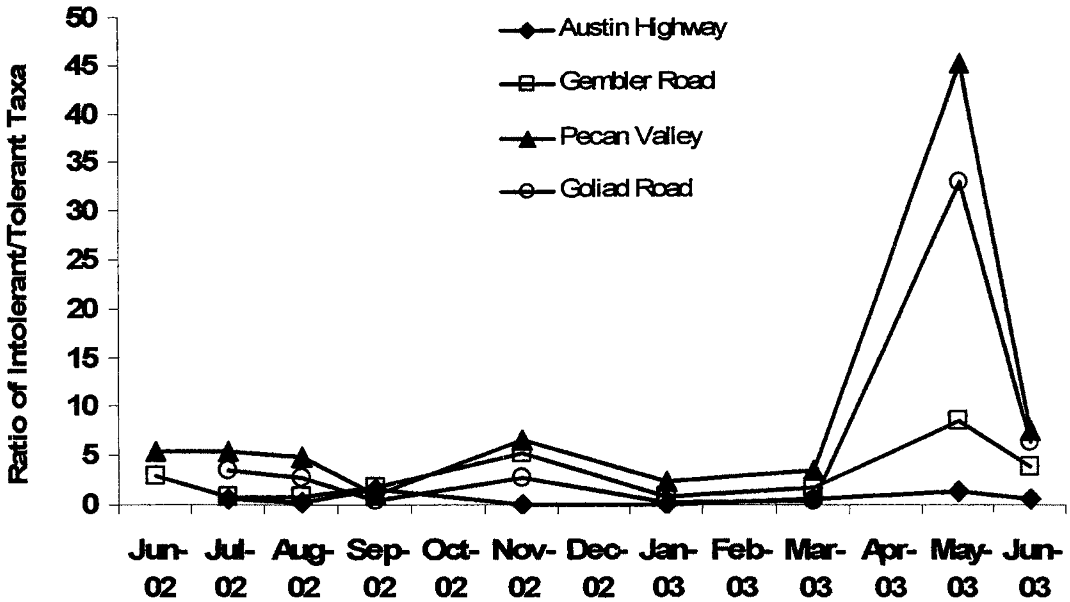


FIGURE 22. Ratio of intolerant to tolerant taxa for all sites and periods.

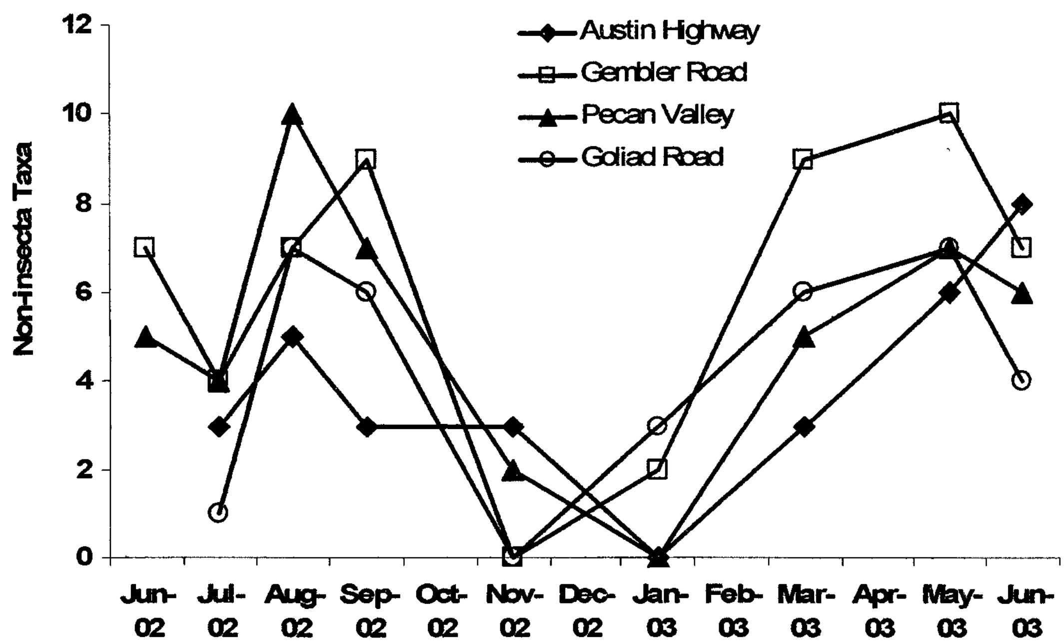


FIGURE 23. Non-Insecta taxa for all sites and periods.

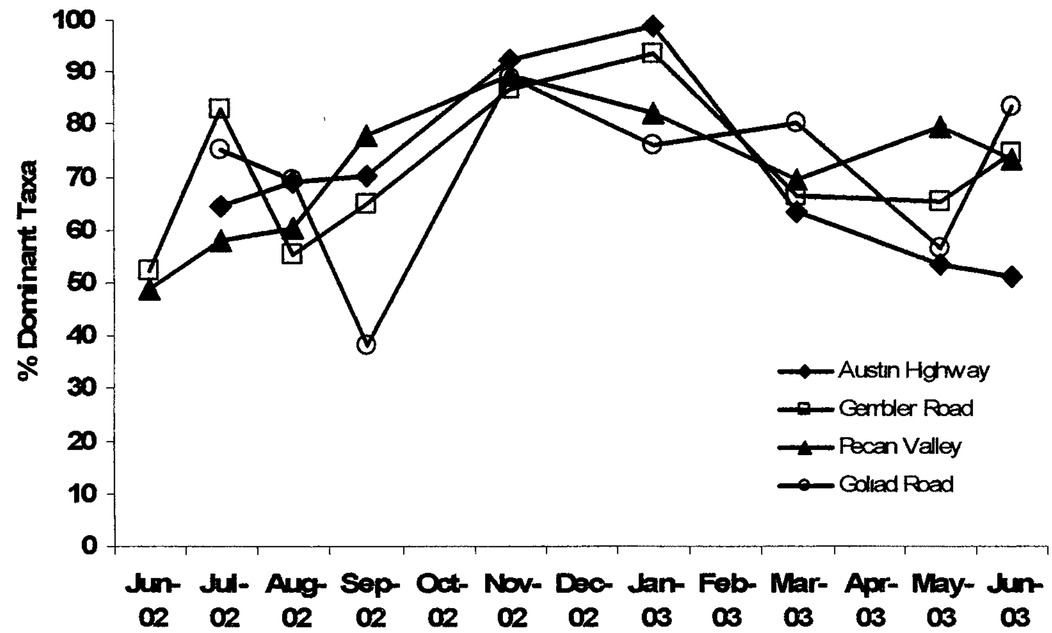


FIGURE 24. Percent dominant taxon for all sites and periods.

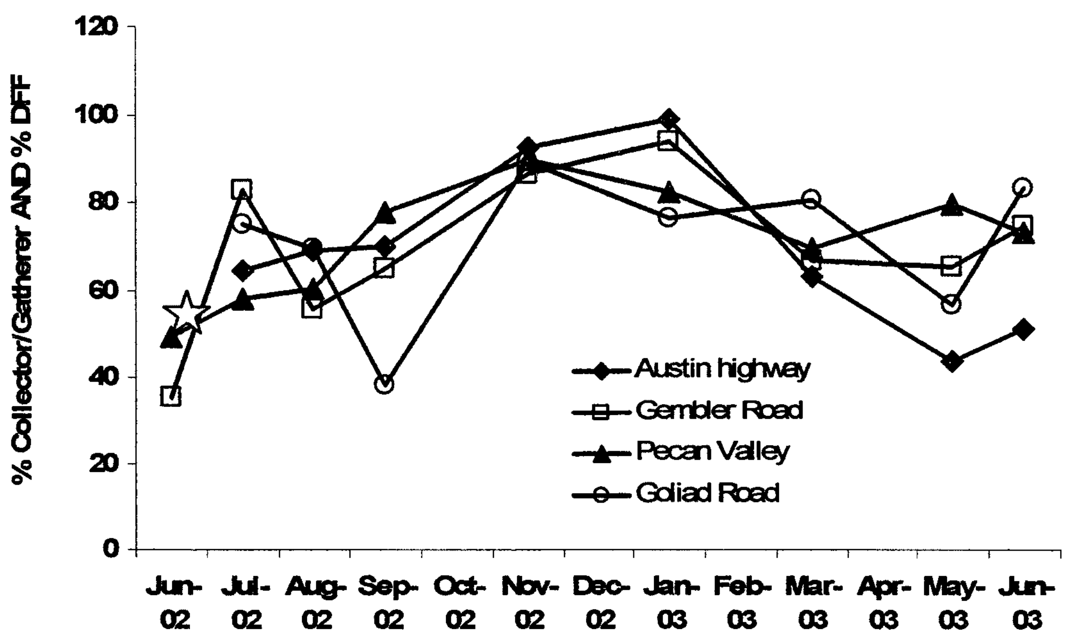


FIGURE 25. Percent of dominant functional feeding group Collector/Gatherers for all sites and sample dates. Both metrics are identical except the June 2002 sample date. The star indicates grazers are dominant at the Gembler Road site in June 2002.

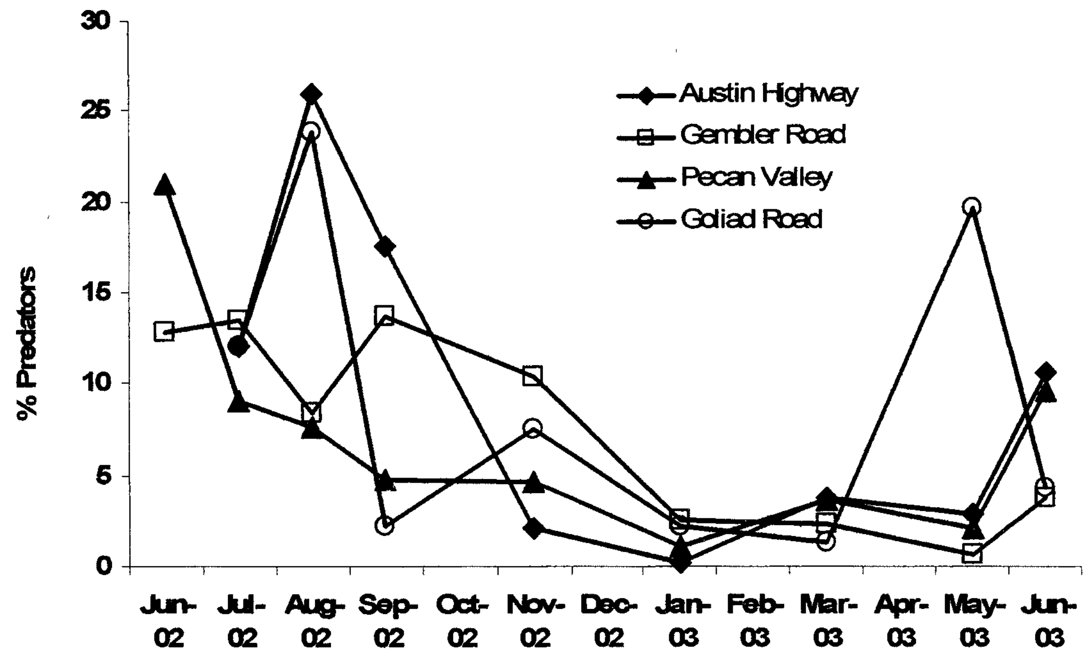


FIGURE 26. Percent predators for all sites and periods.

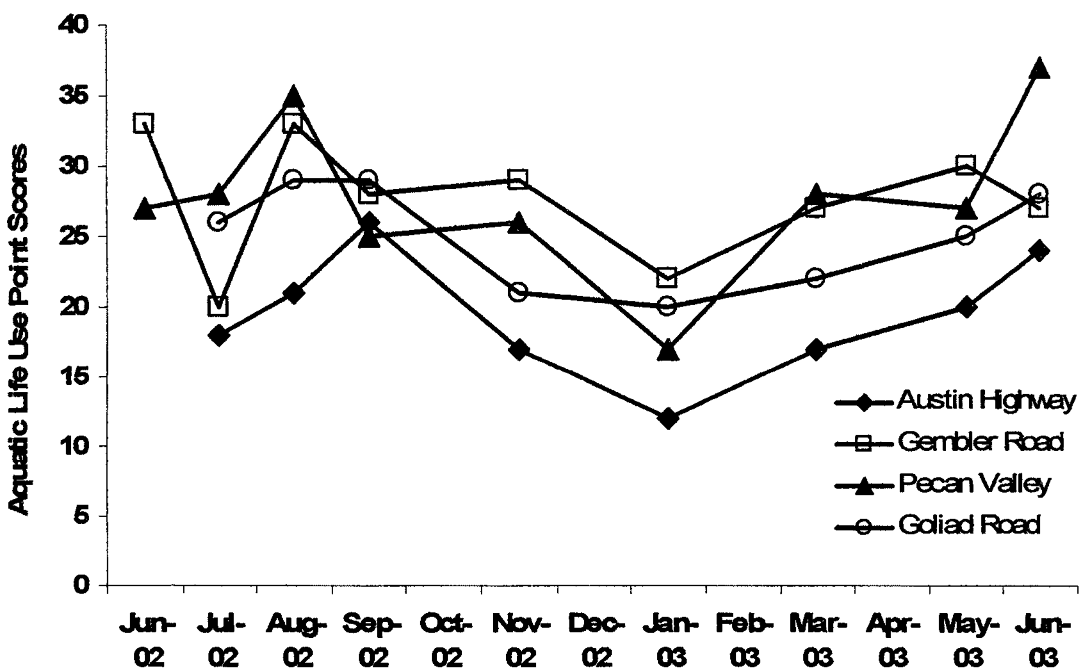


FIGURE 27. Aquatic Life Use point scores for all sites and periods.

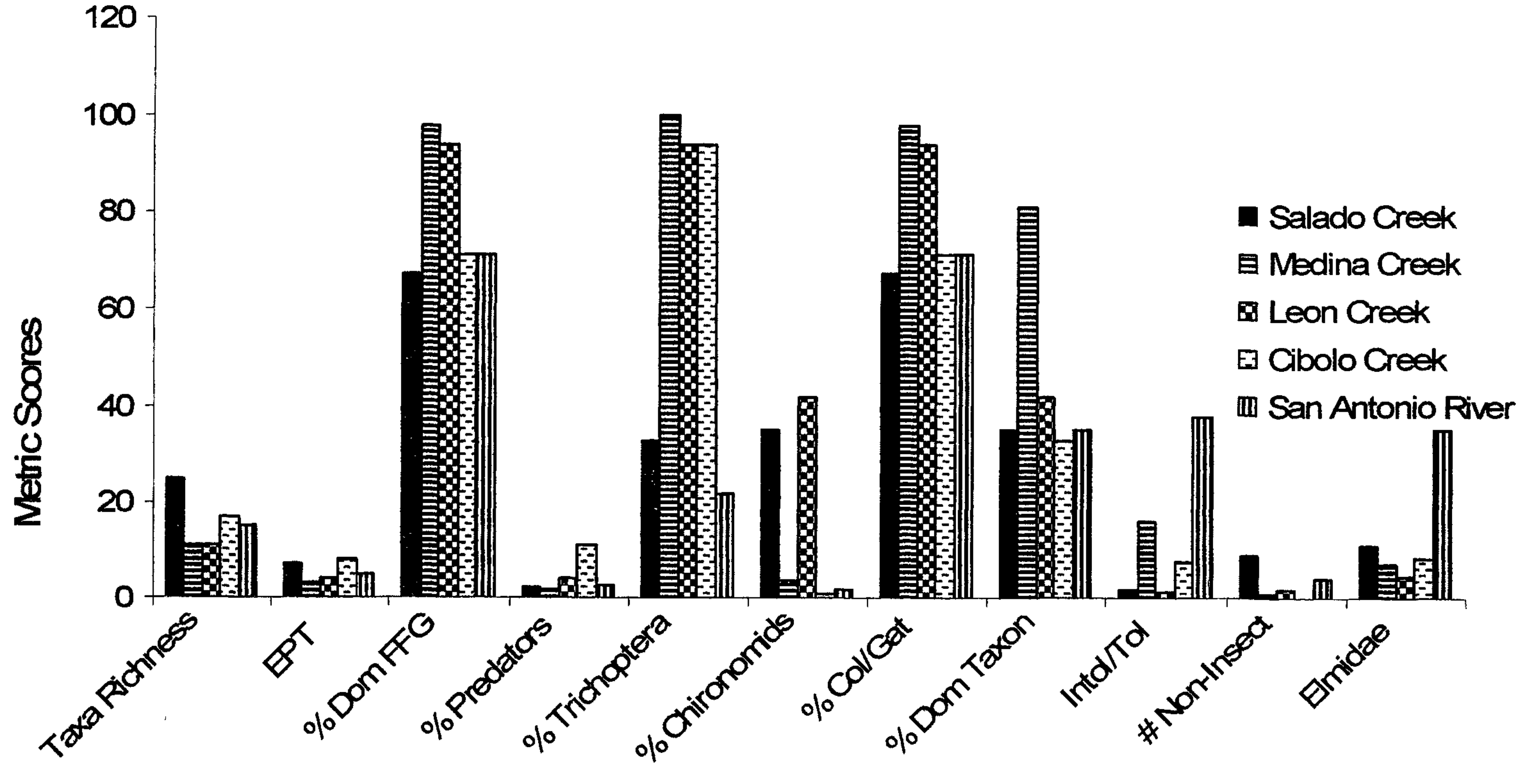


FIGURE 28. Metric score s for rivers in the San Antonio Watershed

APPENCIDES

APPENDIX 1 . Habitat Assessment Field Data Sheet

HABITAT ASSESSMENT FIELD DATA SHEET—LOW GRADIENT STREAMS (FRONT)

STREAM NAME	LOCATION	
STATION # ________ RIVERMILE ________	STREAM CLASS	
LAT ____________ LONG ____________	RIVER BASIN	
STORET #	AGENCY	
INVESTIGATORS		
FORM COMPLETED BY	DATE ________ TIME ________ AM PM	REASON FOR SURVEY

Parameters to be evaluated in sampling reach

Habitat Parameter	Condition Category			
	Optimal	Suboptimal	Marginal	Poor
1. Epifaunal Substrate/ Available Cover	Greater than 50% of substrate favorable for epifaunal colonization and fish cover; mix of snags, submerged logs, undercut banks, cobble or other stable habitat and at stage to allow full colonization potential (i.e., logs/snags that are not new fall and not transient).	30-50% mix of stable habitat; well-suited for full colonization potential; adequate habitat for maintenance of populations; presence of additional substrate in the form of newfall, but not yet prepared for colonization (may rate at high end of scale).	10-30% mix of stable habitat; habitat availability less than desirable; substrate frequently disturbed or removed.	Less than 10% stable habitat; lack of habitat is obvious; substrate unstable or lacking.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
2. Pool Substrate Characterization	Mixture of substrate materials, with gravel and firm sand prevalent; root mats and submerged vegetation common.	Mixture of soft sand, mud, or clay; mud may be dominant; some root mats and submerged vegetation present.	All mud or clay or sand bottom; little or no root mat; no submerged vegetation.	Hard-pan clay or bedrock; no root mat or vegetation.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
3. Pool Variability	Even mix of large-shallow, large-deep, small-shallow, small-deep pools present.	Majority of pools large-deep; very few shallow.	Shallow pools much more prevalent than deep pools.	Majority of pools small-shallow or pools absent.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
4. Sediment Deposition	Little or no enlargement of islands or point bars and less than <20% of the bottom affected by sediment deposition.	Some new increase in bar formation, mostly from gravel, sand or fine sediment; 20-50% of the bottom affected; slight deposition in pools.	Moderate deposition of new gravel, sand or fine sediment on old and new bars; 50-80% of the bottom affected; sediment deposits at obstructions, constrictions, and bends; moderate deposition of pools prevalent.	Heavy deposits of fine material, increased bar development; more than 80% of the bottom changing frequently; pools almost absent due to substantial sediment deposition.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
5. Channel Flow Status	Water reaches base of both lower banks, and minimal amount of channel substrate is exposed.	Water fills >75% of the available channel; or <25% of channel substrate is exposed.	Water fills 25-75% of the available channel, and/or riffle substrates are mostly exposed.	Very little water in channel and mostly present as standing pools.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0

Continued on next page

APPENDIX 1. Continued.

HABITAT ASSESSMENT FIELD DATA SHEET—LOW GRADIENT STREAMS (BACK)

Parameters to be evaluated broader than sampling reach

Habitat Parameter	Condition Category			
	Optimal	**Suboptimal**	**Marginal**	**Poor**
6. Channel Alteration	Channelization or dredging absent or minimal; stream with normal pattern.	Some channelization present, usually in areas of bridge abutments; evidence of past channelization, i.e., dredging, (greater than past 20 yr) may be present, but recent channelization is not present.	Channelization may be extensive; embankments or shoring structures present on both banks; and 40 to 80% of stream reach channelized and disrupted.	Banks shored with gabion or cement; over 80% of the stream reach channelized and disrupted. Instream habitat greatly altered or removed entirely.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
7. Channel Sinuosity	The bends in the stream increase the stream length 3 to 4 times longer than if it was in a straight line. (Note - channel braiding is considered normal in coastal plains and other low-lying areas. This parameter is not easily rated in these areas.)	The bends in the stream increase the stream length 1 to 2 times longer than if it was in a straight line.	The bends in the stream increase the stream length 1 to 2 times longer than if it was in a straight line.	Channel straight; waterway has been channelized for a long distance.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
8. Bank Stability (score each bank)	Banks stable; evidence of erosion or bank failure absent or minimal; little potential for future problems. <5% of bank affected.	Moderately stable; infrequent, small areas of erosion mostly healed over. 5-30% of bank in reach has areas of erosion.	Moderately unstable; 30-60% of bank in reach has areas of erosion; high erosion potential during floods.	Unstable; many eroded areas; "raw" areas frequent along straight sections and bends; obvious bank sloughing; 60-100% of bank has erosional scars.
SCORE ___ (LB)	Left Bank 10 9	8 7 6	5 4 3	2 1 0
SCORE ___ (RB)	Right Bank 10 9	8 7 6	5 4 3	2 1 0
9. Vegetative Protection (score each bank) Note: determine left or right side by facing downstream.	More than 90% of the streambank surfaces and immediate riparian zone covered by native vegetation, including trees, understory shrubs, or nonwoody macrophytes; vegetative disruption through grazing or mowing minimal or not evident; almost all plants allowed to grow naturally.	70-90% of the streambank surfaces covered by native vegetation, but one class of plants is not well-represented; disruption evident but not affecting full plant growth potential to any great extent; more than one-half of the potential plant stubble height remaining.	50-70% of the streambank surfaces covered by vegetation; disruption obvious; patches of bare soil or closely cropped vegetation common; less than one-half of the potential plant stubble height remaining.	Less than 50% of the streambank surfaces covered by vegetation; disruption of streambank vegetation is very high; vegetation has been removed to 5 centimeters or less in average stubble height.
SCORE ___ (LB)	Left Bank 10 9	8 7 6	5 4 3	2 1 0
SCORE ___ (RB)	Right Bank 10 9	8 7 6	5 4 3	2 1 0
10. Riparian Vegetative Zone Width (score each bank riparian zone)	Width of riparian zone >18 meters; human activities (i.e., parking lots, roadbeds, clear-cuts, lawns, or crops) have not impacted zone.	Width of riparian zone 12-18 meters; human activities have impacted zone only minimally.	Width of riparian zone 6-12 meters; human activities have impacted zone a great deal.	Width of riparian zone <6 meters: little or no riparian vegetation due to human activities.
SCORE ___ (LB)	Left Bank 10 9	8 7 6	5 4 3	2 1 0
SCORE ___ (RB)	Right Bank 10 9	8 7 6	5 4 3	2 1 0

Total Score ________

APPENDIX 2. San Antonio River Authority Benthic Worksheet Protocol II, pp 1-2 (San Antonio River Authority)

San Antonio River Authority
Benthic Worksheet Protocol II

100 E. Guenther Street
San Antonio, TX 78204
Ph (210) 227-1373 Fax (210) 302-9694

Tag Id:______________ Sample #:________________
Station Location:______________________________ Station Id:____________ Collector(s) Initials:___________
Collection Date:_________________________

	Family	Storet Code	Number Individuals (A)	Tolerance Value (B)	Feeding Group	A x B (C)	C/D (E)
Coleoptera	Dryopidae	92214		5	Grazer		
	Elmidae	92225		4	Gatherer		
	Psephenidae	92208		4	Grazer (Sc)		
Diptera	Chironomidae (Tendipedidae)	92491		6	Gatherer		
	Empididae	92627		6	Predator		
	Psychodidae	92467		2	Gatherer		
	Rhagionidae	92624		2	Predator		
	Simuliidae	92593		6	Filterer		
	Tipulidae	92420		3	Shredder		
Ephemeroptera	Baetidae	91637		4	Gatherer		
	Ephemerellidae	91615		1	Grazer		
	Heptageniidae	91607		4	Grazer (Sc)		
	Leptophlebiidae	91549		2	Gatherer		
	Siphlonuridae	91639		4	Gatherer		
	Tricorythidae	91583		4	Gatherer		
Mollusca	Ancylidae	92899		7	Grazer (Sc)		
	Corbiculidae (Cyrenidae)	93035		4	Gatherer		
	Lymnaeidae	92876		2	Grazer (Sc)		
	Physidae	92871		8	Grazer (Sc)		
	Planorbidae	92881		7	Grazer (Sc)		
Hemiptera	Naucoridae	92053		5	Predator		
	Veliidae	91918		5	Predator		
Lepidoptera	Pyralididae	92662		5	Shredder		
Odonata	Agrionidae (Coenagrionidae)	91676		9	Predator		
	Calopterygidae	91666		5	Predator		
	Gomphidae	91706		1	Predator		
	Libellulidae	91771		9	Predator		
Plecoptera	Perlidae	91876		1	Predator		
Trichoptera	Helicopsychidae	92375		3	Grazer (Sc)		
	Hydropsychidae	92289		4	Gatherer		
	Hydroptilidae	92321		4	Grazer		
	Philopotamidae	92267		3	Gatherer		
	Glossosomatidae	92315		0	Grazer (Sc)		
Tricladida	Planariidae	90074		4	Grazer (Sc)		
Megaloptera	Corydalidae	92071		0	Predator		
Hirudinea	Glossiphoniidae	90914		8	Grazer (Sc)		
	Piscicolidae	90942		8	Predator		
	Total Number of Individuals (D) [89906]				Biotic Index ($\sum$E) [90007]		

Parameter	Storet	Value	Parameter	Storet	Value
Duration of Collection	89904	5 (min.)	Kicknet Effort, Area Kicked	89903	(m²)
Biological Reporting Units	89899	1 (Subsamples)	Mesh Size-avg bar	89946	0.13 (cm)
			Number of Subsamples Sorted		

APPENDIX 2. Page 2

SAN ANTONIO RIVER AUTHORITY
Benthic Worksheet Protocol II

Station Location:______________________________ Collection Date:________________________

Parameter	Storet Code	Value
Total Number of Families	90012	#/families
EPT Index	90008	#
Dominant FFG	90010	%
Predators	90036	%
Trichoptera as Hydropsychidae	90069	%
Chironomidau	90062	%
Collector-Gatherers	90025	%
Dominant Taxon	90042	%
Ratio of Intolerant: Tolerant Individuals	90050	
Non-insect Taxa	90052	#
Total Number as Elmidae	90054	%
Benthic Kick Distance		m

Definitions	
Total Number of Families:	Total number of benthic macroinvertebrate taxa (families).
EPT Taxa:	Total number of distinct taxa (families) within the orders of Ephemeroptera, Plecoptera and Trichoptera.
Dominant Functional Feeding Group:	Ratio of the number of individuals in the numerically dominant functional feeding group to the total number of individuals x 100.
Predators:	The ratio of the number of individuals in the predator functional feeding group to the total number of individuals x 100.
Trichoptera as Hydropsychidae:	The ratio of the number of individuals in the family Hydropsychidae to the total number of individuals in the order Trichoptera x 100.
Collector-Gatherers:	The ratio of the number of individuals in the collector-gatherer functional feeding group to the total number of individuals in sample x 100.
Dominant Taxon:	The ratio of the number of individuals in the numerically dominant taxon to the total number of individuals x 100.
Ratio of Intolerant : Tolerant Individuals:	Ratio of the number of individuals in taxa with tolerance values < 6 to the number of individuals in taxa with tolerance values ≥ 6.
Non-insect Taxa:	The number of non-insect taxa (families) represented in sample.
Percent Elmidae:	The ratio of the number of individuals from the family Elmidae to the total number of individuals in sample x 100.

Table 11. Metrics and Scoring Criteria for Kick Samples, Rapid Bioassessment Protocol - Benthic Macroinvertebrates
(Harrison, 1996)

	Scoring Criteria			
Metric	**4**	**3**	**2**	**1**
Taxa Richness	> 21	15-21	8-14	< 8
EPT Taxa Abundance	> 9	7-9	4-6	< 4
Biotic Index (HBI)	< 3.77	3.77-4.52	4.53-5.27	>5.27
% Chironomidae	0.79-4.10	4.11-9.48	9.49-16.19	< 0.79 or > 16.19
% Dominant taxon	< 22.15	22.15-31.01	31.02-39.88	> 39.88
% Dominant FFG	< 36.50	36.50-45.30	45.31-54.12	> 54.12
% Predators	4.73-15.20	15.21-25.67	25.68-36.14	< 4.73 or > 36.14
Ratio of Intolerant:Tolerant Taxa	> 4.79	3.21-4.79	1.63-3.20	< 1.63
% of Total Trichoptera as Hydropsychidae	< 25.50	25.51-50.50	50.51-75.50	> 75.50 or no trichoptera
# of Noninsect Taxa	> 5	4-5	2-3	< 2
% Collector-Gatherers	8.00-19.23	19.24-30.46	30.47-41.68	< 8.00 or >41.68
% of total number as Elmidae	0.88-10.04	10.05-20.08	20.09-30.12	< 0.88 or >30.12

Aquatic Life Use Point Score Ranges:

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

APPENDIX 4. Regional Index of Biotic Integrity metric scoring (Gonzalez . 1988).

Metric	1	3	5
# fish species	<5	5-10	>10
# darter species	0	1-3	≥3
# sunfish species	0	1-2	>2
# sucker species	0	1-2	>2
# intolerant	0	1-2	>2
% green sunfish	>20%	5-20%	<5%
% omnivores	>45%	20-45%	<20%
% insectavores	0	0-45%	>45%
% piscivores	0	0-5%	>5%
# individuals in sample	<50%	50-300	>300
% hybrids	>1%	0-1%	0
% diseased	>5%	2-5%	<2%

Total Score	Integrity Class
58-60	Excellent
53-57	E-Good
48-52	Good
45-47	G-Fair
40-44	Fair
36-39	F-Poor
28-35	Poor
24-27	P-Very Poor
≤23	Very Poor

APPENDIX 5. Invertebrate taxa identified in this study.

Family	Genus	Percent
Chironomidae		24 02%
Hydropsychidae	Cheumatopsyche	16 71%
Planariidae	Dugesia	13.99%
Elmidae Stenelmis	Stenelmis	11 11%
Baetidae Baetis	Baetis	9 27%
Tricorythidae	Leptohyphes	4 05%
Simuliidae	Simulium	3.78%
Coenegrionidae	Enallagma	2 90%
Caenidae	Caenis	2 21%
Tricorythidae	Tricorythodes	2 16%
Corbiculidae	Corbicula	1.30%
Viviparidae		0 75%
Planorbidae		0 70%
Helicopsychidae	Helicopsyche	0.57%
Hydrobiidae		0.55%
Ceratopogonidae		0 48%
Physidae		0 42%
Baitidae	Camelbaetidius	0.38%
Psephenidae	Psephenus	0.37%
Leptophlebiidae	Thraulodes	0.35%
Hydropsychidae	Smicridea	0 34%
Hydroptilidae	Stactobiella	0 34%
Calopterygidae	Hetaerina	0.31%
Gammaridae	Gammarus	0.31%
Libellulidae	Brechmorhoga	0 23%
Sphaeridae		0.22%
Ancylidae		0.22%
Veliidae	Rhagovelia	0.15%
Hydrophilidae	Berosus	0 15%
Thiaridae		0.15%
Elmidae	Hexacylloepus	0.13%
Baetidae	Callibaetis	0 11%
Pilidae		0 11%
Limnephilidae (Goeridae)	Goerinae	0.11%
Hydroptilidae	Hydroptila	0.11%
Corydalidae	Corydalus	0.10%
Pyralidae	Petrophila	0 10%
Ostracoda (Order)		0 09%
Gomphidae	Erpetogomphus	0.07%
Haliplidae	Haliplus	0.07%
Glossiphoniidae		0 06%
Stratiomyidae	Odontomyia	0 06%
Tabanidae	Tabanus	0.05%
Hydropsychidae	Leptonema	0.04%
Pyralidae	Pyralus	0.04%

Continued on next page

APPENDIX 5. Continued.

Family	Genus	Percent
Gomphidae	Gomphus	0.04%
Coenagrionidae	Argia	0.04%
Dryopidae	Helichus	0.03%
Gomphidae	Phyllogonphoides	0.02%
Corduliidae	Somatochlora	0.02%
Philopotamidae	Chimarra	0.02%
Hydrophilidae	Enochrus	0.02%
Tipulidae		0.02%
Pleuroceridae		0.02%
Veliidae	Microvelia	0.01%
Leptoceridae	Mystacides	0.01%
Corduliidae	Neurocordulia	0.01%
Dytiscidae	Eretes	0.01%
Gerridae	Rheumatobates	<0.01%
Athericidae	Suragina	<0.01%
Tabanidae	Chrysops	<0.01%
Sialidae	Sialis	<0.01%
Polycentropodidae	Cyrnellus	<0.01%
Macromiidae	Macromia	<0.01%
Leptophlebiidae	Traverella	<0.01%
Leptoceridae	Nectopsyche	<0.01%
Lampyridae	Lampyridae	<0.01%
Hydroptilidae	Ochrotrichia	<0.01%
Hydrophilidae	Helochares	<0.01%
Glossosomatidae	Glossoma	<0.01%
Daphniidae		<0.01%
Curculionidae		<0.01%
Colembola (Order)		<0.01%
Coenagrionidae	Ischnura	<0.01%
Cambaridae	Procambarus	<0.01%

Macroinvertebrates were captured with a triangle frame dip net

APPENDIX 6. Taxon percent of total fish.

Genus/Species(selected)	Percent
Notropis	15.4%
Campostoma anomalum	15.1%
Astyanax mexicanus	13.8%
Lepomis cyanellus	12.0%
Gambusia	12 0%
Poecilia latipinna	9.4%
Cichlasoma cyanoguttatum	6 7%
Lepomis auritus	3.8%
Ictalurus puncatatus	3.3%
Lepomis macrochirus	2.7%
Lepomis gulosus	2 2%
Notropis amabilis	1.8%
Micropterus salmoides	0.7%
Lepomis megalotis	0.7%
Ameiurus natalus	0 4%

Fish were captured with backpack electrofisher and seine nets.

Appendix 7. Summary of IBI and ALU scores for historic Salado Creek fish and macroinvertebrate studies, (Webb 1988), (Buzan 1982) this study 2002.

Index of Biotic Integrity	Webb Study	This Study	Webb Study	This Study	Webb Study	This Study
Dates	Spring 1988	Oct-02	Spring 1988	Oct-02	Spring 1988	Oct-02
Sites	Rittiman	Austin highway	KOA Camp/ Gembler Road	Gembler Road	Goliad Road	Goliad Road
IBI Scores	38	32	40	40	36	32
	Fair	Poor	Fair	Fair	Poor to Fair	Poor

Rapid Bioassessment	Buzan Study	This Study	Buzan Study	This Study	Buzan Study	This Study
Dates	Jul-81	2002-2003	Jul-81	2002-2003	Jul-81	2002-2003
Sites	II	Austin Highway	D	Pecan Valley	B	Goliad Road
ALU Scores	24	19 4	31	27 8	25	25
	Intermediate	Limited	High	Intermediate	Intermediate	Intermediate

APPENDIX 8. Fish surveys, Buzan (1982) and this study.

Taxa Collected in this Study	*Taxa Collected by Buzan*
Astyanax mexicanus	*Astyanax mexicanus*
Campostoma anormalum	
Chaenobryttus gulosus	
Cichlasoma cyanoguttatum	*Cichlasoma cyanoguttatum*
Gambusia	*Gambusia affiniis**
Ictalurus natalus	
Ictalurus puncatatus	*Ictalurus puncatatus*
Lepomis auritus	*Lepomis auritus*
Lepomis cyanellus	
Lepomis macrochirus	*Lepomis macrochirus*
Lepomis megalotis	
Micropterus salmoides	*Micropterus salmoides*
Notropis	Notropis
Notropis amabilis	
Notropis atrocaudalis	
Notropis lutrensis	
Poecilia latipinna	*Poecilia latipinna*
	Dorsoma cepedianum
	Lepomis symmetricus
	Phenacobius mirabilis
	Polydictis olivaris

* - indicates possible match

APPENDIX 9. Summary of metric scoring for Salado Creek benthic communities, TCEQ (Davis 2003) 2001-2002, this study 2001-2003.

	TCEQ Study		This Study		TCEQ Study		
Dates	Site 1	Dates	Austin highway	Dates	Site 2	Dates	Gembler Road
Aug-01	29	Jun-02		Aug-01	30	Jun-02	33
Mar-02	32	Jul-02	18	Mar-02	28	Jul-02	20
Sep-02	24	Aug-02	21	Sep-02	30	Aug-02	33
		Sep-02	26			Sep-02	28
		Oct-02	17			Oct-02	29
		Jan-03	12			Jan-03	22
		Mar-03	17			Mar-03	27
		May-03	20			May-03	30
Mean Score		Jun-03	24			Jun-03	27
ALU Rating	28.3		19.4		29.3		27.7
	intermediate-high		limited		high		intermediate

	TCEQ Study		This Study		TCEQ Study		This Study
Dates	Site 3	Dates	Pecan Valley	Dates	Site 4	Dates	Goliad Road
Aug-01	33	Jun-02	27	Aug-01	35	Jun-02	
Mar-02	30	Jul-02	28	Mar-02	33	Jul-02	26
Sep-02	28	Aug-02	35	Sep-02	33	Aug-02	29
		Sep-02	25			Sep-02	29
		Oct-02	26			Oct-02	21
		Jan-03	17			Jan-03	20
		Mar-03	28			Mar-03	22
		May-03	27			May-03	25
		Jun-03	37			Jun-03	28
Mean Score	30.3		27.8		33.7		25 0
ALU Rating	high		intermidiate		high		intermidiate

VITA

Lene Louise Griego was born in Chicago, Illinois, on May 22, 1963, the daughter of Shirley Schrojda, wife of Al Griego and mother to Daniel, Robert, James and Elizabeth. After completing her work at St. Philips Community College, San Antonio, Texas, in 1998, she entered Texas State University-San Marcos. From August 2000-May 2001 Lene was librarian for the Department of Geography. She received the degree of Bachelor of Science in Resource and Environmental Management from Texas State University-San Marcos in May of 2001. In September of 2001 she entered the Graduate College of Texas State University-San Marcos. During the summer of 2001 she had an internship with Texas Commission on Environmental Quality. From August 2001-December 2001 Lene taught General Biology labs. From January 2003-May 2003 and again in January 2004-May 2004 she taught entomology labs. From August 2004-December 2004 she taught aquatic biology labs.

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