Benthic Community Structure and Surfactants in the Trinity River

Presented to
The Soap and Detergent Association
Surfactants in Sediments Task Force

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Executive Summary

The Trinity River in North Central Texas flows through the Dallas-Ft. Worth (DFW) metroplex area and is typical of many urban rivers in the Southwestern United States that have flows dominated by input from wastewater treatment plants (WWTPs). The domination of Trinity River flow by discharges from DFW WWTPs presents an opportunity to examine the environmental behavior of down-the-drain household chemicals in a major river system that represents near-worse case conditions. The Soap and Detergent Association (SDA) "Surfactants in Sediments Task Force" sponsored the current study in collaboration with the University of North Texas (UNT) Institute of Applied Sciences and EA Engineering, Science, and Technology, Inc., to examine potential ecological effects of surfactants in the Trinity River in the DFW metroplex area by looking at sources of surfactants, fate, and possible indicators of effects due to surfactants in environmental media. A workshop and a series of conference calls between SDA, UNT, and EA, produced a study design that examined the Dallas-Ft. Worth area as a single, internally variable source of surfactants to the Trinity River. The study looked at reference sites upstream of Dallas WWTP inputs, WWTP effluent and mixing zone sites within the metroplex, and downstream sites where inputs and concentrations were expected to decrease.

All field sampling was conducted between 9/30/05 and 10/07/05. Surface water, sediment interstitial water, and sediment were collected from each riverine location and effluent from each of 4 major WWTPs in DFW. Samples were analyzed for the surfactants alcohol ethoxylates (AE), alkyl ethoxysulfates (AES), and linear alkyl benzene sulfonates (LAS), as well as general in-stream chemistries and characteristics. Surfactant concentrations were converted to equivalent Toxic Units (TU) for surface water and pore water by the members of the SDA Surfactants in Sediments Task Force. Benthic macroinvertebrate community structure and habitat were assessed. Population metrics for the benthic macroinvertebrate populations were total number of individuals, richness, diversity, evenness, and population changes and community composition. Furthermore, Geographical Information Systems (GIS) was used to characterize several geospatial factors that may influence surfactant sources and fate.

Individual surfactant TUs were found to be very low in the Trinity River flowing through DFW, and thus were combined to produce total TUs for surface water and pore water. Total TUs, though, were still very low, ranging from 0.06-0.14 for surface water and 0.11-0.31 for pore water. WWTPs did not appear to be as big a contributing factor to surfactants TUs as previously thought, i.e., TU distribution along the Trinity River did not show the same pattern as WWTP-dependent parameters, such as total dissolved solids. There was no correlation between surfactant surface water or pore water toxic units with any benthic variable (Pearson's correlation procedure).

Historical data and analyses from 1987 and 1992 allowed for comparisons with current in-stream chemistries, benthic macroinvertebrate communities, and geospatial factors in this rapidly urbanizing region. In general, in-stream water quality has improved in the upper Trinity River since the last ecological survey conducted by UNT. However, there was little or no change in distribution and pattern for in-stream water quality parameters throughout the DFW metroplex. The benthic data collected in October 2005 was compared to the August 1988 data. Clear Creek was not included in the comparison as it was not sampled in August 1988, and represents a distinctly different benthic habitat compared to that found in the Trinity River. Fifty taxa are reported from the 1988 data as compared to 112 taxa in 2005, with higher numbers of Oligochaeta and Chironomidae in 2005. Benthic macroinvertebrate population densities

decreased downstream of wastewater treatment plant outfalls in 2005 and 1988, with the exception of downstream of Dallas Central WWTP (station 10). In 1988, benthic populations downstream of the confluence with the East Fork (station 14) to Palestine (station 15) increased, whereas in 2005 they decreased. Species richness is higher in 2005 except at stations 06, 08, 12, and 15. Location community similarities changed from 1988 to 2005. Clustering analysis indicate that in 2005, a major cluster of the metroplex locations is formed, whereas in 1988 there is a separation of the upstream and downstream sites of the metroplex. This analysis indicates that community compositions of the 2005 study locations within the metroplex are more homogeneous than that of the 1988 study. Land use has also changed rapidly over the past 18 years, with dramatic increases in residential and urban land uses and corresponding decreases in agricultural and forested land uses.

In-stream, benthic, and geospatial data were then used in multiple regression and multivariate analyses to predict surfactant TUs and benthic macroinvertebrate ecology. With 18 geospatial parameters, 26 in-stream water quality parameters, 2 toxic unit parameters, and 12 benthic macroinvertebrate ecology and habitat parameters, models predicting TUs and benthic ecology would violate statistical limitations. Thus, the number of parameters were limited by statistical criteria, such as Pearson's correlation analyses, Mallow's C(p) statistical analyses, and subjective evaluation (**Table Executive Summary-1**). Fifteen parameters were useful for predicting TUs, with slope, average annual rainfall, near-field residential land use, and near-field area as the top 4 parameters. Seven parameters were useful for predicting benthic ecology, with in-stream cover, width, surface water total organic carbon as the top 3 parameters. Near-field urban land use was useful for predicting both TUs and benthic ecology. While we were quite capable of predicting many in-stream benthic ecology characteristics, few of these predictions were substantially influenced by surfactant toxic units (**Figure Executive Summary-1**). The parameters in Table Executive Summary-1 indicated that these variables may be important for analyzing surfactant TUs and benthic ecology in the upper Trinity River watershed, and may be worth further evaluation in future projects.

Table Executive Summary-1 – Parameters analyzed and occurrence in models.

Analysis of Parameters Used to Analyze Surfactant Toxic Units and Benthic Community Health			
Total Parameters	**Parameters Utilized for Statistical Analyses**	**Number of Times Occurring in Final Models**	
58 total	**52 total**	**Toxic Units**	**Benthos**
Geospatial Parameters (18 total)			
Slope	X	2	
Avg Annual Rainfall	X	2	
Avg Soil Erodibility	X	1	
Avg Organic Matter Content	X	1	
Near-Field Land Use			
Agriculture	X	1	
Forest	X [b]		3
Residential	X	2	
Urban	X [b]	1	3
Water	X		
Area	X	2	
2000 Population Density	X	1	
Far-Field Land Use	X		
Agriculture	X		
Forest	X		
Residential	X		
Urban	X		
Water	X [b]		5
Area	X		
2000 Population Density	X		
Surfactant Toxic Units (2 total)			
Surface water sums	X [a]		5
Pore water sums	X [a]		
In-Stream Water Quality Parameters (26 total)			
Surface Water			
Flow	X		
Temp	X		
Conductivity	X		
DO	X		
pH	X		
Redox Potential	X		
Turbidity	X		
TSS	X		
COD	X	1	
Hardness	X	1	
TDS	X		

Analysis of Parameters Used to Analyze Surfactant Toxic Units and Benthic Community Health			
Total Parameters	**Parameters Utilized for Statistical Analyses**	**Number of Times Occurring in Final Models**	
58 total	**52 total**	**Toxic Units**	**Benthos**
TOC	X [b]		5
Chloride			
Pore Water			
TSS	X		
Hardness	X	1	
TDS	X	1	
TOC	X	1	
Sediment			
Cation Exchange Capacity	X	1	
Nitrogen, Total Kjeldahl	X		
Phosphorus, Total	X		
Sulfide	X		
TOC	X		
Gravel	X		
Sand	X		
Fines	X		
Moisture	X		
Benthic Community (12 total)			
Habitat Quality Index Score (HQIS)	X		3
In Stream Cover	X		7
Width	X		6
Depth			
Riffle			
Erosion			
Subjective Designation of Habitat Aesthetics			
Bottom Substrate Stability Score			
Dimensions of Largest Pool			
Sinuosity			
Sediment shaker analysis			
Native vegetation			
Average Flow			
# Total Models		2	8

[a] indicates that these independent variables were included in the multiple regression models at the request of SDA and otherwise would not have passed the decision criteria to be used for modeling purposes.
[b] indicates that these independent variables were used for both toxic unit and benthos modeling.

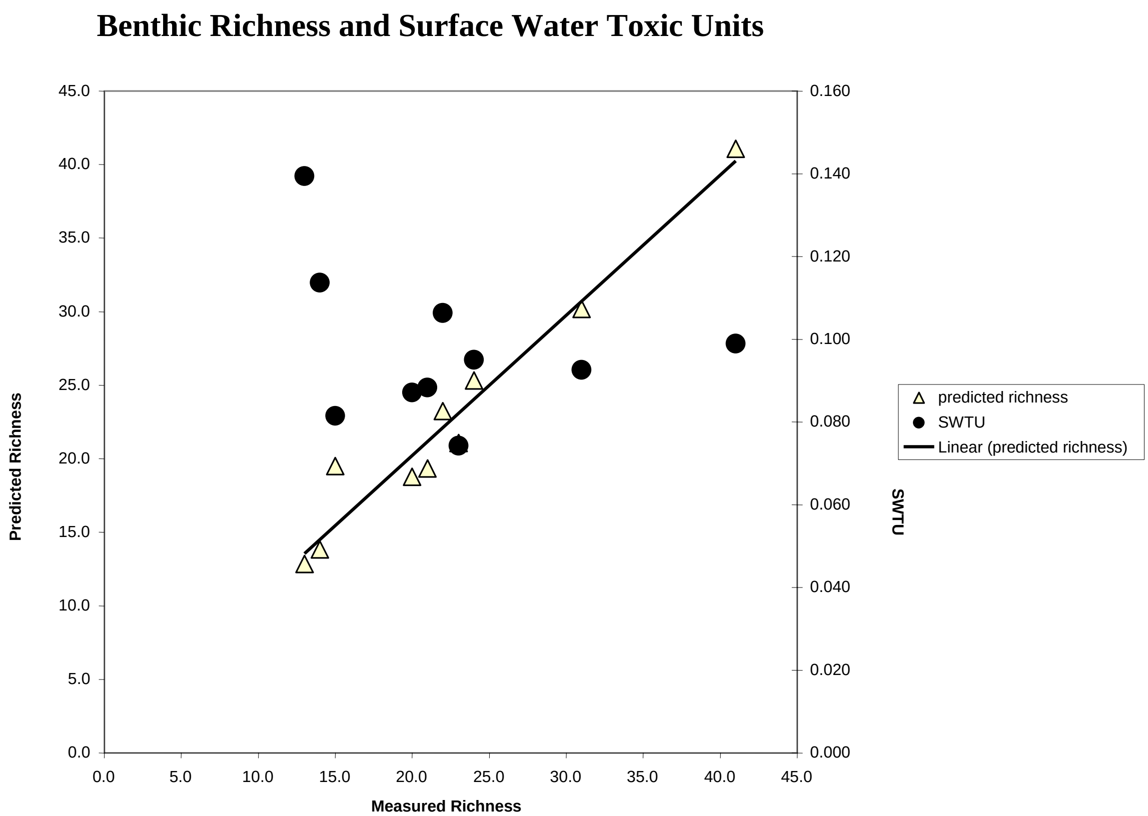


Figure Executive Summary 1. Measured and predicted benthic macroinvertebrate taxa richness at 10 Trinity River sites (triangles) and corresponding surface water toxic units (SWTUs) for each site (circles).

Table of Contents

Table of Contents (contd.)

LIST OF FIGURES

LIST OF FIGURES (contd.) Page

LIST OF FIGURES (contd.) Pages

LIST OF FIGURES (contd.) Pages

LIST OF TABLES

Introduction

The Trinity River in North Central Texas flows through the Dallas-Ft.Worth (DFW) metroplex area and is typical of many urban rivers in the Southwestern United States that have flows dominated by input from wastewater treatment plants (WWTPs). There are 15 WWTPs discharges to the Trinity River in DFW that enter the system below reservoirs on the West, Elm and East Forks of the river. The first and largest discharge (capable of processing 166 mgd) comes from the City of Fort Worth's Village Creek WWTP. Under low flow conditions this discharge contributes 95% or greater of the flow of the river. The next large WWTP discharge to the river is from the Trinity River Authority (TRA) Central Plant (162 mgd). Just below this discharge, the Elm Fork of the Trinity joins the West Fork. The West Fork carries more than 22 mgd of flow from three WWTPs. The City of Lewisville is the largest (12 mgd) followed by the City of Flower Mound (10 mgd). The next large plant downstream is the City of Dallas' Central WWTP (200 mgd) followed by Dallas' Southside Plant (110 mgd) and then the TRA Ten Mile Creek plant (20 mgd). Below the discharge of the Ten Mile Creek plant, the East Fork of the Trinity River joins the West and East Forks to create the main stem of the Trinity River. The East Fork carries discharges from seven WWTPs with a total flow of 86 mgd. The total discharge to the Trinity River in the DFW metroplex, excluding those plants that first discharge into a reservoir, is in excess of 900 mgd.

The domination of Trinity River flow by discharges from DFW presents an opportunity to examine the environmental behavior of down-the-drain household chemicals in a major river system that represents near worst-case conditions. The Soap and Detergent Association (SDA) "Surfactants in Sediments Task Force" sponsored the current study in collaboration with University of North Texas Institute of Applied Sciences and EA Engineering, Science and Technology Inc. to examine potential ecological effects of surfactants in the Trinity River in the DFW metroplex area. The study was initiated via a workshop and series of conference calls conducted to determine the general goals for the project and selection of the study sites. The workshop, held at UNT August 17-18, 2005, included presentations by UNT, SDA and local authorities on the general characteristics of the Trinity River watershed and its WWTP inputs to the watershed and resulted in the study design described below. The overall intent of the project was to provide a preliminary assessment of the influences of watershed land use, drainage/soil characteristics, WWTP discharges and in-stream physical/chemical characteristics on the distribution of surfactant residues and macrobenthic community structure. This preliminary assessment was to identify the most important influences, place them in historical context of previous studies and lay the groundwork for preparation of a more comprehensive plan of study to be used in seeking outside funding for future research.

Chapter I

The Trinity River Watershed

"A stench from its inky surface putrescent with the oxidized processes to which the shadows of the over-reaching trees add styxian blackness and the suggestion of some mythological river of death. With this burden of filth the purifying agencies of the stream are prostrated; it lodges against obstructions in the stream and rots, becoming hatcheries of mosquitoes and malaria. A thing of beauty is thus transformed into one of hideous danger."

-Texas Department of Health description of the Trinity River in 1925

General Description

The Trinity River basin is one of the most heavily developed watersheds in Texas, despite making up only 6% of the state's area. It provides the drinking water for the Dallas-Ft. Worth metroplex to the north, as well as Houston to the south. In all, the Trinity River basin provides drinking water for approximately half of the State's population (TRA, 2006a).

The Trinity River consists of three main branches, the West Fork, the Elm Fork, and the East Fork, all of which converge into the main stem of the Trinity River near or within the Dallas-Fort Worth metroplex (DFW). A minor branch of the Trinity River, the Clear Fork, converges with the West Fork near Ft. Worth. The Trinity River runs 423 miles from the headwaters of the West Fork to the Gulf of Mexico, making it the longest river completely contained within Texas (Handbook, 2001a). Overall, the Trinity River basin encompasses 17,969 square miles, and the watershed area encompassed by this study includes 12,866 square miles of the upper Trinity River watershed, approximately 70% of the entire Trinity River watershed (Figure I-1).

All four Forks of the Trinity River are found in the upper Trinity River watershed. The West Fork begins southeast of Archer City in Archer County (approximately 350.8 meters (1157.6 feet) mean sea level (MSL)) and runs southeast for 145 miles through Jack, Wise, and Tarrant counties, until it converges with the Elm Fork to form the main stem of the Trinity River (Handbook, 2001b). The West Fork contains six reservoirs: Lake Amon G. Carter, southwest of Bowie; Lake Bridgeport, west of Bridgeport; Eagle Mountain Lake, northwest of Ft. Worth; Lake Worth, in western Ft. Worth; Lake Arlington, east of Ft. Worth; and Joe Pool Lake, south of Grand Prairie.

The Elm Fork begins south of the city of Saint Jo in Montague County (approximately 344.6 meters (1137.2 feet) MSL) and runs southeast for 85 miles through Cooke, Denton, and Dallas Counties before the confluence with the West Fork to form the main stem of the Trinity River (Handbook, 2001c). The Elm Fork contains 3 reservoirs: Lewisville Lake, north of Lewisville; Lake Ray Roberts, a few miles north of Lewisville Lake; and Grapevine Lake, north of the city of Grapevine.

The East Fork begins northwest of Dorchester in Grayson County (approximately 264.0 meters (871.2 feet) MSL) and runs south for 85 miles through Collin, Rockwall, Dallas, and Kaufman Counties before converging with the main stem northeast of the city of Ennis (approximately 96.2 meters (317.5 feet) MSL)(Handbook, 2001d). The East Fork contains 2 reservoirs: Lake Lavon, southeast of McKinney; and Lake Ray Hubbard, a few miles south of Lake Lavon and northwest of Rockwall.

The smaller Clear Fork begins south of the Jack County/Parker County border (approximately 364.0 meters (1201.2 feet) MSL) and runs 56 miles through Parker and Tarrant counties before convergence with the West Fork (approximately 156.9 meters (517.8 feet) MSL) (Handbook, 2001e). The Clear Fork contains 2 reservoirs: Weatherford Lake, east of Weatherford; and Benbrook Lake, southwest of Ft. Worth. The reservoirs in the upper region of the Trinity River basin were constructed to control seasonal flooding and to provide municipal water supplies (Handbook, 2001a).

The main stem of the Trinity River—at the confluence of the West Fork with the Elm Fork (approximately 121.3 meters (400.3 feet) MSL)—to Palestine, TX, runs through Dallas, Kaufman, Ellis, Henderson, Navarro, Freestone, and Anderson Counties. The main stem contains several reservoirs, including White Rock Lake, near downtown Dallas; Cedar Creek Reservoir, near the city of Trinidad; Lake Waxahachie and Bardwell Reservoir, near Waxahachie and Ennis, respectively; and Richland-Chambers Reservoir, south of Trinidad.

Climate

The climate in the upper Trinity River watershed varies due to its geographical location. The DFW area is described as humid subtropical with hot summers, but also continental with a wide annual temperature range (NWS, 2005a). Figure I-2 shows average monthly temperatures, as recorded by the National Weather Service for 1898 through 2005, as well as the average temperatures for the 12 months prior to the collection period (NWS, 2005b). The average coldest temperatures occur in January (44.1º F/6.72º C), and the average hottest temperatures occur in July (85º F/29.4º C). The year prior to the collection period showed slightly warmer than normal temperatures during the winter months (December, January, and February) and the summer months (June, August, and September). Spring and fall months were consistent with average monthly temperatures.

There is also a wide variation of precipitation that falls in the upper Trinity River watershed (Figure I-3). There is an approximately 10-inch difference in rainfall between the rainfall at the headwaters of the West Fork and the bottom of the watershed. Figure I-4 shows average monthly precipitation, as well the average precipitation for the year prior to the collection period, and Figure I-5 shows the cumulative precipitation for the year prior to the collection period. In general, there is a wet season and a dry season in the upper Trinity River watershed. Maximum precipitation occurs in May (5.15 inches) and minimum precipitation occurs in January (1.9 inches), resulting in a yearly average of 34.73 inches (NWS, 2005b). Summer months (July, August, and September) rarely produce more than 2.5 inches of rain per month. During the year prior to the collection period, monthly precipitation declined in February and continued to be lower than average for the remaining months. This ultimately resulted in a 7.02-inch deficiency in cumulative precipitation from September 2004 to September 2005 (Figure I-5), causing stream, river, and reservoir levels to be well below average for that time of year (see flow section below).

Ecoregions, Soils, and General Land Cover/Land Use

An ecoregion is an area with general similarities in ecosystems and in the type, quality, and quantity of environmental resources (USEPA, 2006). The upper Trinity River watershed spans 10 different level IV EPA ecoregions, as defined by the level IV classification method (Figure I-6) (Anderson et al., 1976). However, there are 8 that best characterize the upper Trinity River watershed: Red Broken Plains, the Cross Timbers (east and west), Grand Prairie, Northern Blackland Prairie, the Post Oak Savannah (northern and southern), and the floodplains and low terraces.

Broken red plains (Level IV Texas ecoregion 27i): This region is located in the western most area that feeds streams and tributaries of the West Fork. Part of the Central Great Plains, soils consist mainly of sand and red clay. The terrain is near level to hilly and covered with natural vegetation. This ecoregion is used primarily for grazing. Cattle are the main agriculture product of this region. Oil and gas production have also been important business in this ecoregion (Land et al., 1998).

Western and Eastern Cross timbers (Level IV Texas ecoregions 29b & 29c): The Cross Timbers are transitional regions between the once prairie to the west and the forested low mountains or hills of eastern Texas and Oklahoma (USEPA, 2006). They encompass the areas that feed most of the streams and tributaries of the West Fork, and feed the Elm Fork in the north and the Clear Fork to the south. The Cross Timbers contain irregular plains with low hills and tablelands, as well as a mosaic of forest, woodland, savannah, and prairie (USEPA, 2006). Oil, natural gas, and coal production has occurred in this region for the past 80 years.

The Western Cross Timbers region is located northwest of Ft. Worth. It has fine sandy loams with clay sub soils that retain water (USEPA, 2006). Eastern portions support the dairy industry, pasture land, and farming (forage sorghum, silage, corn, and peanuts). Sample site SDA05-02 is located within the Western Cross Timbers.

The Eastern Cross Timbers region crosses through east Ft. Worth and many of the mid-cities of DFW, including Denton to the north. Located between the Grand Prairie and the Blackland Prairies, the Eastern Cross Timbers consists of sandy substrate that has been leached of nutrients (USEPA, 2006). Extensive urban development occurs within the Eastern Cross Timbers, yet there is still a lot of rural land used for cattle grazing and farming (peanuts, grain sorghum, pecans, peaches, and vegetables). Sample site SDA05-04 is located within the Eastern Cross Timbers.

Grand Prairie (Level IV Texas ecoregion 29d): This ecoregion crosses through most of Ft. Worth. It feeds the streams and tributaries to the West, Elm, and Clear Forks. The terrain of the Grand Prairie has a rougher, yet nearly level, appearance due to the erosion-resistant Lower Cretaceous limestone (Land et al., 1998; USEPA, 2006). Grazing occurs in the shallow soils, while farming (corn, grain sorghum, and wheat) occurs in the deeper soils. Sample site SDA05-03 is within the Grand Prairie.

Northern Blackland Prairie (Level IV Texas ecoregion 33a): The Blackland Prairies ecoregion covers most of the rest of DFW, including Dallas and the cities to the northeast of the watershed. It also extends down to the region around Navarro Mills Lake. The Blackland Prairie ecoregion feeds all the streams and tributaries of the East Fork, the eastern streams and tributaries that run to the Elm Fork, and streams and tributaries to the Trinity River main stem from the confluence of the West and Elm Forks to approximately Ennis, TX. This region distinguishes itself from adjacent regions by fine-textured, clayey soils and predominantly prairie potential natural vegetation (USEPA, 2006). There is a higher proportion of cropland than adjacent regions due to its fertile soil, though pasture for livestock is common (Land et al, 1998). This region is being encroached by human development, resulting in land conversion to urban and industrial uses. Sample sites SDA05-02, 6, 8, and 10 are within the Blackland Prairies.

Northern and Southern Post Oak Savannah (Level IV Texas ecoregions 33a and 33b): Consisting of irregular plains originally covered with post oak trees, this region is a subtle transition of soil and vegetation. Soils tend to be acidic, with sands and sandy loams in the uplands and clay to clay loams in the low-lying areas (USEPA, 2006). Many areas have a dense, underlying clay pan affecting water movement and available moisture for plant growth (USEPA, 2006). Pasture and range are the main functions of this ecoregion today. The Northern Post Oak Savannah's current land cover consists of more improved pasture and less post oak woods and forests (USEPA, 2006), while the Southern Post Oak Savannah's current land use consists of a mix of post oak woods, improved pasture, and rangeland (USEPA, 2006).

Floodplains and Low Terraces (Level IV ecoregions 32d & 33f): Floodplains and low terraces are mainly described within the Blackland Prairie and Post Oak Savannah ecoregions. Many floodplains contain hardwood forests, though much of the land has been converted to cropland and pastures, especially in the Blackland Prairies ecoregion (USEPA, 2006). More of the hardwood forests are retained in the floodplains and low terraces in the Northern and Southern Post Oak Savannahs than in the Blackland Prairies (USEPA, 2006). The creation of major reservoirs within the Trinity River basin has significantly reduced the historical magnitude and the frequency of floods within the floodplains (Land et al., 1998). Sample sites SDA05-12 and 13 are located within the floodplains and low terraces within the Blackland Prairie ecoregion, and sample sites SDA05-14 and 15 are located within the floodplains and low terraces within the Post Oak Savannah ecoregions.

Population

North central Texas has experienced significant growth within the past one hundred years (TWDB, 2006). In 1900, the population in north central Texas was approximately 600,000. Growth was relatively flat until 1960 when significant growth occurred in Dallas and Tarrant counties. In 1980, the total population of north central Texas was over 3 million people. In 2000, the total population was 5.25 million people, a 70% increase in 20 years (Figure I-7) (TWDB, 2006). Future predictions put the north central Texas population at 8 million in 2020 and over 13 million by 2060. The majority of this growth is expected to occur in Dallas, Denton, and Collin counties (> 1,000,000 people); Tarrant, Rockwall, Grayson, Ellis, and Kaufman counties (100,000-1,000,000 people); and Parker and Henderson counties (80,000-100,000 people) (TWDB, 2006).

This population influx is having a big change in land usage in the region around the Dallas-Ft. Worth metroplex (DFW). Figure I-9 is a satellite image of DFW in 1987 and Figure I-10 is a satellite image of DFW in 2004. From these pictures alone it is easy to tell that there has been a dramatic increase in residential and urban land usage around DFW in a 17-year period. Additional land use analysis in the upper Trinity River watershed is described below in the GIS analysis section of this report.

Trinity River

Since the founding of Dallas by settlers in the mid 1800s, The Trinity River has been highly impacted by human activity. Decades of abuse and neglect by industry, agriculture, and livestock processing plants resulted in the less-than-desirable reputation of being a "river of Death" as reported by the Texas Department of Health in 1925. With the passing of the Federal Water Pollution Control Act of 1972 and the Clean Water Act of 1977, the Trinity River waters began to slowly improve. The improvements in water quality in the Trinity River basin is a welcome change since much of the Trinity River and its streams have been altered to meet citizens' needs for flood control, drinking water, and recreation sources.

Flow. The Trinity River flow is closely related to both natural and anthropogenic sources. Rainfall patterns in north central Texas result in high river flow in the spring, a dramatic decline in the summer, and a rise to moderate levels in the fall. During the summer, most of the river flow is a result of the effluent discharge from wastewater treatment plants (WWTPs). In fact, up to 95% of summertime flow can be attributed from WWTPs. This attribute makes the Trinity River ideal for studying surfactants at the end of summertime.

Figures I-11a-h show the average monthly flows (blue bars) measured by USGS monitoring stations from 1987 to 2005 at or near this study's sample sites. These data show that flow in these river segments follow the typical seasonal flow pattern. These graphs also show the monthly flow from September 2004 through September 2005 (pink bars). The seven inch rainfall deficit mentioned above is reflected in the September 2004-2005 river flows. This feature was ideal for this study. Closer inspection of the flows shows that there was very little change in flow in the 30 days prior to the study sample collection period (September 30-October 5) (Figures I-12a-h). There was a rain event around September 15, but flows quickly returned to normal. Furthermore, flows were not affected by Hurricane Rita, as shown by flow data on September 23-25, 2005 (indicated as the red bar in Figures I-12a-h). The one exception may be sample site SDA05-12 (East Fork), as shown by the flow increase around September 29.

Drinking water usage. The Trinity River watershed is the main source (90%) for drinking water for residents in north central Texas. Much of the drinking water for DFW is provided by reservoirs within the Upper Trinity River Watershed (Table I-1). However, because of the growth and demand for more water in north central Texas, water supplies are more complex than simply the local reservoir, and include interbasin transfers from other reservoirs (TRA, 2006a). The largest drinking water suppliers in the upper Trinity River watershed are the Trinity River Authority (TRA), the City of Dallas, the City of Ft. Worth, Tarrant Regional Water District (TRWD), and North Texas Municipal Water District (NTMWD).

Trinity River Authority (TRA) operates several regional water treatment systems, though only one treatment facility is within the Upper Trinity River Watershed (TRA, 2006a). The Tarrant County Water Supply Project draws raw water from Cedar Creek and Richland-Chambers Lakes in East Texas and in the southern portion of the Upper Trinity River Watershed. The water is piped into Village Creek, the principal tributary of Lake Arlington in south central DFW. Water is piped out of Lake Arlington, treated, and delivered to the cities of Bedford, Euless, and Colleyville, and parts of Grapevine and North Richland Hills. Several expansions since its establishment in 1974 allow this treatment facility to provide 72 MGD of water to customers, with the potential for further upgrades in excess of 100 MGD. The Lakeview Regional Water Supply Project provides raw water from Joe Pool Lake for the cities of Cedar Hill, Duncanville, and Grand Prairie, though no treatment plant has been built yet. The Ellis County Water Supply Project supplies several entities within Ellis County with a raw water supply (more than 14 MGD) from Tarrant Regional Water District's Richland-Chambers and Cedar Creek reservoirs. But like the Lakeview Project, the Ellis County Project also does not currently have a treatment facility.

The City of Dallas' Water Utilities Department provides water for about 2.3 million customers in and around Dallas, a service area of 699 square miles (Dallas, 2006). Water for Dallas is supplied by Lake Lewisville, Lake Grapevine, Lake Ray Hubbard, and Lake Ray Roberts, as well as interbasin transfer from Lake Tawakoni. Dallas runs three water treatment plants that are capable of treating 875 MGD (Dallas, 2006). The City of Ft. Worth's Water Department uses surface water from six reservoirs, two owned by Ft. Worth and managed by the U.S. Army Corps of Engineers (Lake Worth and Benbrook Lake) and four owned and managed by Tarrant Regional Water District (City, 200b).

The Tarrant Regional Water District (TRWD) pumps raw water from Lake Bridgeport, Eagle Mountain Lake, Cedar Creek Reservoir, and Richland-Chambers Reservoir, to treatment plants in DFW. TRWD supplies treated water to over 30 customers, including Ft. Worth, Arlington, and TRA, representing over 1.6 million people in north central Texas (TRWD, 2006). TRWD pumps raw water from Cedar Creek Reservoir and Richland-Chambers Reservoir to Benbrook Lake, where it is then pumped to local water treatment plants. A pipeline from Eagle Mountain Lake to Benbrook Lake will be completed in 2008.

The North Texas Municipal Water District (NTMWD) provides drinking water to cities and communities in northeastern DFW (83.9 billion gallons of water for August 2004-July 2005). Lake Lavon is the main source of NTMWD's raw water supply, but NTMWD does also rely on interbasin transfers from Lake Chapman and Lake Texoma (NTMWD, 2005). NTMWD has also started the East Fork Reuse Project that will pump water from the Trinity River into 1,840 acres of man-made wetlands located southeast of Dallas in Crandall, TX (NTMWD, 2005). The naturally-cleansed raw water will then be pumped to the north end of Lake Lavon.

Wastewater Treatment Plants. There are 54 wastewater treatment plants (WWTPs) licensed by the Texas Commission on Environmental Quality (TCEQ) within the upper Trinity River watershed (Figure I-13; Table I-2). The Upper Trinity Water Quality Compact, consisting of the city of Ft. Worth, the city of Dallas, TRA, and the North Texas Municipal Water District (NTMWD), takes care of wastewater treatment, discharge, and reuse to provide the citizens in north central Texas cost-effective management of water and wastewater services. Dallas and Ft. Worth take care of their respective cities; TRA's five WWTP facilities take care of wastewater for much of the mid-cities region of DFW; and NTMWD takes care of operations of northeast DFW, including Plano, Allen, and McKinney (Figure I-15).

All the WWTPs in the upper Trinity River watershed discharge effluent into streams or Forks of the Trinity River. Subwatershed #2, encompassing most of the Elm Fork, has 11 WWTPs discharging 62.031 MGD (Figure I-16). The largest WWTP in this sub-watershed is the City of Denton's Pecan Creek WWTP (21 MGD). Subwatershed #3, encompassing most of the rural region of the West Fork, has 2 WWTPs discharging 2.45 MGD (Figure I-17). Subwatershed #4, encompassing Weatherford and most of Ft. Worth, as well as most of the Clear Fork, contains 1 WWTP (4.5 MGD) (Figure I-18). Watershed #6, encompassing east Ft. Worth, west Arlington, and Burleson, contains 1 WWTP, Ft. Worth's Village Creek WWTP, discharging 166 MGD (Figure I-19). Watershed #8 contains the convergence of the West and Elm Forks, so it contains WWTPs from both Forks (Figure I-20). This subwatershed encompasses many of the larger mid-cities, as well as west Dallas. Ten WWTPs are in this subwatershed, discharging 250.4 MGD into the Trinity River. The largest WWTP is the TRA Central (189 MGD), treating 75% of all the wastewater in this subwatershed. Subwatershed #10 consists mostly of Dallas, as well as sections of Plano and Richardson. Two WWTPs reside in this subwatershed, discharging 204.75 MGD (Figure I-21). The Dallas-Central WWTP (200 MGD) resides in this subwatershed. Subwatershed #12, encompassing the eastern cities of DFW and most of the East Fork, contains 17 WWTPs that discharge a total of 220.MGD (Figure I-22). Subwatershed #13 resides in south Dallas and only contains 1 WWTP, the Dallas-Southside

WWTP, that discharges 110 MGD (Figure I-23). Subwatershed #14 contains the confluence of the East Fork and the main stem. Only 2 WWTPs are in this rural subwatershed, discharging 27.5 MGD (Figure I-24). Subwatershed #15 (Figure I-25) contains smaller cities, such as Waxahachie, Terrell, Corsicana, Trinidad, and Palestine. Seven WWTPs are in this subwatershed, discharging 18.34 MGD into streams that run into the Trinity River main stem. Only subwatershed #1 did not contain a WWTP. Overall, 6 WWTPs are on the West Fork (362.85 MGD), 19 WWTPs are on the Elm Fork (122.531 MGD), 17 WWTPs are on the East Fork (220.35 MGD), and the remaining 12 WWTPs discharge into the Trinity River main stem (360.59 MGD), a total of 1066.321 MGD discharged into the rivers and streams of the upper Trinity River watershed.

There are four main WWTPs in the upper Trinity River watershed, Village Creek Wastewater Treatment Plant (VCWTP), TRA Central Regional Wastewater System (TRA CRWS), Dallas-Central Wastewater Treatment Plant (D-Central), and Dallas-Southside Wastewater Treatment Plant (D-Southside). These 4 WWTPs treat and discharge 665 MGD, or 62 % of all effluent, into the upper Trinity River watershed. Below are brief descriptions of each WWTP's operations.

<u>Village Creek Wastewater Treatment Plant (VCWTP) (City, 2006a)</u>: Village Creek Wastewater Treatment Plant (VCWTP) started operations in 1958 as a 5 MGD facility for east Ft. Worth. Over time and several expansions, VCWTP is now capable of treating 166 MGD from the 900,000 people and industries of Tarrant County and parts of Johnson County. VCWTP has a pretreatment program to monitor commercial and industrial influent. All influent is treated with chlorine for odor control before the treatment process begins. Wastewater at VCWTP goes through secondary and tertiary treatment process, then chlorination and dechlorination before direct discharge into the West Fork of the Trinity River. The average daily effluent flow generated at VCWTP is 108.5 MGD, and its yearly treated flow is 39.7 billion gallons. VCWTP is also actively involved in several conservation programs, such as reusing over 68 million gallons of treated wastewater which are reused on nearby golf courses and land application of biosolids (see below).

<u>Trinity Regional Authority (TRA) Central Regional Wastewater System (CRWS) (TRA, 2006b)</u>: TRA CRWS started operations in 1959 for Irving, Grand Prairie, Farmers Branch, and parts of western Dallas. After several expansions over the past 47 years, CRWS now serves over 450 square miles in DFW, with a capacity of 162 MGD and a daily maximum of 335 MGD. CRWS implements an aggressive pretreatment program to minimize toxic compounds in the wastewater influent. CRWS utilizes total secondary (activated sludge) and tertiary (filtration) treatments. It also has a dechlorination facility capable of chlorine removal to less than 0.1 mg/l. CRWS has an on-site biomonitoring facility to facilitate rapid toxicity testing of its treated effluent. Treated effluent is then discharged into the West Fork of the Trinity River. CRWS is also involved in several resource conservation programs, such as reusing treated wastewater for irrigation of local golf courses and maintaining lakes and ponds in the Las Colinas area of Irving, TX, as well as biosolid land application (see below).

<u>City of Dallas Wastewater Treatment Plants (Dallas, 2006)</u>: The City of Dallas has two main WWTPs—Central and Southside—that serve approximately 1.9 million people in Dallas and 26 surrounding communities. Both located on the Trinity River, Dallas-Central (D-Central) and Dallas-Southside (D-Southside) have the capacity to treat 200 and 110 MGD, respectively. The cumulative amount of wastewater treated by both WWTPs in 2001-2002 was 75.3 billion gallons, or approximately 206 MGD.

Figure I-1. The Upper Trinity River Watershed.

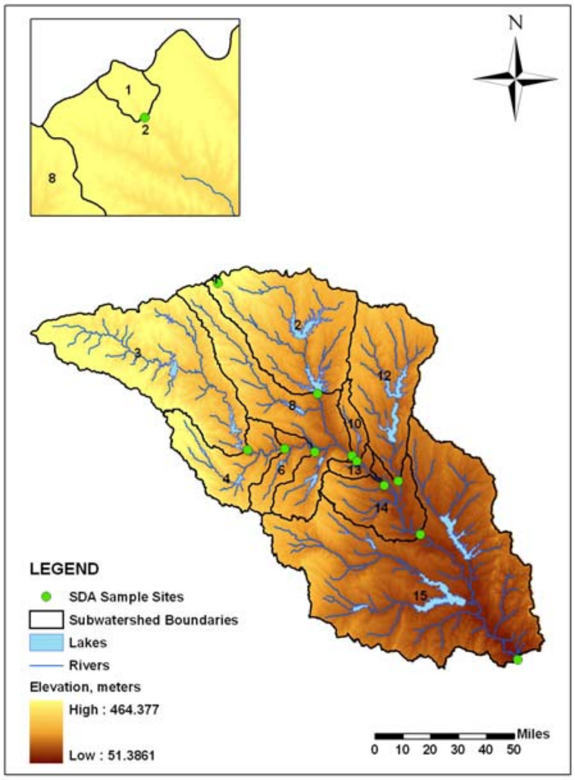


Figure I-2. Mean monthly temperatures in north central Texas. Mean monthly temperatures (blue) are comprised of records from 1989 to 2005, and the mean monthly temperature of September 2004- September 2005 is shown in pink.

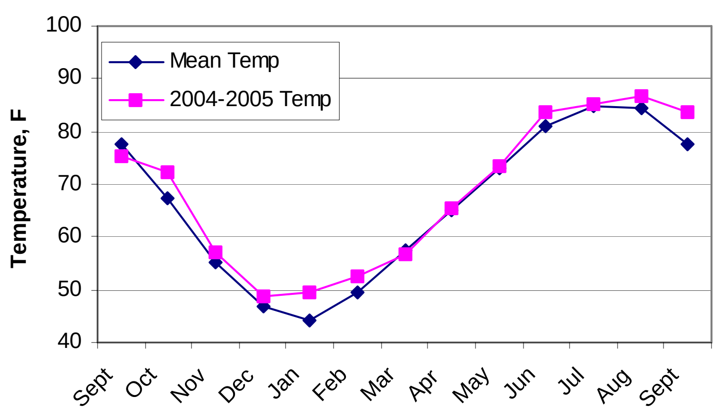


Figure I-3. Average rainfall for the state of Texas. The upper Trinity River watershed is outlined in black.

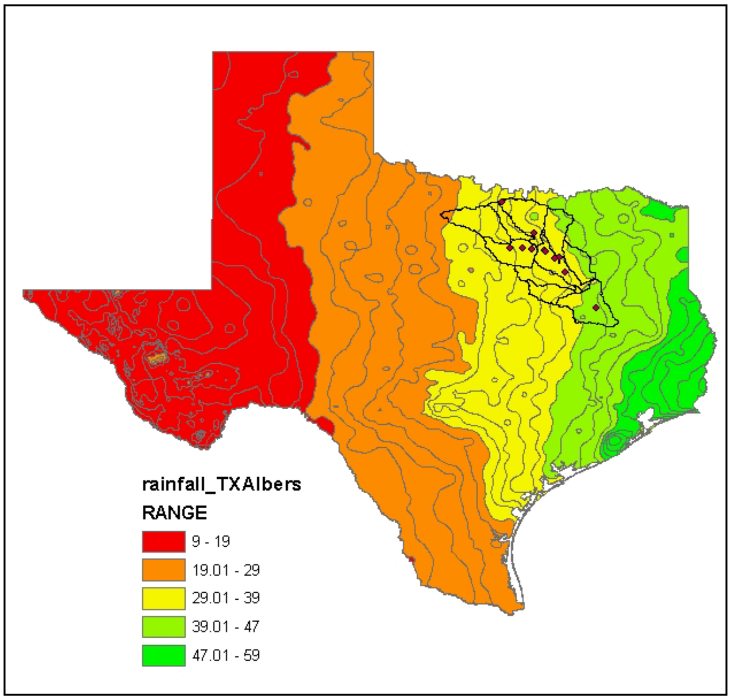


Figure I-4. Mean monthly precipitation in north central Texas. Mean monthly precipitation (blue) are comprised of records from 1989 to 2005, and the mean monthly precipitation of September 2004- September 2005 is shown in pink.

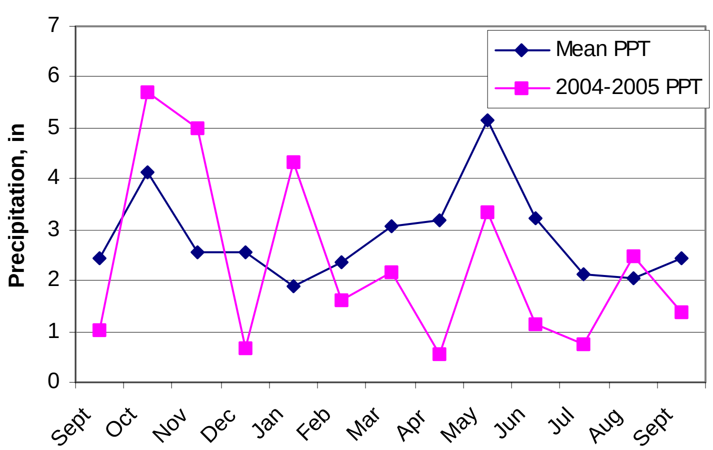


Figure I-5. Cumulative precipitation from September 2004 to September 2005. Zero cumulative precipitation represents the average cumulative precipitation since records were kept in 1898. The cumulative monthly precipitation from September 2004- September 2005 is shown in pink.

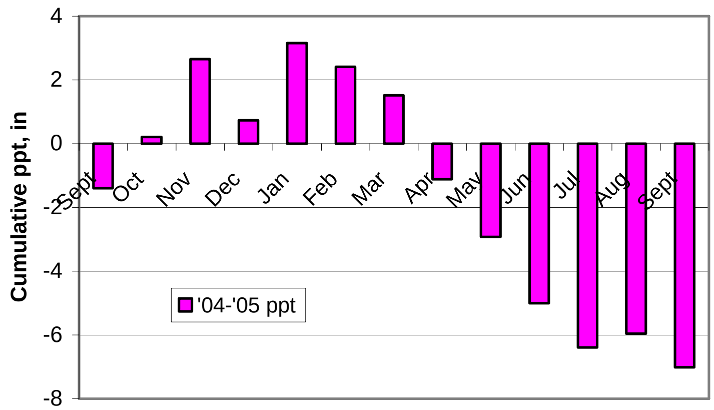


Figure I-6. The ecoregions of Texas.

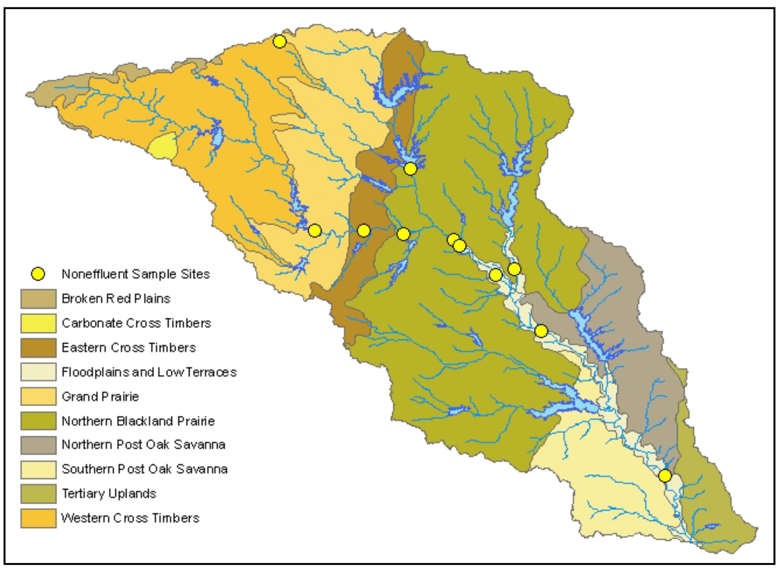


Figure I-7. Population estimates and predictions for north central Texas. Population values in blue represent census data collected by the U.S. Census Bureau. Population values in red represent predicted population growth by decade through the year 2060.

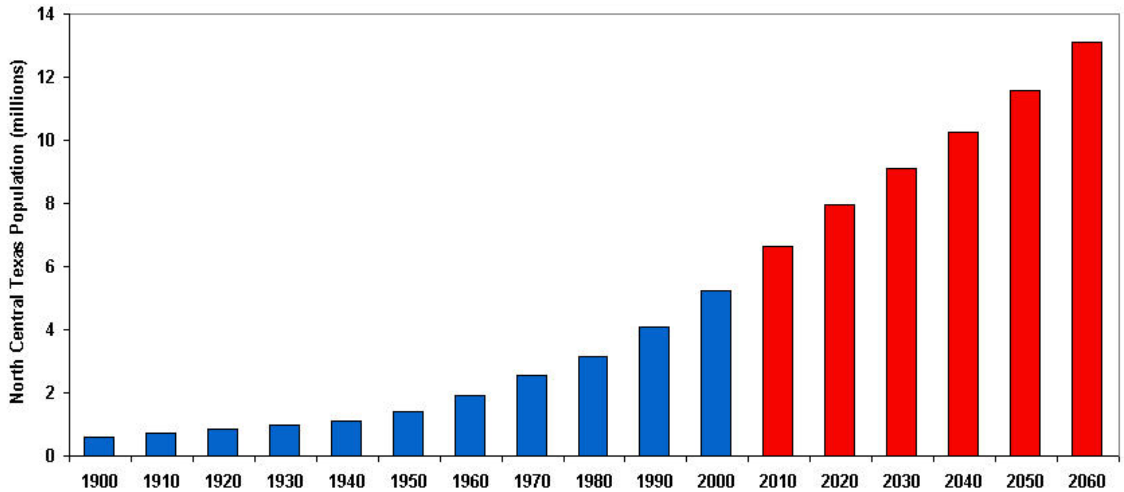


Figure I-9. Satellite imagery of the Dallas-Ft. Worth metroplex in 1987.

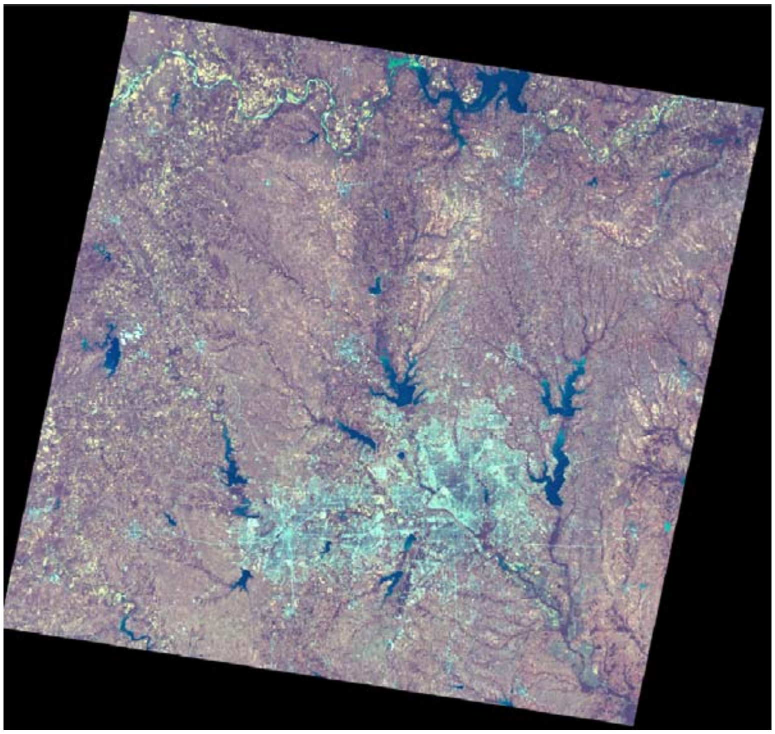
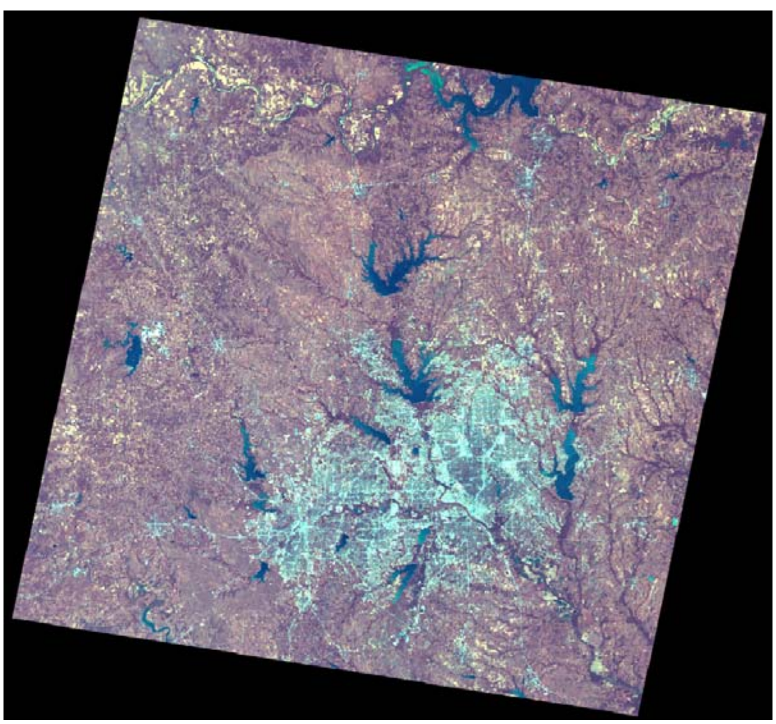


Figure I-10. Satellite imagery of the Dallas-Ft. Worth metroplex in 2005.



Figures I-11a-h. Mean monthly flows of the Trinity River. Flows were measured at USGS measurement stations at or near the current sample sites. Flow in blue represent the mean monthly flows for 1987 through 2005. Flow in pink represent the mean monthly flows for September 2004 through September 2005.

Figure I-11a. Flow at SDA05-02 (downstream of the Lake Lewisville dam).

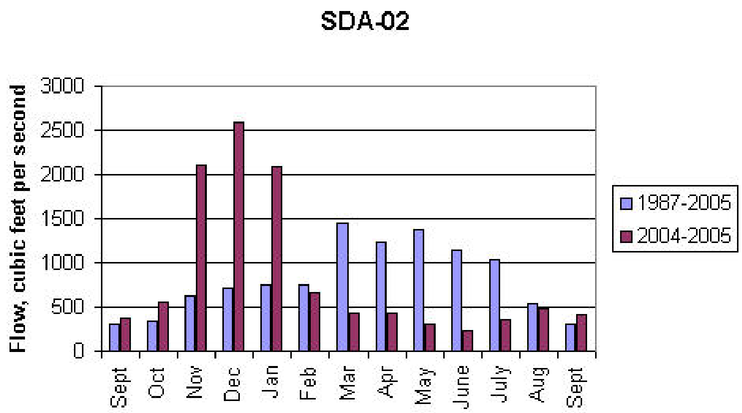


Figure I-11b. Flow at SDA05-04 (upstream of Village Creek WWTP).

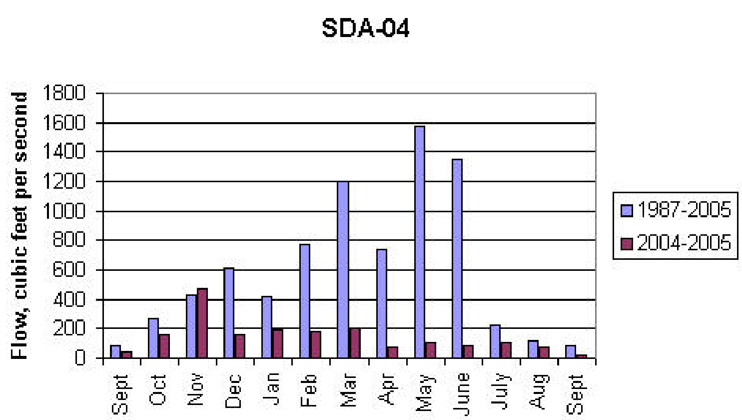


Figure I-11c. Flow at SDA05-06 (downstream of the Village Creek WWTP/upstream of the TRA Central WWTP).

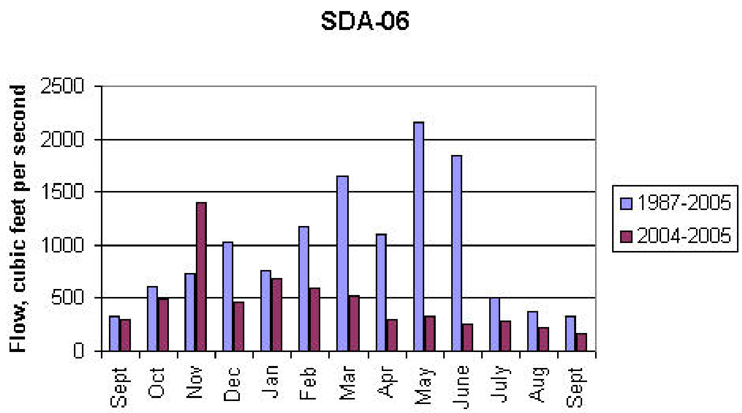


Figure I-11d. Flow at SDA05-08 (downstream of the TRA Central WWTP/upstream of Dallas-Central WWTP).

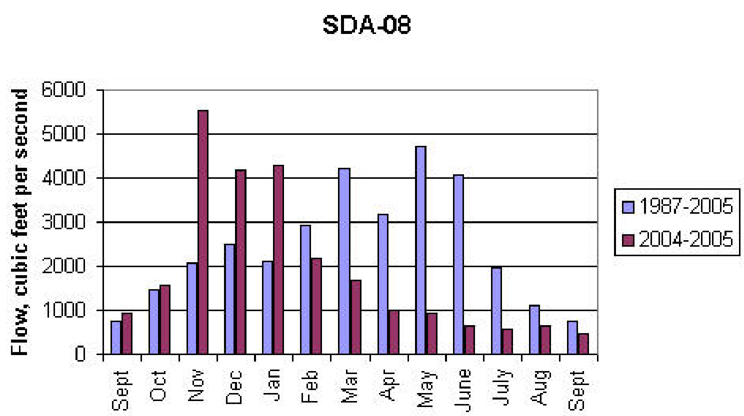


Figure I-11e. Flow at SDA05-10 (downstream of Dallas-Central WWTP/upstream of Dallas-Southside WWTP).

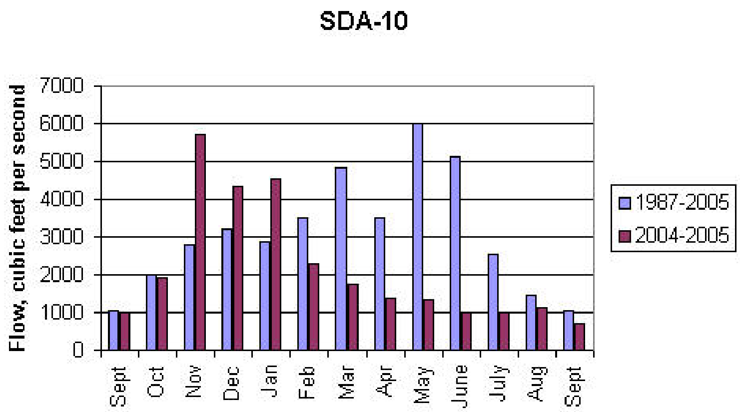


Figure I-11f. Flow at SDA05-12 (bottom of East Fork).

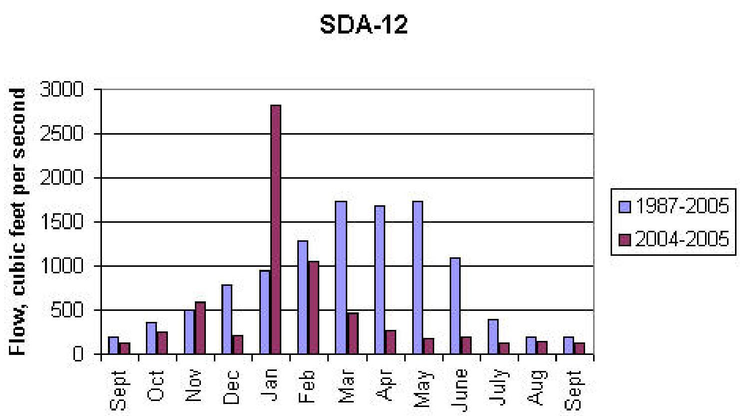


Figure I-11g. Flow at SDA05-14 (downstream of confluence of main stem and East Fork/Ennis, TX).

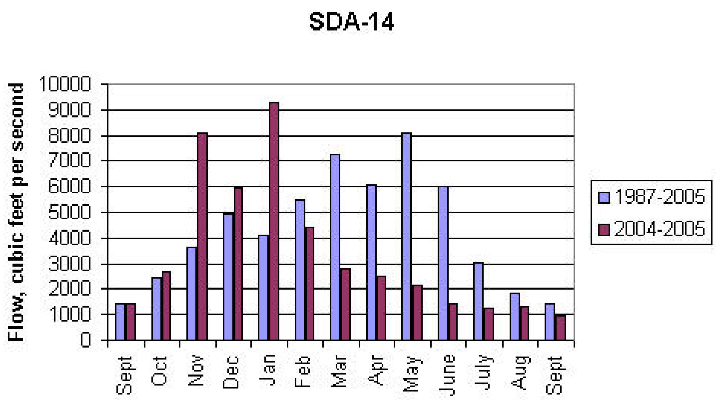
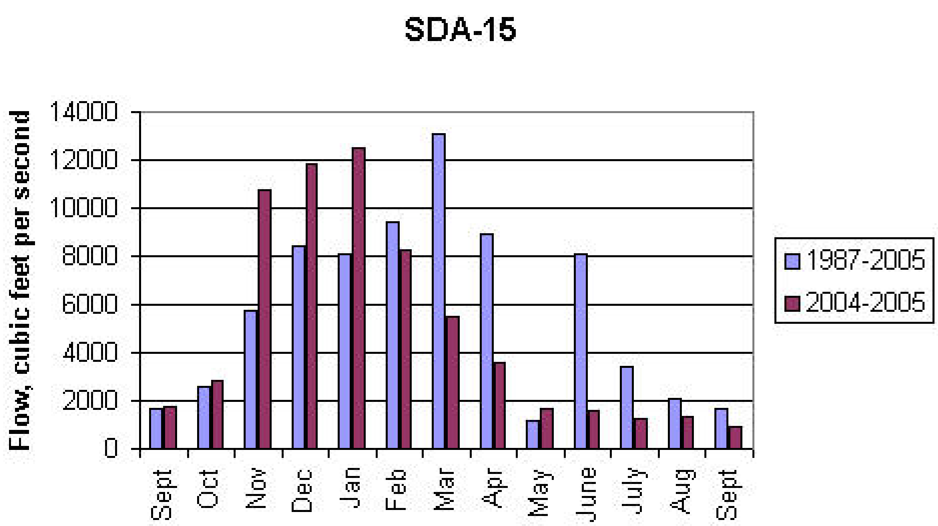


Figure I-11h. Flow at SDA05-15 (Palestine, TX).



Figures I-12a-h. Daily flows of the Trinity River in the month of September. Flows were measured at USGS measurement stations at or near the current sample sites. Flow in blue represent the daily flows for Septembers from 1987 through 2005. Flow in pink represent the daily flows for September 2005. The red bar indicates the time period that Hurricane Rita passed through east Texas-west Louisiana.

Figure I-12a. September flow at SDA05-02 (downstream of Lake Lewisville dam).

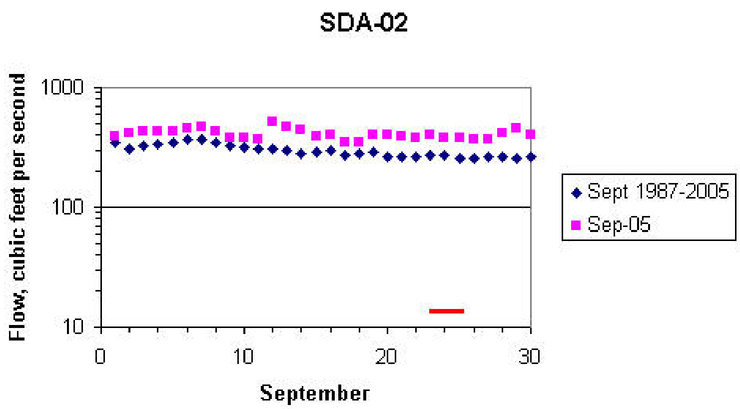


Figure I-12b. September flow at SDA05-04 (upstream of Village Creek WWTP).

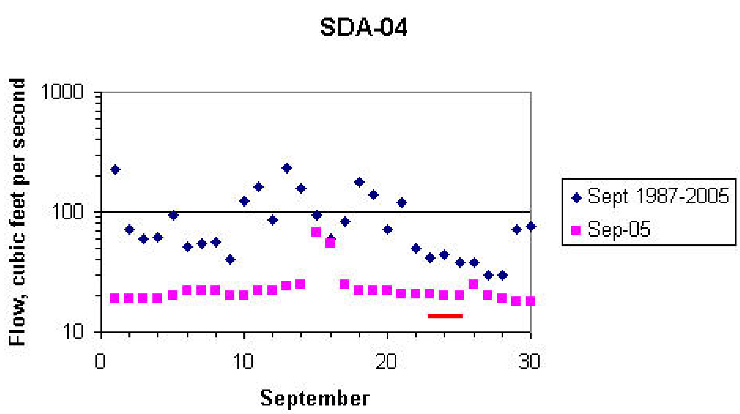


Figure I-12c. September flow at SDA05-06 (downstream of Village Creek WWTP/upstream of TRA Central WWTP).

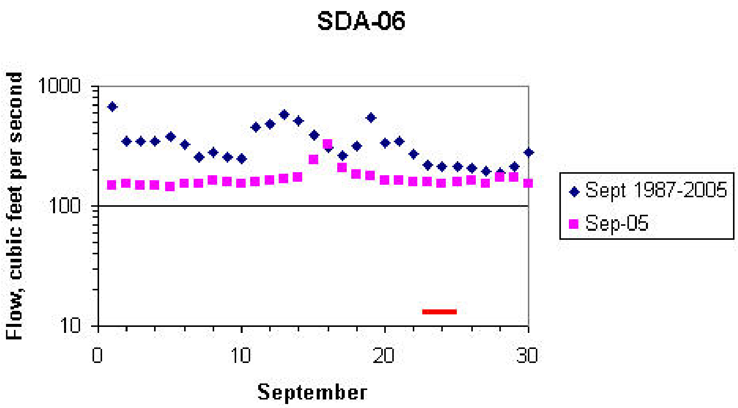


Figure I-12d. September flow at SDA05-08 (downstream of TRA Central WWTP/upstream of Dallas-Central WWTP).

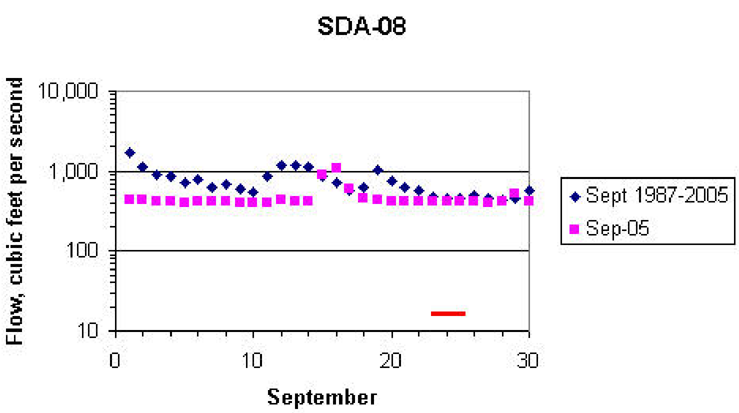


Figure I-12e. September flow at SDA05-10 (downstream of Dallas-Central WWTP/upstream of Dallas-Southside WWTP).

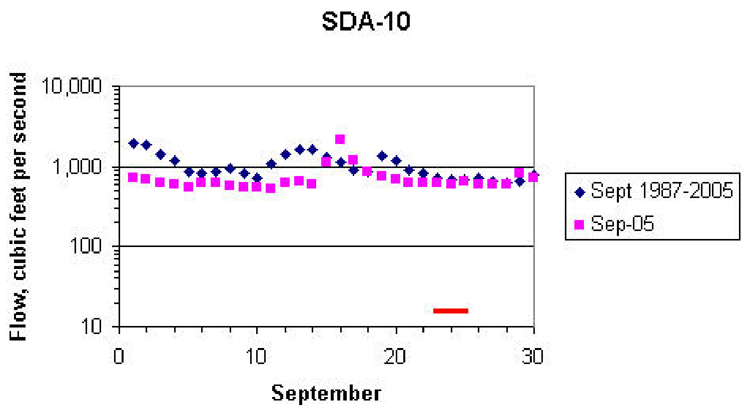


Figure I-12f. September flow at SDA05-12 (bottom of East Fork).

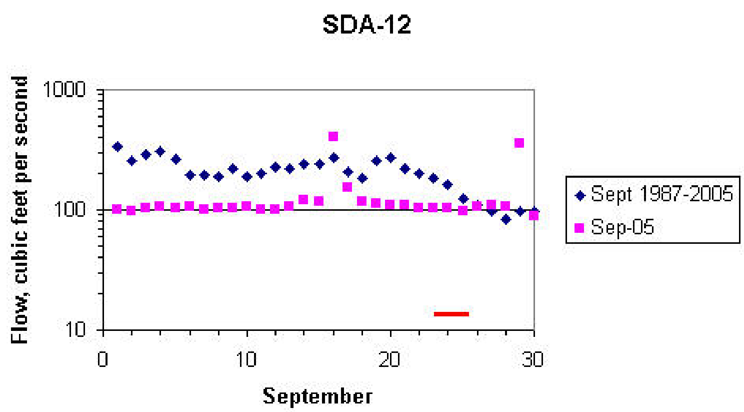


Figure I-12g. September flow at SDA05-14 (downstream of the confluence of the main stem and the East Fork/Ennis, TX).

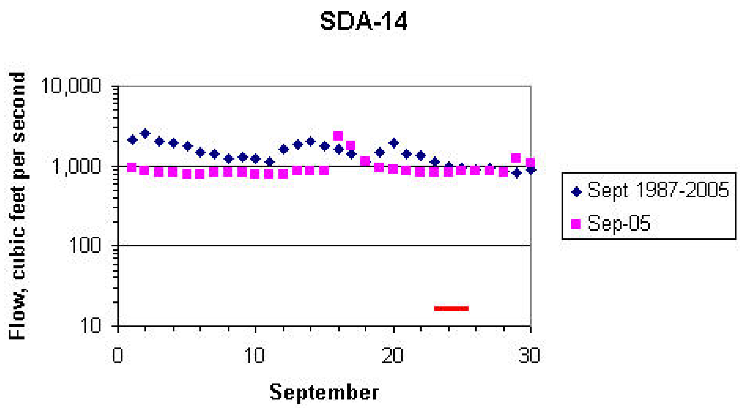


Figure I-12h. September flow at SDA05-15 (Palestine, TX).

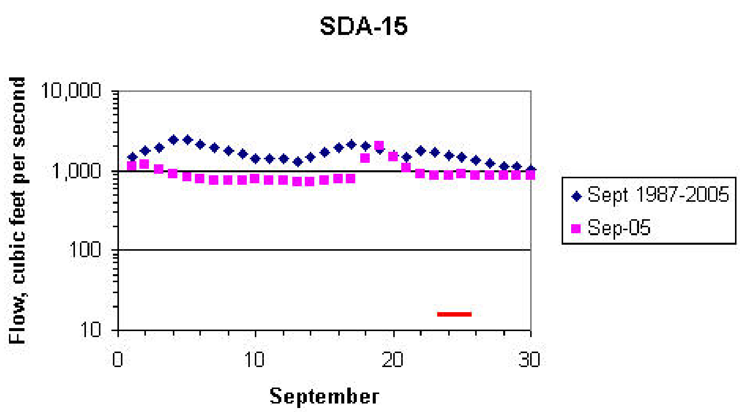


Figure I-13. Wastewater treatment plants in the upper Trinity River watershed. WWTPs are represented as gold diamonds.

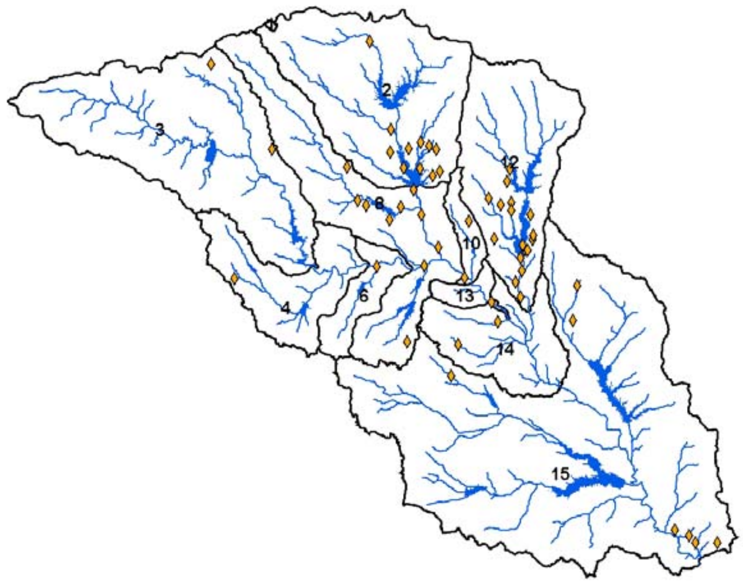


Figure I-14. Upper Trinity Water Quality Compact Service Area Map (Source: Trinity River Authority, http://www.trinityra.org)

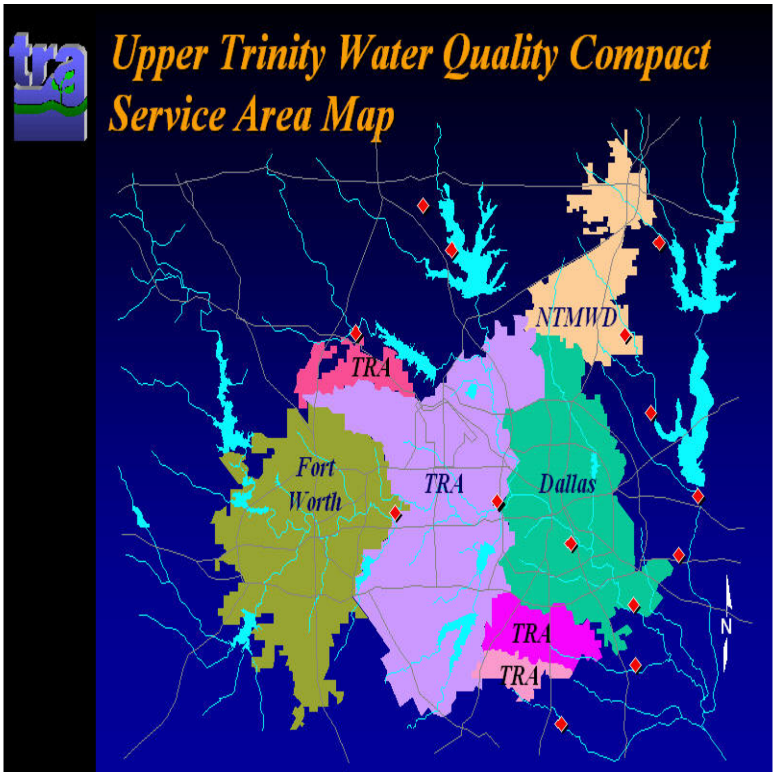


Figure I-15b. 2006 wastewater providers in north central Texas (source: http://www.nctcog.org)

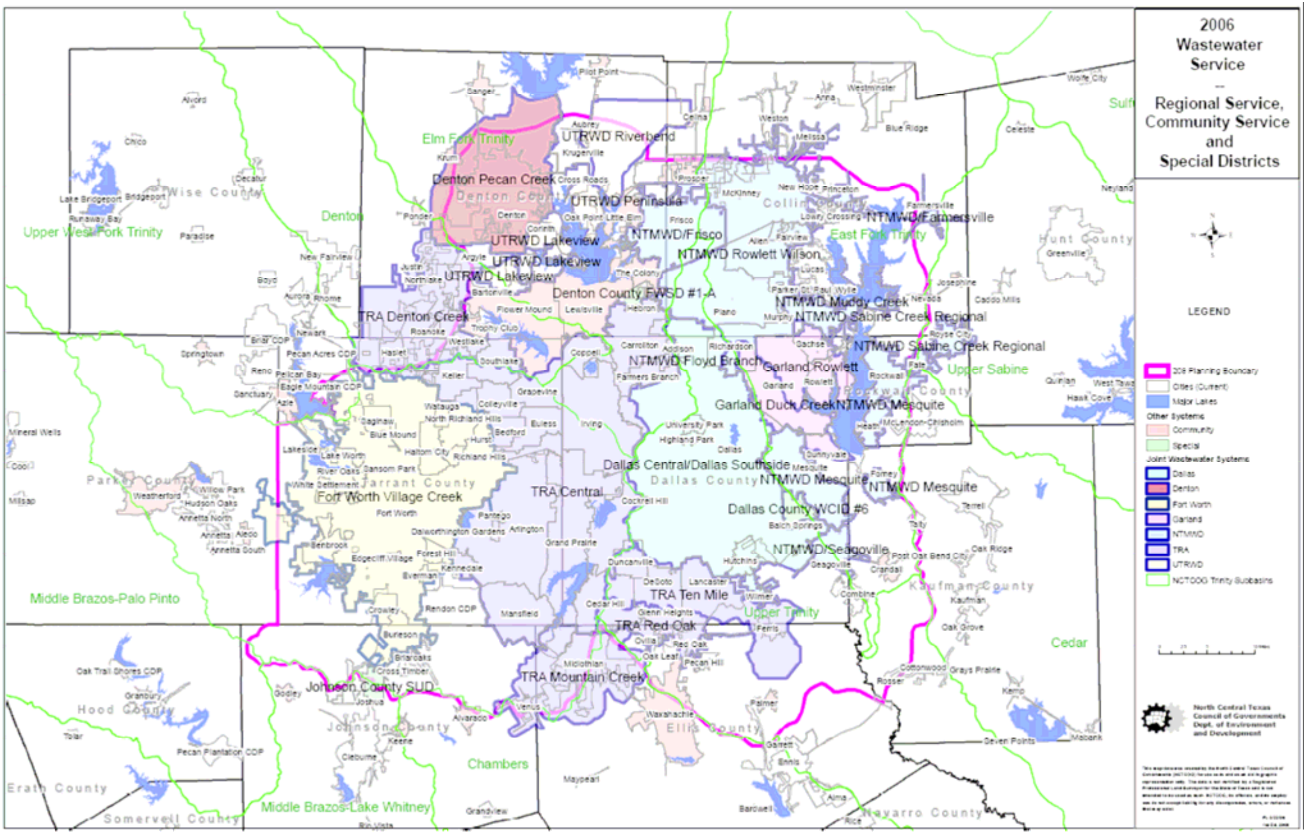


Figure I-16. WWTPs in subwatershed #2.

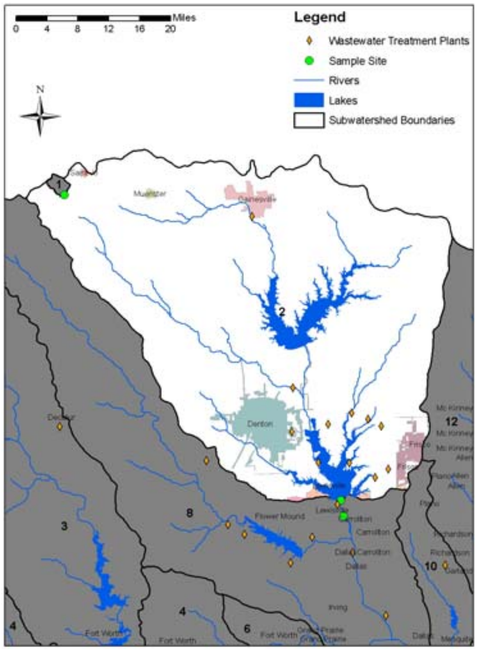


Figure I-17. WWTPs in subwatershed #3.

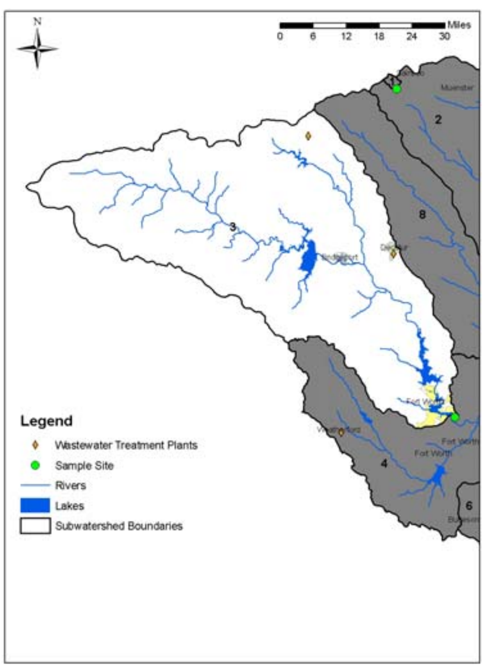


Figure I-18. WWTPs in subwatershed #4.

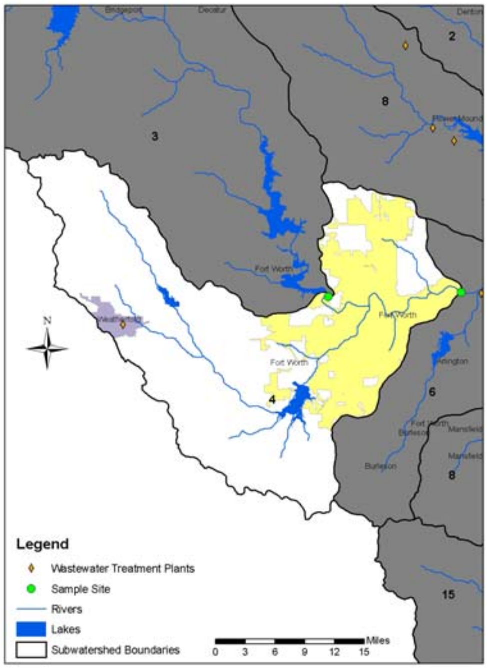


Figure I-19. WWTPs in subwatershed #6.

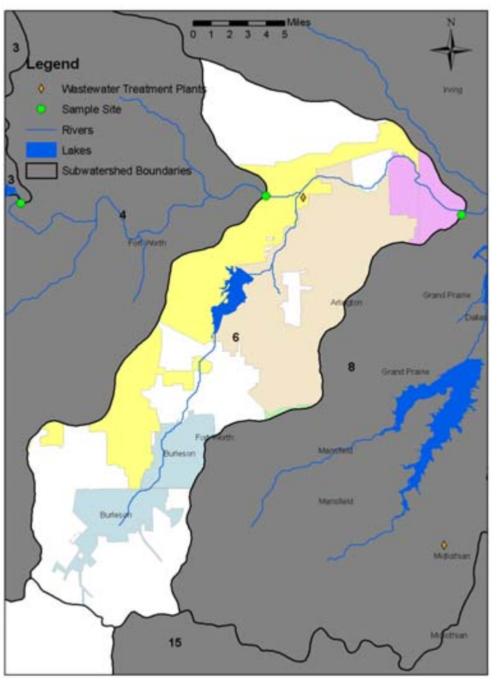


Figure I-20. WWTPs in subwatershed #8.

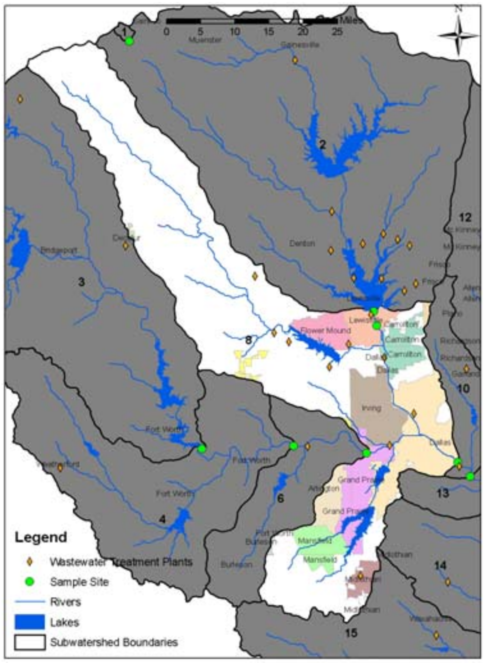


Figure I-21. WWTPs in subwatershed #10.

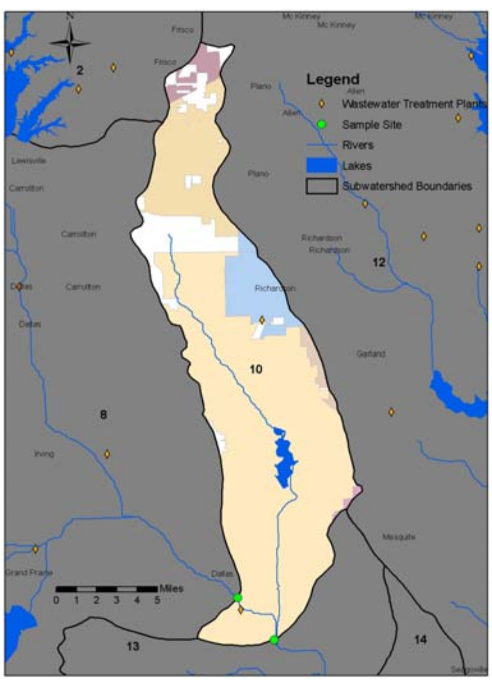


Figure I-22. WWTPs in subwatershed #12.

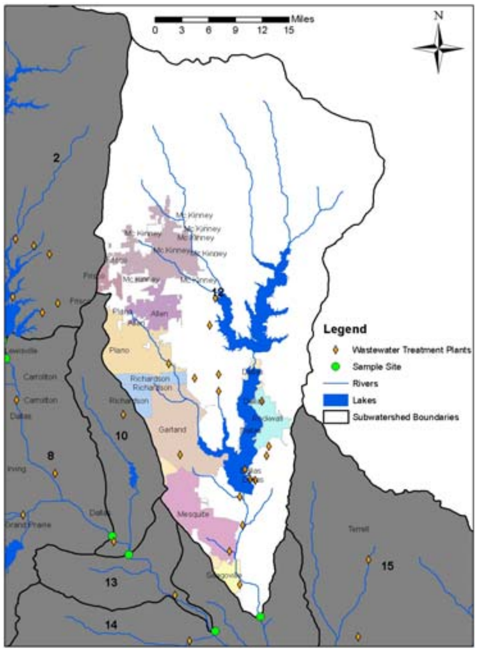


Figure I-23. WWTPs in subwatershed #13.

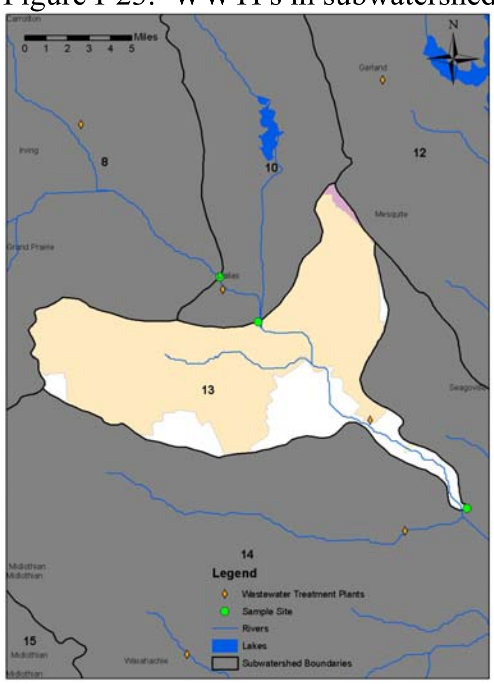


Figure I-24. WWTPs in subwatershed #14.

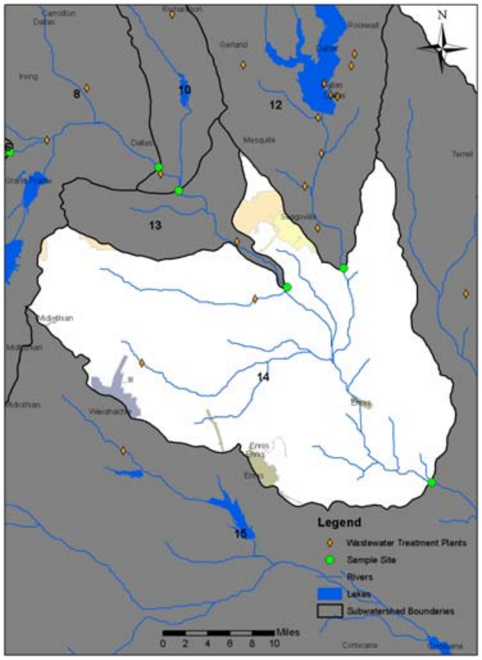


Figure I-25. WWTPs in subwatershed #15.

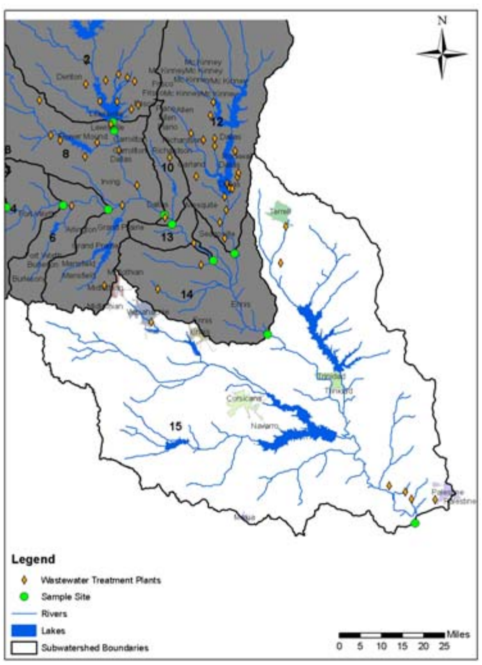


Table I-1. Reservoirs in the upper Trinity River watershed.

Lakes and Reservoirs of the Upper Trinity River Watershed

Subwatershed	Body of Water	Years Built	Owner/ Management	Size / Capacity [a] (acres/acre-feet)	Water supply?	Supplier	Wetlands?	Ref
2	Lake Ray Roberts	1982-1987	USACE	29,350	Yes	Dallas Water Utilities		(Dallas, 2006)
				799,600				(USACE, 2006)
	Lake Lewisville	1948-1955	USACE	29,592	Yes	Dallas Water Utilities		(Dallas, 2006)
				640,986				(USACE, 2006)
3	Amon G. Carter Lake	1955-1956	City of Bowie	1,540	Yes	City of Bowie		(Handbook, 2001f)
				20,050				
	Bridgeport Lake	1929-1931	TRWD	11,954	Future use for TRWD	TRWD		(TRWD, 2005)
				366,236				
	Eagle Mountain Lake	1929-1932	TRWD	8,702	Yes (in 2008)	TRWD		(TRWD, 2005)
				182,505				
	Lake Worth	1916	City of Ft. Worth	3,458	Yes	City of Ft. Worth		(Handbook, 2001g)
			USACE	33,600				(TPWD, 2006)
4	Benbrook Lake	1949-1950	City of Ft. Worth	3,770	Yes	TRWD		(USACE, 2006)
			USACE	88,250				
6	Lake Arlington	1956-1957	City of Arlington	2,275	Yes	City of Arlington		(Handbook, 2006h)
				45,710		TRA		(TRA, 2006a)
8	Lake Grapevine	1948-1952	USACE	7,280	Yes	Dallas Water Utilities		(USACE, 2006)
				181,100				(Dallas, 2006)
	Joe Pool Lake	1987-1991	USACE	7,470	Yes	TRA		(USACE, 2006)
				176,900				
	Mountain Creek Lake	1929-1937	Dallas Power &	2,710	No			(Handbook, 2006i)
			Light Co.	22,840				
	North Lake	1956-1957	Dallas Power &	800	No			(Handbook, 2006j)
			Light Co.	17,000				
10	White Rock Lake	1910-1911	City of Dallas	1,254	No			(Handbook, 2006k)
				18,610				
12	Lake Ray Hubbard	1964-1969	City of Dallas	22,745	Yes	Dallas Water Utilities		(Dallas, 2006)
				490,000				(Handbook, 2006l)
	Lake Lavon	1948-1953	USACE	21,400	Yes	NTMWD		(USACE, 2006)
				456,500				(NTMWD, 2005)
15	Cedar Creek Reservoir	1961-1965	TRWD	32,623	Yes	TRWD		(TRWD, 2005)
				637,924				
	Richland-Chambers Reservoir	1982-1987	TRWD	45,365	Yes	TRWD	Yes	(TRWD, 2005)
				1,137,204				
	Lake Waxahachie	1956	ECWCID #1	645	n/a			(Handbook, 2006m)
				13,500				
	Bardwell Reservoir	1963-1965	USACE	3,570	Yes	TRA		(USACE, 2006)
				54,900				
	Navarro Mills Lake	1960-1963	USACE	5,070	Yes	TRA		(USACE, 2006)
				63,300				
Interbasin Transfers								
	Lake Chapman							
	Lake Tawakoni							
	Lake Texoma							

[a] Surface area and storage capacity at conservation levels

Abbreviations: ECWCID #1, Ellis County Water Control and Improvement District #1; NTMWD, North Texas Municipal Water District; TRA, Trinity River Authority; TRWD, Tarrant Regional Water District; USACE, U.S. Army Corps of Engineers

Table I-2. Wastewater treatment plants in the upper Trinity River watershed.

Watershed	NPDES #	PERMITTEE	FLOW, MGD	COUNTY	LAT, Digital Degrees	LONG, Digital Degrees
2	0022357	CITY OF GAINESVILLE	4.14	COOKE	33.6039980	-97.1494570
	0047180	CITY OF DENTON	21.00	DENTON	33.1963190	-97.0721880
	0119849	CITY OF DENTON	0.25	DENTON	33.1453990	-97.2652950
	0020354	UPPER TRINITY REGIONAL WATER DISTRICT	7.50	DENTON	33.1365090	-97.0155640
	0124745	UPPER TRINITY REGIONAL WATER DISTRICT	2.00	DENTON	33.2084190	-96.9905850
	0123781	UPPER TRINITY REGIONAL WATER DISTRICT	1.70	DENTON	33.2286180	-96.9372830
	0125172	UPPER TRINITY REGIONAL WATER DISTRICT	5.23	DENTON	33.2159180	-96.9013810
	0123901	NORTH TEXAS MUNICIPAL WATER DISTRICT	10.00	DENTON	33.2020620	-96.8716690
	0093696	CITY OF THE COLONY	0.02	DENTON	33.1339680	-96.9454920
	0053112	CITY OF THE COLONY	4.50	DENTON	33.1060160	-96.8890720
	0103501	NORTH TEXAS MUNICIPAL WATER DISTRICT	5.00	DENTON	33.1206760	-96.8586130
3	0111325	CITY OF BOWIE	1.25	MONTAGUE	33.5334400	-97.8519800
	0024911	CITY OF DECATUR	1.20	WISE	33.2165060	-97.5919730
4	0047724	CITY OF WEATHERFORD	4.50	PARKER	32.7465180	-97.7680870
6	0047295	CITY OF FORT WORTH	166.00	TARRANT	32.7798520	-97.1436220
8	0125628	CITY OF DENTON	0.95	DENTON	33.2792180	-97.0670880
	0104957	TRINITY RIVER AUTHORITY OF TEXAS	5.00	DENTON	33.0237340	-97.2208490
	0055735	TROPHY CLUB MUD 1	1.75	DENTON	33.0045670	-97.1841800
	0032018	CITY OF GRAPEVINE	5.75	TARRANT	32.9484580	-97.0833440
	0020711	TOWN OF FLOWER MOUND	10.00	DENTON	32.9959560	-97.0330640
	0052892	CITY OF LEWISVILLE	18.00	DENTON	33.0567890	-96.9747280
	0002372	CITY OF DALLAS	5.00	DALLAS	32.9651240	-96.9441720
	0002381	CITY OF DALLAS	15.00	DALLAS	32.8437380	-96.8733370
	0022802	TRINITY RIVER AUTHORITY	189.00	DALLAS	32.7771300	-96.9367830
	0025011	TRINITY RIVER AUTHORITY OF TEXAS	0.90	ELLIS	32.5012490	-97.0197270
10	0023931	NORTH TEXAS MUNICIPAL WATER DISTRICT	4.75	DALLAS	32.9362350	-96.7377770
	0047830	CITY OF DALLAS	200.00	DALLAS	32.7292310	-96.7630780
12	0088633	NORTH TEXAS MUNICIPAL WATER DISTRICT	64.00	COLLIN	33.1217850	-96.5524890
	0024988	NORTH TEXAS MUNICIPAL WATER DISTRICT	0.25	COLLIN	33.0773410	-96.5652680
	0047911	NORTH TEXAS MUNICIPAL WATER DISTRICT	24.00	COLLIN	33.0176210	-96.6466610
	0069001	NORTH TEXAS MUNICIPAL WATER DISTRICT	0.25	COLLIN	32.9928990	-96.5974920
	0025950	NORTH TEXAS MUNICIPAL WATER DISTRICT	2.00	COLLIN	32.9976210	-96.5505460
	0123561	NORTH TEXAS MUNICIPAL WATER DISTRICT	20.00	DALLAS	32.9701220	-96.5513790
	0024686	CITY OF GARLAND	24.00	DALLAS	32.8679030	-96.6299940
	0022241	NORTH TEXAS MUNICIPAL WATER DISTRICT	1.20	ROCKWALL	32.9515110	-96.4685980
	0078565	NORTH TEXAS MUNICIPAL WATER DISTRICT	2.25	ROCKWALL	32.8772610	-96.4576320
	0074306	NORTH TEXAS MUNICIPAL WATER DISTRICT	0.45	ROCKWALL	32.8620690	-96.4627640
	0113921	NORTH TEXAS MUNICIPAL WATER DISTRICT	0.03	ROCKWALL	32.8404040	-96.5058220
	0024813	NORTH TEXAS MUNICIPAL WATER DISTRICT	0.04	ROCKWALL	32.8245700	-96.4960990
	0113182	NORTH TEXAS MUNICIPAL WATER DISTRICT	0.18	ROCKWALL	32.8223480	-96.4860980
	0024678	CITY OF GARLAND	40.00	KAUFMAN	32.7959270	-96.5168660
	0002364	CITY OF DALLAS	15.00	KAUFMAN	32.7490180	-96.5133220
	0047431	NORTH TEXAS MUNICIPAL WATER DISTRICT	25.00	DALLAS	32.7073530	-96.5405450
	0054526	CITY OF SEAGOVILLE	1.70	DALLAS	32.6523550	-96.5227670
13	0047848	CITY OF DALLAS	110.00	DALLAS	32.6381900	-96.6480500
14	0022811	TRINITY RIVER AUTHORITY	24.00	DALLAS	32.5626360	-96.6230480
	0104345	TRINITY RIVER AUTHORITY OF TEXAS	3.50	ELLIS	32.4837500	-96.8005530
15	0027537	CITY OF WAXAHACHIE	8.00	ELLIS	32.3704210	-96.8327750
	0022527	CITY OF TERRELL	4.50	KAUFMAN	32.6862420	-96.2724790
	0079391	CITY OF KAUFMAN	1.20	KAUFMAN	32.5604140	-96.2972020
	0031577	TEXAS DEPT OF CRIMINAL JUSTICE	2.85	ANDERSON	31.7807250	-95.8885730
	0075388	TEXAS DEPT OF CRIMINAL JUSTICE	1.44	ANDERSON	31.7568370	-95.8260710
	0089044	TEXAS DEPT OF CRIMINAL JUSTICE	0.35	ANDERSON	31.7312820	-95.8016260
	0025453	CITY OF PALESTINE	4.70	ANDERSON	31.7265600	-95.7060680

Chapter II

Field Study Design

Introduction

Based on the information gathered at the workshop and the background information described above, a study design was developed that examines the Dallas-Fort Worth area as a single, internally variable source of surfactants to the Trinity River. The study therefore looks at reference sites upstream of Dallas WWTP inputs; effluent and mixing zone sites within the metroplex; and downstream sites where inputs and concentrations are expected to decrease. Sample locations are shown in Figure II.1; sample names and the rationale for their selection are presented in Table II.1. Sample analyses for each of the sampled media are presented in Table II.2.

Sampling Locations

As presented in Table II.1, a single sample location (SDA05-01) was selected at the headwaters of Clear Creek, which is over 80 miles north of Dallas. This location was chosen to represent minimally impacted reference conditions outside the influence of WWTP effluent and urban land use. Four additional reference samples were selected at locations on the Elm Fork (SDA05-02), West Fork (SDA05-03 and SDA05-04), and East Fork (SDA05-12) upstream of any major inputs from WWTP. Samples SDA05-02 and –03 were selected to characterize baseline (i.e. before addition of effluent) river conditions in less urbanized areas, and SDA05-04 was selected to represent baseline river conditions in urban areas. Sample SDA05-12 was selected to characterize inputs from the East Fork before its confluence with the Trinity River.

To characterize potential surfactant inputs to the river from Dallas' four major WWTPs, described in the previous section, a sample of effluent was collected from each plant. SDA05-05 was collected from the Village Creek WWTP; SDA05-07 was collected from the Trinity River Authority (TRA) WWTP; SDA05-09 was collected from the Dallas Central WWTP; and SDA05-11 was collected from the Dallas Southside WWTP.

Four samples were collected to characterize the mixing of effluent and river water as the Trinity River passes through the Dallas-Fort Worth Area. Each sample was collected downstream from a major WWTP and immediately upstream of inputs from the next WWTP. These sample locations are SDA05-06, -08, and -10.

Finally, the study design included collection of three samples downstream of Dallas. These are samples SDA05-13, -14 and –15. Sample SDA05-15 is over 100 miles southeast of Dallas. All field sampling was conducted between 9/30/05 and 10/07/05.

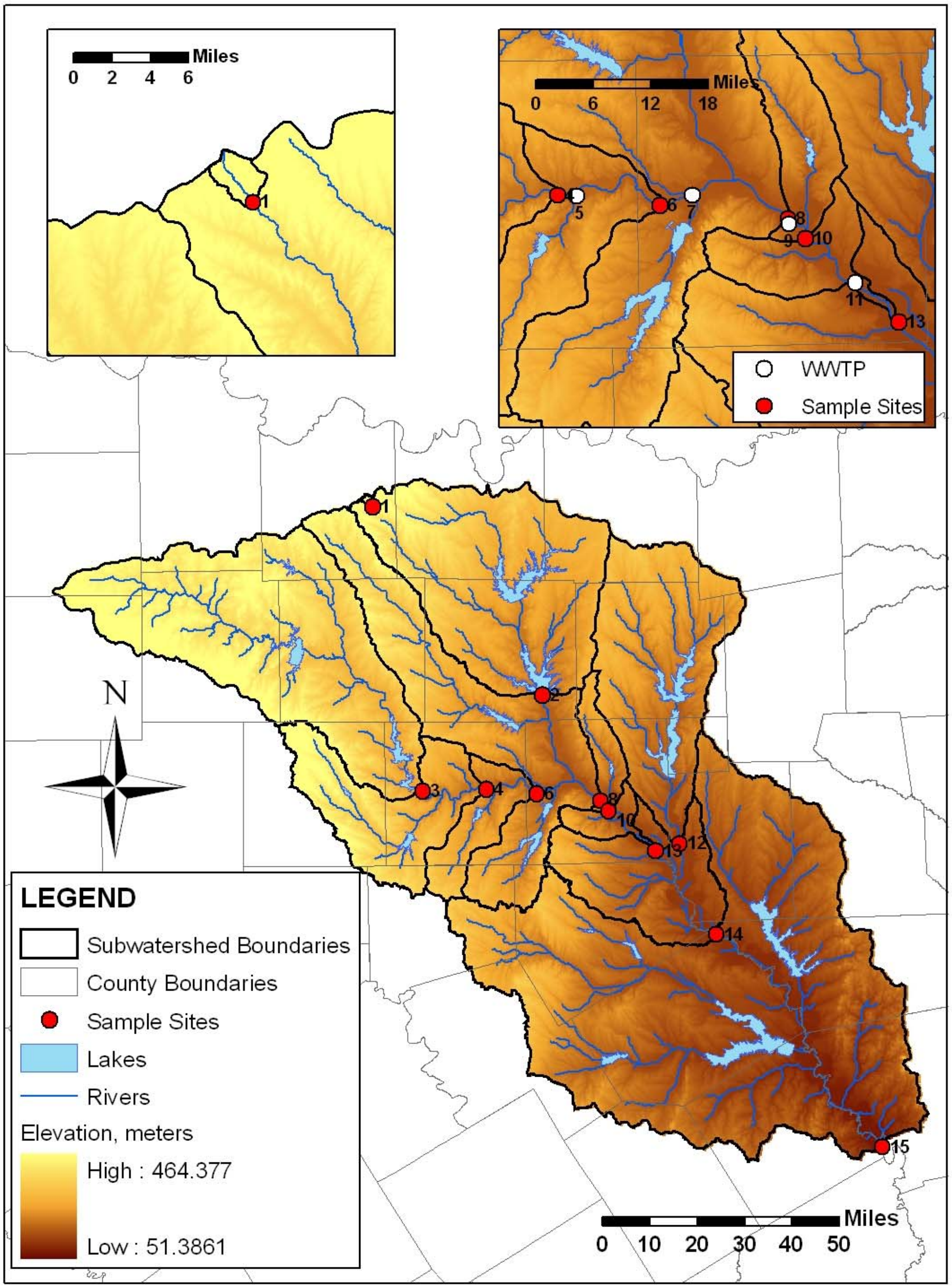


Figure II.1 Trinity River Basin with identification of sampling locations. Main map scaled at 1:1,800,000; left insert scaled at 1:445,000 and right insert scaled at 1:89,000.

Sample Media

The study design includes collection of sediment, sediment interstitial water, and surface water from each riverine location and effluent from each of four WWTPs. Samples of sediment, interstitial water and surface water were collected to better understand partitioning of surfactants among media as well as likely mechanisms of transport and potential routes of exposure for aquatic life. Effluent samples were collected to better understand sources of surfactants within the Trinity River watershed. All sampling was performed between September 30 and October 7, 2005.

Sample Analyses

Targeted analyses for each media are presented in Table II.2. The primary focus of the study is the distribution and concentration of surfactants in environmental media and their possible effects. Therefore sediment, surface water, interstitial water, and effluent were selected for analysis for AE, AES, and LAS. Samples were sent to Shell Global Solutions in the United Kingdom for surfactant LC/MS analyses. Details of the sample handling, extraction, analytical methods and results were presented to SDA in a report entitled "Surfactant Analysis for SDA Sediment Taskforce Study" (Shell Global Solutions document identified as GS. 06.51264 by Martin Selby). Data from this report were converted to equivalent Toxic Units for surface water and pore water by the members of the SDA Surfactants in Sediments Task Force. All subsequent evaluations of the presence and distribution of surfactants in the study area were based on the sum of effects attributable to all surfactant classes analyzed expressed as Toxic Units.

Details of the methods and results of field measurements of habitat quality, in situ and laboratory chemistry measurements and benthic sampling were presented to SDA in a report (Appendix B) entitled "Field Report for Surfactant Sampling and Habitat Surveys of the Trinity River in Dallas, Texas" (EA Engineering, Science and Technology, Inc. and University of North Texas, December 2005). Results of benthic identification and enumeration are presented in this report for the first time.

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Table II.1 - Sample Locations and Selection Rationale for the SDA Trinity River Study

Sample Name	Geographic Location	Rationale for Site Selection	Latitude	Longitude
SDA05-01	Headwaters of Clear Creek near St. Jo	Selected as a **minimally impacted reference** site upstream of WWTP inputs and away from urban land use	N33º39'10.4"	W97º34'12.15"
SDA05-02	Elm Fork below Lake Lewisville Dam	Upstream of the influence of the Dallas WWTPs on the Elm Fork.	N33º3'50.8"	W96º57'57.87"
SDA05-03	West Fork downstream of Lake Worth	Upstream of the influence of the Dallas WWTPs on the West Fork.	N32º46'51.43"	W97º24'36.12"
SDA05-04	West Fork upstream of Village Creek	Upstream of the influence of the Dallas WWTPs on the West Fork; distinct from SDA05-03 because it may receive inputs from urban land use.	N32°46'54.2"	W97°10'43.6"
SDA05-05	Village Creek WWTP Effluent	Selected as a source of surfactants to the Trinity River via WWTP **effluent.**	N32º46'47.65"	W97º8'37.76"
SDA05-06	Upstream of TRA Central WWTP	Selected to characterize the effect of transport and urban land use on effluent inputs within the Dallas-Forth Worth **mixing zone**.	N32º45'46.52"	W96º59'41.07"
SDA05-07	TRA Central WWTP Effluent	Selected as a source of surfactants to the Trinity River via WWTP **effluent.**	N32º46'43.57"	W96º56'15.07"
SDA05-08	Upstream of Dallas Central WWTP	Selected to characterize the effect of transport and urban land use on effluent inputs within the Dallas-Forth Worth **mixing zone**.	N32°44'16.1"	W96°45'55.4"
SDA05-09	Dallas Central WWTP Effluent	Selected as a source of surfactants to the Trinity River via WWTP **effluent.**	N32º43'44.67"	W96º45'46.09"
SDA05-10	Upstream of Dallas South WWTP	Selected to characterize the effect of transport and urban land use on effluent inputs within the Dallas-Forth Worth **mixing zone**.	N32°42'24.6"	W096°44'7.5"
SDA05-11	Dallas South WWTP Effluent	Selected as a source of surfactants to the Trinity River via WWTP **effluent.**	N32º38'14.06"	W96º38'47.86"
SDA05-12	East Fork Trinity River Upstream of the confluence of the East Fork and Trinity Rivers	Located upstream of the confluence of the East Fork and Trinity Rivers; site aids in characterizing any surfactant inputs from WWTPs on the East Fork.	N32°35'55.7"	W096°29'5.38"
SDA05-13	Downstream of Dallas South WWTP	Selected to identify conditions immediately **downstream** of the Dallas-Fort Worth mixing zone before inputs from the East Fork.	N32º34'36.47"	W96º34'20.98"
SDA05-14	Downstream of the East Fork and Trinity River confluence	Selected to identify conditions **downstream** of the Dallas-Fort Worth mixing zone after inputs from the East Fork.	N32°18'59.92"	W96°21'34.13"
SDA05-15	Palestine	Selected to identify conditions **far downstream** of the Dallas-Fort Worth mixing zone.	N31°38'54.13"	W95°47'22.9"

Table II.2. Sample and Site Evaluation Methods

Media/Analysis Type	Specific parameter (Standard method)
Effluent	
Surfactants	Alcohol ethoxylates
	Alkyl ethoxy sulfates
	Linear alkyl sulfonates
General Chemistry and Physical Parameters	Total dissolved solids (EPA 160.1)
	Total organic carbon (EPA 415.1)
	Biological oxygen demand (EPA 405.1)
	Chemical oxygen demand (EPA 410.1)
	Hardness (EPA 130.1)
Sediment	
Surfactants	Alcohol ethoxylates
	Alkyl ethoxy sulfates
	Linear alkyl sulfonates
General Chemistry and Physical Parameters	Moisture content (ASTM D2216)
	Grain size (ASTM D422)
	Total organic carbon (EPA 415.1)
	Total sulfide (EPA 376.1)
	Kjeldahl nitrogen (EPA 351.2)
	Total phosphorous (EPA 365.1)
	Cation exchange capacity (EPA SW846 9080)
Surface water	
Surfactants	Alcohol ethoxylates
	Alkyl ethoxy sulfates
	Linear alkyl sulfonates
General Chemistry and Physical Parameters	Total dissolved solids (EPA 160.1)
	Total organic carbon (EPA 415.1)
	Biological oxygen demand (EPA 405.1)
	Chemical oxygen demand (EPA 410.1)
	Hardness (EPA 130.1)
Field measured parameters	Temperature
	Dissolved oxygen
	pH
	Conductivity
	Oxidation-reduction potential
	Turbidity
Sediment Interstitial Water	
Surfactants	Alcohol ethoxylates
	Alkyl ethoxy sulfates
	Linear alkyl sulfonates
General Chemistry and Physical Parameters	Total dissolved solids (EPA 160.1)
	Total organic carbon (EPA 415.1)
	Hardness (EPA 130.1)

Chapter III

GIS Data Acquisition

Introduction

Several physical, chemical, and anthropogenic variables are likely factors involved in the accumulation of surfactants in the Trinity River. In order to analyze these variables on a large geospatial scale, Geographic Information System (GIS) analyses were performed. Variable data, in the form of shapefiles or raster images, were obtained from several government agencies (Table III.1.). The upper Trinity River watershed (UTRW) spans several mapping projection systems (e.g., UTM, state plane, etc.), so the current data have been reprojected in a Texas-specific projection system called Texas Centric Mapping System/Albers Equal Area (TX Albers) (Table III.2.). As its name implies, this projection system is based on the Albers Equal Area projection and is optimized for mapping the entire state within a single dataset. The available variables were analyzed by individual subwatersheds within the UTRW. Data derived from the GIS analyses were used for multiple regression analysis (watershed characteristics) and multivariate analyses (benthic ecology), described below.

Table III.1. Sources of Geographic Information Systems (GIS) and Database

Table intro-1. Source of Geographic Information Systems (GIS) Maps and Databases

Parameter	Source
Elevation	National Elevation Dataset (NED) of the U.S. Geological Survey (USGS) website http://ned.usgs.gov/
Hydrography	National Hydrography Dataset (NHD) of the U.S. Geological Survey (USGS) website http://nhd.usgs.gov/
Soil	Soil Data Mart of the Natural Resources Conservation Service (NRCS) division of the U.S. Department of Agricultu http://soildatamart.nrcs.usda.gov/
1992 Land Use-Land Cover	The National Map of the U.S. Geological Survey (USGS) website http://nationalmap.gov/
Digital Orthophoto Quadrangles (DOQs)	Data Distribution System of the Texas Natural Resources Information System (TNRIS) http://www.tnris.state.tx.us/digital.htm
Satellite Imagery	TexasView Remote Sensing Consortium for Texas http://www.texasview.org
Trinity River Basin Rivers Lakes Cities and Towns Permitted Wastewater Treatment Plants	GIS data for the Atlas of Texas Surface Waters at the Texas Commission on Environmental Quality (TCEQ) websi http://www.tceq.state.tx.us/implementation/water/tmdl/atlas.html
Population Density	U.S. Census Bureau website http://www.census.gov/
Rainfall	GIS Data from Texas General Land Office website http://www.glo.state.tx.us/gisdata/gisdata.html

Additional non-GIS data

Parameter	Source
River Flow	Real-Time Water Data for Texas at the U.S. Geological Survey (USGS) website http://waterdata.usgs.gov/tx/nwis/rt
Ecoregions of Texas, level IV	Ecoregions of Texas at the U.S. Environmental Protection Agency (EPA) website http://www.epa.gov/wed/pages/ecoregions/tx_eco.htm

Table III.2. Texas Centric Mapping System/Albers Equal Albers

Table intro-2. Texas Centric Mapping System/Albers Equal Albers

Projection	Albers Equal Area Conic
Spheroid	GRS80
Datum	North American Datum of 1983 (NAD83)
Longitude of Origin	100 degrees west (-100)
Latitude of Origin	18 degrees north (18)
1st Standard Parallel	27 degrees, 30 minutes north (27.5)
2nd Standard Parallel	35 degrees, 0 minutes north (35)
False Easting	1,500,000 meters
False Northing	6,000,000 meters
Units	meters

2002 Land Use Analysis

Purpose: Satellite images covering north central Texas were used to classify land use patterns within the upper Trinity River watershed as well as the 11 sample site-defined subwatershed.

Methods: Satellite images from LandSat7 ETM+ were obtained from the Texas View Remote Sensing Consortium for Texas (http://www.texasview.org). Four satellite images (p26/r38, p26/r37, p27/r37, and p27/r38) from November 2002 and one satellite image (p28/r37) from February 2002 were clipped into smaller images and processed for land use classification. Smaller images were imported into Definiens Professional Earth software (version 5; Definiens AG, Munchen, Germany). Multiresolution segmentation was used to divide the image into smaller land segments (i.e., polygons) which were then classified. Polygons were classified using a semi-supervised classification method. Classification hierarchy consisted of agriculture, forest, residential, urban, water, and unclassified. Classification hierarchy was defined by known land segments, as determined by ground truthing; several land segments were used to generate the overall spectra for each classification. Each image was then classified according to the classification hierarchy. Images were then manually inspected and, if needed, reclassified according to visual observations, spectral image layer mixing, and fuzzy logic analysis. Images were then exported to ArcMap (version 9; ESRI, Inc., Redlands, CA). Images were clipped into their respective subwatersheds and merged. All overlapping image segments were erased from the final subwatershed images. Area coverage was calculated using the geodatabase feature.

Results: The upper Trinity River watershed encompasses approximately 13,000 square miles (Figure III.1-3). The watershed was divided into 11 subwatersheds, as defined by (1) either the area between the headwaters of the Trinity River Forks and sample sites, or by (2) the area between upstream and downstream sample sites. Land uses for individual and cumulative subwatersheds are described in Table III-3.

<u>Subwatershed 1</u>: Subwatershed 1 is the smallest subwatershed at 5 square miles (Figure III.4). The sample site is approximately 3.8 river miles downstream from the headwaters of Clear Creek. Agriculture (48%) and forest (47%) made up the majority of the land use in the subwatershed. Only a small fraction of the subwatershed was residential (1%) or urban (3%), occurring primarily at the northern segment of the subwatershed.

<u>Subwatershed 2</u>: Subwatershed 2, at 1650 square miles, the third largest subwatershed, encompasses the upper Elm Fork branch of the Trinity River (approximately, 71 river miles) (Figure III.5). It spans from the Elm Fork headwaters to the sample site downstream of the Lake Lewisville dam. The majority of the land was used for agriculture (62%) in this subwatershed. Forest land (24%) was found primarily near the upper reaches of Clear Creek, north of Lake Ray Roberts, and in the greenbelt between Lake Ray Roberts and Lake Lewisville. The cities of Gainesville, Sanger, Denton, Corinth, Argyle, The Colony, and portions of Lewisville and Frisco are located in this subwatershed. Urban and residential land uses of the subwatershed were 3% and 6%, respectively, most of which was located in the southern region of the subwatershed. Because of the presence of Lake Ray Roberts and Lake Lewisville (approximately 96 square miles), water consisted of 6% of the land use in this subwatershed, the highest percentage for all subwatersheds.

<u>Subwatershed 3</u>: This subwatershed (Figure III.6) encompasses the majority of the West Fork of the Trinity River, from the West Fork headwaters to the sample site SDA05-03, downstream of Lake Worth dam (approximately 119 river miles). At 2062 square miles, subwatershed is the second largest subwatershed in the study. Lake Bridgeport, Eagle Mountain Reservoir, and Lake Worth are the 3 main reservoirs in the subwatershed, resulting in 2% of subwatershed land. Land use in subwatershed 3 consisted of 49% agriculture, 42% forest (the largest forest land use per subwatershed), 6% residential, and 2% urban. Most of the residential and urban land use was in the downstream part of the subwatershed, which includes parts of Fort

Worth, Eagle Mountain, Azle, Reno, Briar, and Pecan Acres. However, Bridgeport, Decatur, and Jacksboro are located in the central region of the subwatershed.

Subwatershed 4: This subwatershed incorporates the Clear Fork of the Trinity River (approximately 50 miles), as well as the confluence of the Clear Fork with the West Fork in Ft. Worth (approximately 23 river miles) (Figure III.7). Subwatershed 4 is 713 square miles, and it incorporates the land between sample sites SDA05-03 (downstream of Lake Worth dam) and SDA05-04 (upstream of Village Creek WWTP). Benbrook Lake is the only major reservoir in this subwatershed, resulting in less than 2% water land use. Urbanization is found with the city of Weatherford to the west and the cities of Ft. Worth, Benbrook, White Settlement, and Saginaw to the east. Most of the land was used for agriculture (51%) and forest (19%), but increased urbanization (7%) and residences (20%) was primarily seen to the east as the river approaches the West Fork and the DFW area.

Subwatershed 6: Subwatershed 6 (Figure III.8) is downstream from subwatershed 4 and is almost entirely within DFW. It includes the land between sample site SDA05-04 (upstream of Village Creek WWTP) and SDA05-06 (downstream of Village Creek WWTP/upstream of TRA Central WWTP). It also includes the Village Creek WWTP, a major point source of surfactant discharge in to the West Fork via WWTP effluent. At 280 square miles, it contains eastern Ft. Worth, Burleson and Crowley to the south, North Richland Hills, Hurst, Bedford, and Euless to the north, and western Arlington and northern Grand Prairie to the east. The amount of agriculture (26%) and forest (23%) lands continued to decrease, while residential (37%) and urban (12%) lands continued to increase. Lake Arlington is located in Subwatershed 6, resulting in less than 3% land use.

Subwatershed 8: Subwatershed 8 is one of the unique subwatersheds because it contains the confluence of the West Fork with the Elm Fork to create the main stem of the Trinity River (1407 square miles) (Figure III.9). Because of this, this subwatershed incorporates the land between 3 sample sites, SDA05-02 (downstream of the Lake Lewisville dam) to the north, #6 (downstream of Village Creek WWTP/upstream of TRA Central WWTP) to the west, and SDA05-08 (downstream of TRA Central WWTP/upstream of Dallas Central WWTP) to the east. In all, this includes about 35 river miles. It also includes the TRA Central WWTP, a major point source of surfactant discharge in to the West Fork via WWTP effluent. Subwatershed 8 includes the mid cities, with Keller Euless, Irving Flower Mound, Lewisville, and Carrollton to the north, and eastern Dallas, Grand Prairie, eastern Arlington, Cedar Hill, Mansfield, and Midlothian to the south. Approximately half of the subwatershed resides within DFW, however the north and the south are primarily rural land. Because of this, agriculture (46%) and forest (23%) land uses diluted the high residential (20%) and urban (9%) land uses within DFW. Lake Grapevine, Joe Pool Lake, Mountain Creek Lake, and North Lake made up approximately 3% land use.

Subwatershed 10: Subwatershed 10 (Figure III.9) is completely encompassed by DFW, with Frisco, Plano, Carrollton, and Richardson to the north and Dallas to the south. At 147 square miles, it incorporates the approximately 3 river miles between sample sites SDA05-08 (downstream of TRA Central WWTP/upstream of Dallas Central WWTP) and SDA05-10 (downstream of Dallas Central WWTP/upstream of Dallas Southside WWTP). It also includes the Dallas Central WWTP, a major point source of surfactant discharge in to the Trinity River via WWTP effluent. Because it is completely incorporated within DFW, urban (19%) and residential (56%) land uses were the highest of all the subwatersheds. Consequently, agriculture (13%) and forest (9%) were the lowest of all the subwatersheds. White Rock Lake was the primary source for the 2% water land use in this subwatershed.

Subwatershed 12: The majority of the East Fork of the Trinity River (approximately 73 river miles) is incorporated within this subwatershed of 1257 square miles (Figure III.11). It includes the river between the headwaters of the East Fork and sample site SDA05-12 (East Fork). This subwatershed is in the eastern DFW area, including Westminster, McKinney, eastern Plano, Wylie, eastern Richardson, Garland, Rockwall, Mesquite, and eastern Seagoville. Despite the presence of these cities, subwatershed 12 was still primarily rural, especially to the north of the subwatershed. Agriculture and forest made up 52% and 24% of land use, respectively. Residential and urban made up 13% and 5% of land use, respectively. Lakes Lavon and Ray Hubbard are the second largest amount of water of all the subwatersheds (74 square miles), but due to the size of the subwatershed they only constituted 6% of land use within the subwatershed.

Subwatershed 13: This subwatershed (Figure III.12) incorporates the 18 river miles between sample sites SDA05-10 (downstream of Dallas Central WWTP/upstream of Dallas Southside WWTP) and SDA05-13 (downstream of Dallas Southside WWTP/upstream of the main stem/East Fork confluence). It also includes the Dallas Southside WWTP, a major point source of surfactant discharge in to the Trinity River via WWTP effluent. This subwatershed is 109 square miles and includes portions of south Dallas and north Lancaster. The majority of this subwatershed is located in the southern DFW area, but most of the urbanization is in the north and western parts of the subwatershed. Residential land use (34%) was the highest land use for this subwatershed. Urban land use made up 9% of the land use. Twenty-eight percent of the land was agriculture and 27% of the land was forest. Water land use was low (less than 3%) because no reservoirs are located in this subwatershed.

Subwatershed 14: Subwatershed 14 is the other unique subwatershed that contains the confluence of the East Fork with the main stem of the Trinity River, a cumulative total of approximately 64 river miles (Figure III.13). The 693 square mile subwatershed is defined by sample sites # 12 (East Fork), SDA05-13 (downstream of Dallas Southside WWTP/upstream of the main stem/East Fork confluence), and SDA05-14 (Ennis, TX/downstream of the main stem/East Fork confluence). This subwatershed is south of DFW and is mainly rural. Agriculture and forest made up 70% and 19% of the land use, respectively. Most of the cities in the subwatershed—Lancaster, DeSoto, Duncanville, eastern Cedar Hill, northern Waxahachie, and northern Ennis—are primarily in the west. Rural and urban land use only consisted of 9%. Water made up only 2% of land use.

Subwatershed 15: This subwatershed (the largest at 4541 square miles) incorporates the remaining approximately 86 river miles between sample sites SDA05-14 (Ennis, TX/downstream of the main stem/East Fork confluence) and SDA05-15 (Palestine, TX) (Figure III.14). This subwatershed contains 6 reservoirs—Cedar Creek Reservoir, Lake Waxahachie, Bardwell Reservoir, Navarro Mills Lake, Richland-Chambers Reservoir, and Fairfield Lake—that is the third largest water land use per subwatershed (4%; 188 square miles). This subwatershed was predominantly rural, with 54% agriculture and 38% forest land use (the second largest forest land use). Waxahachie, Ennis, Terrell, Athens, Trinidad, Corsicana, and Palestine are the main cities within this subwatershed. Residential and urban land uses were 3% and 1%, respectively.

Land Use Analysis

Agriculture was overall the predominant land use in the upper Trinity River watershed. High levels of agriculture were found in subwatershed #2 (in the upper central region of the watershed) and in subwatershed #14 (south of DFW and the confluence of the Trinity River main stem and the East Fork) (Figure III.15). Agriculture levels began to decrease as the West and Elm Forks entered the central DFW area. Lowest agriculture levels were seen subwatersheds #6 (containing east Ft. Worth, Burleson, Arlington, North Richland Hills, Hurst, Bedford, and northern Grand Prairie), #10 (containing Dallas, Richardson, and west Plano), and SDA05-13 (containing south Dallas and north Lancaster), all within the central DFW area. However, as the Trinity River leaves DFW, agriculture land dramatically increases again and remains high land use through the rest of the upper Trinity River watershed. Similarly, cumulative agriculture land use along the Trinity River decreases as the river flow through DFW (Figure III.16), with lowest cumulative agriculture land use in subwatersheds #6. Cumulative agriculture land also increases as the Trinity River flows out of DFW and remains high throughout the rest of the watershed.

High levels of *forest* land use (Figure III.16) were found in subwatershed #3 (the West Fork headwaters subwatershed) and SDA05-15 (downstream of DFW). Moderate levels of forest were found in the upper, central, and eastern subwatersheds. The lowest level of forest was in subwatershed #10, a highly urbanized area of Dallas. When looked at cumulatively, forest land use along the West Fork starts high, but then begins to decrease as it flows in to DFW. Both the upper Elm Fork and East Fork had low forest land use. Forest land use increased along the Elm Fork as it flowed downstream of Lake Lewisville. Moderate forest land use continued downstream of the confluence of the West and Elm Forks, even through downtown Dallas. Forest land use decreased at the confluence of the Trinity River main stem and the East Fork in subwatershed 14, probably due to the high agriculture land use in this subwatershed. However, high forest land use in subwatershed 15 raised the cumulative forest land use to a moderate level.

Residential land use was low in the largest three subwatersheds (#2, 3, and 15) due to their size and abundance of agriculture and forest (Figure III.17). As expected, residential land quickly increased as the West and Elm Forks flow into DFW. The East Fork, however, had moderate residential land use due to heavy growth of suburban communities in eastern DFW. Residential land peaked in subwatersheds #6 (containing east Ft. Worth, Burleson, Arlington, North Richland Hills, Hurst, Bedford, and northern Grand Prairie), #10 (containing Dallas, Richardson, and west Plano), and #13 (containing south Dallas and north Lancaster), the reverse pattern seen with agriculture. Cumulative residential land use was mostly at moderate to high levels with much of the entire watershed. Residential land use increased from moderate to high as the river flowed through DFW. Interestingly, the highest cumulative values were seen in subwatersheds 10, 12, 13, and 14, all in the northeast and central regions of the watershed. Residential land use decreased as the Trinity River flowed in to #15, but despite its size it only reduced cumulative residential land use to a moderate level.

Urban land use (Figure III.18) followed a very similar pattern as residential land use. Little urban land use was seen in subwatersheds #2, 3, and 15, yet moderate urban land use was seen in subwatershed SDA05-12 due to the suburban communities in eastern DFW. Urbanization was moderate-high in subwatersheds #6, 8, and 13 in the center of DFW, and highest in subwatershed #10 in Dallas. Cumulatively, urban land use was low along the West and upper Elm Forks, but rapidly increased as the rivers flowed into DFW. After the confluence of the West and Elm Forks, cumulative urban land use was highest in subwatersheds #10, 12, 13, and 14, similar to the pattern seen in cumulative residential land use. However, urban land use rapidly decreased to a low level from subwatersheds #14 to SDA05-15 due to the lack of highly urbanized communities.

Since Texas only has one natural lake, *water* land use is a function of elevation and topology that makes it possible for the creation of dammed reservoirs. Highest water land use was seen in subwatersheds #2 (containing Lakes Ray Roberts and Lewisville) and 12 (containing Lakes Lavon and Ray Hubbard), moderate-high in #15 (containing Cedar Creek and Richland-Chambers Reservoirs), and moderate in subwatersheds #3 (Bridgeport Lake, Amon G. Carter Lake, Eagle Mountain Lake, and Lake Worth), #6 (Lake Arlington), 8 (Lake Grapevine, Joe Pool Lake, Mountain Creek Lake, and North Lake), and 13 (Figure III.19). Cumulatively, water land use was low along the West Fork (subwatersheds #3, 4, and 6) until it entered the mid-cities region of DFW. Water land use along the Elm Fork was high (subwatershed #2) prior to entering northern DFW, where it decreased to a moderate level after converging with the West Fork (subwatershed #8) and remained moderate through the rest of DFW (subwatersheds #10 and 13). Water land use along the East Fork (subwatershed SDA05-12) was high, and decreased to moderate-high after convergence with the Trinity River main stem in subwatershed #14. Water land use remained moderate-high in #15.

Table III.3. 2002 Land Use in the Upper Trinity River Watershed According to Individual Subwatershed (near) and Cumulative Subwatershed (far) Analyses

Sub-water-sheds	Ag near (% Total)	Ag far (% Total)	Forest near (% Total)	Forest far (% Total)	Resi-dential near (% Total)	Resi-dential far (% Total)	Urban near (% Total)	Urban far (% Total)	Water near (% Total)	Water far (% Total)
1	47.80	47.80	46.50	46.50	1.25	1.25	3.37	3.37	1.07	1.07
2	61.98	61.94	23.93	24.00	5.74	5.73	2.50	2.51	5.80	5.79
3	48.96	48.96	41.52	41.52	5.57	5.57	1.78	1.78	2.12	2.12
4	51.43	49.59	19.44	35.85	20.14	9.31	7.32	3.20	1.64	2.00
6	25.82	47.41	23.05	34.67	36.88	11.84	11.81	3.99	2.40	2.04
8	45.52	50.91	22.65	29.02	19.92	12.04	9.13	4.77	2.75	3.21
10	13.30	50.02	9.39	28.56	56.34	13.08	18.97	5.11	1.96	3.19
12	51.69	51.69	23.95	23.95	13.33	13.33	5.12	5.12	5.89	5.89
13	28.06	49.65	26.63	28.52	33.55	13.43	9.25	5.18	2.47	3.17
14	69.84	51.64	19.07	27.05	6.07	12.81	3.20	5.00	1.81	3.47
15	55.40	52.96	36.94	30.54	2.56	9.19	0.95	3.57	4.14	3.70

Figure III.1. Land use in the upper Trinity River watershed.

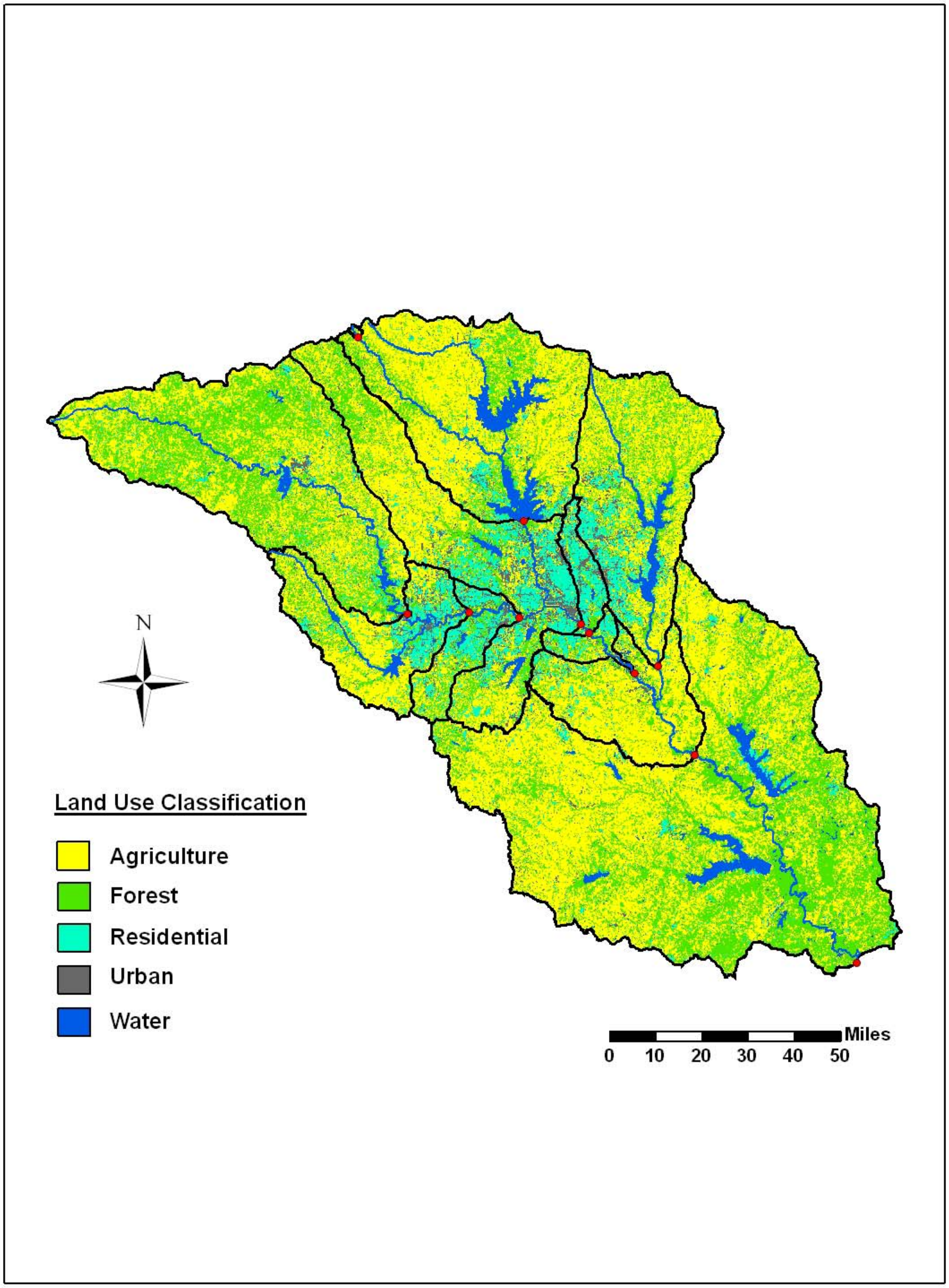


Figure III.2. Individual and cumulative subwatershed sizes in the upper Trinity River watershed.

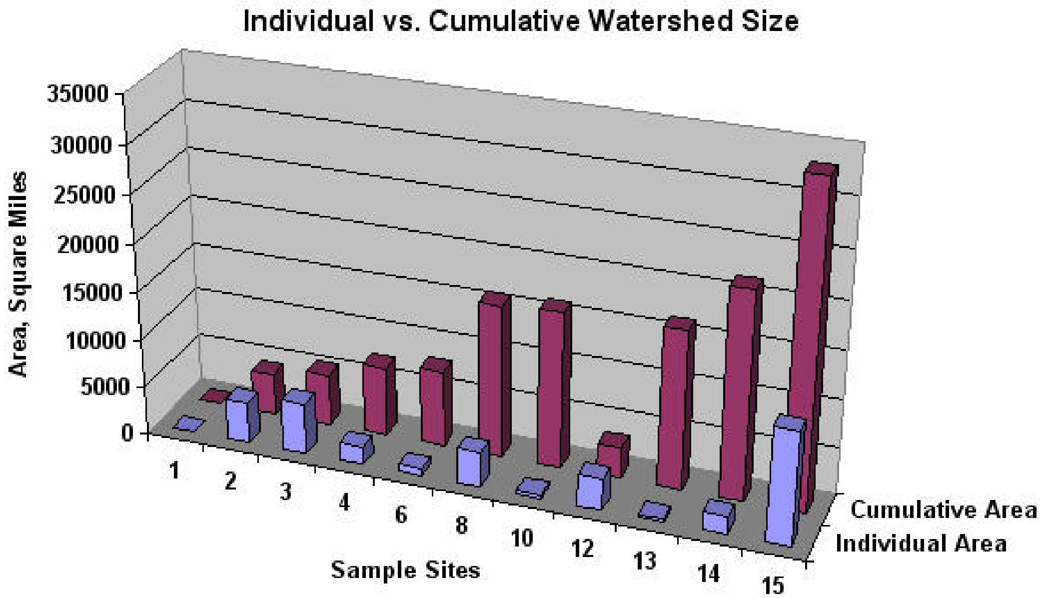


Figure III.3. Land uses in the upper Trinity River watershed.

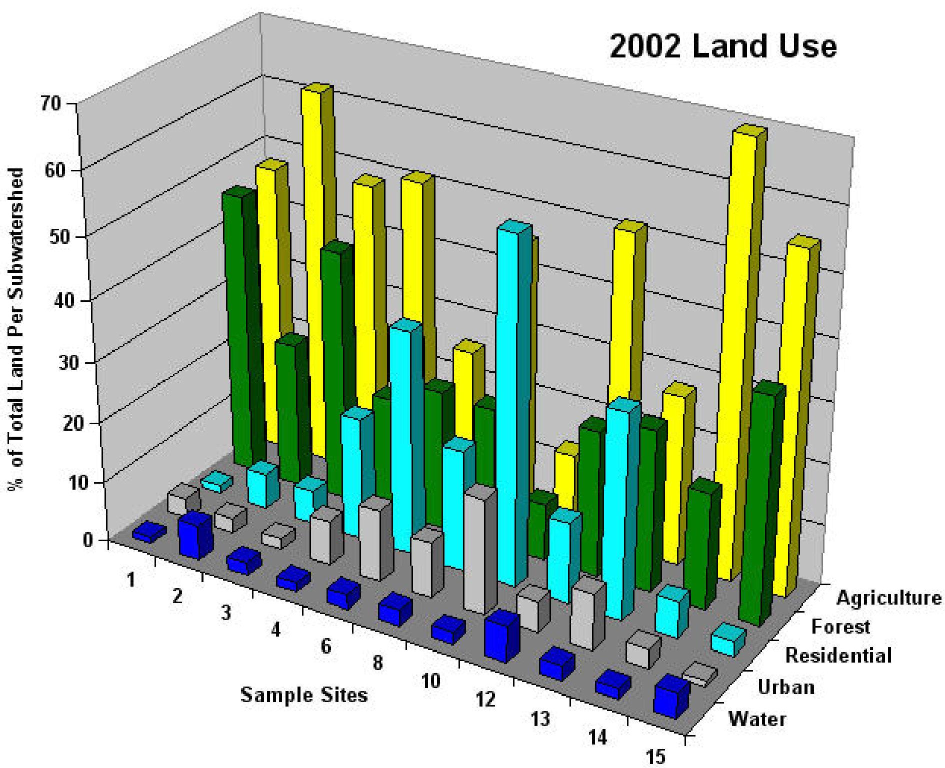


Figure III.4: Subwatershed 1 land use.

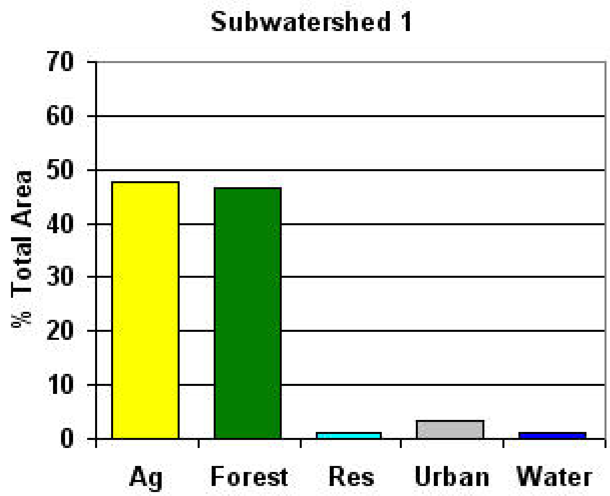


Figure III.5: Subwatershed 2 land use.

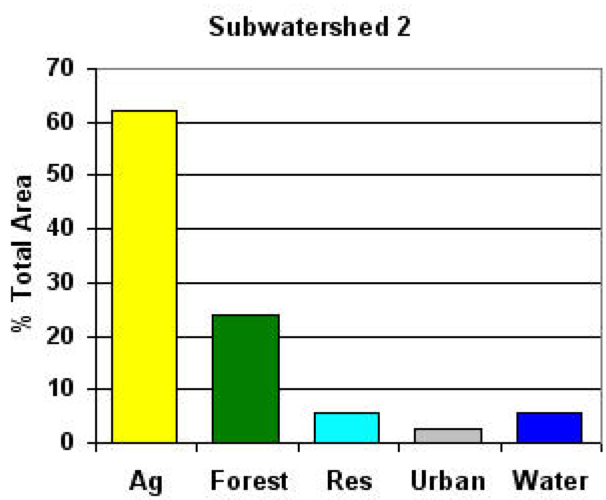


Figure III.6: Subwatershed 3 land use.

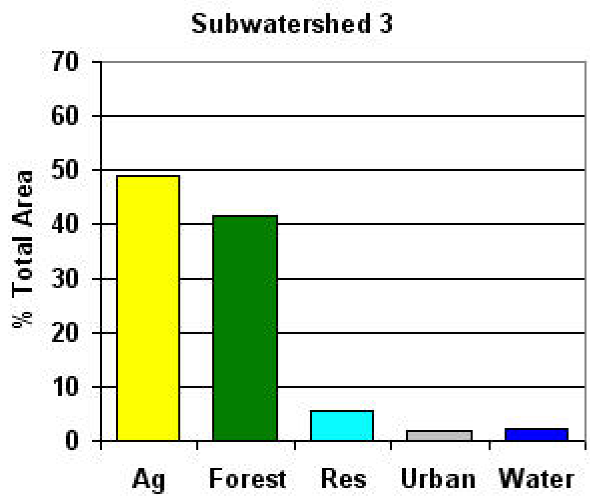


Figure III.7: Subwatershed 4 land use.

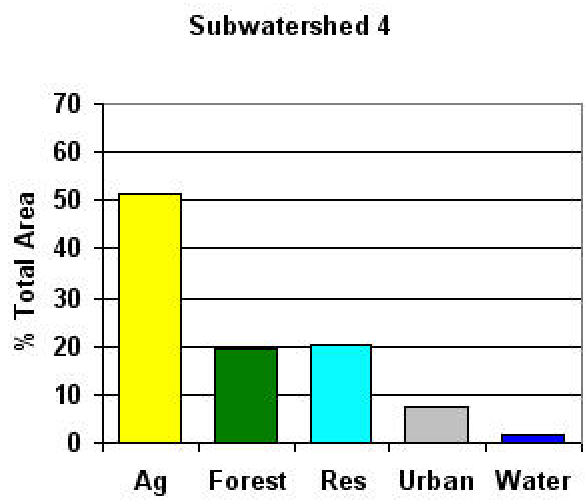


Figure III.8: Subwatershed 6 land use.

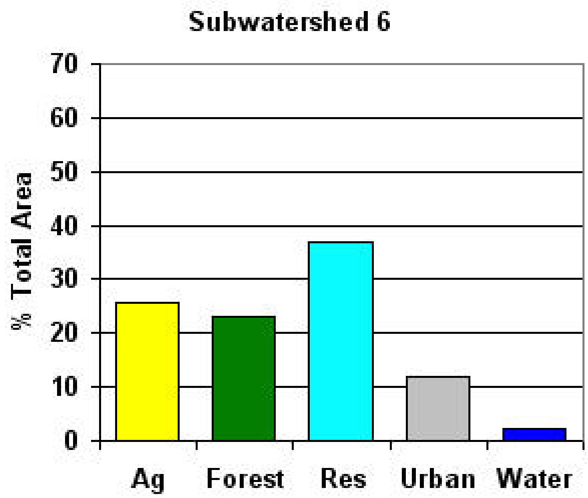


Figure III.9: Subwatershed 8 land use.

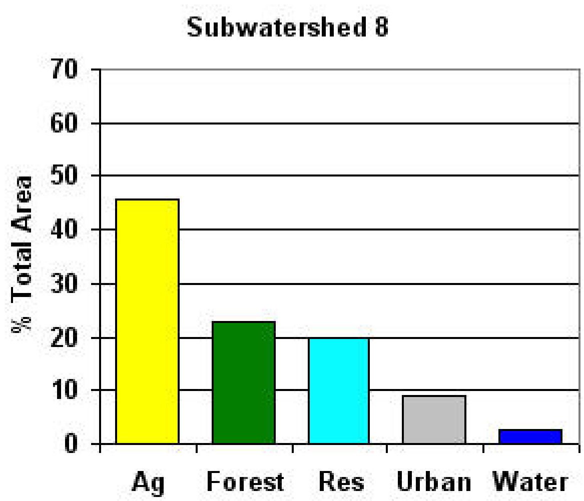


Figure III.10: Subwatershed 10 land use.

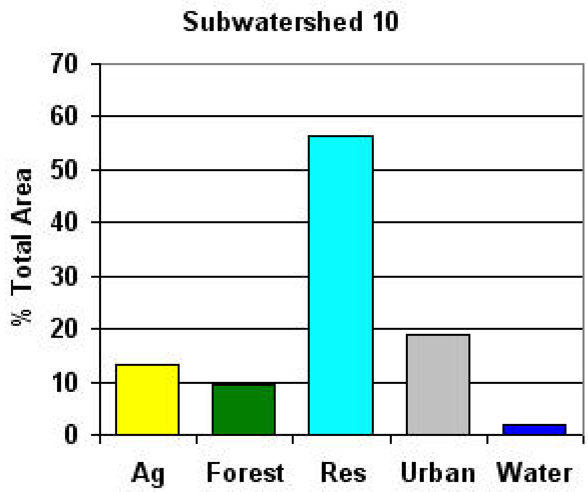


Figure III.11: Subwatershed 12 land use.

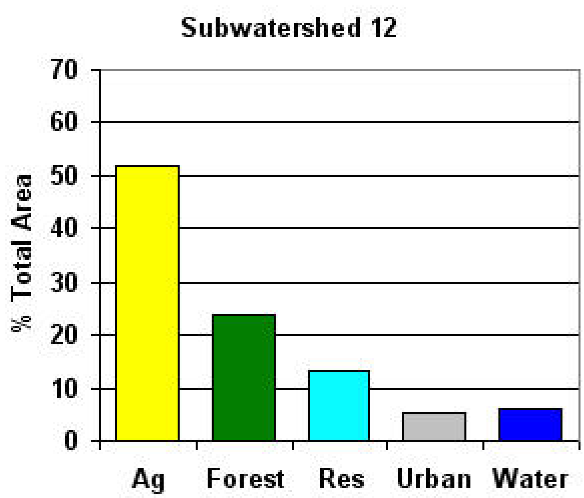


Figure III.12: Subwatershed 13 land use.

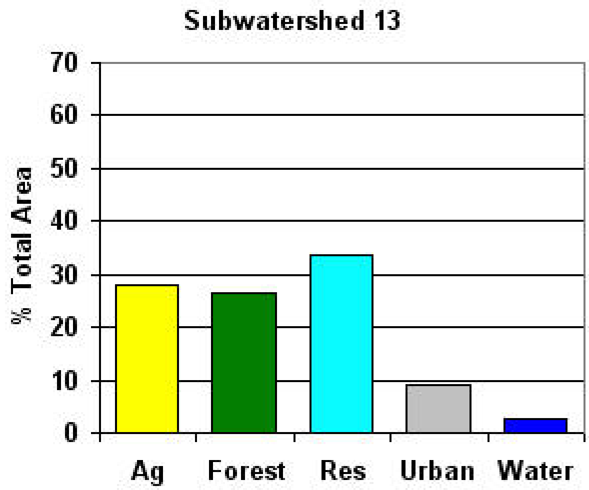


Figure III.13: Subwatershed 14 land use.

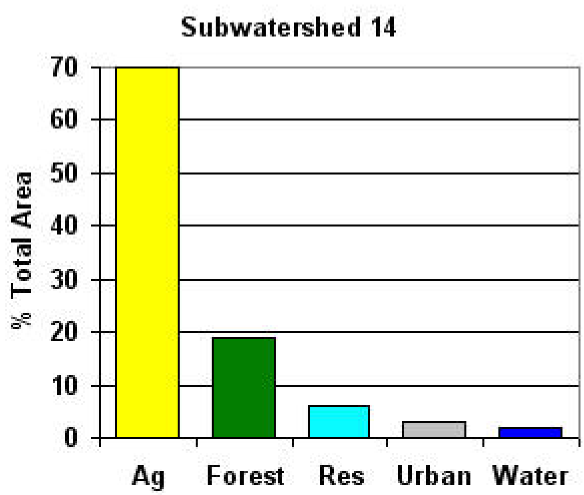


Figure III.14: Subwatershed 15 land use.

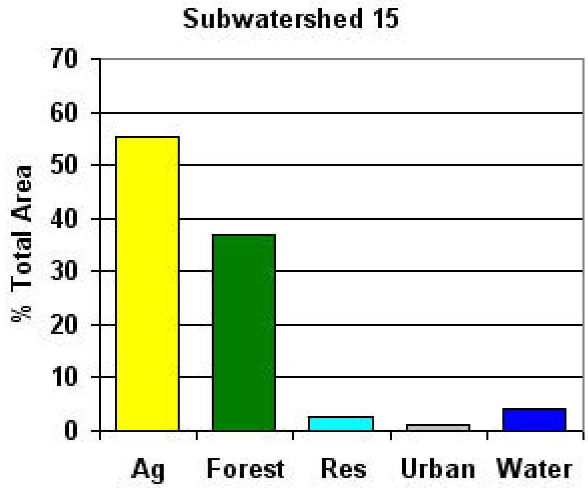


Figure III.15: Agriculture land use in the upper Trinity River watershed.

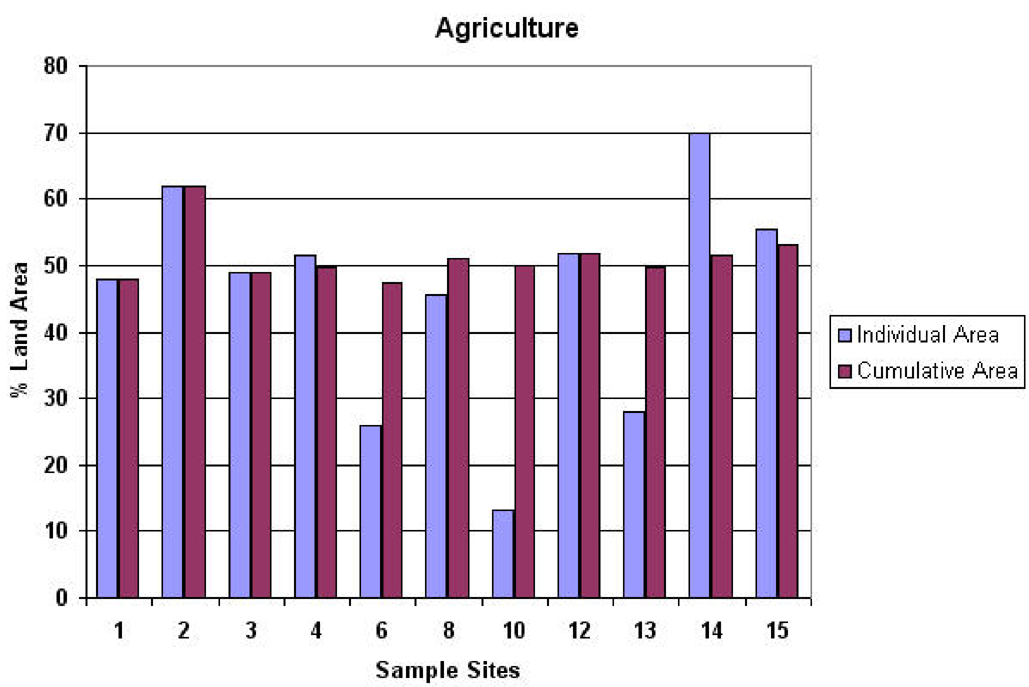


Figure III.16: Forest land use in the upper Trinity River watershed.

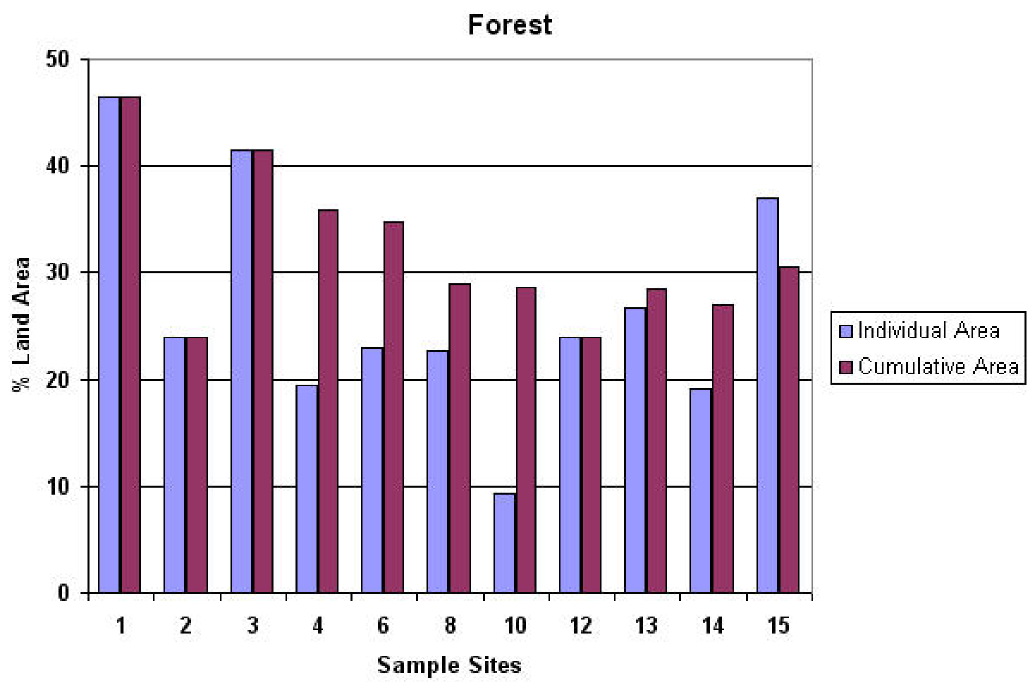


Figure III.17: Residential land use in the upper Trinity River watershed.

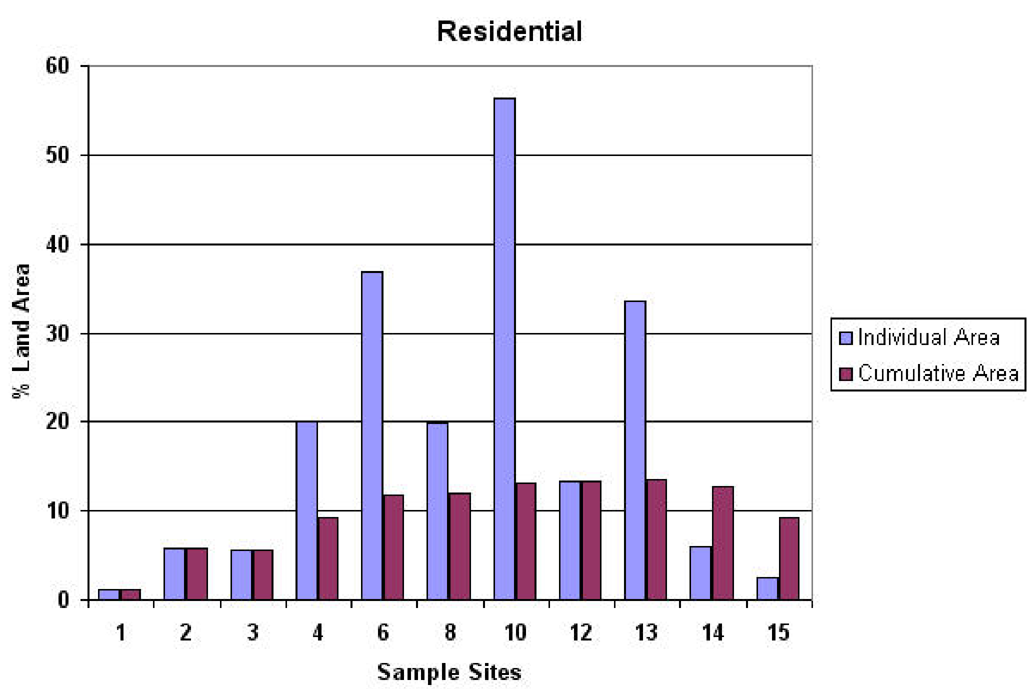


Figure III.18: Urban land use in the upper Trinity River watershed.

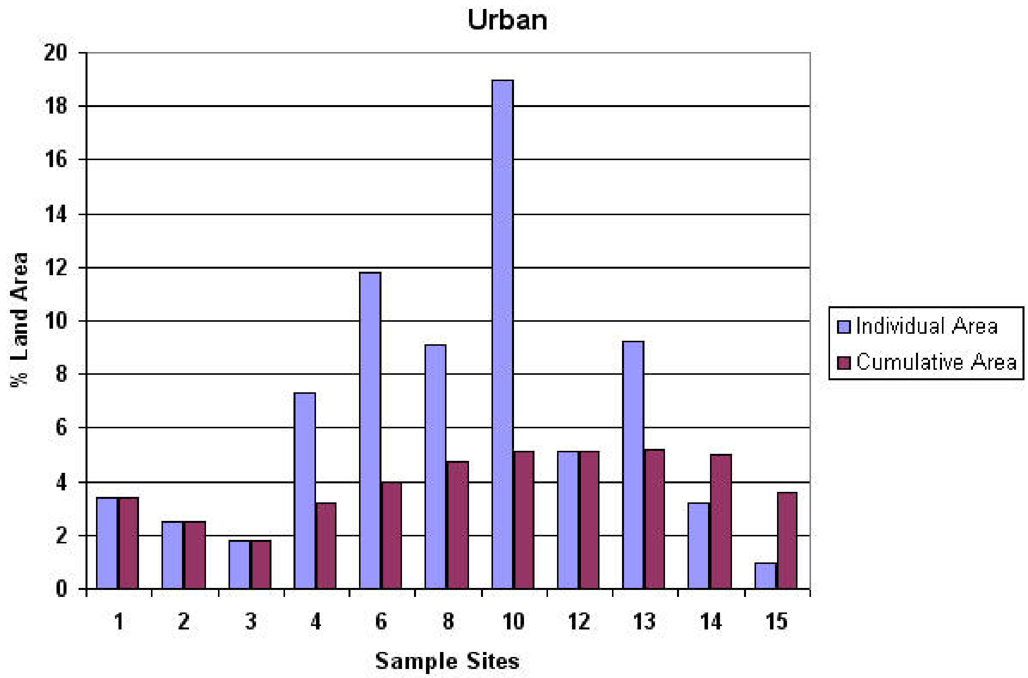
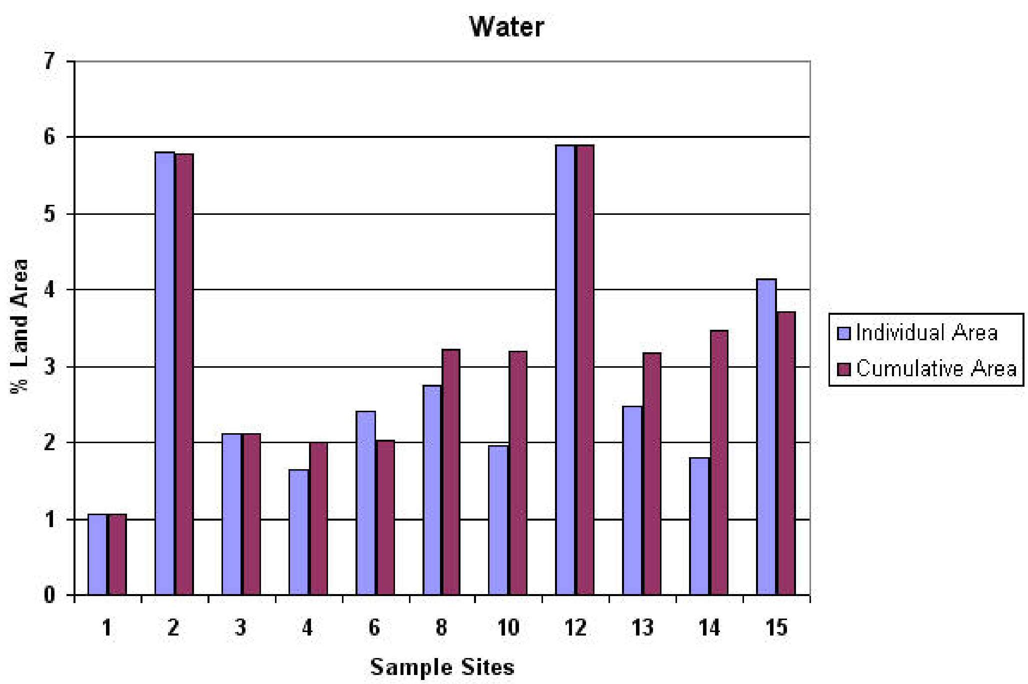


Figure III.19: Water use in the upper Trinity River watershed.



2000 Population Density Analysis

Purpose Population density may be an important variable for surfactant loading into the Trinity River. It can also represent non-point source loading, i.e., surfactants from car washing that run off to storm drains.

Methods The 2000 census data from 26 counties involved in the UTRW were obtained from the U.S. Census Bureau website. Population per census block were divided by the area (in hectares) of the census block to create population density. The county shapefiles were merged, clipped to the shape of the UTRW, and further clipped by subwatersheds. Average population density was then calculated by individual subwatershed (near field) and by cumulative subwatersheds (far field). Categorization of population densities was done by natural breaks in the data.

Results Population densities of census tracts for the UTRW and the individual subwatersheds are displayed in Figure III.20. Population densities for individual subwatersheds are displayed in Figure III.21, and population densities for cumulative subwatersheds are displayed in Figure III.22 (numerical listings are found in Table III.4). Average subwatershed population densities fell into three categories: low (<125 individuals/km^2), medium (393 > x > 125 individuals/km^2), and high (>393 individuals/km^2). All of the subwatersheds with low population densities were rural and used primarily for agricultural purposes (#1, 2, 3, 14, and 15). Subwatersheds with moderate population densities were found around DFW and had a mix of agriculture and urban/residential land use (#4, 8, and 12). The subwatersheds with high population density were subwatersheds #6, 10, and 13. Subwatershed #6 contains high residential tracts in several mid-cities; subwatershed #10 is located in east Dallas and contains many census tracts that are heavily residential; and subwatershed #13 contains high residential tracts in south Dallas. When analyzed cumulatively, population density starts low for the West and Elm Forks, and increases as the river flows through DFW. The subwatersheds in Dallas, the East Fork, and immediately downstream of Dallas have high cumulative population densities. Cumulative population density drops to moderate levels by subwatershed #15.

Figure III.20. Population densities of census tracts in the upper Trinity River watershed. The map is displayed at 1:2,000,000 scale.

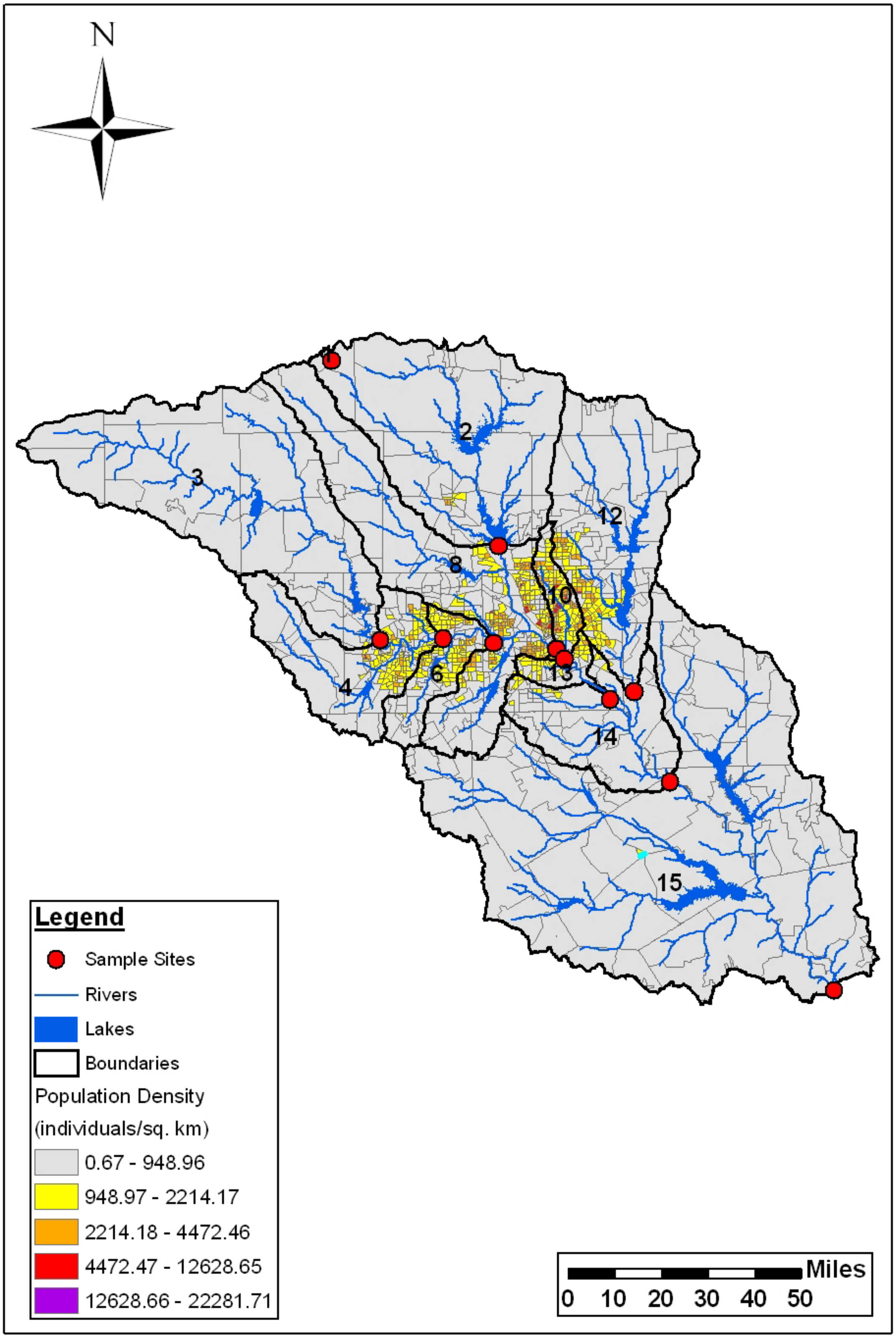


Table III.4. Population densities of individual (near) and cumulative (far) subwatersheds.

Subwatershed	Near Field Pop Density (individuals/square km)	Far Field Pop Density (individuals/square km)
1	4.848484848	4.85
2	63.28236064	63.10
3	23.87077442	23.87
4	343.4035069	106.02
6	747.2576865	164.80
8	392.9468427	189.73
10	1668.264744	224.49
12	257.6253955	257.63
13	815.4866008	234.64
14	124.81	228.97
15	24.68	156.87
total	**156.87**	**182.48**

Figure III.21. Population densities of individual subwatersheds (near field) in the upper Trinity River watershed. The map is displayed at 1:2,100,000 scale.

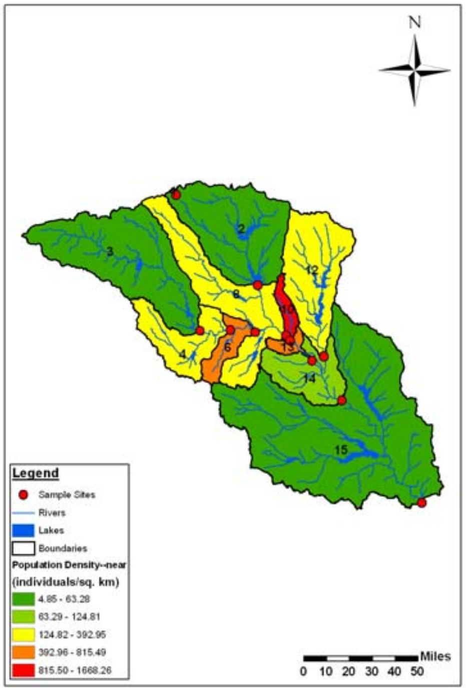
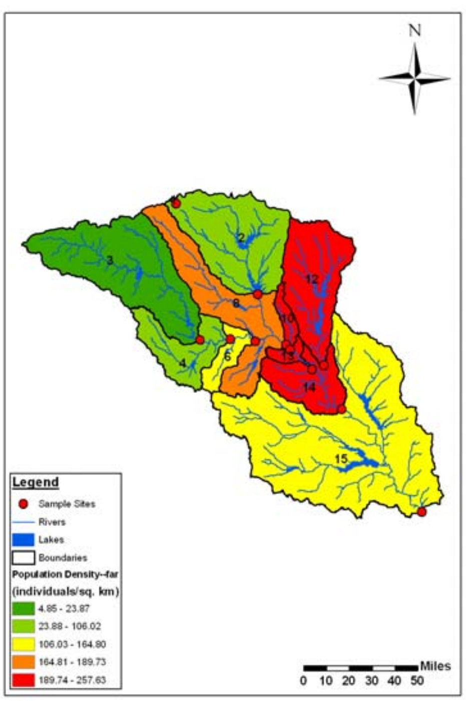


Figure III.22. Population densities of cumulative subwatersheds (far field) in the upper Trinity River watershed. The map is displayed at 1:2,100,000 scale.



Organic Matter Analysis

Purpose The organic matter content of soils is an important parameter to consider when evaluating the fate of organic chemicals. Both animal and plant-derived organic matter can sequester organic chemicals due to adsorption. Adsorption occurs on land soils as well as in river sediments. The surfactants in this study are likely to adsorb to sediment with high organic content so it is of value to examine the soil organic matter content in the upper Trinity River watershed. Analysis of organic matter by subwatershed may (1) help predict organic matter content measured at each sample site, (2) may be an important variable in predicting surfactant concentrations at sample sites, and (3) may help future predictions of organic chemical sequestration sites within the upper Trinity River subwatersheds (UTRW).

Methods Soil data were provided by the Soil Data Mart of the Natural Resources Conservation Service (NRCS) division of the U.S. Department of Agriculture (USDA) website. Representative organic matter (OMR)—the average value for organic matter content of the soil layer or horizon, expressed in percent by weight—was extracted for the 26 counties that are part of the UTRW. The county OMR shapefiles were corrected for overlaps, then merged together and clipped to the shape of the UTRW. New OMR shapefiles were generated for each of the subwatersheds. The partial areas were calculated for each organic matter value within the subwatersheds. The average organic matter per subwatershed was then calculated. One caveat to the data is that subwatersheds 3 and 4 have artificially low average organic matter values due to what appears to be incomplete soil data for Archer and Parker Counties.

Results The OMR in the UTRW is shown in Figure III.23, and the average organic matter in each subwatershed is shown in Table III.5 and Figures III.24. The OMR content of the UTRW ranged from 0-6.5 %. In general, OMR content fell along ecoregion boundaries (see Ecoregions section). The Grand Prairie and Blackland Prairie ecoregions had higher OMR content than the Eastern and Western Cross Timbers and the Post Oak Savannah ecoregions. However, because of the size of the subwatersheds and their tendencies to span several ecoregions, OMR for several subwatersheds are averages between low and high organic matter levels. For example, subwatershed #2 encompasses portions of rich-soiled Grand Prairie and Blackland Prairie ecoregions and poorer-soiled Eastern and Western Cross Timbers. However, subwatersheds #10, 12, 13, and 14 are primarily within the Blackland Prairie ecoregion and have high OMR values (2.29, 2.28, 1.96, and 2.14%, respectively). In addition, if soil data for Parker County were more accurate, it is likely that subwatershed #4 would have a higher OMR due to a large portion of the subwatershed within the Grand Prairie ecoregion.

The OMR in the subwatersheds was compared to total organic carbon content measured at each of the sample sites. OMR per subwatershed is shown in Figure III.24, and total organic carbon per environmental media (i.e., surface water, pore water, and sediment) are shown in Table III.6. and Figure III.25. TOC was chosen as the approximate equivalent of OMR. OMR was relatively stable (ranging from 1.25-1.69%) for sample sites 1-8 and 15, but sample sites SDA05-10-14 (i.e., sample sites located in the Blackland Prairie ecoregion) were elevated >1.95. TOC for surface water, pore water, and sediment at sample sites did not follow the same geospatial distribution as the representative OMR for the subwatersheds. TOC in surface water increased downstream of the Village Creek WWTP and remained elevated through DFW.

Surface water TOC then decreased downstream of the Trinity River main stem-East Fork confluence and remained lower to sample site SDA05-15. Pore water TOC seemed to decrease at sample sites in DFW, whereas upstream and downstream sample sites had higher TOC values. However, these data need to be interpreted with caution because (1) our inability to collect pore water at all sample sites and (2) the extra centrifugation needed to remove fines from pore water at some sites. Sediment TOC was generally low for all samples sites, but there seemed to be a decreasing trend as the river flowed downstream (i.e., sample sites SDA05-01-3 had higher TOC than sample sites SDA05-14-15). Sample site SDA05-10 had the highest TOC, but this should be read with caution since this may be a sampling artifact due to the nature of the heavy clay sediment.

Figure III.23. Representative organic matter for the upper Trinity River watershed. The map is displayed at 1:640,000 scale.

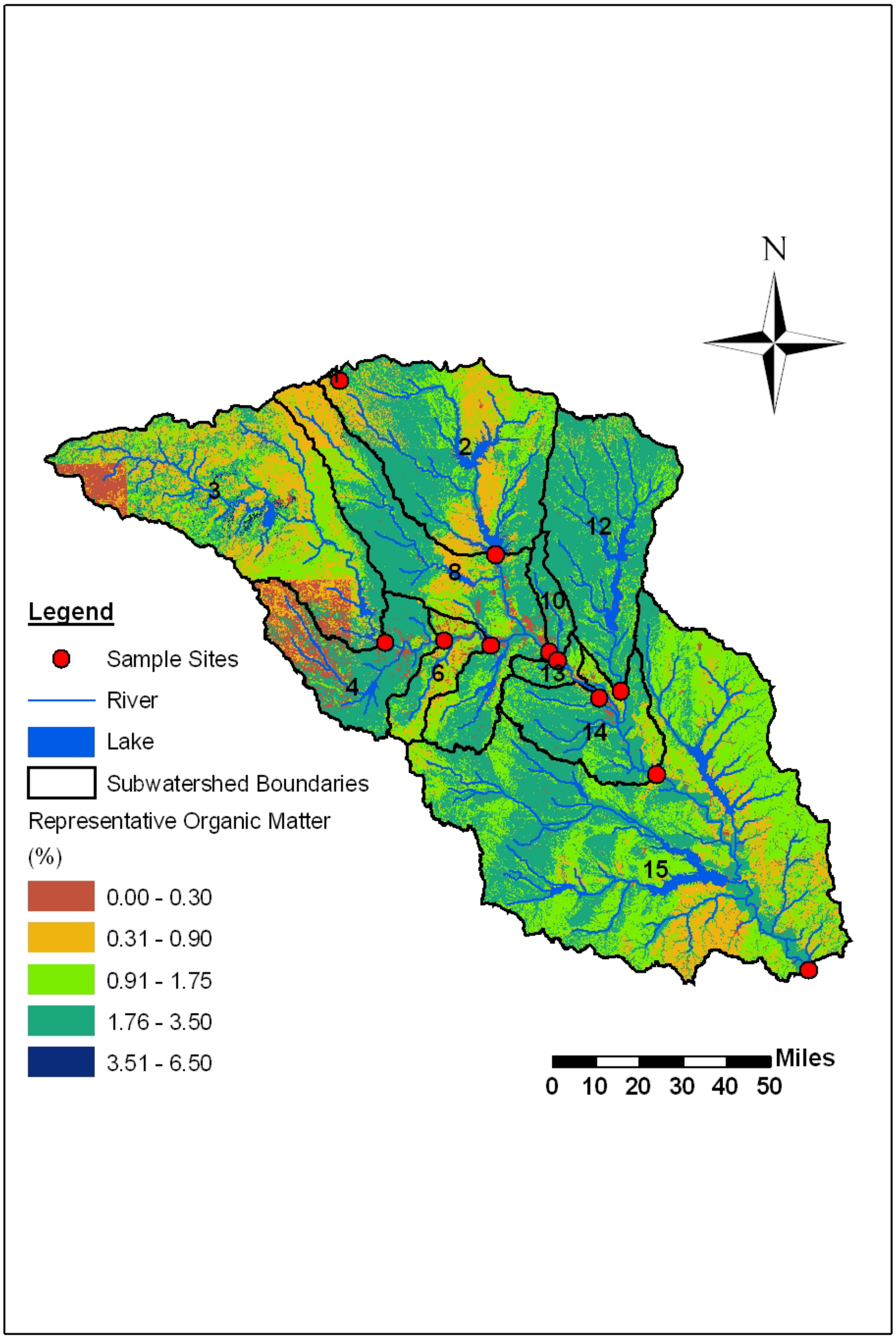


Table III.5. Average representative organic matter (%) for subwatersheds in the upper Trinity River watershed.

Subwatershed	Rep Organic Matter %
1	1.5975
2	1.5500
3	1.2527
4	1.4282
6	1.2864
8	1.6907
10	2.2899
12	2.2811
13	1.9590
14	2.1389
15	1.6175

Figure III.24. Average representative organic matter (%) at each sampling location.

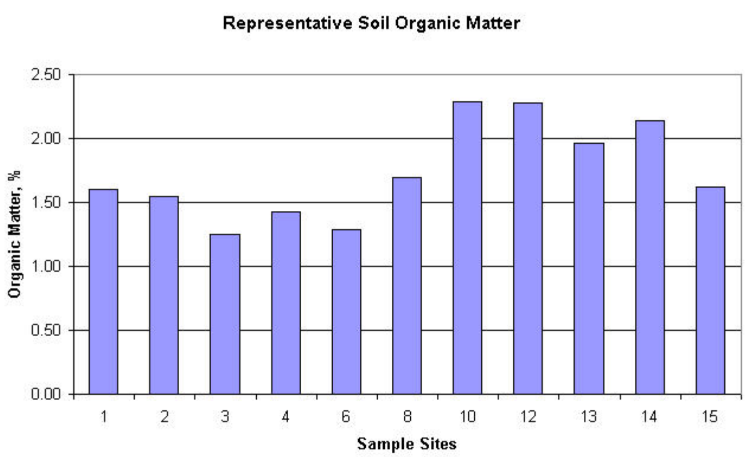
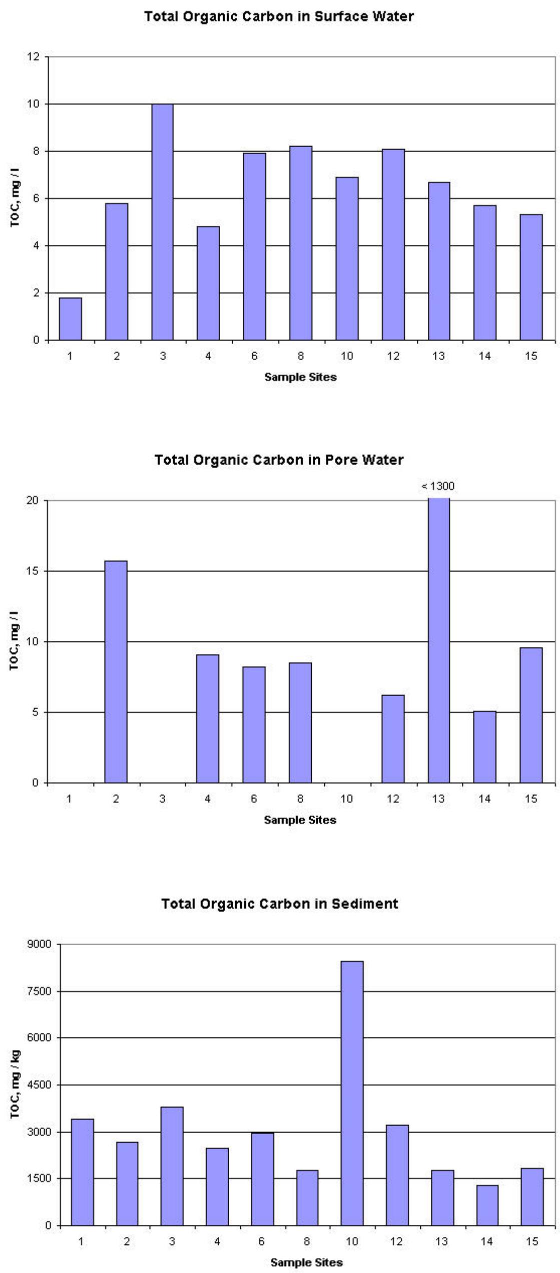


Table III.6. Total Organic Content measured at each sample site.

Subwatersheds	TOC-sw mg/l	TOC-pw mg/l	TOC-sed mg/kg
1	1.8		3410
2	5.8	15.7	2680
3	10		3800
4	4.8	9.1	2470
6	7.9	8.2	2970
8	8.2	8.5	1770
10	6.9		8450
12	8.1	6.2	3220
13	6.7	1200	1770
14	5.7	5.1	1299
15	5.3	9.6	1820

Figure III.25. Organic matter content measured in surface water (top), pore water (middle), and sediment (bottom) at each sample site.



Soil Erodibility Factor (K factor) Analysis

Purpose The soil erodibility factor (K Factor) is a variable in the universal soil loss equation that represents soil loss due to both detachment (erosion) and water movement (runoff rate). Soils with low K Factor values (< 0.25, such as clays) are less likely to detach and runoff, whereas soils with high K Factors (> 0.4, such as silts) are more likely to detach and runoff (RUSLE, 2002). Important soil components that determine K Factor are organic matter content (reduces detachment), soil structure, and permeability.

Due to the presence of nine distinct ecoregions within the study area, it was of interest to examine the K Factor in the UTRW. Some subwatersheds may be more susceptible to erosion, resulting in different types of soils entering streams and rivers and potentially sequestering surfactants in the sediments. It is possible that K Factor will play an important role in predicting surfactant toxic units (TUs).

Methods Soil data were provided by the Soil Data Mart of the Natural Resources Conservation Service (NRCS) division of the U.S. Department of Agriculture (USDA) website. K Factor was extracted for the 26 counties that are part of the UTRW. The county K Factor shapefiles were corrected for overlaps, then merged together and clipped to the shape of the UTRW. New K Factor shapefiles were generated for each of the subwatersheds. The partial areas were calculated for each K Factor value within the subwatersheds. The normalized K Factor was then calculated for each subwatershed.

Results The K Factor for the UTRW is shown in Figure III.26. Though there are wide distributions of soils with different K Factor values in the UTRW, there are distinct patterns along defined ecoregion boundaries. The Western and Eastern Cross Timbers tend to have soils with higher K Factor values, perhaps due to the sandy and sandy loam substrates and topology slopes. The Grand Prairie and Blackland Prairie ecoregions, on the other hand, have consistently moderate K Factor values representing fertile soil (fine-textured, clayey soils) that are moderately susceptible to detachment. In the Post Oak Savannah, south of the Blackland Prairie, K Factor values increase in the higher elevations (sandy and sandy loams) yet remain moderate in the low-lying areas (clay and clay loams).

Similar to the soil organic matter values, the size of the subwatersheds tended to moderate the high and low K Factors within the subwatersheds. Averaged K Factor values for subwatersheds ranged from 0.26 to 0.34 (Table III.7 and Figure III.27). The lowest value was seen in subwatershed #4 and the highest value was seen in subwatershed #1. Also similar to the organic matter values is the fact that subwatersheds 3 and 4 have artificially low average organic matter values due to what appears to be incomplete soil data for Archer and Parker Counties. If Parker County soil values were more accurate, subwatershed #4 might have had a higher average K Factor value due to a significant amount of subwatershed residing in the Western Cross Timbers ecoregion.

Figure III.26. Soil erodibility factor (K Factor) in the upper Trinity River watershed. The map is displayed at 1:2,000,000 scale.

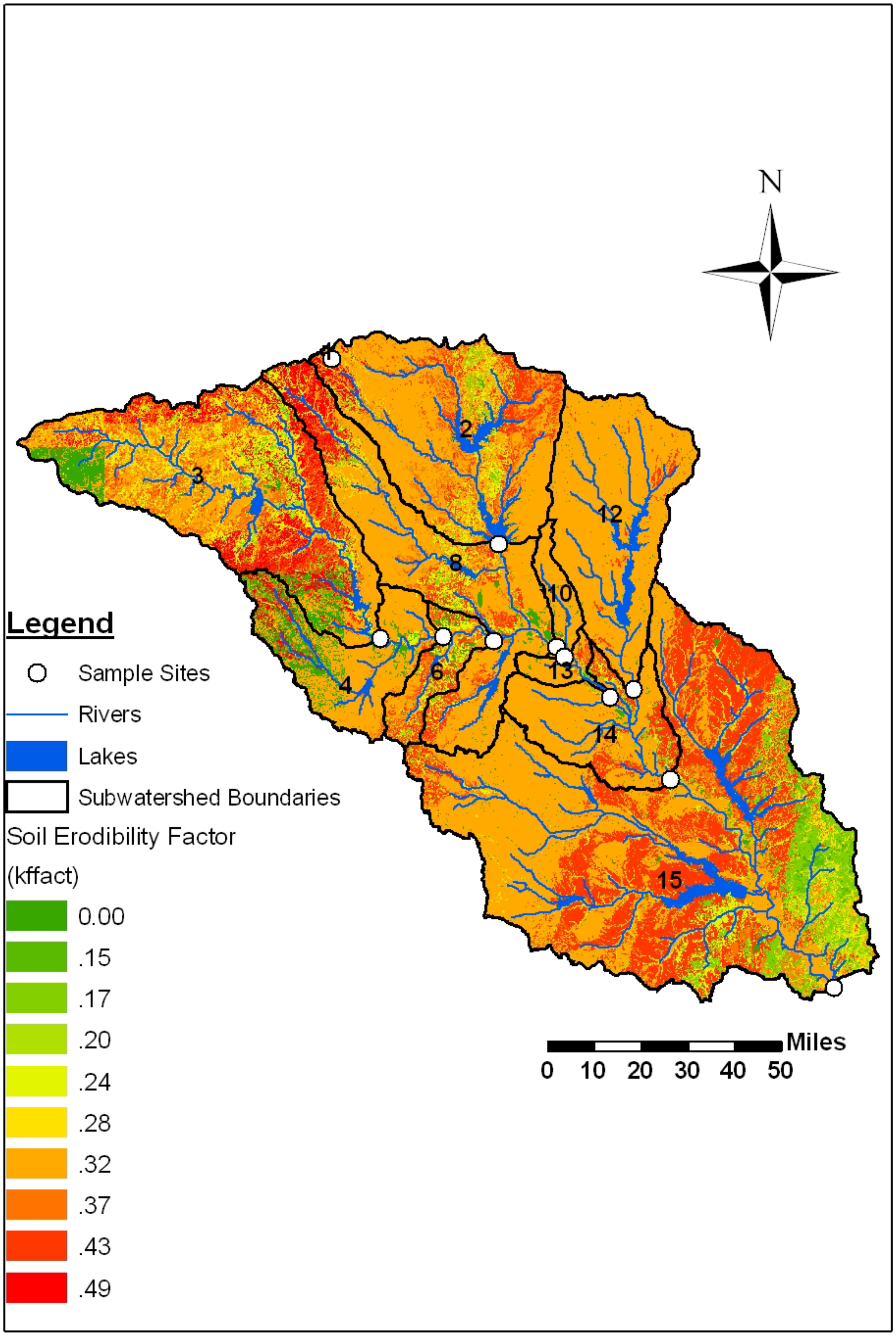
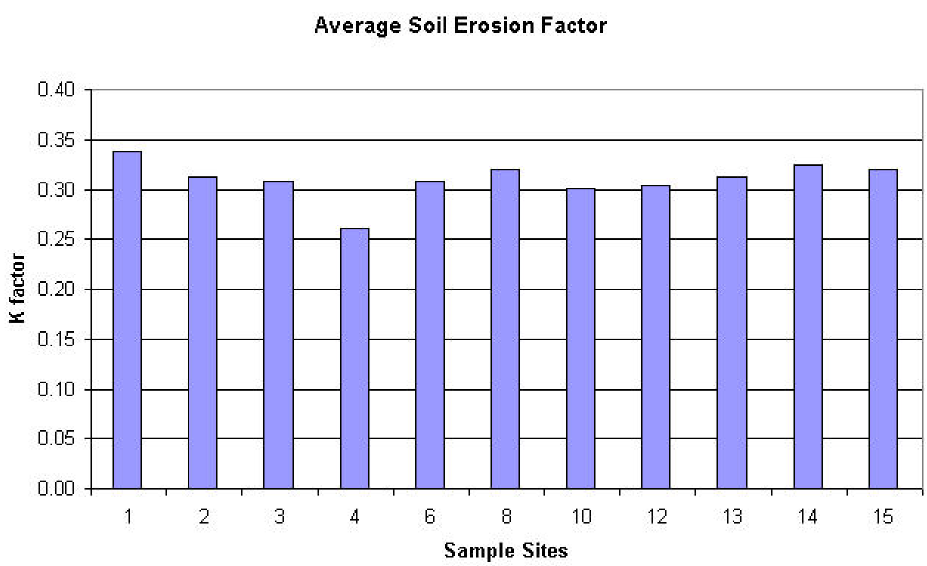


Table III.7. Average soil erodibility factor (K Factor) for subwatersheds in the upper Trinity River Watershed.

Subwatershed	Average k factor
1	0.3372
2	0.3127
3	0.3084
4	0.2610
6	0.3083
8	0.3202
10	0.3006
12	0.3036
13	0.3130
14	0.3246
15	0.3203

Figure III.27. Average soil erodibility factor (K Factor) for subwatersheds in the upper Trinity River Watershed.



Rainfall Analysis

Purpose Rainfall in north central Texas varies by region and season. Despite dominance of Trinity River flow by WWTP discharges, spring high-rainfall events increase the likelihood that sediment on the river bottom will be scoured. In contrast, the lower the rainfall, such as during summer, the less scouring occurs. Decreased scouring may result in more accumulation of sediments and potential adsorption of surfactants. Thus, rainfall in the UTRW was analyzed by subwatersheds.

Methods A shapefile with the rainfall of Texas was obtained from the Texas General Land Office website. Rainfall was clipped and analyzed according to subwatersheds. Since subwatersheds generally spanned several rainfall zones, rainfall was calculated as a weighted average according to the area encompassed by individual rainfall values.

Results Rainfall in the UTRW ranged from 29 inches in the western sections of the West Fork to 43 inches in the eastern section of the watershed (Figure III.28, Table III.8). Rainfall by subwatersheds is shown in Figure III.29. The subwatershed with the least rainfall was subwatershed #3 (32.27 in), located in the northwestern corner of the UTRW. Rainfall gets progressively higher the further east the subwatersheds are located. The subwatershed with the most rainfall was subwatershed #12, located in the northeastern corner of the UTRW.

Figure III.28. Rainfall in the upper Trinity River watershed. Map at 1:1,800,000 scale.

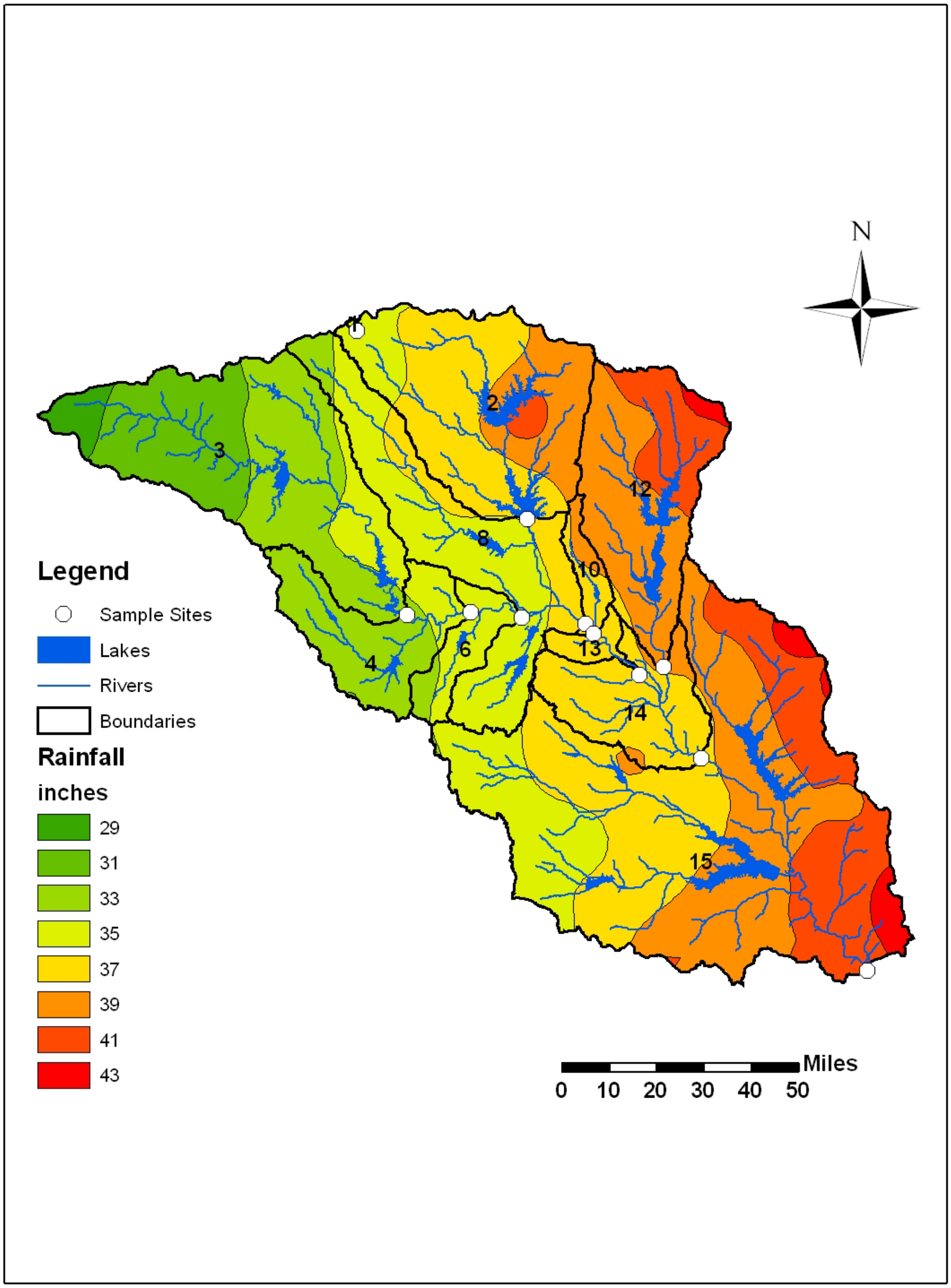
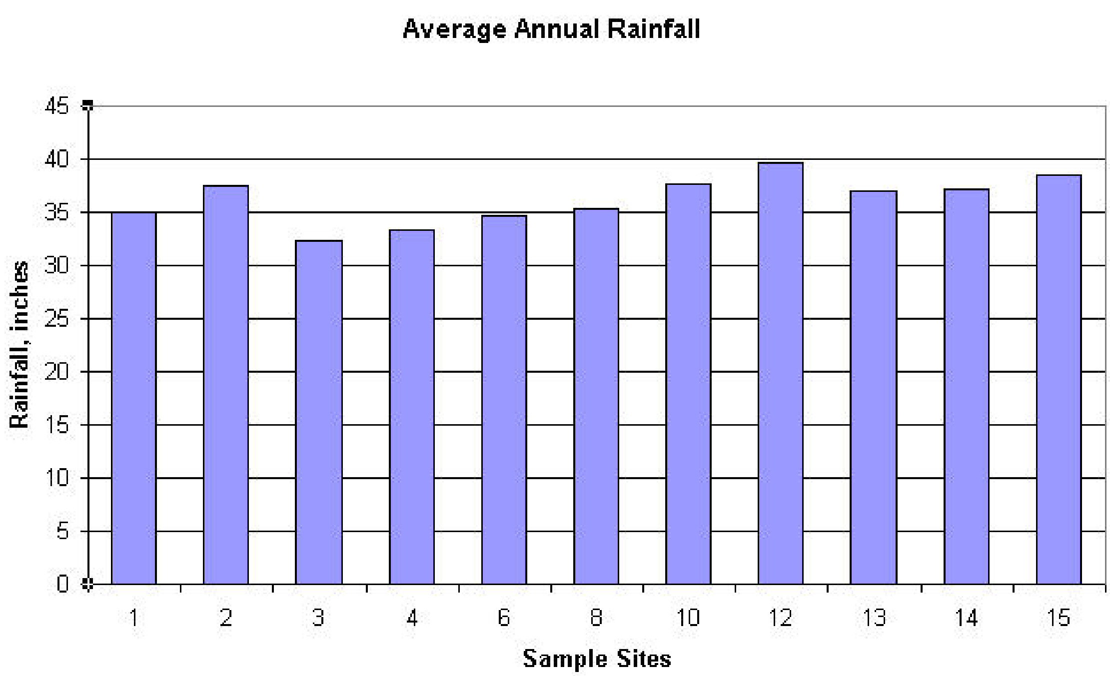


Table III.8. Rainfall by subwatersheds in the upper Trinity River watershed.

Subwatershed	Avg Rainfall inches
1	35.00
2	37.53
3	32.27
4	33.38
6	34.61
8	35.30
10	37.71
12	39.70
13	37.00
14	37.19
15	38.47

Figure III.29. Rainfall by subwatersheds in the upper Trinity River watershed.



Slope Analysis

Purpose Slope of the landscape influences water runoff, soil erosion, and sedimentation in streams and rivers. Hence, average slope of a subwatershed may assist in the prediction of surfactants concentrations at the sample sites.

Methods Seamless elevation raster data files (30x30 m resolution) were obtained from the National Elevation Dataset (NED) website. Due to the large size of the watershed, several elevation raster data files were mosaiced together and then clipped to the shape of the upper Trinity River watershed (UTRW). The UTRW raster file was then clipped to the shapes of the individual subwatersheds. Slope, expressed as a percentage, was determined using the spatial analysis toolbar. This value was then divided by the number of pixels within each subwatershed's raster image to generate the average slope (%).

Results The elevation and the average slope of the UTRW are shown in Figure III.30. The highest elevations were in the western region of the UTRW, especially subwatersheds #1, 3, 4, and part of 8. This is reflected in the average slope in each of these subwatersheds (7.87, 4.18, 4.05, and 3.23%, respectively) (Table III.9; Figure III.31). The slope for subwatershed #1 is especially high because of its small size and its elevation near the headwaters of Clear Creek (Figure III.31). The topology of the other subwatersheds is relatively flat, resulting in average slope values between 2-3%.

Figure III.30. Average slope in the upper Trinity River watershed. Slope values are expressed as a percentage (%). Map at 1:1,800,000 scale.

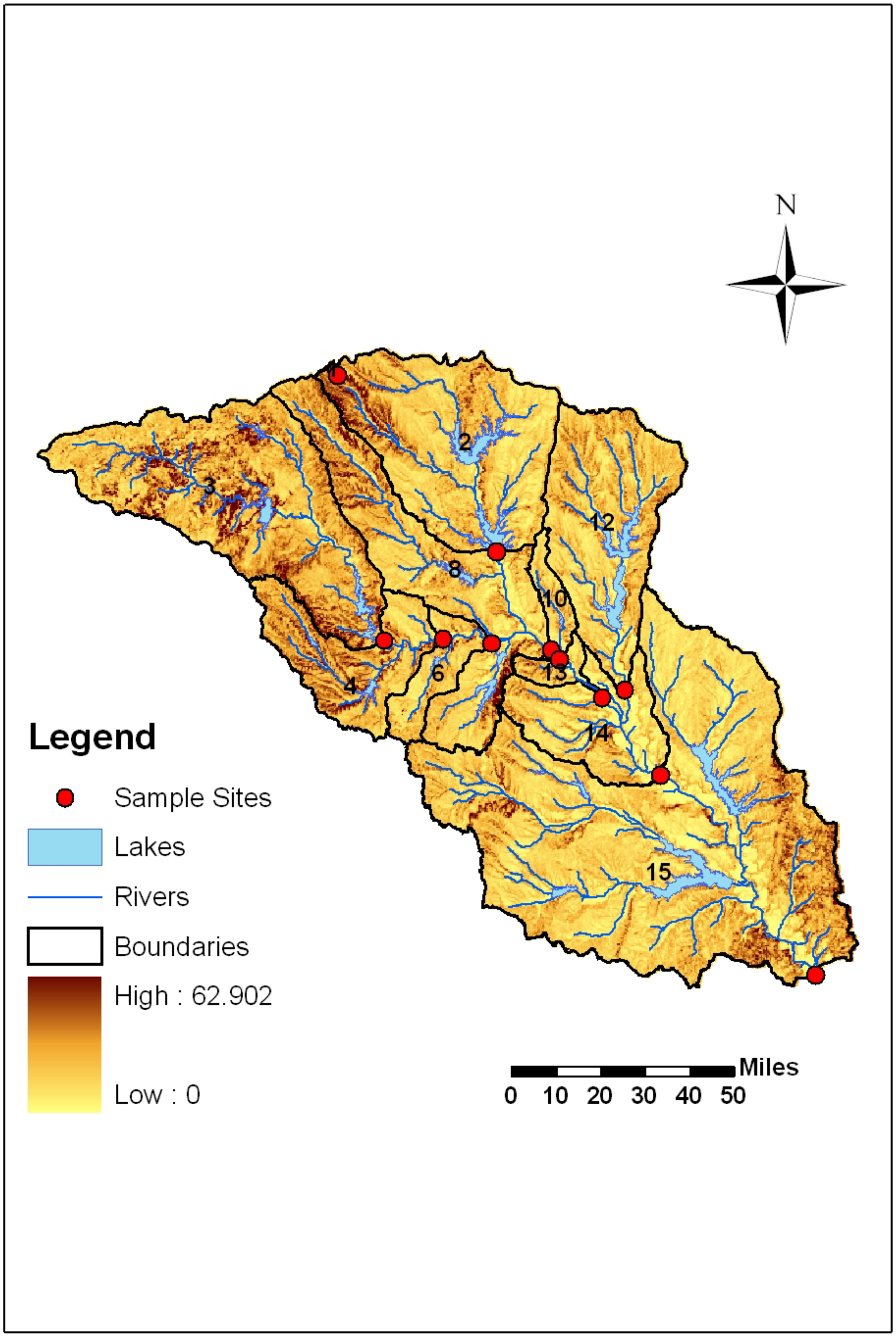
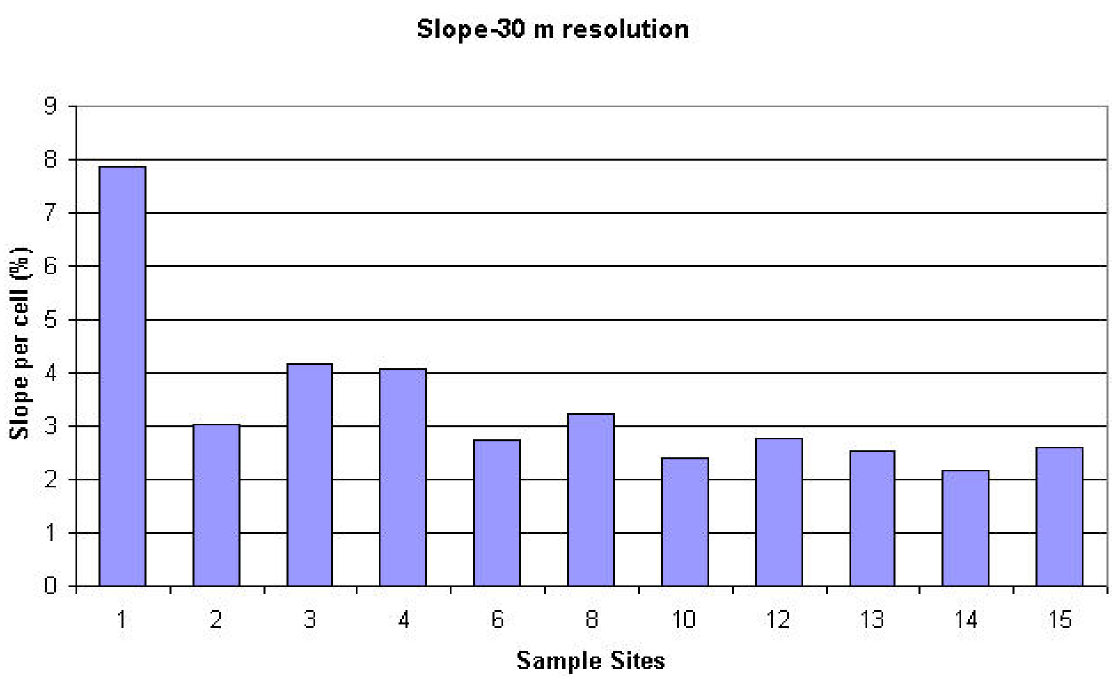


Table III.9. Average slope of subwatersheds in the upper Trinity River watershed.

Subwatershed	Avg Slope per Cell (%)
1	7.87
2	3.03
3	4.18
4	4.05
6	2.75
8	3.23
10	2.39
12	2.76
13	2.54
14	2.17
15	2.61

Figure III.31. Average slope of subwatersheds in the upper Trinity River watershed.



Chapter IV

Summaries of Results

GIS/Land Use Models

Introduction

The study area was subdivided into 11 subwatersheds, based upon river sampling locations. Each sample location defined the hydrologic point of concentration, or the location above which can be defined as the land and river that drains to the sample location. For example, Figure IV.1 represents a highly stylized watershed (solid black lines) that drains a hypothetical river network (blue lines) flowing from top to bottom of figure and river sampling locations (pink circles with numbers) that are used to define a subwatershed that drains to that point of concentration (dashed black lines).

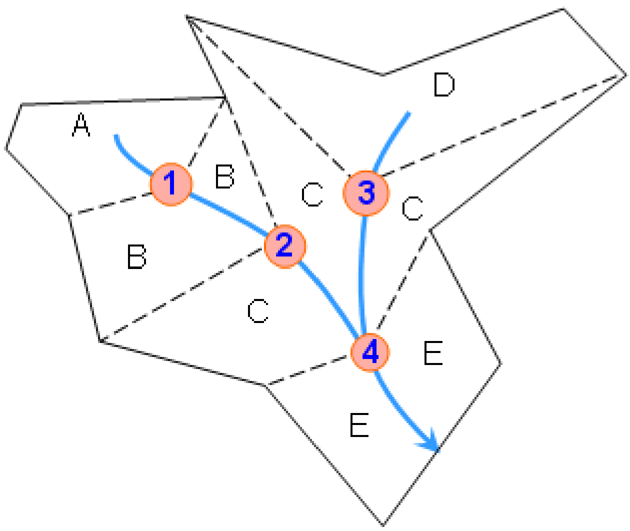


Figure IV.1. Schematic of a hypothetical watershed and 5 subwatersheds (A-E) defined by river sampling locations (1-4).

This approach allowed an analysis of the influence of near-field subwatershed activities versus cumulative subwatershed activities. Near-field subwatersheds are defined as the portion of the watershed above a given sample location, but below the next upstream sample location. The cumulative subwatershed is defined as the entire portion of the watershed above a given sample location. For example, in Figure IV.1, the near-field subwatershed for sample location 2 is the area defined by subwatershed B, but the cumulative subwatershed for sample location 2 includes both subwatersheds A and B. This is because water flowing past sample location 2 could have come from runoff in either subwatershed A or B. Likewise the near-field subwatershed for sample location 4 is only the area labeled C, while the cumulative subwatershed for sample location 4 is includes the areas labeled A, B, C and D, because that entire cumulative area drains to sample location 4, even though the near-field area (C alone in this case), may have more influence on water quality at sample location 4.

For the Trinity River study, each sample location could be analyzed for both near-field and cumulative subwatershed effects. For each of the 11 subwatersheds (both near-field and cumulative), land use data, soils data, topographic data, and subwatershed size were recorded (see previous GIS portion of report for sources of data). These data provided a large number of parameters that could be used to look for relationships between watershed parameters and surfactant toxicity units measured in the river. However, because we only had 11 sampling locations on the Trinity, we had to proceed carefully when selecting regression models that did not violate statistical assumptions because of using too many predictor variables for our sample size (n=11).

Mallows *C(p)* statistic allows examining the residual sum of squares from a model containing *p* parameters, and the residual means square from the largest equation postulated containing all possible variables, and is presumed to be a reliable unbiased estimate of the error variance (Draper and Smith, 1981). When you plot *C(p)* vs. *p*, the point where *C(p)* first approaches *p* indicates that the parameter estimates are unbiased, and so you chose the model with that number of parameters. Parameters selected as independent variables for initial evaluation are listed in Table IV.1. Only those parameters found to contribute significantly to the models are discussed further in the following sections.

Table IV.1. Parameters Used For Statistical Analyses of Surfactant Toxic Units and Benthic Macroinvertebrate Community Health

Near	Far	Subwatershed 1 Excluded	Parameters
			Matrices Chemistries and Characteristics
x			Total Suspended Solids-surface water
x			Total Dissolved Solids-surface water
x			Total Organic Carbon-surface water
x			Chemical Oxygen Demand-surface water
x			Chlorides-surface water
x			Hardness-surface water
x			Total Suspended Solids-pore water
x			Total Dissolved Solids-pore water
x			Total Organic Carbon-pore water
x			Hardness-pore water
x			Cation Exchange Capacity-sediment
x			Total Kjeldahl Nitrogen-sediment
x			Total Phosphorus-sediment
x			Sulfide-sediment
x			Total Organic Carbon-sediment
x			Gravel Content-sediment
x			Sand Content-sediment
x			Fines Content-sediment
x			Moisture Content-sediment
x		x	Dissolved Oxygen
x		x	Temperature
x		x	pH
x		x	Conductivity
x		x	Redox Potential
x		x	Turbidity
			Total Surfactant Toxic Units
x			Surface Water Toxic Units (SWTU)
x			Pore Water Toxic Units (PWTU)
			GIS Analyses
x	x		Agriculture Land Use
x	x		Forest Land Use
x	x		Residential Land Use
x	x		Urban Land Use
x	x		Water Land Use
x	x		2000 Population Density
x	x		Average Slope (%)
x	x		Rainfall
x	x		Soil Erosivity
x	x		Representative Organic Matter
			Habitat
x		x	Habitat Quality Index Score
x		x	Depth
x		x	Riffle
x		x	Erosion
x		x	Instream Vegetation Cover
x		x	Average Width of Natural Buffer Vegetation
x		x	Subjective Designation of Habitat Aesthetics
x		x	Bottom Substrate Stability Score
x		x	Dimensions of Largest Pool
x		x	Sinuosity
x		x	Sediment Shaker on Remainder Samples
x		x	Average Flow Taken by USGS Measurements

Surface Water Toxicity Units

Figure IV.2 shows the *C(p)* vs. *p* plot for surface water toxicity units versus near-field subwatershed parameters, indicating that the correct model is the 6 variable model ($r^2 = 0.936$). Figure IV.3 shows surface water toxicity units versus cumulative subwatershed parameters, indicating the necessity of an 8 variable model, yet with lower a regression coefficient ($r^2 = 0.855$).

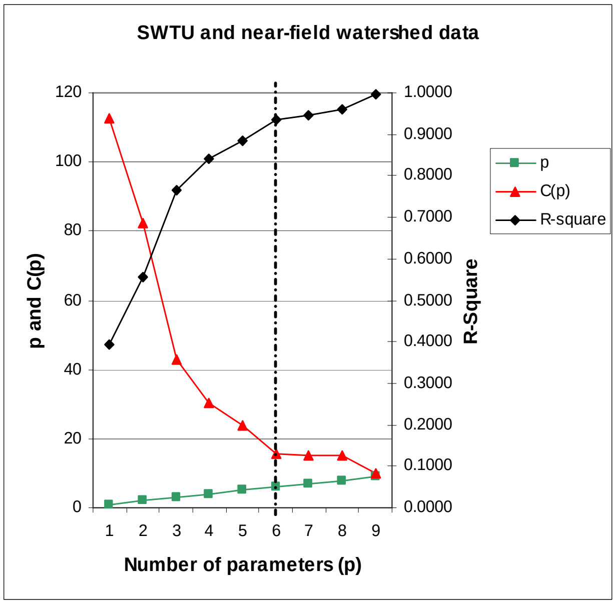


Figure IV.2. Mallow's C(p) statistic showing that a 6 parameter model is a reliable model for the near-field subwatershed analysis of surface water toxicity units.

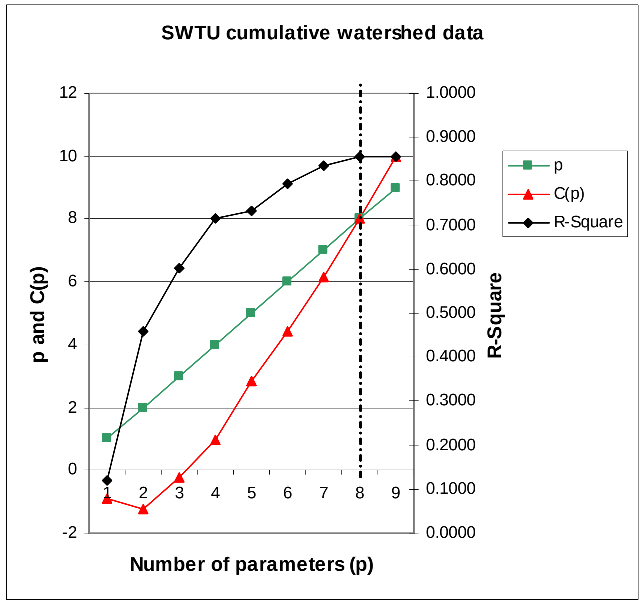


Figure IV.3. Mallow's C(p) statistic showing that an 8 parameter model is a reliable model for the cumulative subwatershed analysis of surface water toxicity units.

These data suggest that near-field subwatershed characteristics are better predictors of surface water toxicity units (SWTU) in the Trinity River flowing through the Dallas/Fort Worth metropolitan area than are cumulative subwatershed characteristics. The best 6-parameter model (r^2=0.936) for our study (with parameters in order of significance, based on F-value) is:

SWTU = -0.19072 + (0.01189) (average topographic %slope in near-field subwatershed)
+ (0.00667) (average annual rainfall in near-field subwatershed, in/yr)
+ (0.00384) (% residential land use in near-field subwatershed)
- (0.00235) (% urban land use in near-field subwatershed)
+ (0.00000307) (area of near-field subwatershed, km^2)
- (0.00005432) (population density in near-field subwatershed, ind/km^2)

indicating that increasing slope, rainfall, residential land and size of subwatershed are correlated to increasing surface water toxicity units, while decreasing urban land and population density are correlated to increasing surface water toxicity units. Figure IV.4 shows a plot of predicted surface water toxicity units versus measured surface water toxicity units.

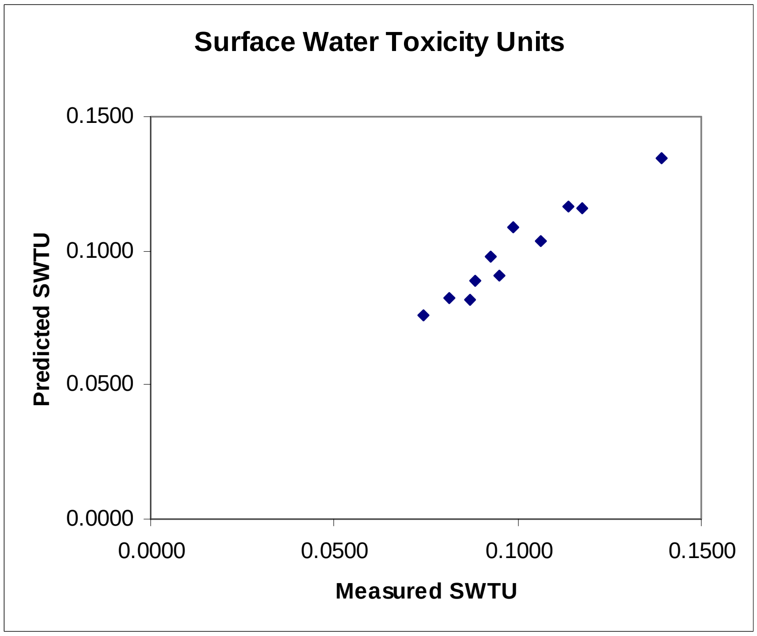


Figure IV.4. Best fitting unbiased regression model of predicted versus measured surface water toxicity units.

Pore Water Toxicity Units

Watershed data are less predictive of pore water toxicity units than surface water toxicity units. Figure IV.5 shows the *C(p)* vs. *p* plot for pore water toxicity units versus near-field subwatershed parameters, indicating that the correct model is the 7 variable model ($r^2 = 0.773$). Figure IV.6 shows pore water toxicity units versus cumulative subwatershed parameters, also indicating that the correct model the is 7 model, yet with a lower regression coefficient ($r^2 = 0.682$).

These data suggest that near-field subwatershed characteristics are better predictors of pore water toxicity units (PWTU) in the Trinity River flowing through the Dallas/Fort Worth metropolitan area than are cumulative subwatershed characteristics (but not as much as the predictive power for surface water toxicity). The best 7-parameter model ($r^2=0.776$) for our study (with parameters in order of significance, based on F-value) is:

PWTU = -1.31862 - (2.51529) (average soil erodibility in near-field subwatershed)
- (0.11526) (average percent organic content of soil in near-field subwatershed)
- (0.00592) (% residential land use in near-field subwatershed)
- (0.00386) (% agriculture land use in near-field subwatershed)
- (0.04396) (average topographic %slope of near-field subwatershed)
+ (0.00886) (average annual rainfall in near-field subwatershed, in/yr)
- (0.00000172) (area of near-field subwatershed, km^2)

indicating that decreasing erodibility of the soil, organic content of the soil, residential land use, agricultural land use, slope, and area of near-field subwatershed, are correlated to increasing surface water toxicity units, while increasing rainfall is correlated to increasing pore water toxicity units. Figure IV.7 shows a plot of predicted pore water toxicity units versus measured surface water toxicity units.

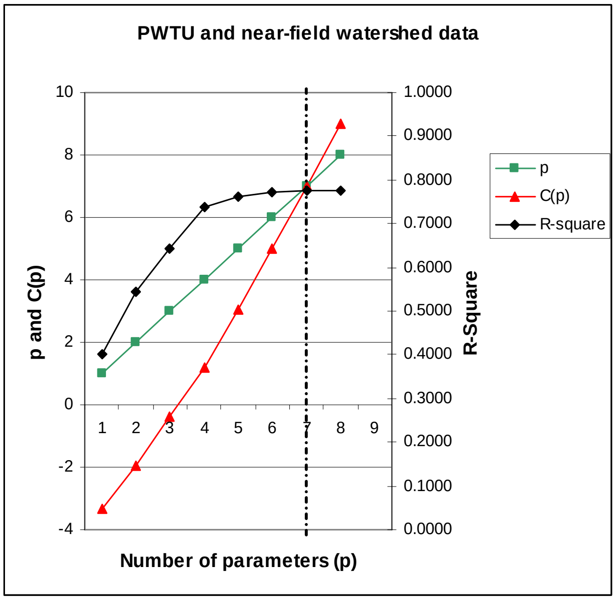


Figure IV.5. Mallow's C(p) statistic showing that a 7 parameter model is a reliable model for the near-field subwatershed analysis of pore water toxicity units.

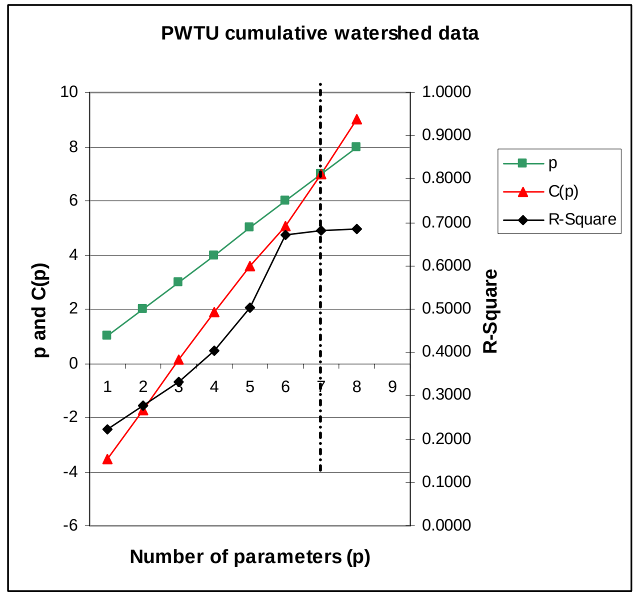


Figure IV.6. Mallow's C(p) statistic showing that a 7 parameter model is a reliable model for the cumulative subwatershed analysis of pore water toxicity units.

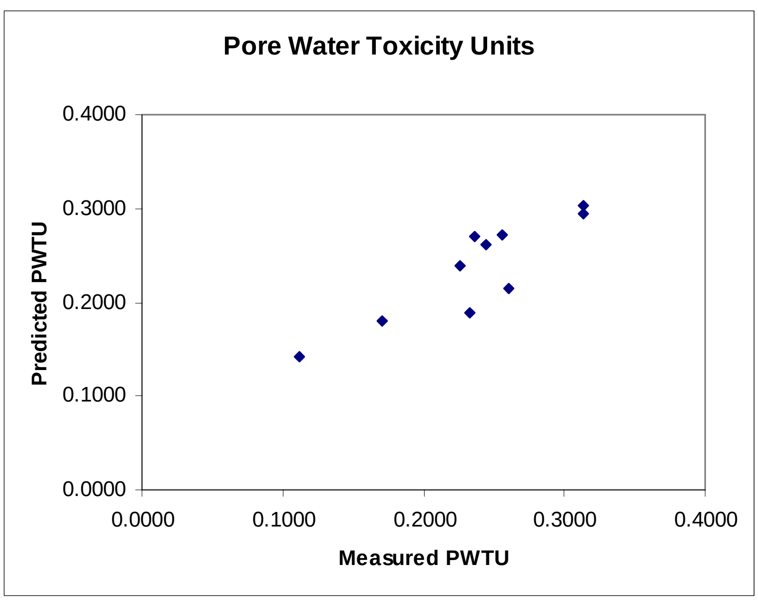


Figure IV.7. Best fitting unbiased regression model of predicted versus measured pore water toxicity units.

Surface Water Total Dissolved Solids

Figure IV.8 shows the *C(p)* vs. *p* plot for surface water total dissolved solids concentration versus near-field subwatershed parameters, indicating that the correct model is the 5 variable model ($r^2 = 0.974$). Figure IV.9 shows surface water total dissolved solids concentration versus cumulative subwatershed parameters, indicating the necessity of a 7 variable model, yet with lower a regression coefficient ($r^2 = 0.941$).

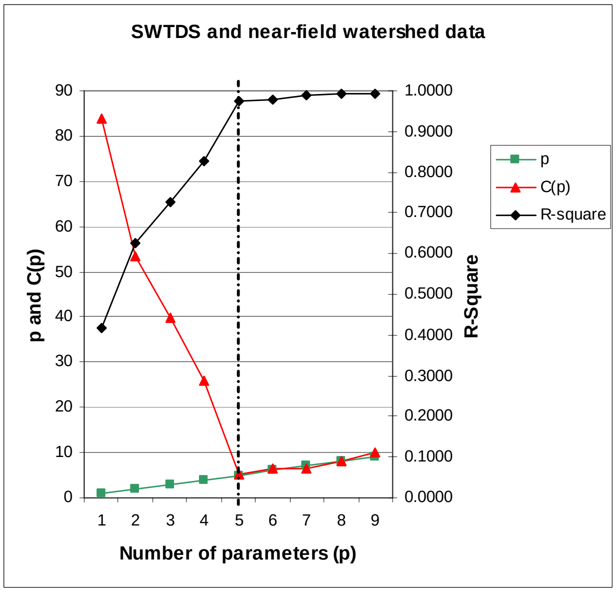


Figure IV.8. Mallow's C(p) statistic showing that a 5 parameter model is a reliable model for the near-field subwatershed analysis of surface water total dissolved solids.

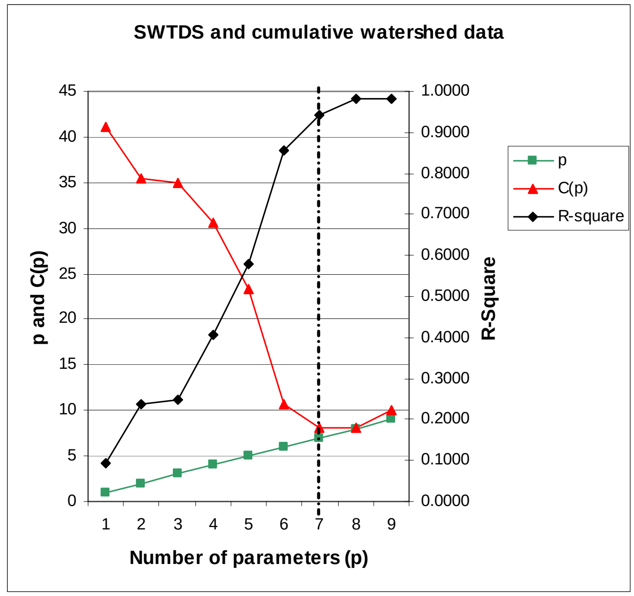


Figure IV.9. Mallow's C(p) statistic showing that a 7 parameter model is a reliable model for the cumulative subwatershed analysis of surface water total dissolved solids.

These data suggest that near-field subwatershed characteristics are better predictors of surface water total dissolved solids (SWTDS) in the Trinity River flowing through the Dallas/Fort Worth metropolitan area than are cumulative subwatershed characteristics. The best 5-parameter model (r^2=0.974) for our study (with parameters in order of significance, based on F-value) is:

SWTDS = - 462.66959 - (13.97235) (% agricultural land use in near-field subwatershed)
- (0.83237) (average population density in near-field subwatershed, ind/km^2)
+ (58.84771) (% urban land use in near-field subwatershed)
+ (36.22142) (average annual rainfall in near-field subwatershed, in/yr)
+ (0.02363) (area of near-field subwatershed, km^2)

indicating that decreasing agricultural land and population density are correlated to increasing surface water total dissolved solids, while increasing urban land, rainfall and area of near-field subwatershed are correlated to increasing surface water total dissolved solids. Figure 10 shows a plot of predicted surface water total dissolved solids versus measured surface water total dissolved solids.

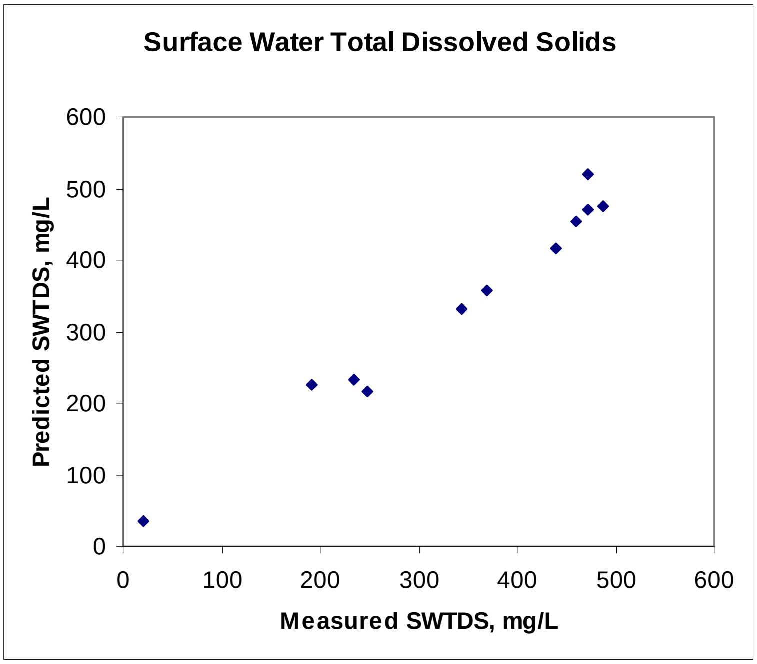


Figure IV.10. Best fitting unbiased regression model of predicted versus measured surface water total dissolved solids.

In-stream Physical/Chemical Parameters Models

Surface Water Toxic Units

Multiple regression statistics were also used to generate a multiple parameter model to predict toxic units based on surface water, pore water, and sediment chemistries and characteristics. The number of variables used in the model was not determined by Mallon's C(p) statistics but rather empirically. R square values were remarkably higher with water chemistry parameters than land use parameters so we able to select a model with fewer variables. Thus, the best 3-variable model ($r^2 = 0.9708$) for predicting surface water toxicity units (SWTU) is:

SWTU = -0.08716 + 0.00296 (surface water chemical oxygen demand (COD), mg/l)
+ 0.000457 (surface water hardness, mg $CaCO_3$/l)
+ 0.00017346 (pore water hardness, mg $CaCO_3$/l)

indicating that both surface water COD and hardness are correlated to increasing surface water toxicity units. Figure IV.11 shows a plot of predicted surface water toxicity units versus measured surface water toxicity units.

Pore Water Toxic Units

The best 3-variable model ($r^2 = 0.9775$) for predicting pore water toxicity units (PWTU) is:

PWTU = -0.16789 + 0.0009082 (pore water total dissolved solids (TDS), mg/l)
+ 0.00007286 (pore water total organic carbon (TOC), mg/l)
- 0.00000772 (sediment cation exchange capacity, mg/kg)

indicating that both pore water TDS and TOC are correlated to increasing pore water toxicity units, and that sediment cation exchange capacity is negatively correlated to increasing pore water toxicity units. Figure IV.12 shows a plot of predicted pore water toxicity units versus measured surface water toxicity units.

Combined GIS/Land Use and In-stream Chemical Parameter Models

Surface Water Toxic Units

The best GIS-watershed data and field chemistry variables used to predict SWTU and PWTU were combined to predict the best overall variables for SWTU and PWTU. The best 3-variable model ($r^2 = 0.973$) for predicting SWTU is:

SWTU = -0.07657 + 0.00423 (surface water chemical oxygen demand (COD), mg/l)
+ 0.0003102 (pore water hardness, mg $CaCO_3$/l)
+ 0.0000437 (area of near-field subwatershed, km2)

indicating that surface water COD, pore water hardness, and near-field area all correlate with increasing SWTU. Figure IV.13 shows a plot of predicted surface water toxicity units versus measured surface water toxicity units.

Pore Water Toxic Units

The best 4-variable model ($r^2 = 0.9793$) for predicting PWTU is:

PWTU = 1.1203 + 0.00226 (surface water hardness, mg $CaCO_3$/l)
- 0.00101 (pore water total dissolved solids (TDS), mg/l)
+ 0.03808 (average topographic % slope in near-field subwatershed)
- 2.92226 (average soil erodibility in near-field subwatershed)

indicating that surface water hardness and percent topographic slope in the near-field subwatershed are correlated with increasing PWTU, and pore water TDS and average soil erodibility in the near-field subwatershed are negatively correlated with increasing PWTU. Figure IV.14 shows a plot of predicted pore water toxicity units versus measured pore water toxicity units.

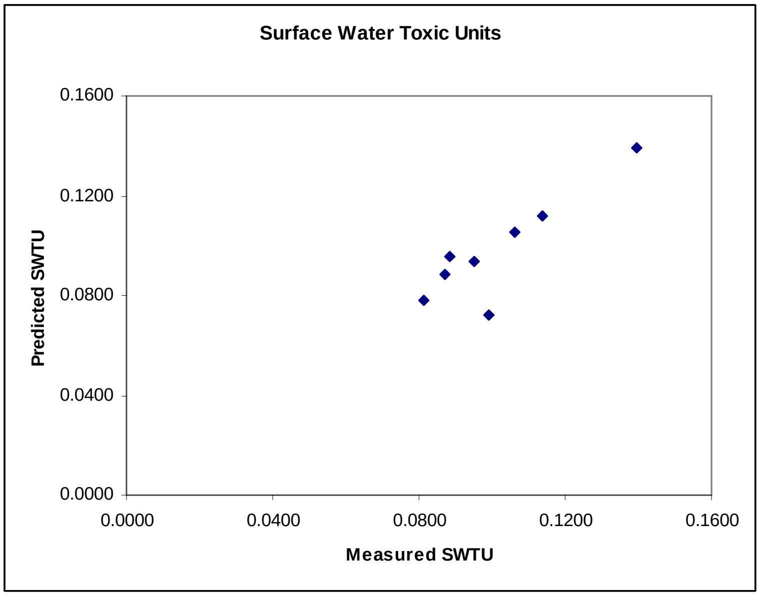


Figure IV.11. Best fitting 3-variable regression model of predicted versus measured SWTU from field chemistries and characteristics.

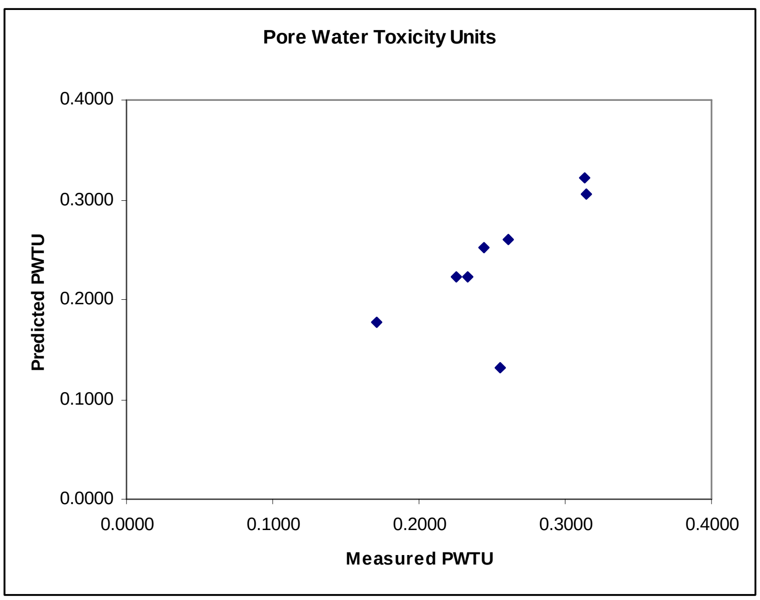


Figure IV.12. Best fitting 3-variable regression model of predicted versus measured PWTU from field chemistries and characteristics.

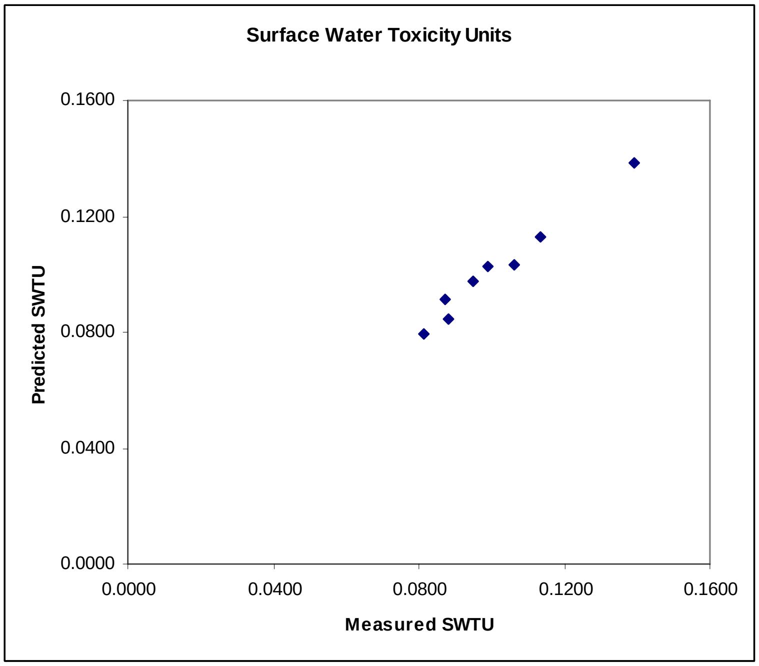


Figure IV.13. Best fitting 3-variable regression model of predicted versus measured PWTU from the best GIS-watershed and field chemistry variables.

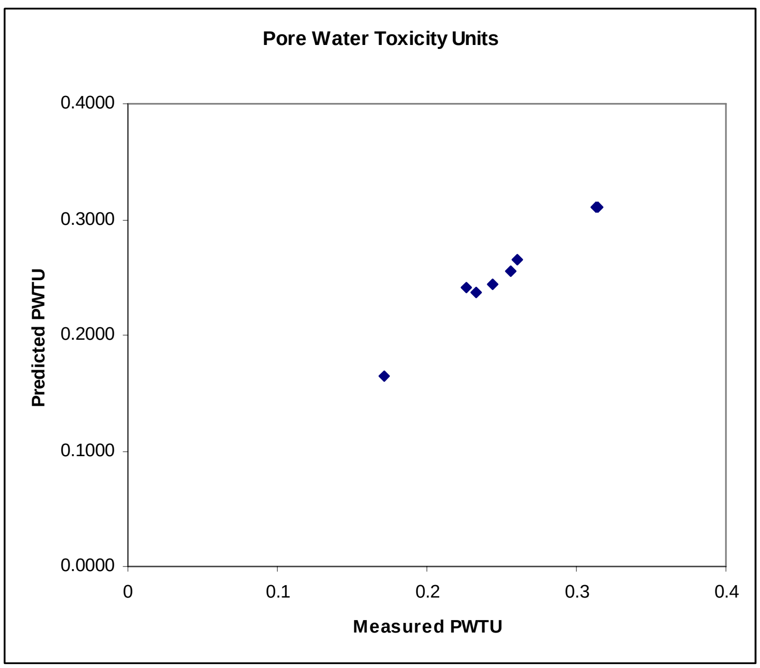


Figure IV.14. Best fitting 4-variable regression model of predicted versus measured PWTU from the best GIS-watershed and field chemistry variables.

Chapter V

Macrobenthos

Introduction

This section presents and summarizes the results of the benthic macroinvertebrate samples collected from the Trinity River during the fall of 2005. This section discusses general trends of the benthic macroinvertebrate community characteristics, including site specific and descriptive statistics. Macroinvertebrate benthic organism population metrics include: average total organisms, total organisms, richness, evenness, Brillouin's diversity, Chironomidae, Chironominae, Tanypodinae, Orthocladiinae, Oligochaeta, Tubificidae, and Naididae. These variables will be used as dependent variables in correlation, regression and clustering analyses. A comparison of benthic population metrics of the 2005 study is made with the 1987-1988 study in Chapter VI.

Materials and methods for the habitat survey, macrobenthic sampling, and processing are discussed in our preliminary report [Appendix B "Field Report for Surfactant Sampling and Habitat Surveys of the Trinity River in Dallas, Texas" (EA Engineering, Science and Technology, Inc. and University of North Texas, December 2005)].

General Results of the Benthic Macroinvertebrates Collected in 2005

A total of 112 taxa (two phyla, 25 families, three sub-families, 82 genera) and 5913 individuals were collected by a petite ponar grab (Table V.1). Lists of the presence and absence of taxa taken at each station are given in Table V.2. Oligochaeta (34%) and Chironomidae (36%) were the most dominant groups.

Clear Creek (station 01), a first order stream, represents a distinctly different benthic habitat compared to that found in the Trinity River. The number of benthic organisms collected by a Hess sampler was 469 individuals. Richness, diversity, average number of naidids (Oligochaeta: Naididae) was also highest at Clear Creek. Because of differences in habitat and collection methods, the results for the remaining 10 stations are presented, without respect to Clear Creek.

The number of macrozoobenthos collected from the Trinity River ranged from an average of 283 individuals per ponar grab (152 mm^2) at the Elm Fork (station 02), downstream of Lake Lewisville, to a minimum of 24 individuals per ponar grab collected at Palestine (station 15) (Figure V.1). A general decrease in the number of benthic macroinvertebrates occurred as the river flowed through the metroplex. A notable exception occurs at station 10, downstream of the Dallas South WWTP. However, low population densities occur at stations 13, 14, and 15 downstream of station 10. The East Fork had benthic population densities similar to those observed at benthic sampling stations located on the main river segment.

Richness, or total number of taxa, was highest at Elm Fork (station 02) and lowest at Palestine (station 15) (Figure V.2). The diversity was highest upstream of Village Creek WWTP (station 04) and lowest at Palestine (station 15). Downstream of Dallas South and Dallas Central WWTP (stations 10 and 13), diversity increased. Evenness was highest upstream TRA Central WWTP (station 06), upstream Dallas Central WWTP (station 08) and Palestine (station

15).   Elm Fork downstream of Lake Lewisville (station 02) and downstream of Lake Worth (station 03) had the lowest evenness values.

Tubificids (Oligochaeta: Tubificidae) were the dominant Oligochaeta with Naididae subdominant, except downstream of Lake Worth (station 03). The most abundant Oligochaeata, 17% of the total individuals collected, were sexually immature Tubificidae with capilliform chaetae. Downstream of Dallas Central WWTP had the highest number of tubificid oligochaetes, and downstream of Lake Worth (station 03) had the highest number of naidids (Figure V.3). The four most abundant Oligochaeta taxa were sexually immature tubificids with capilliform chaetae, *Aulodrilus pigueti*, *Branchiura sowerbyi* , and *Limnodrilus hoffmeisteri* (Figure V.5).

Chironomidae larvae representing Chironominae were more abundant than Tanypodinae and Orthocladiinae at every station except downstream of the confluence with the East Fork (station 14), and Palestine (station 15). At those two stations, Tanypodinae were more abundant (Figure V.4). *Polypedilum* sp., 10% of the total individuals, and *Glyptotendipes* sp., 9% of the total individuals, were the most abundant chironomid genera. There were seven chironomid genera that were predominant in many of the stations: *Polypedilum, Cryptochironomus, Glyptotendipes, Paracladopelma, Cryptotendipes, Dicrotendipes,* and *Paralauterborniella* (Figure V.6). A decline in chironomid populations occurred upstream of TRA Central WWTP (station 06), as well as every station downstream of Dallas Central WWTP (stations 10, 13, 14, and 15).

Stations 10 and 13 were downstream and in close proximity of wastewater treatment plants outfalls. Station 10 downstream of Dallas Central WWTP tended to increase in comparison to station 08 upstream of Dallas Central WWTP in all metrics analyzed, with the exception of evenness, percent Chironominae, percent Tanypodinae, and percent *Cryptotendipes*. Station 13 downstream of Dallas South WWTP had lower values than station 10 in all metrics except for diversity, evenness, number of total Naididae, number of *Branchiura sowerbyi*, and percent *Dicrotendipes*.

Station 06, downstream of Village Creek WWTP / upstream of TRA Central WWTP, represented a more urbanized location than stations 03 and 04. This station had lower values than upstream Village Creek WWTP in every population metric except evenness, percent Orthocladiinae, and percent *Cryptochironomus, Paracladopelma, Paralauterborniella,* and *Cryptotendipes*.

In general, most population values declined steadily downstream of Dallas South WWTP (station 13).

Table V.1 – List of Taxa collected in 2005

Phylum: Nemertina

Phylum: Nematoda

Phylum: Mollusca
Class:
Gastropoda
Order:
Basommatophora
Lymnaeidae
Physidae
Helisoma
Class:
Pelecypoda
Order:
Heterodonta
Corbiculidae
Sphaeriidae
Order:
Eulamellibranchia
Unionidae

Phylum: Annelida
Class:
Clitellata
Subclass:
Oligochaeta
Order:
Haplotaxida
Enchytraeidae
Naididae
Dero
Dero (aulophous) furcata
Nais
Pristina
Pristina aequiseta
Pristina breviseta
Pristina longiseta
Pristina synclita
Pristinella
Pristinella longisoma
Pristinella osborni
Pristinella jenkinae
Stephensoniana trivandrana
Tubificidae
Aulodrilus pigueti
Aulodrilus pleuroseta

Branchiura sowerbyi
Limnodrilus hoffmeisteri
Limnodrilus udekeimanus
Limnodrilus claparedeianus
Tubifex
Imm. tubificid without capilliform chaetae
Imm. tubificid with capilliform chaetae

Phylum Arthropoda
Class:
Insecta
Order:
Ephemeroptera
Baetidae

Baetis

Ephemeridae

Ephemera
Hexagenia

Tricorythidae
Caenidae

Caenis

Order:
Odonata
Suborder:
Anisoptera
Aeshnidae
Gomphidae

Zygoptera
Calopteryigidae
Coenagrionidae
Order:
Hemiptera
Order:
Trichoptera
Hydroptilidae
Polycentropidae
Coleoptera
Staphylinidae
Carabidae
Elmidae
Hydrophilidae
Order:
Diptera
Ceratopogonidae
Chironomidae
Tanypodinae

Ablabesmyia

Ascheum
Conchapelopia
Clinotanypus/Coelotanypus
Coelotanypus
Djalmabatista
Fittkauimyia cf serta
Labrundinia
Larsia
Nilotanypus
Procladius
Tanypus

Telopelopia

Thienemannimyia

Orthocladiinae

Cladopelma
Cricotopus
Eukieferriella
Nanocladius
Orthocladius
Orthocladius/Cricotopus
Paracladopelma
Parakiefferiella
Thienemanniella

Chironominae

Tanytarisini

Cladotanytarsus
Paratanytarsus
Rheotanytarsus
Tanytarsus
Tanytarsus B
Tanytarsini

Chironomini *Axarus*
Chironomus
Cryptochironomus
Cryptoptendipes
Dicrotendipes
Endochironomus
Glyptotendipes
Goeldichironomus
Harnischia
Microchironomus
Microtendipes
Parachironomus
Paralauterborniella
Paratendipes
Polypedilum

Polypedilum (beckiae grp)
Psuedochironomus
Stelechomyia
Stictochironomus
Tribelos

Table V.2 – List of presence (*) and absence (-) of invertebrate taxa collected in 2005

	STATIONS										
TAXA	**1**	**ELM**	**3**	**4**	**6**	**8**	**10**	**EAST**	**13**	**14**	**15**
Nemertea	-	*	-	-	-	-	-	-	-	-	-
Nematoda	*	*	*	*	*	*	*	*	*	*	*
Oligochaeta	*	*	*	*	*	*	*	-	*	*	-
Fragments	*	*	*	*	*	*	*	-	*	-	*
Lumbriculidae	*	-	-	-	-	-	*	-	-	-	-
Dero	*	*	*	*	-	*	*	-	*	-	-
Dero (aulophous) furcata	-	-	-	-	-	-	-	-	*	-	-
Nais	*	*	*	*	*	-	-	-	*	-	-
Pristina	*	*	*	*	*	*	*	*	*	*	-
Pristina aequiseta	-	*	*	-	-	-	-	-	-	-	-
Pristina breviseta	*	*	*	*	-	*	*	-	*	-	-
Pristina longiseta	*	-	*	-	-	-	-	-	*	-	-
Pristina synclita	*	-	-	-	-	-	-	-	-	-	-
Pristinella	-	*	*	-	*	*	*	-	*	*	-
Pristinella longisoma	-	-	*	-	-	-	-	-	-	-	-
Pristinella osborni	*	-	*	*	-	-	-	-	-	-	-
Pristinella jenkinae	*	-	*	*	-	-	*	-	-	*	-
Stephensoniana trivandrana	-	-	-	*	-	*	-	-	-	-	-
Aulodrilus pigueti	*	*	*	*	*	*	*	-	*	*	-
Aulodrilus pleuroseta	-	-	-	-	-	-	*	-	-	-	-
Branchiura sowerbyi	*	*	-	*	*	*	*	*	*	*	*
Limnodrilus hoffmeisteri	*	*	*	*	*	*	*	-	*	*	*
Limnodrilus udekeimanus	*	*	*	*	-	*	*	-	-	*	*
Limnodrilus claparedeianus	-	-	-	-	-	-	*	-	-	-	-
Tubifex	*	-	*	-	-	-	-	-	-	-	-
Immature tubificid w/oc	*	*	*	*	*	*	*	*	*	*	*
ITWCAP	*	*	*	*	-	*	-	*	-	-	*
Bivalvia	*	-	-	*	-	-	-	-	*	-	-
Corbicula	-	*	-	-	*	-	-	*	*	-	-
Sphaeriidae	*	-	*	*	-	*	*	*	*	*	-
Unionidae	*	-	-	-	-	*	-	-	-	*	*

TAXA	STATIONS									
	1	ELM	3	4	6	8	10	EAST	13	14	15
Gastropoda	-	-	-	-	-	*	-	-	-	-	-
Lymnaeidae	*	-	-	*	-	-	-	-	-	-	-
Physidae	*	-	-	-	*	-	-	-	-	-	-
Helisoma	*	-	-	-	-	-	-	*	-	-	-
Ephemeroptera	*	*	*	-	-	*	-	-	*	*	*
Baetidae	*	*	*	*	-	-	-	*	-	*	-
Hexagenia	*	-	-	-	-	*	-	-	*	*	*
Ephemera	-	-	-	-	-	*	-	-	-	-	-
Caenidae	*	*	*	*	-	*	*	*	-	*	-
Tricorythidae	*	-	-	-	-	-	-	*	*	-	-
Anisoptera	*	-	-	-	-	*	-	-	-	-	-
Coenagrionidae	*	-	-	*	-	-	-	-	-	-	-
Calopteryigidae	*	-	-	-	-	-	-	-	-	-	-
Gomphidae	*	-	-	-	-	*	*	-	-	*	*
Aeshnidae	*	-	-	-	-	-	-	-	-	-	-
Hemiptera	*	-	-	-	-	-	-	-	*	-	-
Coleoptera	*	-	-	*	-	*	*	-	*	-	*
Staphylinidae	-	-	-	-	-	*	*	-	*	-	-
Carabidae	-	-	-	-	-	*	-	-	-	-	-
Elmidae	*	-	-	*	-	*	*	*	*	*	*
Hydrophilidae	*	-	*	-	-	-	-	-	-	-	-
Trichoptera	*	-	*	-	*	-	-	*	-	-	-
Hydroptilidae	*	-	*	-	*	-	*	-	-	-	-
Hydroptilidae pupae	-	-	-	-	-	-	-	-	-	*	-
Hydropsychidae pupae	-	-	-	-	-	-	-	-	*	-	-
Polycentropidae	*	-	-	-	-	-	-	-	-	-	-
Chironomidae	*	*	-	-	*	*	*	-	*	*	*
Tanypodinae	*	-	*	-	*	*	*	-	-	-	*
Ablabesmyia	*	-	-	*	-	-	*	*	-	-	-
Ablabesmyia pupae	*	-	-	-	-	-	-	-	-	-	-
Ascheum	-	*	-	*	-	-	-	-	-	-	-
Conchapelopia	*	-	-	-	-	-	-	-	-	-	-

	STATIONS										
TAXA	**1**	**ELM**	**3**	**4**	**6**	**8**	**10**	**EAST**	**13**	**14**	**15**
Clinotanypus/Coelotanypus	*	-	-	-	-	*	-	-	-	*	-
Coelotanypus	-	-	-	-	-	*	-	-	-	*	*
Djalmabatista	*	*	-	-	-	-	-	-	-	-	-
Fittkauimyia cf serta	*	-	-	-	-	-	-	-	-	-	-
Labrundinia	*	*	*	-	-	-	-	-	-	-	-
Larsia	-	-	*	-	-	-	-	-	-	-	-
Nilotanypus	-	*	-	-	-	-	-	-	-	-	-
Procladius	*	-	*	*	-	-	-	-	-	-	-
Tanypus	*	-	*	-	*	-	*	-	*	-	-
Telopelopia	*	-	-	-	-	-	-	*	-	*	-
Thienemannimyia	*	-	-	-	-	-	-	-	-	-	-
Orthocladinae	-	*	*	-	-	-	-	-	-	-	-
Cladopelma	-	-	-	-	-	-	*	-	-	-	-
Cricotopus	-	*	*	-	-	-	-	-	-	-	-
Eukieferriella	-	-	*	-	-	-	-	-	-	-	-
Nanocladius	*	-	*	-	*	-	-	-	-	-	-
Orthocladius	-	-	-	-	-	*	-	-	*	-	-
Orthocladius/Cricotopus	*	*	-	-	-	-	-	*	*	-	-
Paracladopelma	-	*	-	*	*	*	*	*	*	-	-
Parakiefferiella	-	-	*	-	-	-	-	-	-	-	-
Thienemanniella	-	-	-	-	-	-	-	*	*	-	-
Chironominae	-	-	*	-	-	-	-	-	-	-	-
Chironominae pupae	*	*	-	-	-	-	-	-	-	-	-
Axarus	-	-	-	-	-	-	*	-	-	*	-
Chironomus	-	*	-	*	-	*	-	-	-	-	-
Chironomus pupae	-	-	-	-	-	-	*	-	-	-	-
Cryptochironomus	*	*	*	*	*	*	*	*	*	*	-
Cryptoptendipes	*	*	*	-	*	*	*	-	-	-	-
Dicrotendipes	*	*	-	*	-	*	-	*	*	-	-
Dicrotendipes pupae	-	*	*	-	-	-	-	-	-	-	-
Endochironomus	*	-	*	-	-	-	-	-	-	-	-

	STATIONS										
TAXA	**1**	**ELM**	**3**	**4**	**6**	**8**	**10**	**EAST**	**13**	**14**	**15**
Endochironomus pupae	-	*	-	-	-	-	-	-	-	-	-
Glyptotendipes	-	*	*	*	-	-	-	-	-	-	-
Glyptotendipes pupae	-	*	-	-	-	-	-	-	-	-	-
Goeldichironomus	-	*	-	-	-	-	-	-	-	-	-
Harnischia	-	-	-	-	*	*	-	-	-	-	-
Microchironomus	-	-	-	*	*	*	-	-	-	*	-
Microtendipes	*	-	-	-	-	-	-	-	-	-	-
Parachironomus	-	*	-	-	-	-	-	-	-	-	-
Paralauterborniella	*	-	-	*	*	*	*	-	-	-	-
Paratendipes	-	-	-	-	-	-	-	-	-	-	*
Polypedilum	*	*	*	*	*	*	*	*	*	*	-
Polypedilum (beckiae grp)	-	*	-	-	-	-	-	-	-	-	-
Psuedochironomus	*	-	-	-	-	*	-	-	-	-	-
Stelechomyia	-	-	*	-	-	-	-	-	-	-	-
Stictochironomus	-	-	-	-	-	-	-	-	-	*	*
Tribelos	-	-	*	-	-	-	-	-	-	-	-
Chironomini	-	-	-	-	-	-	-	*	-	-	-
Chironomini pupae	*	-	-	*	-	-	-	-	-	-	-
Cladotanytarsus	*	*	*	-	*	-	-	-	-	-	-
Paratanytarsus	-	-	-	*	-	-	-	-	-	-	-
Rheotanytarsus	-	*	-	-	-	*	-	-	-	-	-
Tanytarsus	*	*	*	*	-	-	-	*	-	-	-
Tanytarsus B	*	-	-	-	-	-	-	-	-	-	-
Tanytarsini	*	-	-	-	*	*	*	-	-	-	-
Tanytarsini pupae	*	-	-	*	*	*	-	-	-	-	-
Ceratopogonidae pupae	-	-	-	-	*	*	*	-	-	-	-
Ceratopogonidae	*	*	*	-	*	-	*	*	*	*	*
TOTAL TAXA	73	46	48	39	30	46	38	24	35	29	19

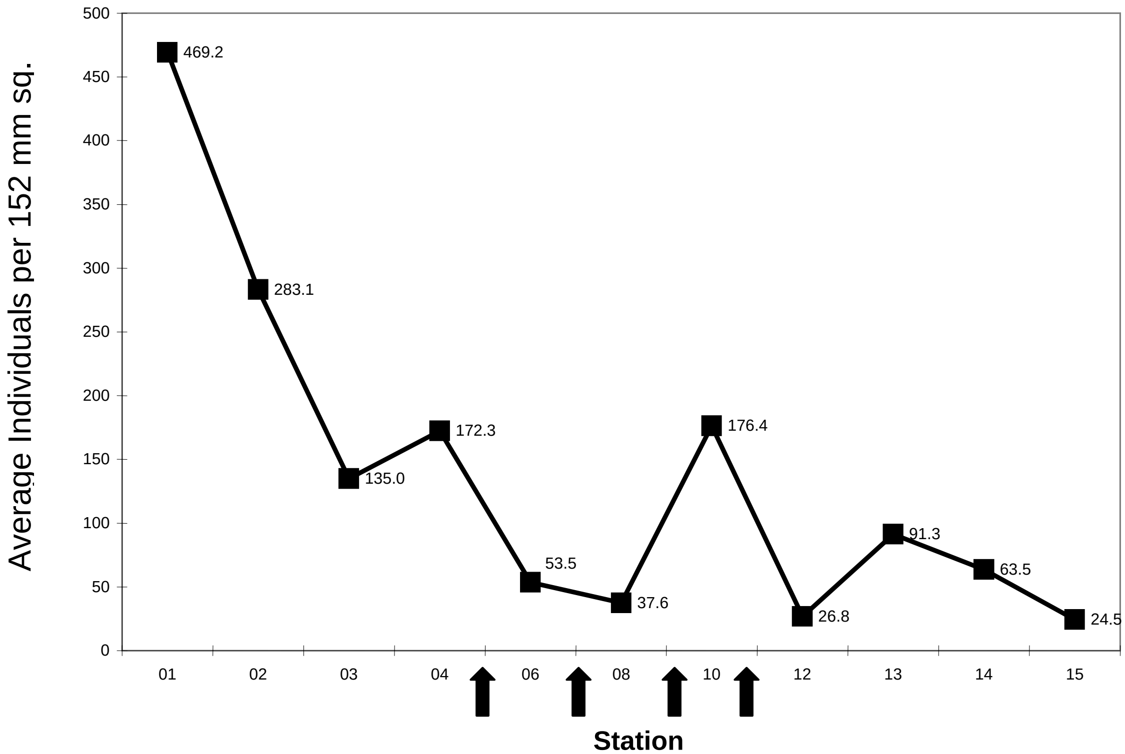


Figure V.1 – Average total individuals per ponar grab (152 mm^2). Arrows indicate WWTP location.

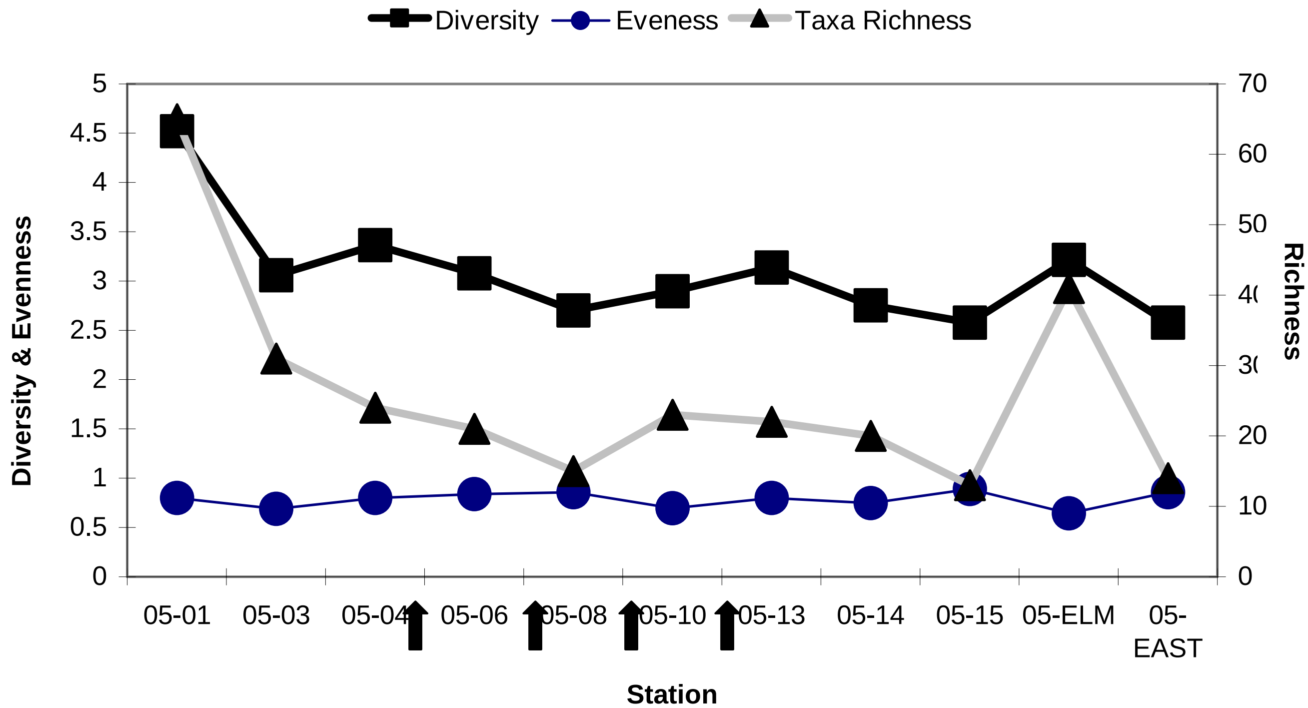


Figure V.2 – Diversity, Evenness, and Richness for 2005 data. Arrows indicate WWTP's.

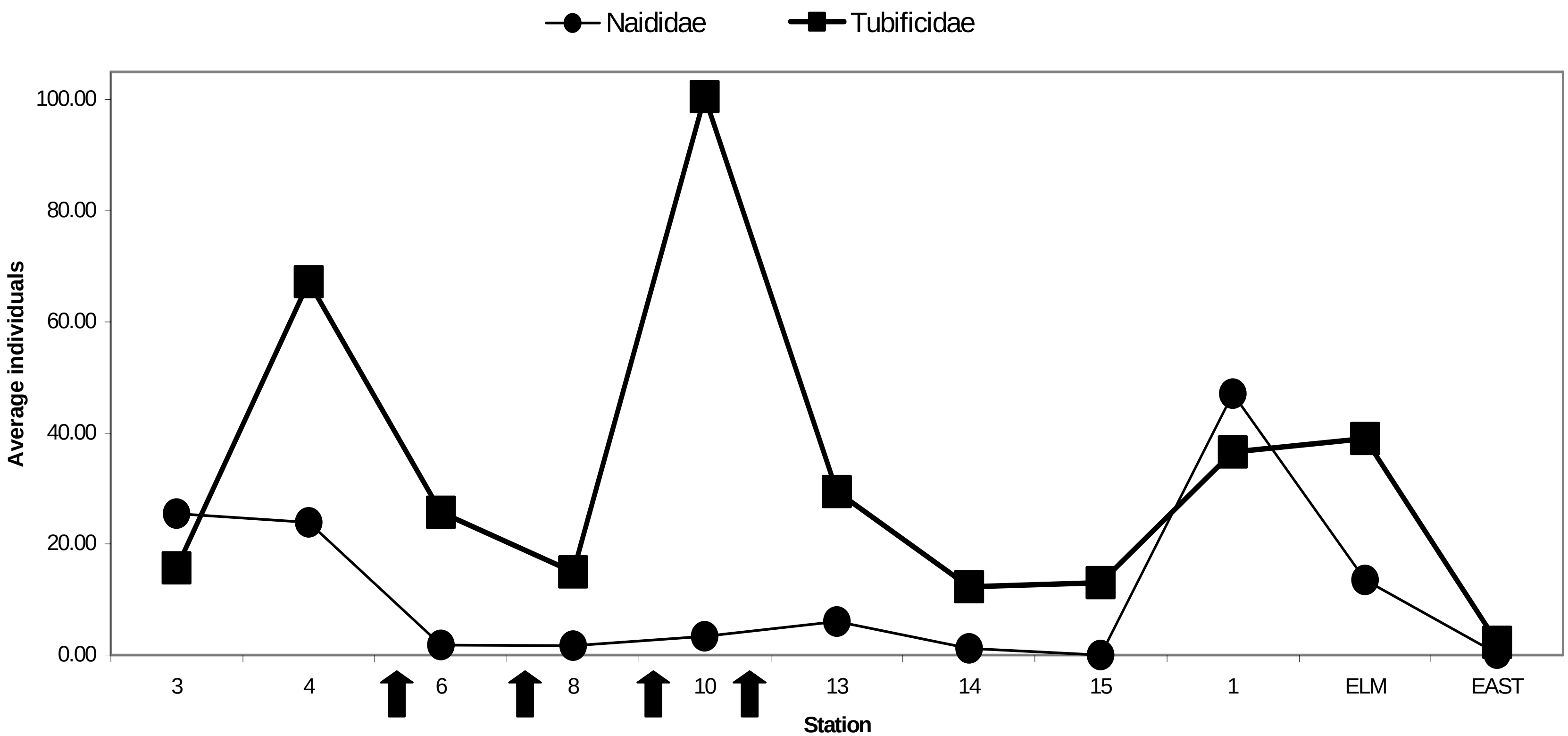


Figure V.3- Average number of individuals belonging to Oligochaeta families Naididae and Tubificidae. Arrows indicate WWTP’s.

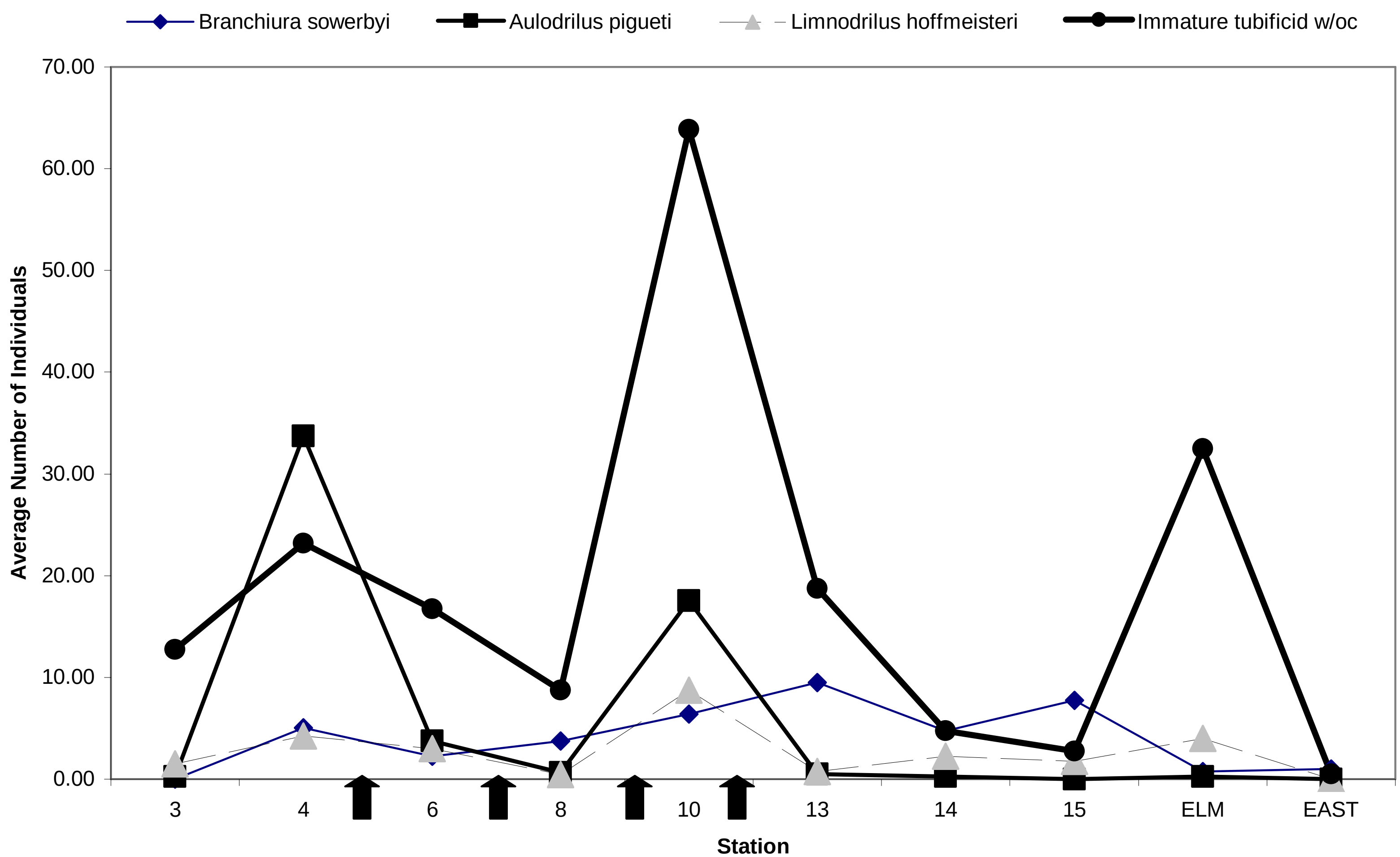


Figure V.4 – Average number of individuals of the most abundant taxa of Oligochaeta family Tubificidae. Arrows indicate WWTP's.

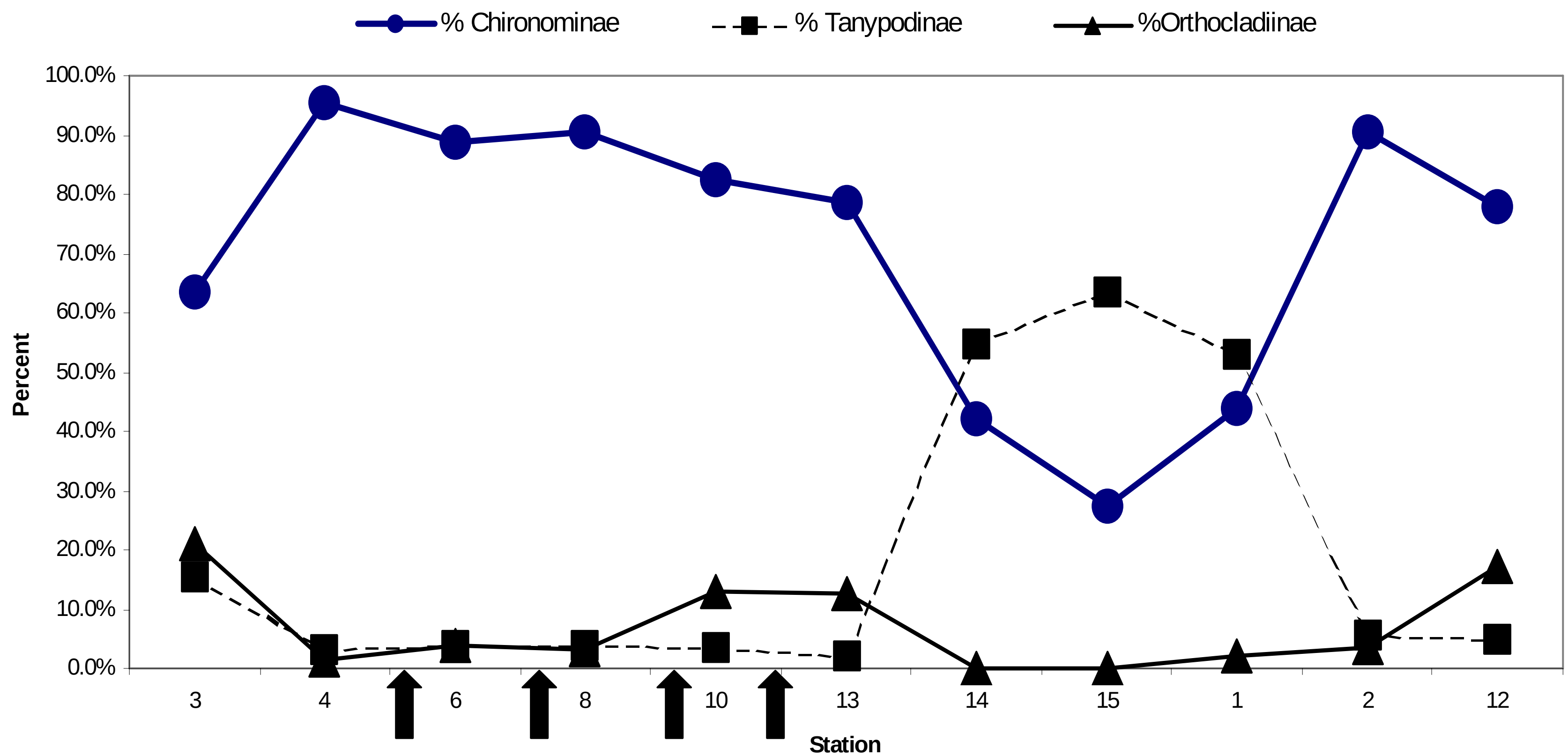


Figure V.5 – Percent of average individuals found by sub-family in Chironomidae. Arrows indicate WWTP's.

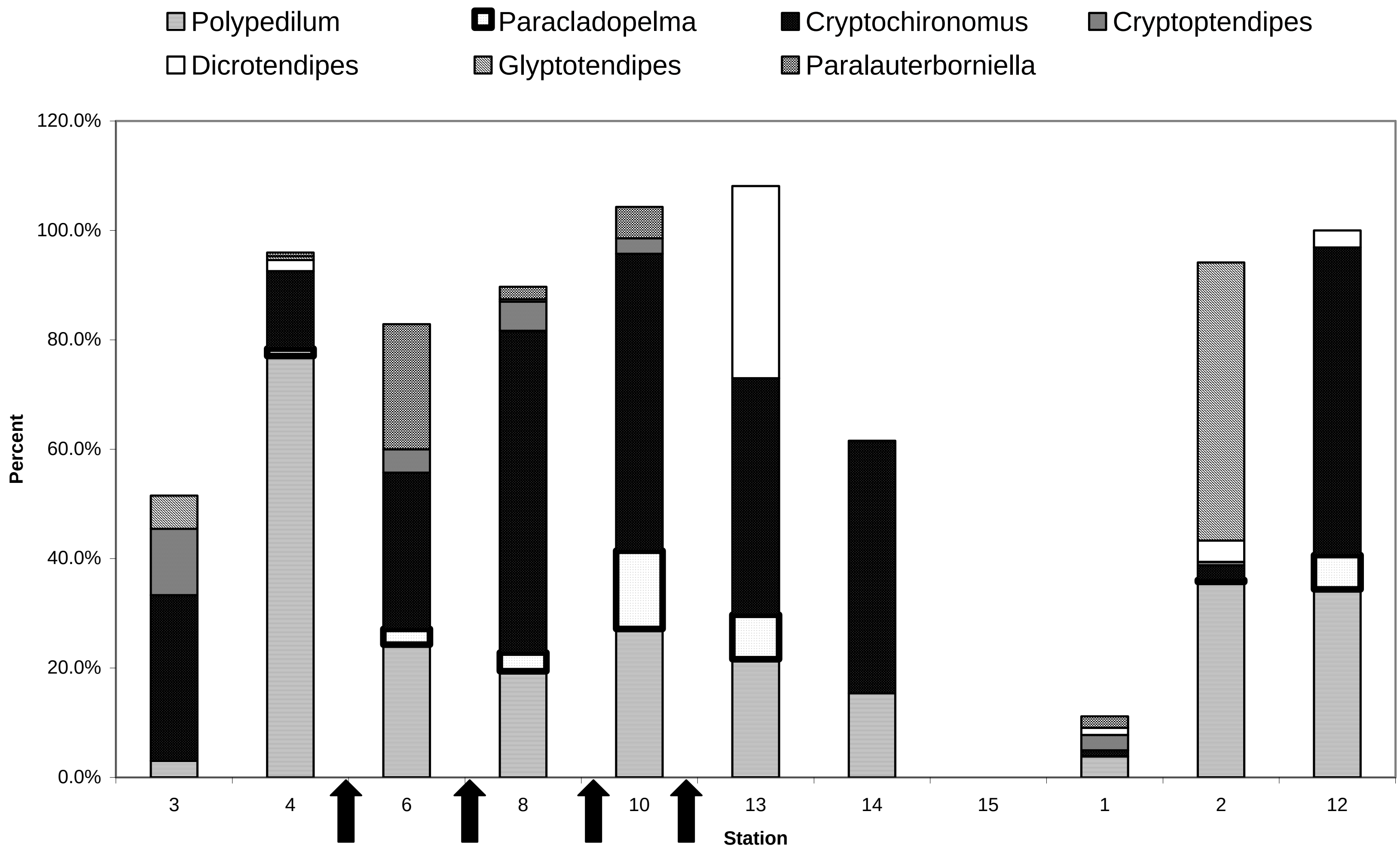


Figure V.6 – Percent of total individuals of 6 most abundant genera from family Chironomidae. Arrows indicate WWTP's.

CORRELATION ANALYSIS

Surfactant surface water and pore water toxic units were not significantly correlated with any of the benthic population metrics (Pearson's Correlation, α level = 0.05) (Table V.3).

Table V.3 – Results of Pearson's Correlation procedure of surfactant surface and pore water toxic units and benthic population metrics.

	SWTU		PWTU	
Benthic Metrics	r	probability	r	probability
Average total organisms	-0.318	0.370	-0.076	0.834
Total Organisms	-0.322	0.365	-0.079	0.828
Richness	-0.289	0.418	-0.016	0.965
Evenness	0.477	0.163	0.437	0.207
Diversity	-0.325	0.360	0.253	0.480
Chironomidae	-0.050	0.892	0.128	0.724
Chironominae	-0.051	0.888	0.139	0.702
Tanypodinae	0.045	0.901	0.027	0.940
Orthocladiinae	-0.112	0.757	-0.113	0.755
Oligochaeta	-0.447	0.196	0.172	0.635
Tubificidae	-0.466	0.175	-0.343	0.332
Naididae	-0.156	0.668	0.337	0.341

REGRESSION ANALYSIS

Since Clear Creek represents a distinctly different benthic habitat than the other 10 stations, it was not used in regression analyses. The independent variables were chosen from land use, water chemistry, sediment chemistry, physical characteristics, and habitat assessment parameters measured, providing a large number of parameters that could be used to look for relationships between river characteristics and benthic data. The variables ultimately chosen were determined by careful examination of correlation values, as well as best professional judgment. A total of 8 variables (Table V.4) were chosen from these data sets to be sure not to violate statistical assumptions. Surfactant surface water toxicity units were used as one of the eight variables at the request of the SDA taskforce, but otherwise would not have passed the a priori screening.

Table V.4 – List and description of eight variables chosen as independent variables in regression analyses with benthic data.

Variable	Description
Habitat Quality Index Score (HQIS)	descriptive value determined by assessing 9 habitat parameters
Near Field Forest	% forest land use in near-field subwatershed
Near Field Urban	% urban land use in near-field subwatershed
Cumulative Water	% water land use in cumulative subwatersheds
Surface Water Total Organic Carbon	Surface water particulate organic carbon (mg/kg)
Instream cover	% physical structures in river
Width	wetted width of the river (m)
Surface water toxic units	surfactant toxic units from surface water

A multiple MAX R regression procedure from SAS (Statistical Analysis System Version 9.1.3) was used to determine the best model for each of the eight dependent benthic variables. Habitat Quality Index Score (HQIS) contributed at least 54% of the regression R^2 value for average total organisms, total organisms, richness, and diversity. The HQIS is based on parameters known to be associated with habitat quality. The habitat assessment was performed in accordance with the Texas Commission on Environmental Quality (TCEQ) Receiving Waters Assessment Procedures Manual (TCEQ 1999). The Stream Physical Characteristics Worksheet Part I (TCEQ 1999) was used to record primary, secondary, and tertiary attributes for each transect based on field observations. The Summary of Physical Characteristics of Water Body Part II (TCEQ 1999) was used to summarize the measurements recorded from Part 1. The Habitat Quality Index Form Part III (TCEQ 1999) was used to calculate a Habitat Quality Index Score (HQIS). Nine parameters were given a score from zero to four to generate the HQIS: available instream cover, bottom substrate stability, number of riffles, dimensions of largest pool, channel flow status, bank stability, channel sinuosity, riparian buffer vegetation, and aesthetics of reach. Once all metrics were scored individually, the total score was derived by adding all individual scores. The assigned aquatic life use based on the habitat quality index score is as follows: 26 - 31 exceptional, 20 - 25 high, 14 -19 intermediate, and < 13 limited.

The HQIS increases with better habitat quality. Percent instream cover contributed at least 30% of the R^2 value for Chironominae and the three families of chironomids. Percent instream cover refers to physical structures which provide shelter for fish and benthic macroinvertebrates, including logs, stumps, woody debris, root wads, leaf packs, gravel or larger sized substrates, boulders, artificial cover (for example, tires, cement slabs), undercut banks, macrophyte beds, and overhanging vegetation.

To determine the best variable model to use with each benthic dependent variable, a Mallow's C(*p*) statistic was considered. Mallows *C(p)* statistic allows examining the residual sum of squares from a model containing *p* parameters, and the residual means square from the largest equation postulated containing all possible variables, and is presumed to be a reliable unbiased estimate of the error variance (Draper and Smith, 1981). When you plot *C(p)* vs. *p*, the point where *C(p)* first approaches *p* indicates that the parameter estimates are unbiased, and so you chose the model with that number of parameters.

Significant regression models (Max R^2 procedure, α level = 0.05) were found for eight of the 12 benthic variables (Figures V.7 - 14).

The best 7-parameter model for average total organisms (R^2 = .9980, p = 0.0069) (with parameters in order of significance, based on F-value) is:

AVERAGE TOTAL ORGANISMS =
778.77 - (25.01) (% forest land use)
+ (28.92) (% instream cover)
- (117.70) (% water land use)
+ (3581.95) (surface water toxic units)
+ (6.63) (river width)
- (31.16) (habitat quality index score)
- (7.15) (% urban land use)

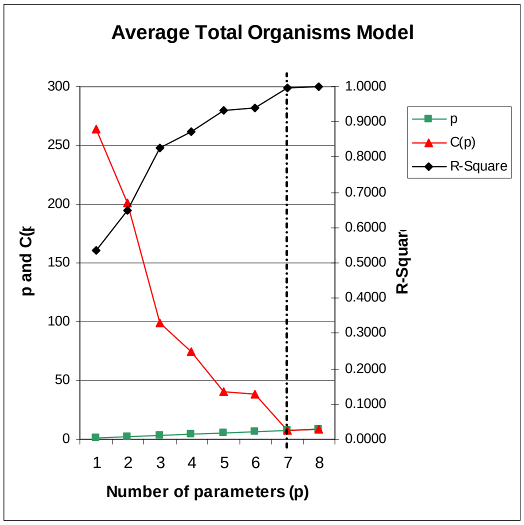


Figure V.7 – Mallow's *C(p)*statistic showing that a 7 variable parameter model is a reliable model for the average total organisms (R^2 = .9980, p = 0.0069).

Figure V.7 indicates that increasing instream cover, surfactant surface water toxicity units, and river width are related to increasing average total organisms, while decreasing forest land use, cumulative water, habitat quality index score, and urban land use are related to increasing average total organisms.

The best 7-parameter model for total organisms (R^2 = .9978, p = 0.0078) (with parameters in order of significance, based on F-value) is:

TOTAL ORGANISMS =
3109.52 - (99.72) (% forest land use)
+ (115.33) (% instream cover)
- (470.92) (% water land use)
+ (26.40) (river width)
+ (14319) (surface water toxic units)
- (124.56) (habitat quality index score)
- (28.17) (% urban land use)

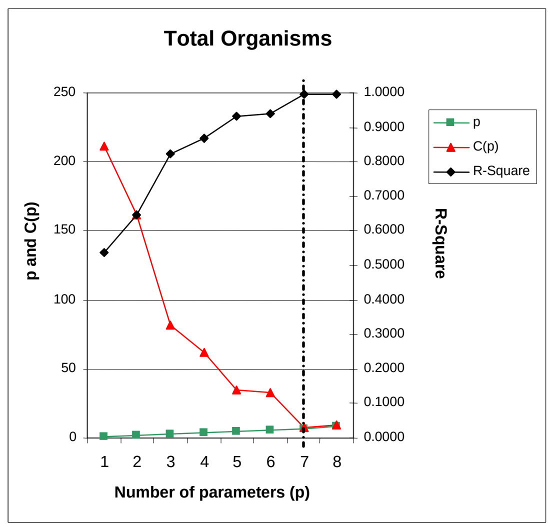


Figure V.8 – Mallow's *C(p)*statistic showing that a 7 variable parameter model is a reliable model for the total organisms (R^2 = .9978, p = 0.0078).

Figure V.8 indicates that increasing instream cover, surfactant surface water toxicity units, and river width are related to increasing total organisms, while decreasing forest land use, cumulative water, habitat quality index score, and urban land use are related to increasing total organisms.

The best 5-parameter model for richness (R^2 = .95, p = 0.01) (with parameters in order of significance, based on F-value) is:

RICHNESS =
50.03 + (1.09) (% instream cover)

- (222.03) (surface water toxic units)
- (2.58) (surface water total organic carbon)
+ (0.27) (river width)
- (1.86) (% water land use)

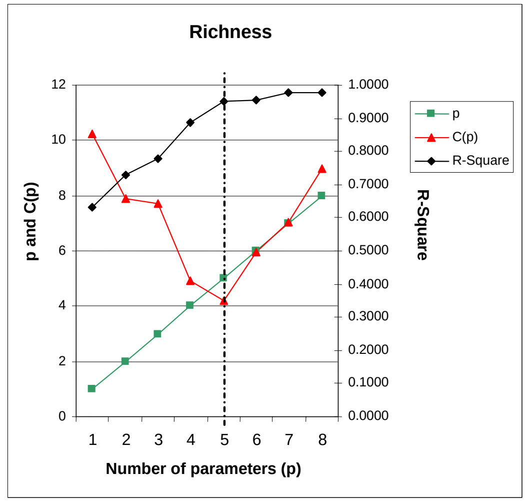


Figure V.9 – Mallow's *C(p)*statistic showing that a 5 variable parameter model is a reliable model for richness (R^2 = 0.95, p = 0.01).

Figure V.9 indicates that increasing instream cover and river width are related to increasing richness, while decreasing surfactant surface water toxic units, surface water total organic carbon, and cumulative water are related to increasing richness.

The best 3-parameter model for diversity (R^2 = .96, p = 0.0002) (with parameters in order of significance, based on F-value) is:

DIVERSITY =
2.39 + (0.08) (habitat quality index score
- (0.07) (% water land use)
- (0.06) (surface water total organic carbon)

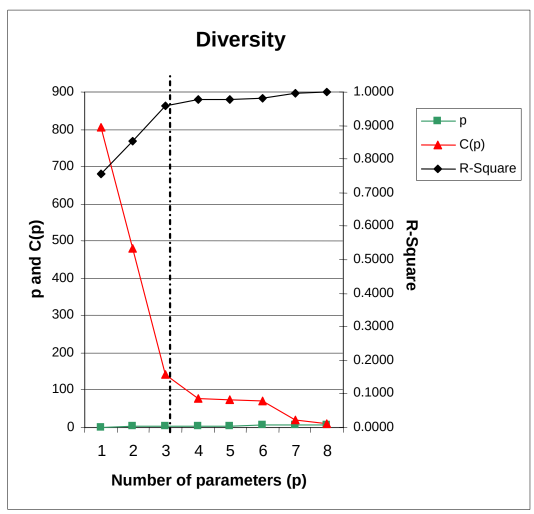


Figure V.10 – Mallow's *C(p)*statistic showing that a 3 variable parameter model is a reliable model for diversity (R^2 = 0.96, p = 0.0002).

Figure V.10 indicates that increasing habitat quality index score is related to increasing diversity, while decreasing cumulative water and surface water total organic carbon are related to increasing diversity.

The best 4-parameter model for Chironomidae (R^2 = .92, p = 0.007) (with parameters in order of significance, based on F-value) is:

CHIRONOMIDAE =
239.08 + (6.86) (% instream cover)
- (25.62) (surface water total organic carbon)
- (1225.25) (surface water toxic units)
+ (0.89) (river width)

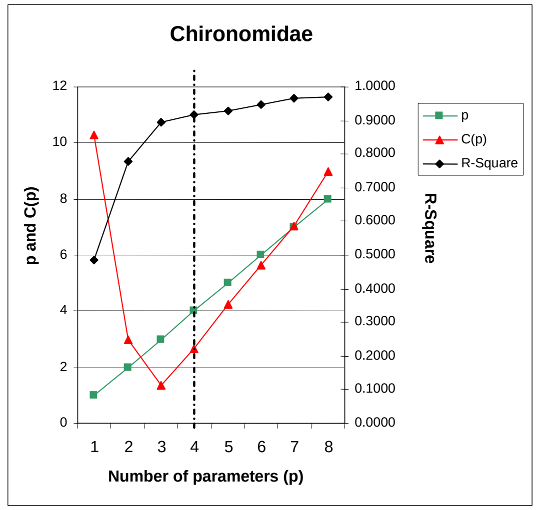


Figure V.11 – Mallow's *C(p)*statistic showing that a 4 variable parameter model is a reliable model for Chironomidae (R^2 = 0.92, p = 0.007).

Figure V.11 indicates that increasing instream cover and river width are related to increasing Chironomidae, while decreasing surface water total organic carbon and surfactant surface water toxic units are related to increasing Chironomidae.

The best 4-parameter model for Chironominae (R^2 = .91, p = 0.008) (with parameters in order of significance, based on F-value) is:

CHIRONOMINAE =
222.89 + (6.25) (% instream cover)
- (23.76) (surface water total organic carbon)
- (1127.32) (surface water toxic units)
+ (0.73) (river width)

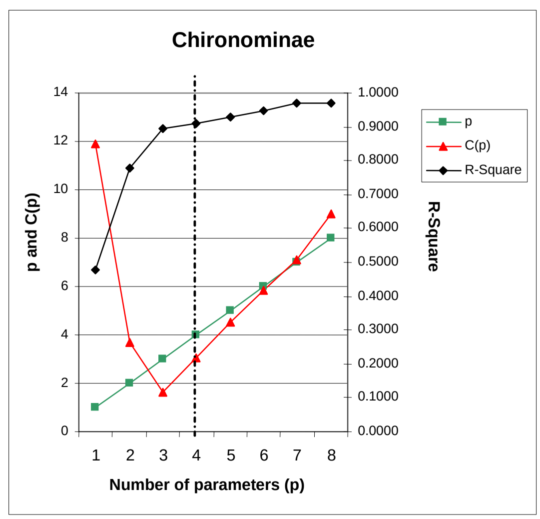


Figure V.12– Mallow's *C(p)*statistic showing that a 4 variable parameter model is a reliable model for Chironominae (R^2 = 0.91, p = 0.008).

Figure V.12 indicates that increasing instream cover and river width are related to increasing Chironominae, while decreasing surface water total organic carbon and surfactant surface water toxic units are related to increasing Chironominae.

The best 3-parameter model for Orthocladiinae (R^2 = .92, p = 0.0011) (with parameters in order of significance, based on F-value) is:

ORTHOCLADIINAE =
0.04 + (0.26) (% instream cover)
- (0.12) (% forest land use)
+ (0.08) (river width)

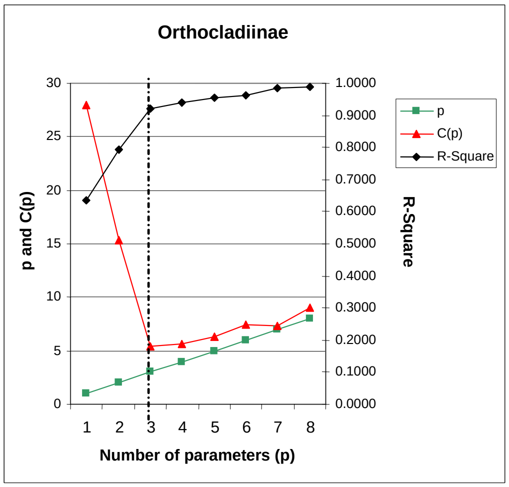


Figure V.13 – Mallow's *C(p)*statistic showing that a 3 variable parameter model is a reliable model for Orthocladiinae analysis (R^2 = 0.92, p = 0.0011)..

Figure V.13 indicates that increasing instream cover and river width are related to increasing Orthocladiinae, while decreasing forest land use is related to increasing Orthocladiinae.

The best 4-parameter model for Tubificidae (R^2 = .85, p = 0.03) (with parameters in order of significance, based on F-value) is:

TUBIFICIDAE=
85.88 + (5.15) (% urban land use)
- (12.31) (surface water total organic carbon)
+ (2.20) (% instream cover)
- (7.41) (% water land use)

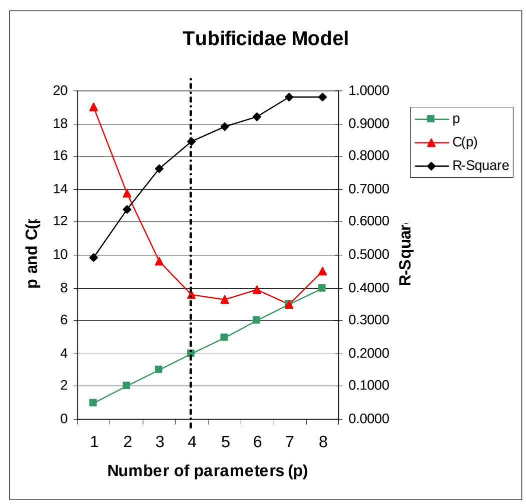


Figure V.14 – Mallow's *C(p)*statistic showing that a 4 variable parameter model is a reliable model for Tubificidae analysis (R^2 = 0.85, p = 0.03).

CLUSTER ANALYSIS

A cluster dendrogram (Figure V.15) for average total organisms for the 2005 data is presented in this section (for comparison to 1988, see Chapter VI). Hierarchical agglomerative methods using average linkage and unweighted pair groups (Morisita's Similarity clustering procedure from Multivariate Statistical Package version 3.13) were used to produce this diagram. The degree of similarity between stations or groups of stations is indicated by the level at which linkage occurs between stations (the vertical lines in the dendrogram). Similarity increases as linkages approach 1.0. For the purposes of this analysis, clusters with similarity values of > 0.50 are considered to be ecologically important.

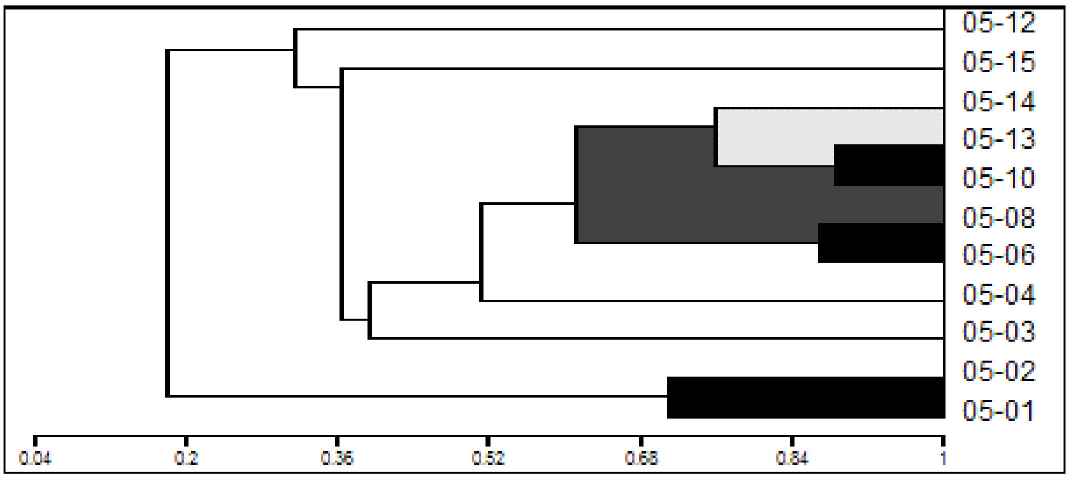


Figure V.15 – Morisita's Similarity Index for average total organisms in 2005.

The cluster dendrogram indicates stations 06 and 08 have a high similarity index of 0.87. The dominant taxa found at both locations are Oligochaeta: immature tubificids without capilliform chaeta, with *Cryptochironomus* and *Polypedilum* (Chironomidae: Chironominae) sub-dominant. Stations 10 and 13 also have a high similarity index value, 0.88, with the dominate taxa of both locations being Nematoda and Oligochaeta: Tubificidae: immature tubificids without capilliform chaeta with *Branchiura sowerbyi* (Oligochaeta: Tubificidae), *Paracladopelma,* (Chironomidae: Orthocladiinae) and *Polypedilum* (Chironomidae: Chironominae) sub-dominant. Stations 01 and 02 have a similarity index of 0.71, with dominate taxa at both locations being Nematoda and Oligochaeta: Tubificidae: immature tubificids without capilliform chaeta, with *Limnodrilus hoffmeisteri* (Oligochaeta: Tubificidae), *Dero* and *Nais* (Oligochaeta: Naididae) subdominate. Stations located in the metroplex (Stations 06, 08, 10, 13, and 14) form a related cluster with a similarity index of 0.61.

Chapter VI

Comparisons with UNT 1988 Study

The benthic and in-stream chemistry data collected in September/October 2005 was compared to a survey of the Trinity River conducted from June 1987 to December 1988 by UNT (Dickson et al., 1989; Appendix A). For the purposes of this report, the benthic data collected in October 2005 was compared to the August 1988 data. Clear Creek will not be included in this comparison as it was not sampled in August 1988, and represents a distinctly different benthic habitat compared to that found in the Trinity River. Fifty taxa are reported from the 1988 data as compared to 112 taxa in 2005 (Table VI.1). A total of 18 Oligochaeta genera were reported in 1988 compared to 22 in 2005. In 2005, four genera of Oligochaeata not identified were present in the 1988 benthic data. A higher number of Chironomidae genera were collected in 2005 (50) than in 1988 (20). In 2005, three genera of Chironomidae not identified were present in the 1988 benthic collection. The in-stream chemistry data are also compared with August 1988 UNT data as well as selected data available from the 2005 TRA report (Appendix A).

In 2005, there were more benthic macroinvertebrates collected than in 1988 at stations 02, 04, 10, 13, and 14 (Figure VI.1). Benthic macroinvertebrate population densities decreased downstream of wastewater treatment plant outfalls in 2005 and 1988, with the exception of downstream of Dallas Central WWTP (station 10). In 1988, benthic populations downstream of the confluence with the East Fork (station 14) to Palestine (station 15) increased, whereas in 2005 they decreased.

A comparison of species richness, diversity, and evenness is given in Figures VI.2-4. Species richness is higher in 2005 except at stations 06, 08, 12, and 15. Evenness is higher in 2005 except stations 02 and 14. Diversity is higher in 2005 except at stations 02, 06, 08, 14, and 15. In reference to downstream of Dallas Central and Dallas South WWTP (stations 10 and 13), in 2005 these stations had either the same or slightly higher richness, diversity, and evenness values. Upstream of TRA Central WWTP (Station 06) and upstream of Dallas Central WWTP (station 08) declined in richness and diversity.

Both the 2005 and 1988 studies were dominated by Oligochaeta and Chironomidae (Figure VI.5). Total number of Oligochaeta were higher at every station in 1988 than 2005, except for upstream of Village Creek WWTP and upstream of Dallas South WWTP (stations 04 and 10 respectively) (Figure VI.6). When compared to 1988, the number of Chironomidae larvae collected equaled or exceeded populations collected at stations in 2005, with the exception of the Elm Fork (station 2) (Figure VI.7). Downstream of Dallas South WWTP, the number of chironomids decreased from the upstream station, whereas in 1988 the number increased downstream of the WWTP. There were more Chironominae larvae collected in 2005 than 1988 at all stations except 06, 12, 13, 14, and 15. Lower numbers of Chironominae were collected downstream of Dallas South WWTP than in 1988 (Figure VI.8). In 1988, all stations had a higher number of Tanypodinae collected than in 2005, except for south of the confluence with the East Fork (Station 14) (Figure VI.9).

The cluster dendrogram of the average total organisms collected in August 1988 indicates differences in similarities among the locations from the 2005 data (2005 dendrogram discussed in Chapter V). In 1988 stations upstream and downstream of the metroplex cluster separately, in contrast to 2005 when all metroplex Stations, 06, 08, 10, 13, and 14, were included in a single cluster. Other clusters present during the 1988 study included Stations 03, 04, 06 and 15 with a similarity index of 0.53, and Stations 10, 13, 14 cluster with a similarity index of 0.72. This analysis indicates that community composition of the 2005 study locations within the metroplex are more homogeneous than that of the 1988 study.

In-stream chemistry measurements for the two studies are compared in Figures VI.12-21. Turbidity levels (Figure VI.12) are subject to local transient conditions and demonstrated no clear historical or downstream trends. Dissolved oxygen concentrations (Figure VI.13) were similar to the 1988 levels or higher. Total organic carbon measurements (Figure VI.14) tended to be somewhat increased in the upstream stations and decreased in the downstream stations. Water hardness (Figure VI.15) tended to have elevated values over the historical data in the downstream stations. Most significantly, decreased levels for conductivity (Figure VI.16), total dissolved solids (Figure VI.17), chlorides (Figure VI.18), nitrate+nitrite (Figure VI.19), total phosphorous (Figure VI.20) and chlorophyll-a in the recent studies all indicate a decline in the influence of nutrient loading and apparent improvement in efficiency of WWTP operation. In general, the comparison indicates an improvement in water quality conditions since the 1988 study.

Table VI.1 – Comparison of taxa from August 1988 and October 2005.

TAXA	AUG 88	OCT 05
Nemertea	-	*
Nematoda	-	*
Oligochaeta	*	*
Fragments	*	*
Lumbriculidae	-	*
Chaetogaster	*	-
Dero	*	*
Dero (aulophous) furcata	-	*
Nais	*	*
Pristina	*	*
Pristina aequiseta	-	*
Pristina breviseta	*	*
Pristina longiseta	*	*
Pristina synclita	-	*
Pristinella	-	*
Pristinella longisoma	-	*
Pristinella osborni	-	*
Pristinella jenkinae	-	*
Stephensoniana trivandrana	*	*
Stephensoniana tandyi	*	-
Aulodrilus limnobius	*	-
Aulodrilus pigueti	*	*
Aulodrilus pleuroseta	*	*
Branchiura sowerbyi	*	*
Ilyodrilus templetoni	*	-
Limnodrilus cervix	*	-
Limnodrilus hoffmeisteri	*	*
Limnodrilus udekeimanus	*	*
Limnodrilus claparedeianus	-	*
Tubifex	*	*
Immature tubificid w/oc	*	*
ITWCAP	-	*
Bivalvia	*	*
Corbicula	*	*
Sphaeriidae	*	*
Unionidae	-	*
Gastropoda	-	*

TAXA	AUG 88	OCT 05
Lymnaeidae	-	*
Physidae	-	*
Helisoma	-	*
Ephemeroptera	*	*
Baetidae	-	*
Hexagenia	-	*
Ephemera	-	*
Caenidae	*	*
Tricorythidae	*	*
Paracloeodes	*	-
Anisoptera	-	*
Coenagrionidae	-	*
Calopteryigidae	-	*
Gomphidae	*	*
Aeshnidae	-	*
Hemiptera	-	*
Gyrinidae	*	-
Coleoptera	-	*
Staphylinidae	-	*
Carabidae	-	*
Elmidae	*	*
Hydrophilidae	-	*
Trichoptera	-	*
Hydroptilidae	*	*
Hydroptilidae pupae	-	*
Hydropsychidae pupae	-	*
Polycentropidae	-	*
Chironomidae	*	*
Tanypodinae	*	*
Ablabesmyia	*	*
Ablabesmyia pupae	-	*
Ascheum	-	*
Conchapelopia	-	*
Clinotanypus/Coelotanypus	-	*
Coelotanypus	*	*
Djalmabatista	-	*
Fittkauimyia cf serta	-	*
Labrundinia	-	*
Larsia	-	*

TAXA	AUG 88	OCT 05
Nilotanypus	-	*
Paramerina	*	-
Procladius	*	*
Tanypus	-	*
Tanypus I	*	-
Tanypus II	*	-
Telopelopia	-	*
Thienemannimyia	-	*
Orthocladinae	-	*
Cladopelma	*	*
Corynoneura	*	-
Cricotopus	*	*
Eukieferriella	-	*
Nanocladius	-	*
Orthocladius	-	*
Orthocladius/Cricotopus	-	*
Paracladopelma	-	*
Parakiefferiella	-	*
Thienemanniella	-	*
Chironominae	-	*
Chironominae pupae	-	*
Axarus	-	*
Chironomus	*	*
Chironomus pupae	-	*
Cryptochironomus	*	*
Cryptoptendipes	-	*
Dicrotendipes	*	*
Dicrotendipes pupae	-	*
Endochironomus	-	*
Endochironomus pupae	-	*
Glyptotendipes	-	*
Glyptotendipes pupae	-	*
Goeldichironomus	-	*
Harnischia	*	*
Microchironomus	*	*
Microtendipes	-	*
Parachironomus	-	*
Paralauterborniella	*	*
Paratendipes	-	*

TAXA	AUG 88	OCT 05
Polypedilum	*	*
Polypedilum (beckiae grp)	-	*
Psuedochironomus	-	*
Stelechomyia	-	*
Stictochironomus	-	*
Tribelos	-	*
Chironomini	-	*
Chironomini pupae	-	*
Cladotanytarsus	*	*
Paratanytarsus	-	*
Rheotanytarsus	*	*
Stempellina	*	-
Tanytarsus	*	*
Tanytarsus B	-	*
Tanytarsini	-	*
Tanytarsini pupae	-	*
Chaoboridae	*	-
Ceratopogonidae pupae	-	*
Ceratopogonidae	*	*

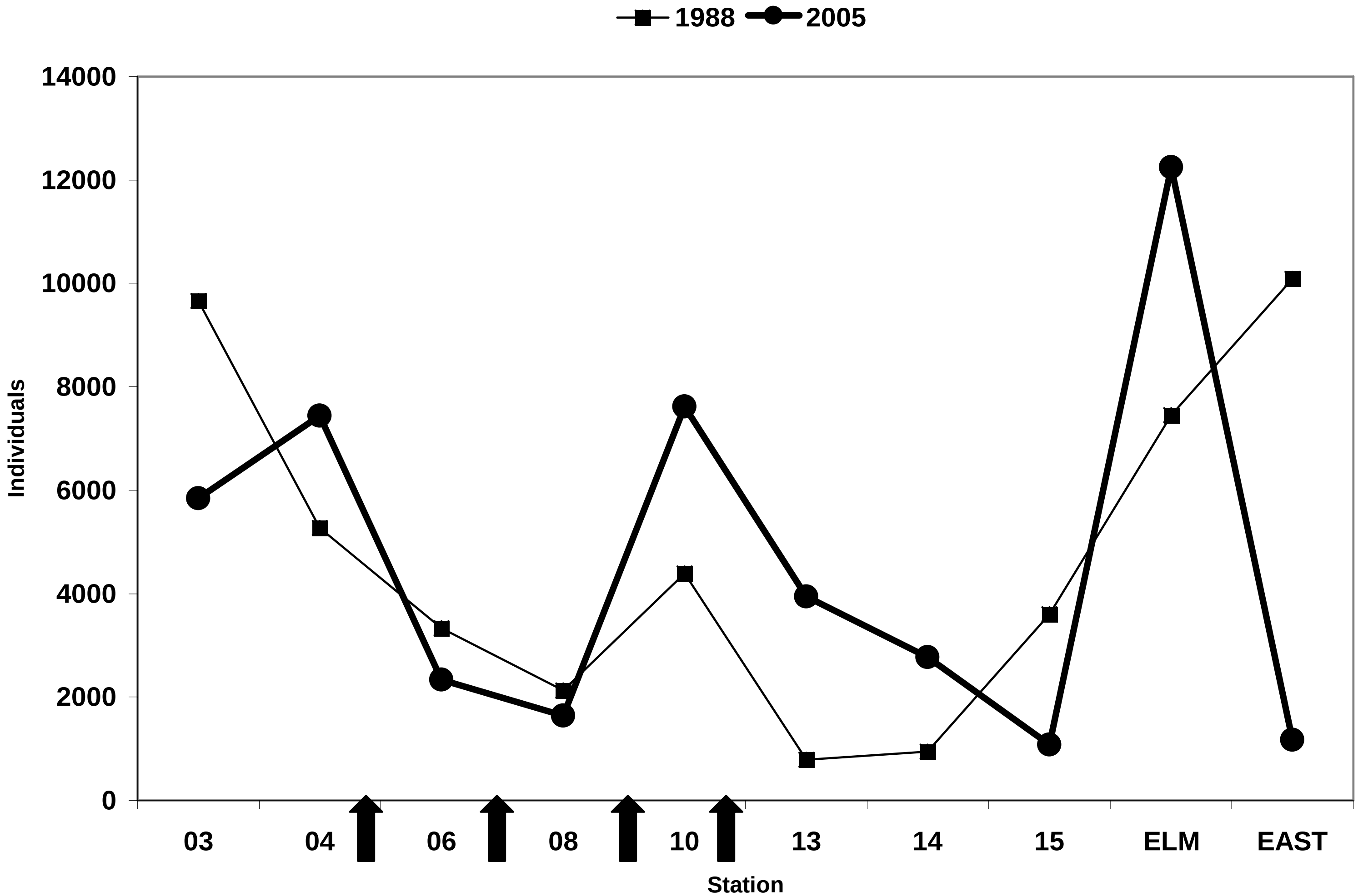


Figure VI.1 – Average total individual organisms collected per m^2 for August 1988 and October 2005. Arrows indicate WWTP's.

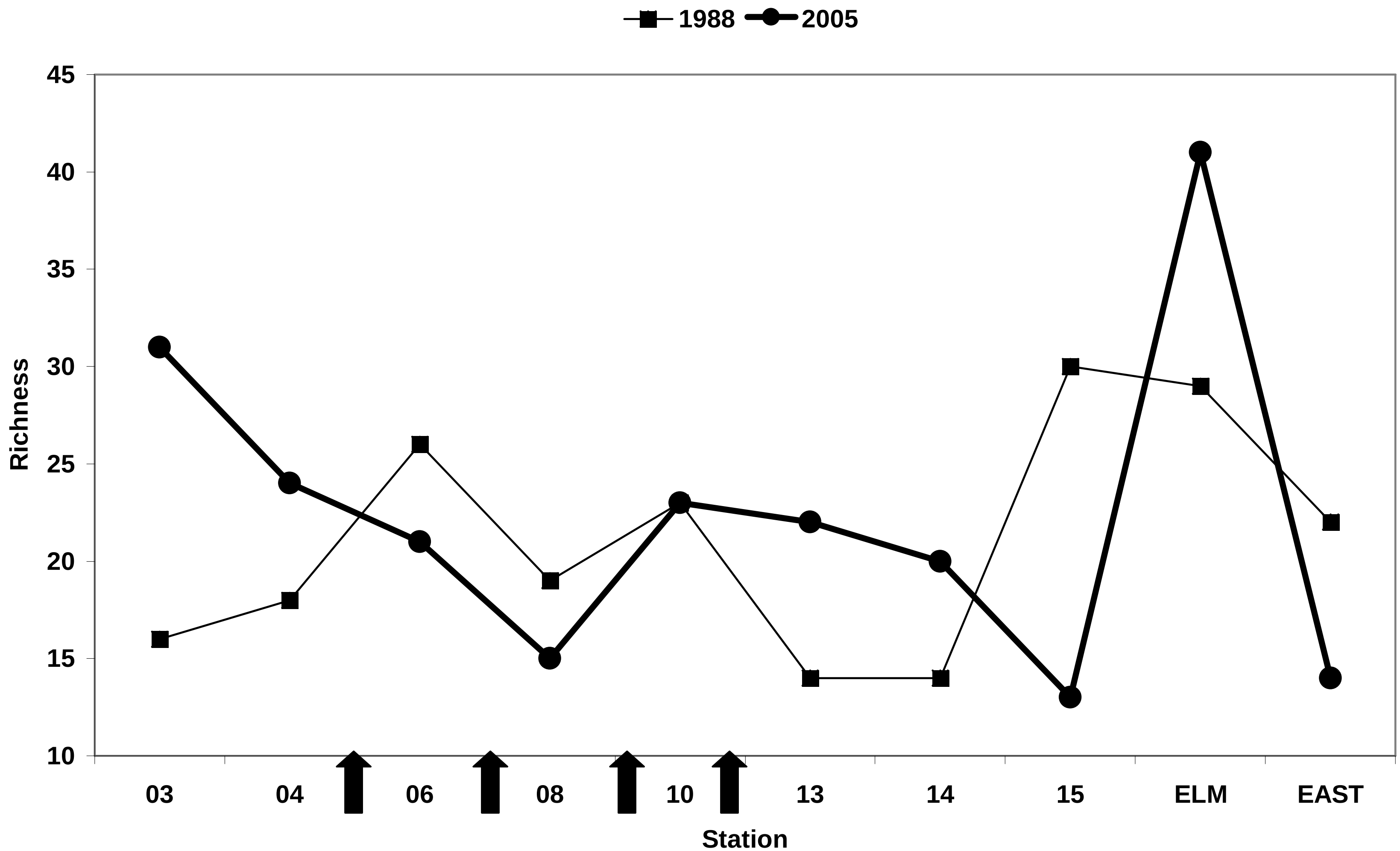


Figure VI.2 – Species richness of each station from August 1988 and October 2005. Arrows indicate WWTP's.

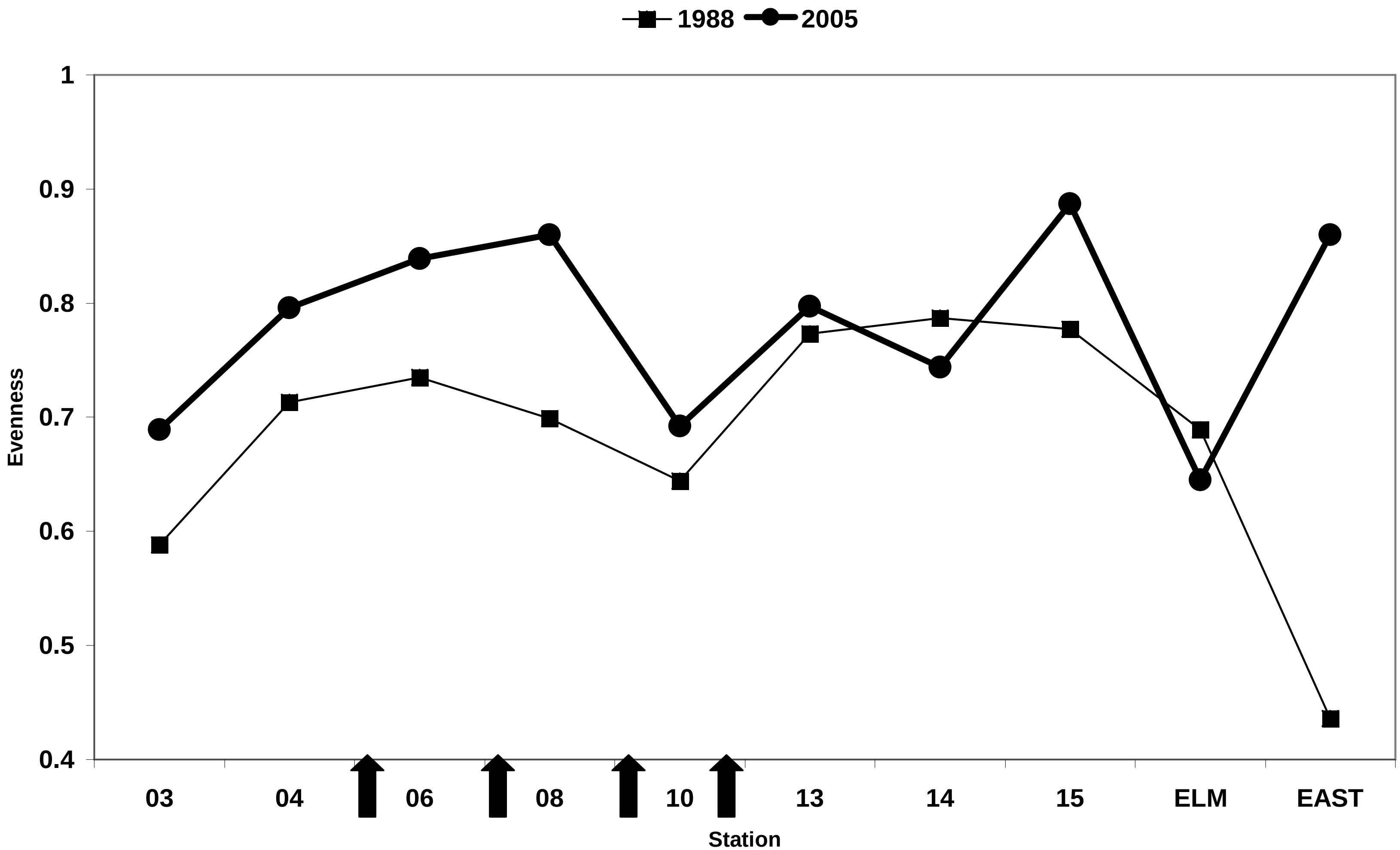


Figure VI.3 – Evenness values for each station from August 1988 and October 2005. Arrows indicate WWTP's.

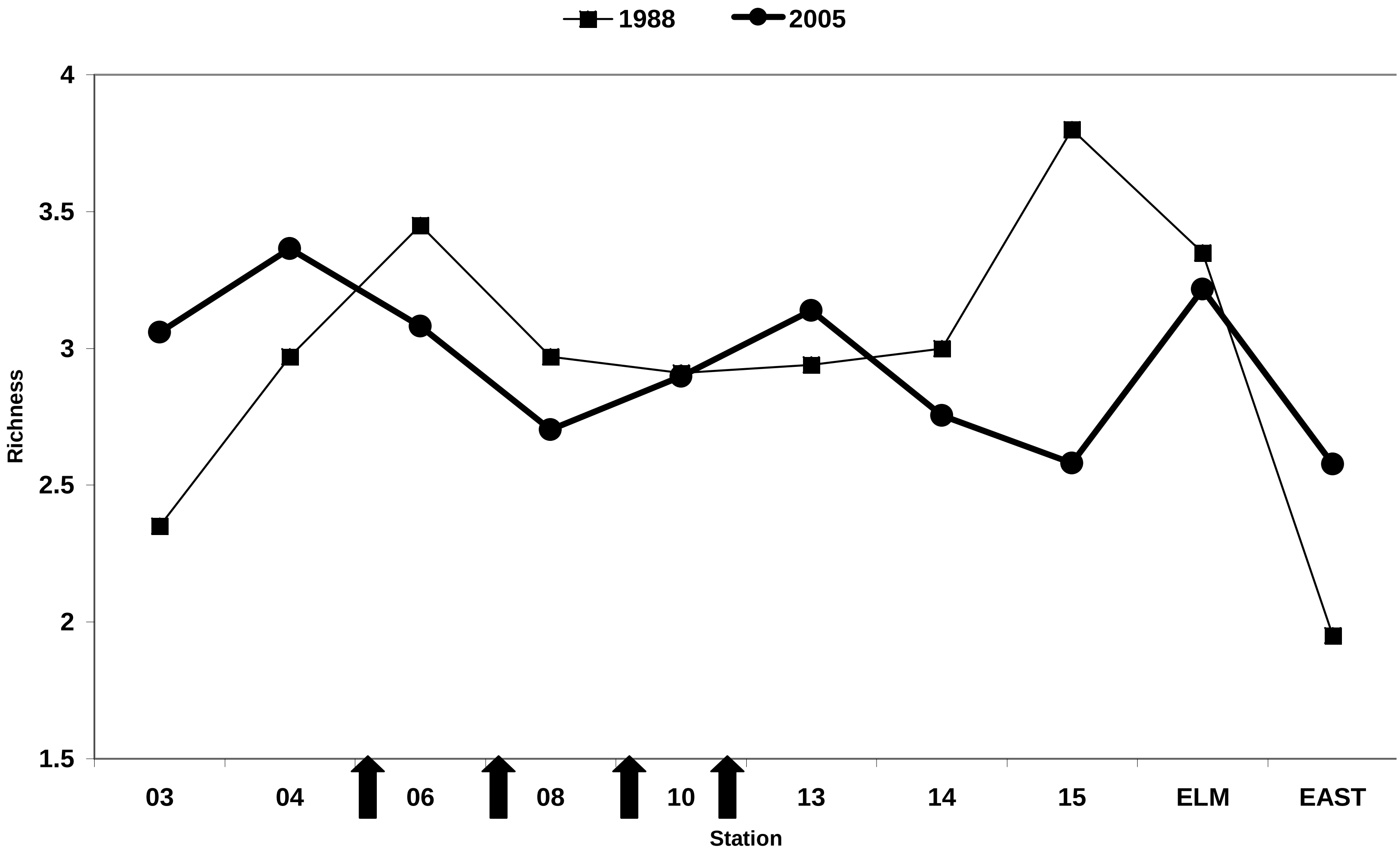


Figure VI.4 – Brillioun's diversity for each station from August 1988 and October 2005. Arrows indicate WWTP's

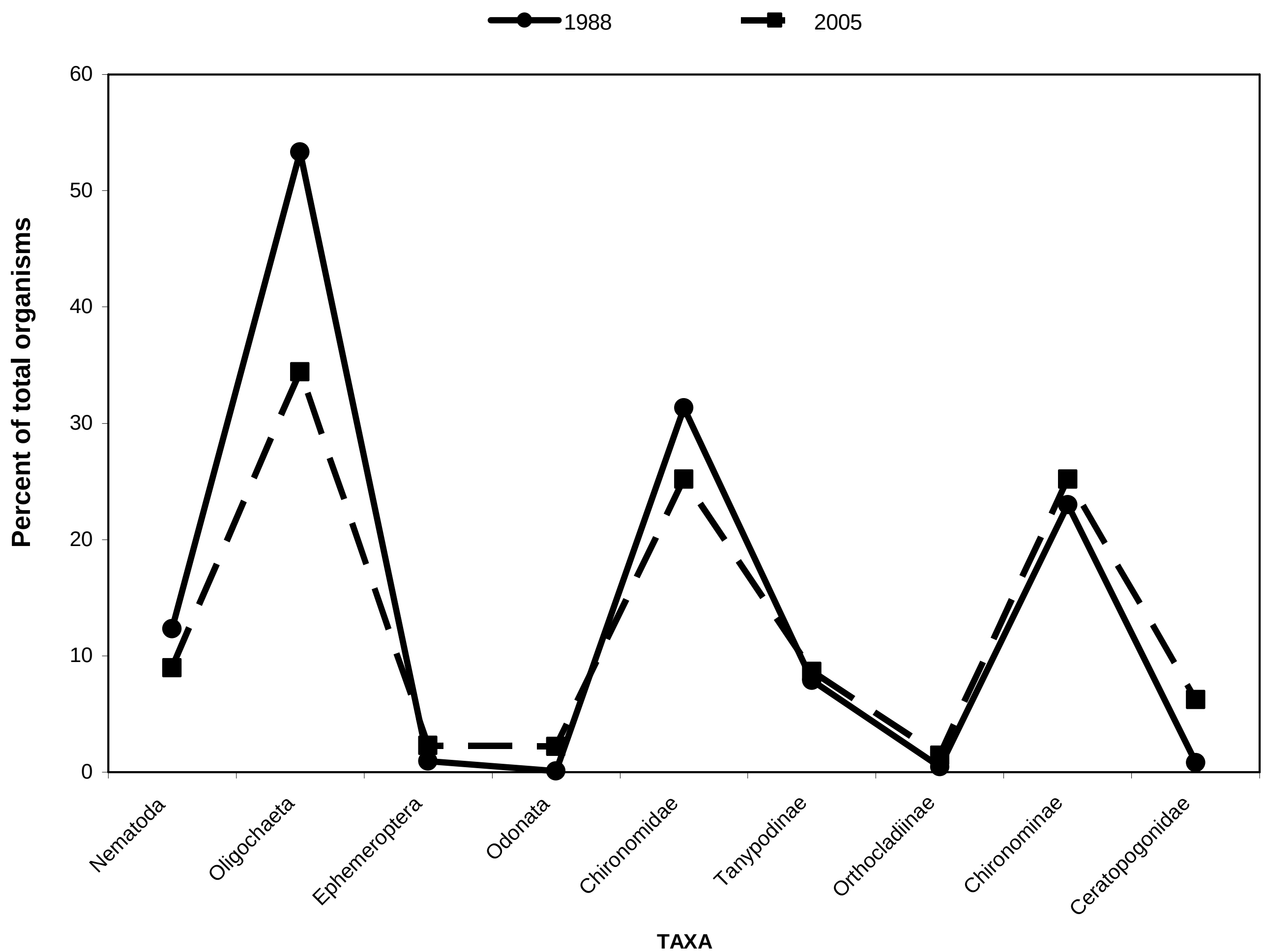


Figure VI.5 – Taxa represented as a percent of total organisms for August 1988 and October 2005 data.

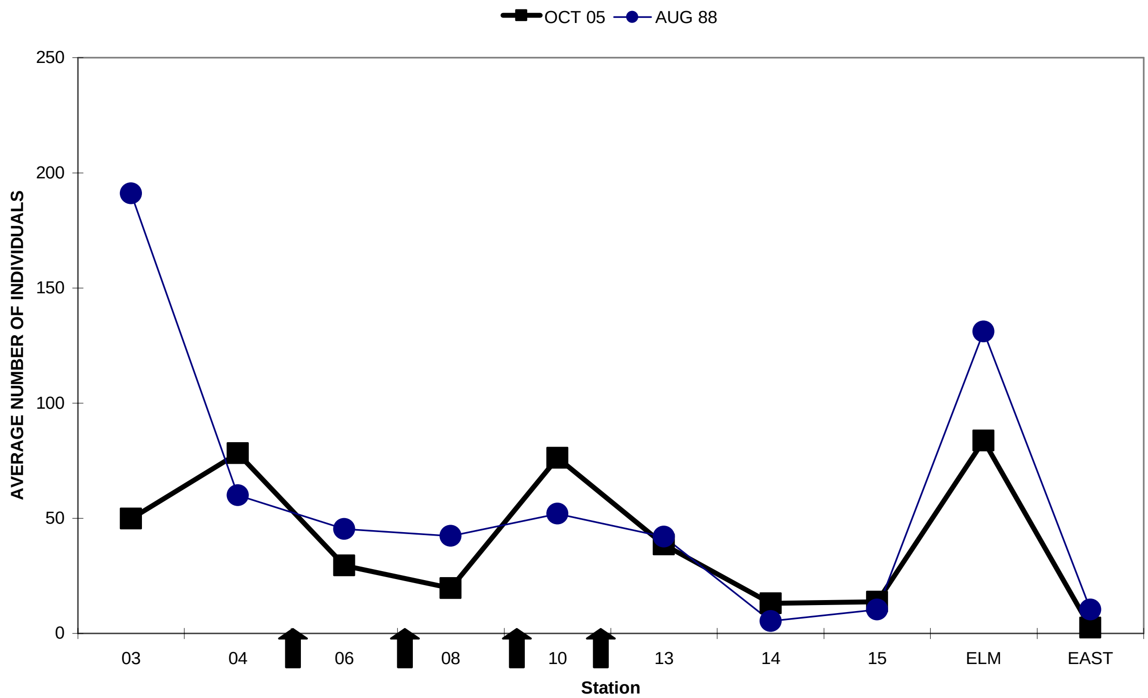


Figure VI.6 – Average total number of Oligochaeta for each station for August 1988 and October 2005. Arrows indicate WWTP's.

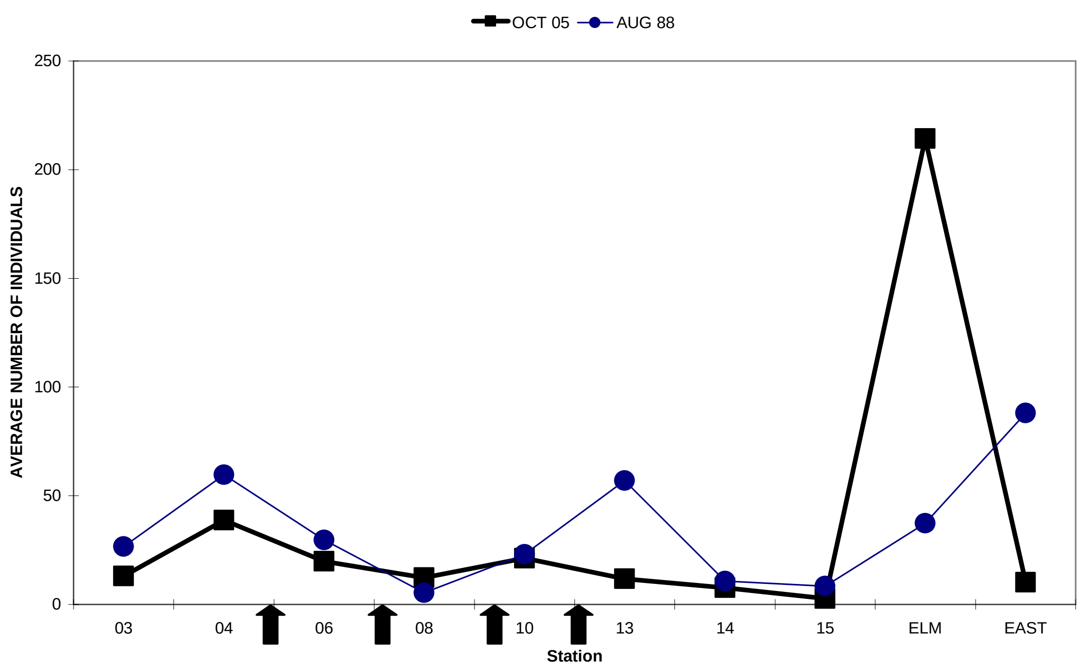


Figure VI.7 – Average total Chironomidae for each station from August 1988 to October 2005. Arrows indicate WWTP's.

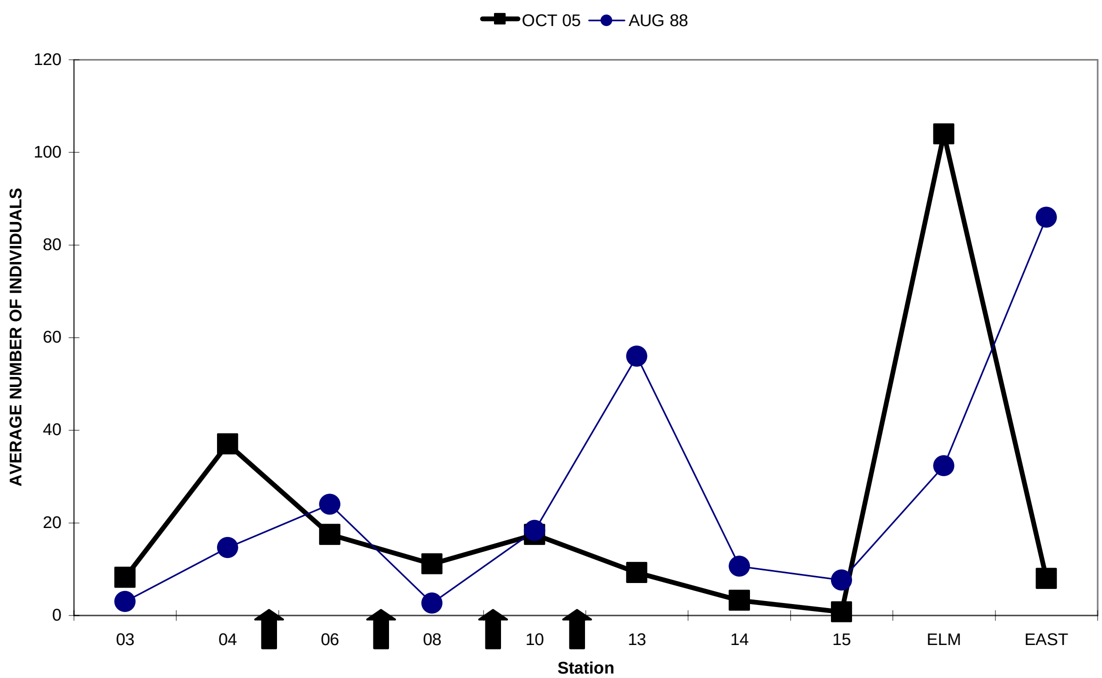


Figure VI.8 – Average total Chironominae for each station from August 1988 to October 2005. Arrows indicate WWTP's.

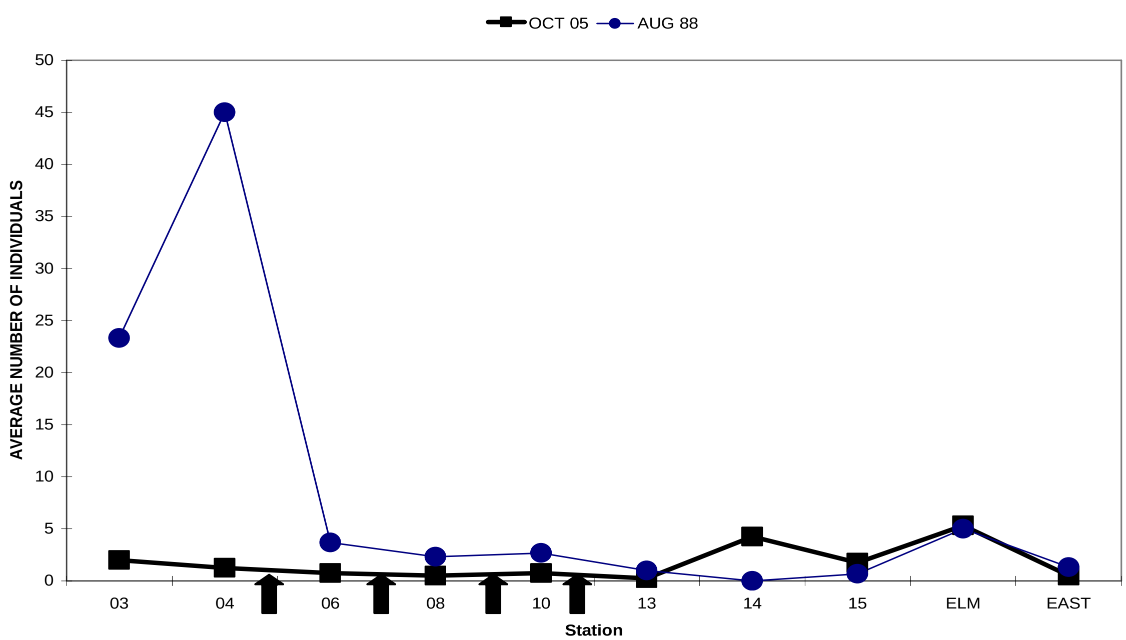


Figure VI.9 – Average total Tanypodinae for each station from August 1988 to October 2005. Arrows indicate WWTP's

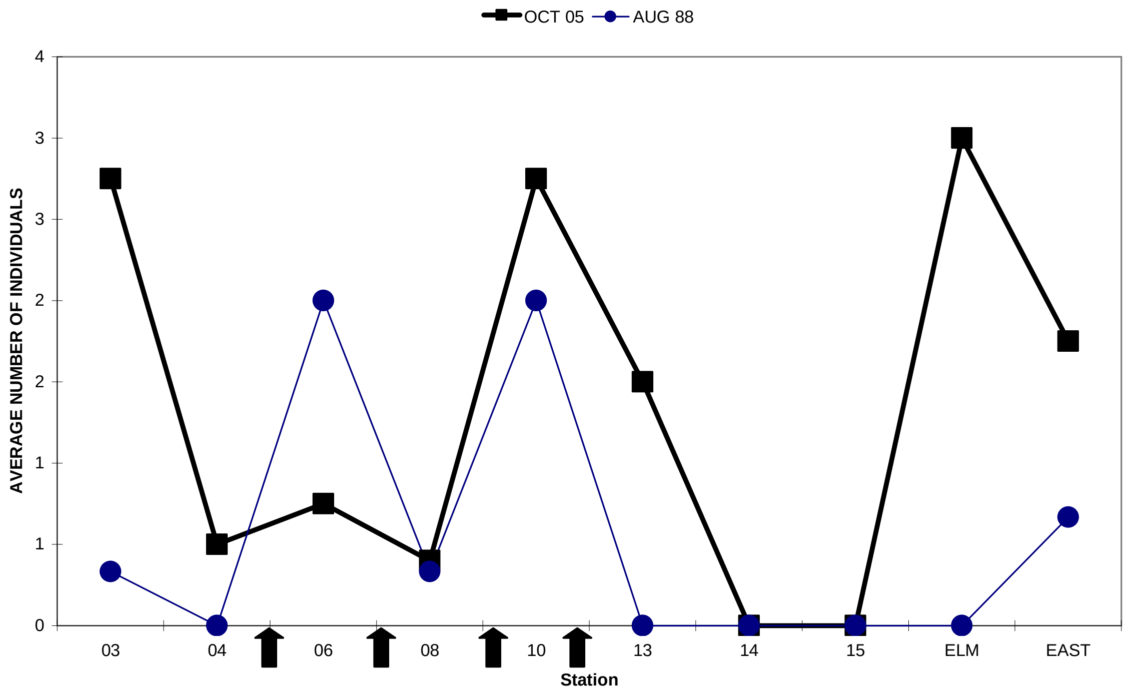


Figure VI.10 – Average total Orthocladiinae for each station from August 1988 to October 2005. Arrows indicate WWTP's.

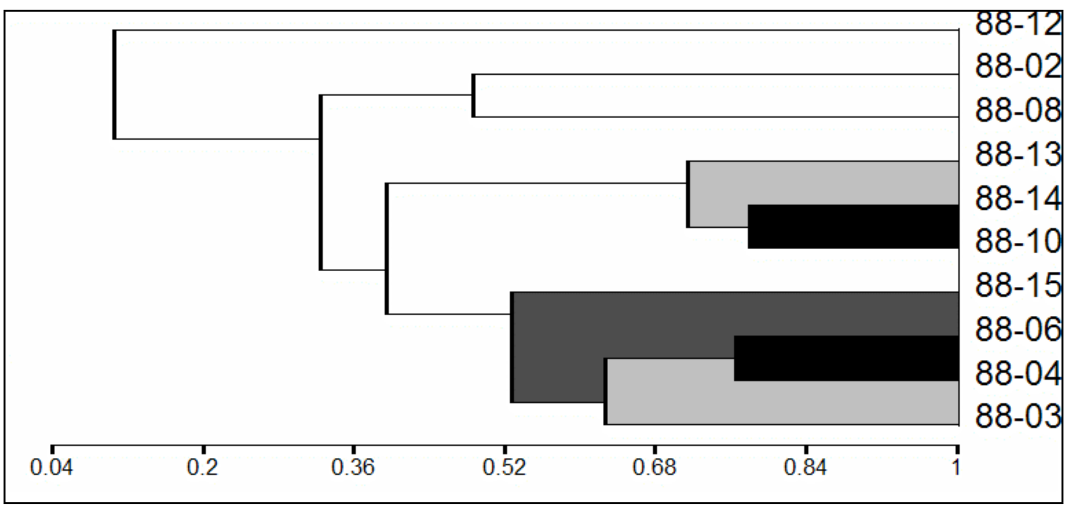


Figure VI.11 – Morisita's Similarity Index for average total organisms in 1988.

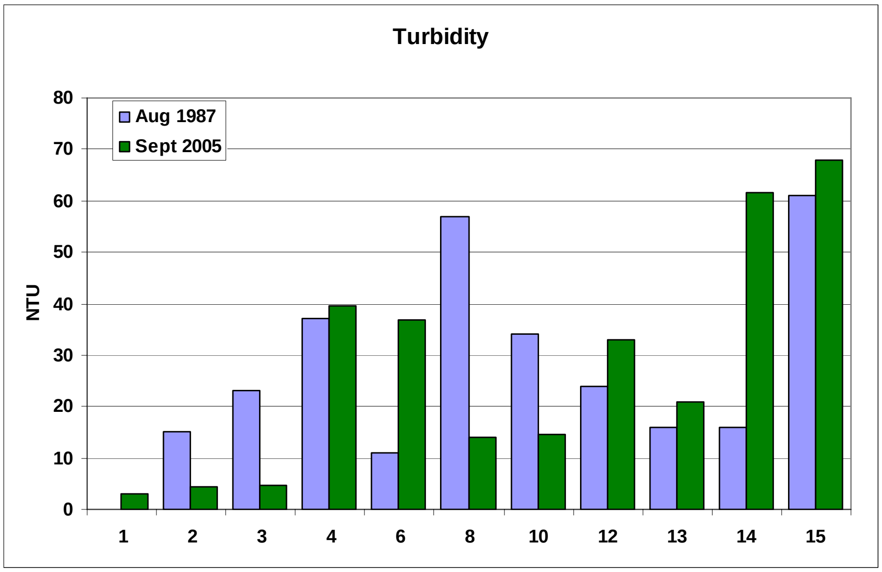


Figure VI.12. Historical comparison of turbidity measurements at Trinity River sites.

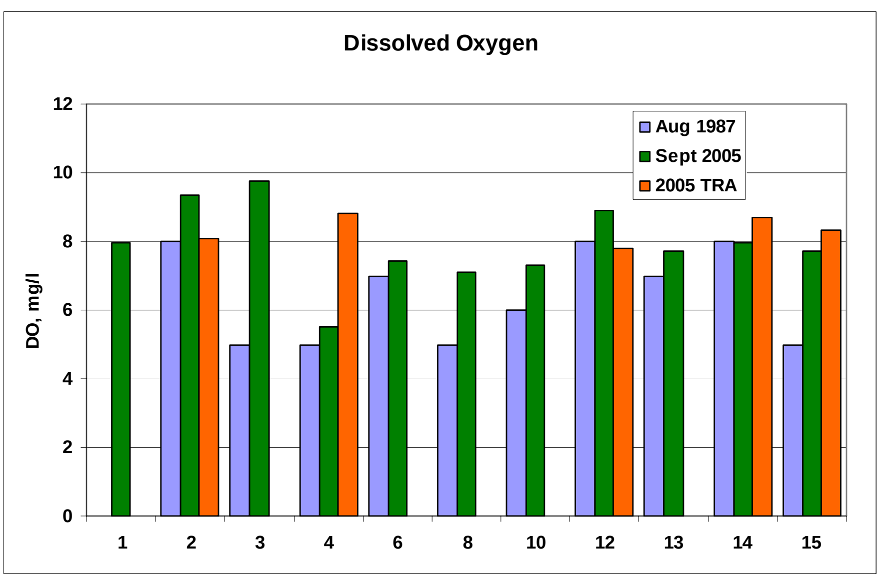


Figure VI.13. Historical comparison of dissolved oxygen measurements at Trinity River sites.

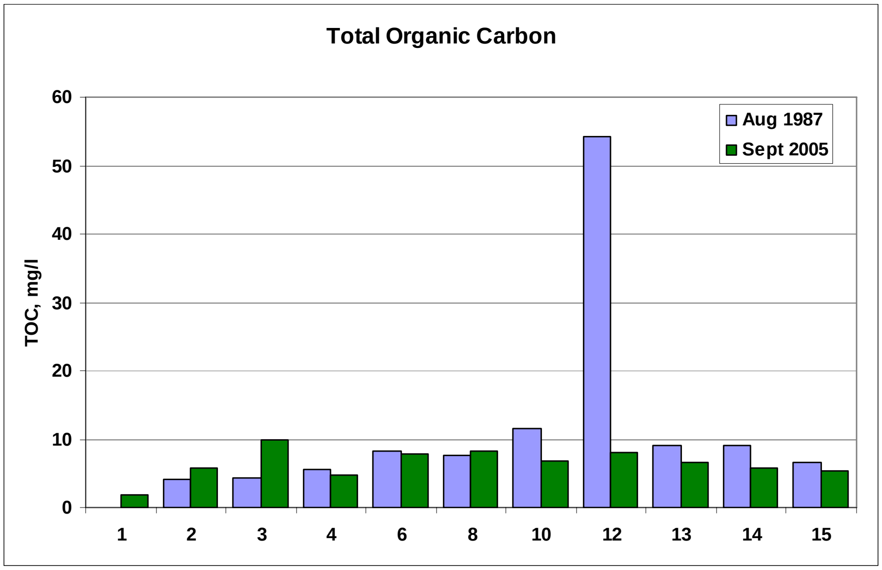


Figure VI.14. Historical comparison of total organic carbon measurements at Trinity River sites.

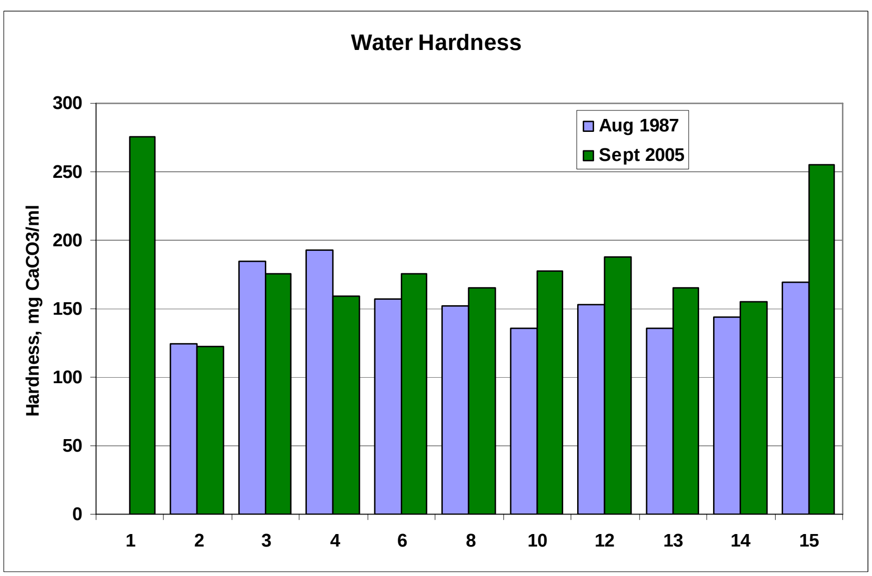


Figure VI.15. Historical comparison of water hardness measurements at Trinity River sites.

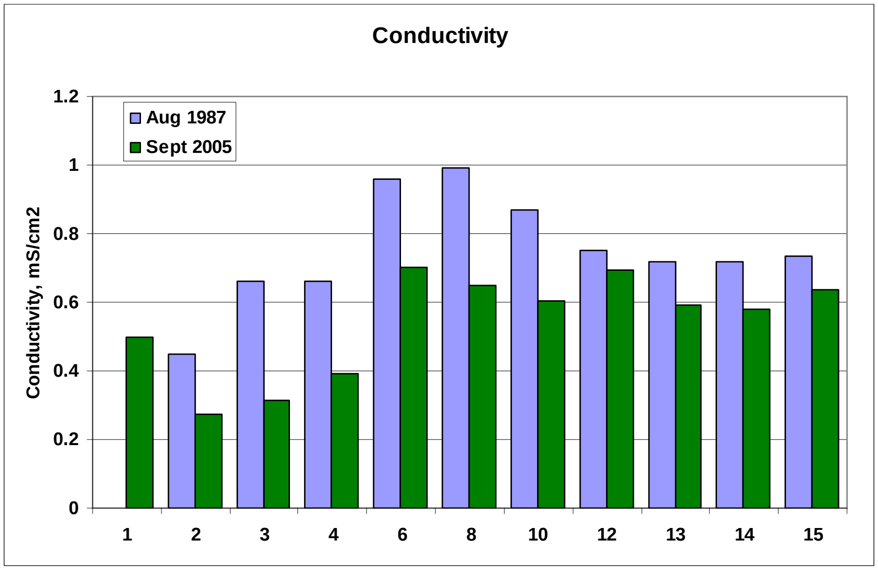


Figure VI.16. Historical comparison of conductivity measurements at Trinity River sites.

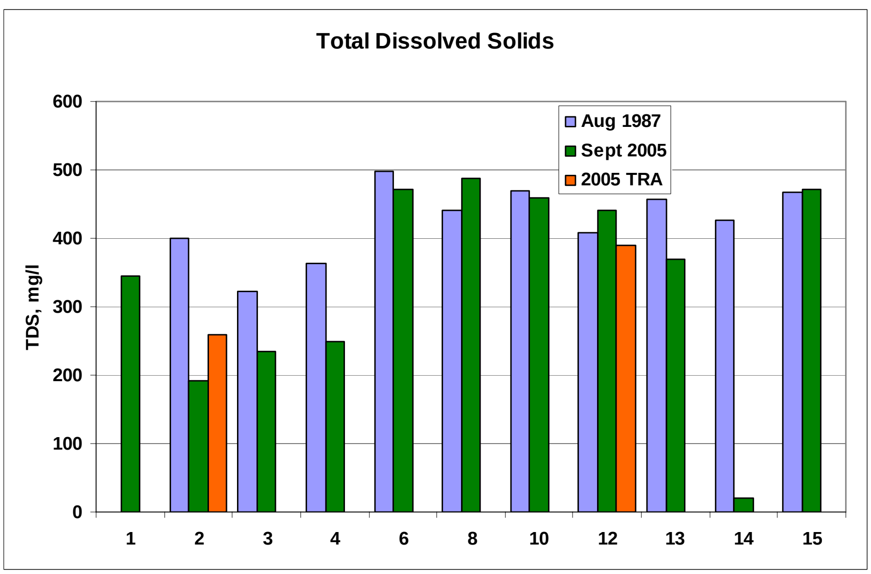


Figure VI.17. Historical comparison of total dissolved solids measurements at Trinity River sites.

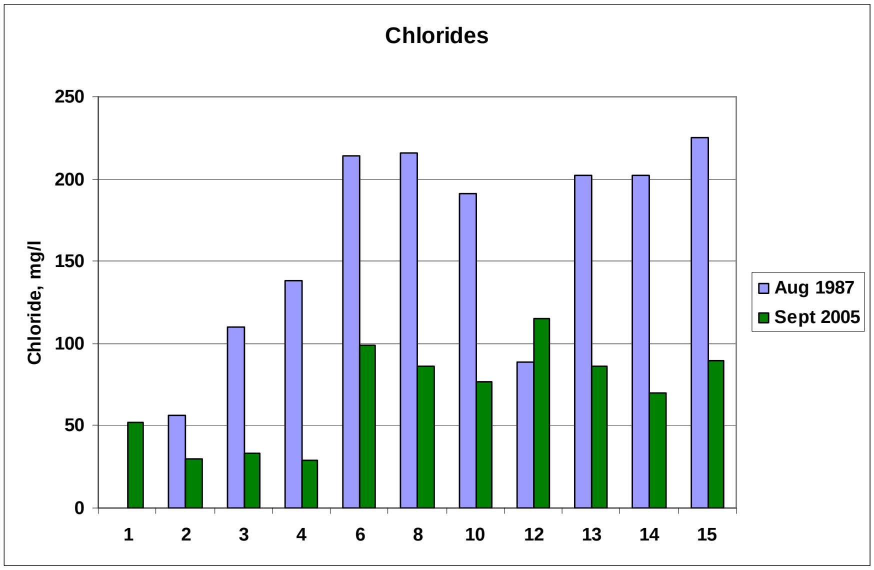


Figure VI.18. Historical comparison of chloride measurements at Trinity River sites.

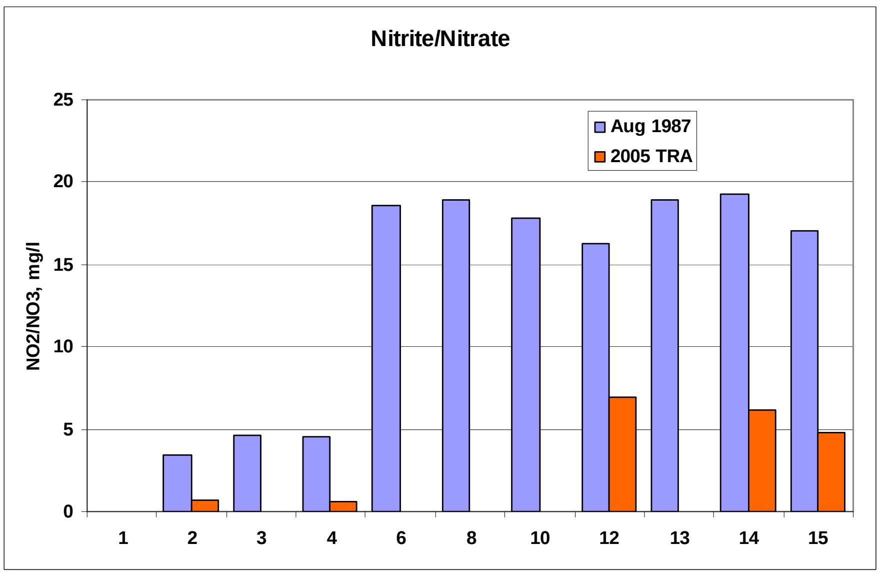


Figure VI.19. Historical comparison of [nitrite+nitrate] measurements at Trinity River sites.

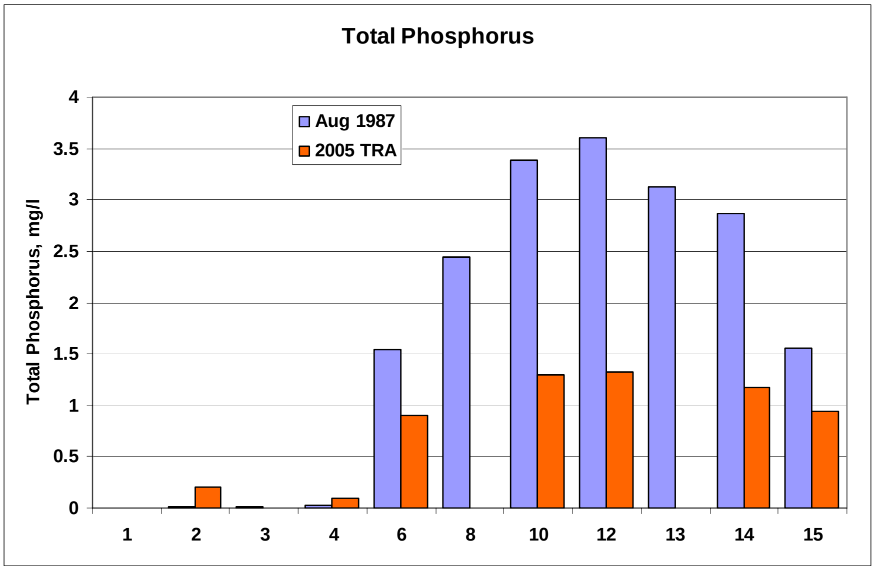


Figure VI.20. Historical comparison of total phosphorous measurements at Trinity River sites.

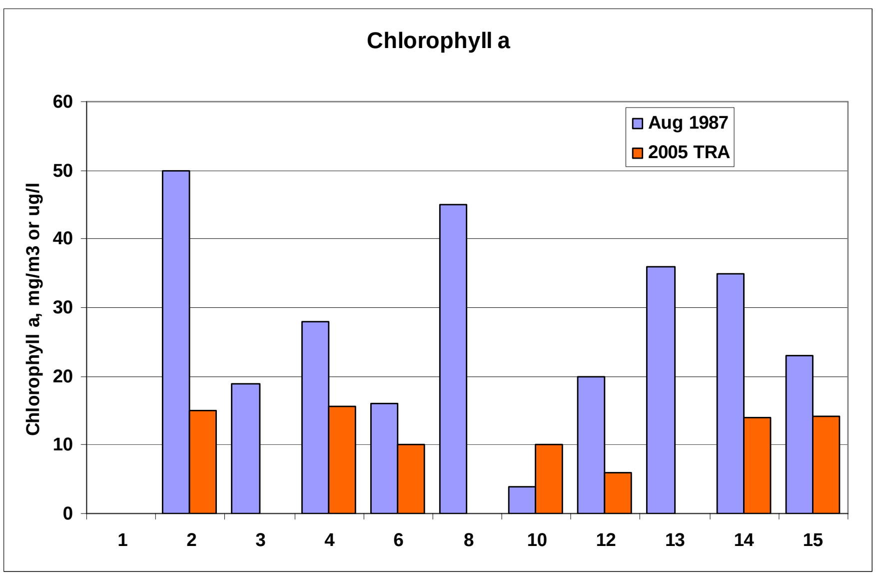


Figure VI.21. Historical comparison of chlorophyll-a measurements at Trinity River sites.

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Appendix

Summaries of Previous Studies

TRA 2005 REPORT

Executive Summary Outline

-2004 statewide water quality assessment listed several violations of stream standards on Trinity, with the most problematic being bacteria (E. coli or fecal coliform), nutrients (P & N species), and DO

-For bacteria, most exceedences associated with stormwater runoff in both rural and urban areas

-A majority of the violations listed are believed to be the result of inappropriate stream standards developed as default criteria applied on a regional basis

-Many of the listings are the result of natural processes; concentration of E.coli effect on human health is poorly understood

-Nutrients currently have no numeric criteria, but screening parameters exceeded

-Nutrients themselves are rarely problematic, but may lead to eutrophication and excess algal growth, thus causing decreased DO, poor taste, and odor

-In Trinity, most segments identified as having [nutrient] don't show significant degradation of response variables (i.e., excessive algae). Furthermore, seems to be net increase in O2 associated with increased algal populations, therefore whole [nutrient] need to be monitored, they aren't believed to pose a direct and immediate threat to water quality in Trinity basin

-Observed violations of DO criteria were found to be associated largely with low order streams that experience seasonal low flows, thought to be result of natural processes; (criteria = 5 mg/l) thought not to be appropriate and may need to be decreased to account for natural conditions

-Trinity basin almost 18,000 sq. miles and travels 715 river miles before reaching Trinity Bay

Technical Summary

-Technical review of each subwatershed based on TCEQ 2004 water quality inventory

-Of the 57 designated segments, 22 were reassessed in 2004 and 35 carried over from the 2002 assessment

-10 major subwatersheds based on major branches and/or impoundments along river

-Data preparation: from TCEQ TRACS database, TRA's Clean River Project (CRP) database, and Dallas' database; duplicates and data collected at depths >1m were removed; chlorophyll a and fecal coliform values modified, too

-Regression preparations: generated from data collected 1-1-94 thru 12-31-03

-Sites for regression analysis selected on data availability and location; sites prioritized as primary or ecoregion sites → total of 91 primary sites and 8 ecoregion sites

-Primary sites: generally in main channel or classified river segments or in the main body or reservoir segments and were representative of the water body

-Ecoregion sites: selected to be as unimpacted and as representative of each ecoregion as possible

-Spatial analysis: Sites were selected to be representative of the main channel of each subwatershed. These sites were also selected for regressions in most cases. Data for 1-1-99 to 12-31-03.

ASSESSMENT RESULTS

West Fork Trinity River:

Terrain—Headwaters area consists of uneven red rock craggy hills, fields of grasses, and patches of post oaks. As river flows southwesterly, the North Central Prairie ecoregion transitions into the Western Cross Timbers. As the river flows south into the City of Ft. Worth, urbanization increases.

Agriculture—predom cattle grazing

Industrial activity—significant amount of oil and gas mining

Negative Assessment Summary (2004 draft 303(d)):

Seg 834-Amon G. Carter: none

Seg 812-West Fork above Bridgeport Rsvr:

1-Aquatic life b/c depressed DO in lower 25 miles; natural cause, low priority

2-General use b/c chloride and TDS in upper 60 and lower 25 miles; natural cause, low priority

Seg 811-Bridgeport Rsvr: none

Seg 810-West Fork below Bridgeport Rsvr:

1-Contact recreation b/c bacteria in lower 25 miles; natural causes, low priority

Seg 809-Eagle Mountain Rsvr: Concerns only

1-Use concern: depressed DO in Old Ranch Cove; natural cause, low priority (insignificant b/c variation in data pts)

2-Algal growth: in various parts of reservoir; pt and non-pt sources, low priority

3-Nutrient enrichment: TP in upper portion or reservoir; pt and non-pt sources, low priority

Seg 808-West Fork below Eagle Mountain Rsvr: none

Seg 807-Lake Worth

1-Fish Consumption: PCBs in fish tissue, entire lake; legacy pollutants, medium priority

Water chemistry

DO: levels ranged from approx 80 to 99% saturated (means 8.18-8.66 mg/l). Overall, levels were consistent among the sampling stations. DO saturation showed a downward trend the further downstream in Eagle Mountain Reservoir.

Conductance: levels ranged from approx. 350-580 umhos/cm, with lowest levels at sampling sites in Bridgeport Reservoir and Eagle Mountain Reservoir, and highest (and the widest range) levels in the middle of the sub-watershed. This phenomenon is likely explained by the fact that it is downstream of the City of Bowie WWTP (1.25

MGD) and the City of Decatur WWTP (1.2 MGD). The upstream site showed a downward trend.

Total Phosphorous: levels ranged from approx. 0.04-.19 mg/l (means 0.04-0.16 mg/l), with the highest concentrations downstream of Bridgeport Reservoir and in the northern site of Eagle Mountain Reservoir, and the lowest concentrations in Bridgeport Reservoir and the southern location of Eagle Mountain Reservoir.

Chlorophyll a: levels ranged from approx. 1-30 ug/l (means 4.62-24.8 ug/l). Chlorophyll a concentrations increased the further downstream traveled on the West Fork, with highest concentrations in Eagle Mountain Reservoir.

Secchi depth (means in m; listed flowing downstream): 1.43, 0.26, 1.02, 0.3

TSS (means in mg/l; listed flowing downstream): 5.75, 1.17, 7.53, 54.3

NO2/NO3 (means in mg/l; listed flowing downstream): 0.08, 0.32, 0.16, 0.16

Dissolved OP (means in mg/l; listed flowing downstream): 0.01, 0.15, 0.01, 0.03

Notes

-Lake Worth for fish consumption and Eagle Mountain Reservoir for concern of eutrophication

-Seg 811-Bridgeport Rsvr showed increased trend in both total Kjeldahl nitrogen (TKN) and ammonia-nitrogen (NH3), concern for potential eutrophication.

-Seg 810 showed decrease trend in total dissolved solids (TDS) and chloride. It also showed an increased trend in chlorophyll a, but seasonal regression showed the trend insignificant. Monitoring should continue because (1) this sampling site is downstream of 2 WWTPs and (2) Eagle Mountain Rsvr, downstream of this sampling site, shows signs of eutrophication.

-Lake Amon G. Carter had no concerns or impairments. Is considered among the least impacted water quality in the basin.

-Seg 809 concerns for eutrophication, possibly more related to nitrogen than phosphorus. All the stations showed similar upward trends in eutrophication (increased TSS and nitrogen, decreased DO at upstream and downstream sites, and decreasing Secchi depth mid-lake and upstream.

-Q1: increased TSS, decreased OP (mid-lake & downstream)

-Q2: increased TKN, decreased DO

-Sedimentation thought to be moving TP downstream in Eagle Mountain Rsvr, though lower site TP and chlorophyll-a exceedences were lower than upper site

-Lake Worth failed 303(d) list support of fish consumption b/c PCB and legacy pollutants. TCEQ preparing TMDL for this segment.

Elm Fork Trinity River:

<u>Terrain</u>—Reaches close to the Red River and Oklahoma and flows southward to confluence with West Fork to form the Trinity River Main Stem. Consists of gently-rolling plains and patches of forests in valleys and lowlands. Three reservoirs: L. Ray Roberts, L. Lewisville (heavy recreation), & L. Grapevine (tremendous growth around shores).

Agriculture—Row-crop ag, cattle grazing, dairy industry (south of Gainesville)

Negative Assessment Summary (2004 draft 303(d)):
Seg 840: Lake Ray Roberts:
1-Use concern: bacteria of unknown cause (no priority)
2-Nutrient enrichment concern: NH3, nitrite nitrate, OP, & TP from non-pt source (no priority)
Seg 826A: Denton Creek:
1-Contact recreation concern: bacteria; natural causes, low priority
2-Concern: nutrient enrichment: NH3 lower 7.9 mi of creek; natural cause, low priority
Seg 826: Grapevine Lake: none
Seg 825: Denton Creek below Lake Grapevine
1-Aquatic life concern: depressed DO in entire segment; unknown cause (deep water releases from Lake Grapevine?), medium priority
2-Contact recreation concern: limited bacteria data; natural cause (no priority)
Seg 824: Elm Fork above Lake Ray Roberts
1-Contact recreation: bacteria; likely from cattle, medium priority
2-Concerns:
A. Nutrient enrichment: OP, TP, nitrite nitrate; pt and non-pt sources, low priority
B. Algal growth in 7.5 mi seg & 2 mi reach downstream of Gainesville WWTP; pt and non-pt sources, low priority
Seg 823A: Little Elm Creek
1-Aquatic Life concern: limited data on silver in water, entire creek; unknown source, medium priority
2-Contact recreation: bacteria; natural causes, low priority
3-Concern: Nutrient enrichment: NH3 entire creek; unknown cause, low priority
Seg 823: Lake Lewisville
1-Concern: nutrient enrichment: NH3 and nitrite nitrate, in Hickory & Little Elm Creek arms; pt and non-pt sources, low priority
Seg 822: Elm Fork below Lake Lewisville
1-Concern: nutrient enrichment: NH3 12 mi around DWU intake, upper 1.5 mi of segment; (NH3) unknown source, low priority
2-Concern: algal growth: 12 mi around DWU intake; pt and non-pt sources, low priority

Water Chemistry

DO: levels ranged from approx. 40-120% (mean 7.85-9.41 mg/l), with lowest % on the Elm Fork north of Gainesville, and the highest % in Lakes Lewisville and Grapevine. DO showed an upward trend in the main branch of Lake Ray Roberts, south of the Lake Ray Roberts dam, the Hickory and Little Elm arms of Lake Lewisville, downstream of Lake Lewisville (at DWU intake), and in Lake Grapevine.

Specific Conductance: levels ranged from approx. 250-1050 umhos/cm. The lowest levels were recorded in Lakes Ray Roberts, Lewisville, and Grapevine, and the greenbelt segment between Lakes Ray Roberts and Lewisville. The highest levels were recorded downstream of the City of Gainesville WWTP (the highest of all sites) and on Denton Creek upstream of Lake Grapevine. Conductance showed an upward trend at the

Isle Du Bois arm of Lake Ray Roberts, the northern segments of the main, the Hickory Creek, and the Little Elm Creek arms of Lake Lewisville; downstream of Lake Lewisville (at DWU intake), and Lake Grapevine.

Total Phosphorus: levels ranged from approx. 0.01-4.18 mg/l (mean 0.05-1.5 mg/l). Most of the sub-watershed exhibited low TP levels, except for the site south of the City of Gainesville WWTP, which had vastly higher mean concentration than the rest of the watershed (15-fold higher mean value). TP trended downward in both branches of Lake Ray Roberts, the greenbelt between Lake Ray Roberts and Lake Lewisville, the Hickory and Little Elm Creeks arms of Lake Lewisville, and Denton Creek upstream of Lake Grapevine; TP trended upward only at the site south of the City of Gainesville WWTP.

Chlorophyll a: levels ranged from approx. 0.5-45 ug/l (mean 2.39-16.4 ug/l). Chlorophyll a concentrations gradually increased to a max mean conc in the main arm of Lake Lewisville, and then declined by the last sampling station downstream of Lake Lewisville (at DWU intake). Chlorophyll a tended to increase in the Isle Du Bois arm of Lake Ray Roberts, the Hickory arm of Lake Lewisville, downstream of Lake Lewisville (at DWU intake), and in Lake Grapevine.

Ammonia (means in mg/l; listed flowing downstream): 0.3, 0.13, 0.2, 0.15, 0.23, & 0.11 (Lake Grapevine 0.8)

TDS (means in mg/l; listed flowing downstream): 496, 183, 188, 228, 260, & 387 (Lake Grapevine 216)

NO2/NO3 (means in mg/l; listed flowing downstream): 5.92, 0.27, 0.35, 0.26, 0.72, & 0.31 (Lake Grapevine 0.31)

Dissolved OP (means in mg/l; listed flowing downstream): 1.32, 0.04, 0.02, 0.02, 0.09, & 0.05 (Lake Grapevine 0.02)

Notes

-Nutrient enrichment is a concern throughout the sub-watershed with additional concern for algal growth in upper and lower river portions.

-Seg 824 on 303(d) list for high bacterial counts above and below Gainesville and WWTP, and high chlorophyll a and nutrients; trends inconclusive; area surrounded by dairy farms (pt source), grazing animals along the banks, likely from dung (non-pt source)

-Seg 840: high bacteria and nutrients likely related to agricultural activity in the sub-watershed. Improved water quality (upward trend analysis) b/c improved secchi depth and TP. DO also appears to be improving, but only b/c first 4 of 9 years of trend improving whereas last 5 of 9 years no trend. Ag runoff most likely source of nutrients

Seg 839: greenbelt b/w Lakes Ray Roberts and Lewisville show improvement in water quality (downward trend in TP and OP)

Seg 823: Lake Lewisville watershed has undergone significant urbanization over the past decade, and high nutrient levels from Hickory Creek and Little Elm Creek arms may be a result of urban and agricultural runoff. Though chlorophyll a levels are high in Hickory and Elm Creeks, DO appears supersaturated, perhaps a result of high algal growth. Elevated nutrients are the likely cause of increased chlorophyll a.

Seg 822: significant DO increase trend in the spring, summer, and fall. This segment of the watershed has undergone significant urbanization in the past decade, and consequently water quality worsening for every nutrient listed. Water quality is significantly impacted by wastewater discharges and releases from the upstream rsvr. Improving NH_3 levels may be due to change in WWTP operation to accommodate the growing population. At Elm Fork at SH121, East of Lewisville, increased trends in TSS ($p=0.045$, $R^2=0.27$) and Conductivity ($p=0.019$, $R^2=0.35$)

Seg 826: (caveat: small data set for this creek) Shows trend of increasing DO levels & decreasing OP levels. TDS and TP show decreasing trends.

East Fork Trinity River:

Terrain—largely characterized by flat prairies with an abundance of row-crop agriculture. Southern portion of watershed (around Lake Ray Hubbard) is heavily urbanized and, consequently, receives a fair amount of water from municipal discharges

Negative Assessment Summary (2004 draft 303(d)):
Seg 821A & B: Pilot Grove and Sister Grove Creek, respectively: none
Seg 821: Lake Lavon:

1-Aquatic life concern: depressed DO in lower portion of rsvr; source unidentified, low priority

2-Concern: nutrient enrichment: nitrite nitrate East Fork arm and lower portion of rsvr; source unidentified, low priority

Seg 820A: Muddy creek

1-Contact recreation: bacteria

2-Aquatic life concern: depressed DO in entire creek

3-Concern: nutrient enrichment: NH_3 and nitrite nitrate entire creek; non-pt source, low priority

Seg 820: Lake Ray Hubbard:

1-Concern: nutrient enrichment: NH_3 and nitrite nitrate in lower portion of I-30 and middle portion of SH66; pt and non-pt sources, low priority

2-Concern: Algal growth: in lower portion at I-30 and middle portion of SH66; low priority

Seg 819: East Fork Trinity River:

1-Concern: nutrient enrichment: OP, NH_3, and nitrite nitrate in entire segment; pt and non-pt sources, low priority

Water Chemistry:

DO: levels range from approx. 65-120% saturated (4-14.9 mg/l). The lowest mean level was in Sister Grove Creek above Lake Lavon (6.93 mg/l), and the highest mean levels were in northern Lake Ray Hubbard (9.06 mg/l) and at the East Fork arm of Lake Ray Hubbard (9.24 mg/l). There was an increased trend in DO at the northern Lake Ray Hubbard site.

Specific Conductance: levels ranged from approx. 200-1700 umhos/cm. The lowest levels were at all three sites in Lake Ray Hubbard, and the highest level was in Sister Grove Creek above Lake Lavon. There was an upward trend in conductance in Lake Lavon and all three sites in Lake Ray Hubbard.

Total Phosphorus: levels ranged from 0.01-1.5 mg/l. The phosphorus remained low (0.0-0.9 mg/l) in the upper portions of the East Fork, but then reached its highest levels by the last sample site, on the East Fork south of Lake Ray Hubbard, at US175 NW of Crandall, south of Lake Ray Hubbard. There was a downward trend in phosphorus in northern Lake Ray Hubbard and the Rowlett Creek arm of Lake Ray Hubbard.

Chlorophyll a: levels ranged from 0.5-55 ug/l. The lowest mean level was detected in Lake Lavon (14.1 ug/l), and the highest mean level was detected in the Rowlett Creek arm (mid-Lake area) of Ray Hubbard at IH-30. There was in increased trend in chlorophyll a at both upper and mid Lake Ray Hubbard.

Secchi depth (means in m; listed flowing downstream): 0.92, 0.81, .071, 0.53, 0.24

Dissolved ammonia (means in mg/l; listed flowing downstream): 0.18, 0.14, 0.09, 0.09, 0.22

Chloride (means in mg/l; listed flowing downstream): 11.9, 36.7, 8.45, 21.8, 22, 21.3, 59.3

TDS (mean in mg/l; listed flowing downstream): 298, 249, 267, 190, 206, 193, 389

NO2/NO3 (mean in mg/l; listed flowing downstream): 0.46, 0.32, 0.36, 0.19, 6.94

Notes:

Seg 821 (Lake Lavon): Evidence of a decrease in OP in Pilot Grove Creek, a trend of improving water quality. The increasing trend in specific conductivity and TDS are a result of the importation of water from Lake Texoma (transferred and discharged into Sister Grove Creek and then flows into Lake Lavon), which began around the same time as the observed increases in dissolved solids.

Seg 820 (Lake Ray Hubbard): Chlorophyll a at all stations frequently exceeded screening levels, generally more than 50% of observations. Also, concentrations of nitrogen-based nutrients also appear elevated. Numerous trends were noticed in the East Fork arm of Lake Ray Hubbard (the main stem of the reservoir), such as increasing trends in specific conductivity, chlorophyll a, and DO, as well as decreasing trends for OP, TP, NO2/NO3, and TSS. Increasing trends in specific conductivity and chlorides may be due to several factors such as long-term hydrologic events (e.g., wet vs. dry years), importation of Lake Texoma water into the watershed, and increased discharges of reclaimed water. Several trends were also noticed in southern Lake Ray Hubbard by the DWU intake near the dam, including increasing trends for specific conductivity, TDS, NH3, and chlorophyll a. Trends detected in Rowlett Creek (western branch of Lake Ray Hubbard) include increasing trends for specific conductivity, TDS, NO2/NO3, NH3, and DO, as well as decreasing trends for TP and OP. In summary, nutrient enrichment (NH3 and NO2/NO3) and algal growth have been concerns in the lower and middle portions of Lake Ray Hubbard. The concerns listed are based upon screening criteria, and no direct observations of use impairment have been identified. There were fewer trends in relevant parameters in the lower portions of the reservoir. More trends relevant to nutrients and eutrophication were found further up in the reservoir.

Seg 819 (East Fork Trinity River): No parameters were included in the 2004 draft 303(d) list for this segment, but the concern list of the assessment includes nutrient enrichment. For example, at the sample station (10991) downstream of Lake Ray Hubbard and several water reclamation plants, TP exceeded the screening level more than 50% of the observations. An increasing trend in chloride was detected, but there are large variations around the regression analysis.

In summary, there is a consistent indication of increases in parameters related to salinity: specific conductivity, TDS, and chloride. At some locations, data suggests decreases in TP and OP (Pilot Grove and Rowlett Creeks, and Lake Ray Hubbard). NH3 and NO2/NO3 displayed a mix of increasing and decreasing trends. Chlorophyll a displayed increases at two sites in Lake Ray Hubbard. Many of these trends observed in long data series were not consistent over the ten years of observations, either leveling off or reversing at some time.

The increases in salinity-related parameters could be of concern, because high salinity can preclude some water uses. Another potential concern is that elevated salinity has been associated with blooms of golden algae. Increases in Sister Grove Creek and Lake Lavon are probably due to the importation of Lake Texoma water, and are believed to have leveled-off in recent years. More data is needed to adequately assess this. The imported water may also be affecting downstream segments (Lake Ray Hubbard and the Lower East Fork). Other possible causes may be increases in discharges from WWTPs and meteorological events.

Clear Fork Trinity River:

Terrain—Mostly flat terrain to rolling prairie, much like the West Fork to the north. The area is sparsely populated in general, but downstream portions near Ft. Worth are heavily urbanized. Contains 2 reservoirs, Weatherford and Benbrook, serving their respective cities. Because of the sparse population, there are few point sources of pollution. Primary economic activity is cattle grazing and little row-crop agriculture. Approx 65 river miles from headstream in Parker Co. to West Fork confluence.

Negative Assessment Summary (2004 draft 303(d)):

Seg 833: Clear Fork above Lake Weatherford:

1-Aquatic life: Partially supporting; depressed DO in various portions

2-Concern: contact recreation, limited data of bacteria

Seg 832: Lake Weatherford: none

Seg 831: Clear Fork below Lake Weatherford

1-Aquatic life: partially supporting/not supporting: depressed DO in various portions

2-Contact recreation: bacteria

3-Concerns: nutrient enrichment-OP in lower 12.75 mi downstream of South Fork confluence

Seg 830: Benbrook Lake

1-Concerns:

Nutrient enrichment: NH3 in lower portion of rsvr

Algal growth: in various portions of rsvr

Seg 829A: Lake Como

1-Fish consumption: PCBs, chlordane, DDE, and dieldrin in fish tissue, entire reservoir

Seg 829: Clear Fork below Benbrook Lake

1-Fish consumption: PCBs and chlordane in fish tissue, lower mile of segment

Water Chemistry:

Dissolved oxygen: levels ranged from approx. 50-130% saturated (3.44-12.2 mg/l). Lowest mean level was the Clear Fork below Lake Weatherford at IH20, east of Weatherford (6.05 mg/l), and highest mean level was mid Lake Weatherford (10.4 mg/l). There was a downward trend in DO at the site on the Clear Fork below Lake Weatherford at IH20. (means in mg/l; listed flowing downstream): 10.4, 6.05, 8.51, 8.8, 9.73.

Specific conductivity: levels ranged from approx. 300-730 umhos/cm. Lowest mean level was at lower Benbrook Lake, east end of the dam, near intake (approx. 310 umhos/cm), and highest mean level was at the site on the Clear Fork below Lake Weatherford at IH20 (approx. 690 umhos/cm).

Total phosphorus: levels ranged from approx. 0.025-0.15 mg/l. Lowest mean levels were at mid-Lake Weatherford and lower Clear Fork in Ft. Worth (0.04 mg/l), and highest mean level was the Clear Fork below Lake Weatherford at IH20 (0.1 mg/l). There was an increasing trend in total phosphorus at the site on the Clear Fork below Lake Weatherford at IH20, and a decreasing trend in total phosphorus in the lower Clear Fork in Ft. Worth. (means in mg/l; listed flowing downstream): 0.04, 0.1, 0.06, 0.08, 0.04.

Chlorophyll a: levels ranged from approx. 1-39 ug/l. Lowest mean level was in the Clear Fork downstream of Lake Weatherford at IH20 (3.67 ug/l), and highest mean level was in upper Benbrook Lake (24 ug/l). (means in ug/l; listed flowing downstream): 9.94, 3.67, 20.3, 24, 3.95.

Secchi depth (means in m; listed flowing downstream): 0.74, 0.38, 0.87, 0.58, 0.29.

TSS (means in mg/l; listed flowing downstream): 11.4, 24.9, 8.18, 18.4, 18.4.

Ammonia (means in mg/l; listed flowing downstream): 0.05, 0.08, 0.11, 0.1, 0.06.

NO2/NO3 (means in mg/l; listed flowing downstream): 0.05, 0.45, 0.15, 0.17, 0.35.

Notes:

Seg 833: This segment is included on the 2004 draft 303(d) list for depressed DO. However, previous analysis concluded that the low DO concs are the result of natural, seasonal low flows.

Seg 830: Exceedence of chlorophyll a screening levels in Benbrook Lake is common. Benbrook Lake receives water diversions from Richland-Chambers rsvr and Cedar Creek rsvr, where chlorophyll a exceedances are frequent. Several trends were found relating to nutrients and eutrophication. TKN and OP increased at the upper rsvr site, while TKN and NH3 increased at the lower rsvr site. In general, these trends suggest a potential deterioration in water quality concerning nutrients. This is strengthened by the increase in TSS, which can be indicative of high algal concentrations.

Seg 829: PCBs and chlordane in fish tissue were included on the previous 303(d) list, but are no longer included because the EPA has approved a TMDL to address this issue.

Main Stem Trinity River:

Terrain—Begins where the West Fork leaves Lake Worth. Heavily urbanized through DFW. Row crop agriculture south of DFW. Undeveloped piney woods in south near Lake Livingston. White Rock Lake, Lake Como, Lake Echo, and Lake Fosdic located in upper part of subwatershed, and Houston County Lake and Lake Livingston in lower part of subwatershed. Approx. 421.1 miles from Lake Worth dam to Lake Livingston dam.

Negative Assessment Summary (2004 draft 303(d)):
Seg 841A: Mountain Creek Lake:
Fish consumption: DDD, DDE, DDT, PCBs, chlordane, dieldrin, and heptachlor epoxide in fish tissue; entire rsvr
Seg 841: Lower West Fork Trinity River:
1-Fish consumption: PCBs and chlordane, in lower 14 mi and upper 13 mi segments
2-Contact recreation: bacteria, in lower 14 mi segment
3-Concerns:
Nutrient enrichment: nitrite nitrate, TP, and OP, in lower 14 mi segment
Seg 835: Richland Creek below Richland-Chamber rsvr: none/not fully assessed
Seg 827: White Rock Lake: not assessed
Seg 813: Houston County Lake: none/not fully assessed
Seg 806B: Echo Lake:
1-Fish consumption: PCBs in fish tissue, entire reservoir
Seg 806A: Fosdic Lake:
1-Fish consumption: DDE, PCBs, chlordane, and dieldrin in fish tissue, entire reservoir
Seg 806: West Fork below Lake Worth:
1-Contact recreation: bacteria in lower 22 mi of segment
2-Fish consumption: PCBs and chlordane in fish tissue in lower 22 mi of segment
3-Concern:
algal growth in lower 22 mi of segment
Seg 805: Upper Trinity River:
1-Contact recreation: bacteria in various portions of segment
2-Fish consumption: PCBs and chlordane in fish tissue in various portions of segment
3-Concern:
nutrient enrichment in various portions of segment
Seg 804: Trinity River above Lake Livingston:
1-Concerns:
nutrient enrichment in various portions of the river

algal growth in upper segment

<u>Water Chemistry</u>:
Dissolved oxygen: Levels ranged from approx. 70-160% saturated (2.4-15.4 mg/l). Lowest mean level was at Catfish Creek between Fairfield and Palestine, between sites SDA05-14 and SDA05-15 (6.7 mg/l), and highest mean level was on the West Fork in Ft. Worth, close to site SDA05-04 (8.81 mg/l). There was an increasing trends in DO concentration in main stem downstream of confluence with White Rock Creek, close to site SDA05-10, and main stem downstream of confluence with East Fork, close to site SDA05-14. (mean in mg/l; listed flowing downstream): 8.81, 8.68, 6.7, 8.31, 9.29, 9.87.

Specific conductance: levels ranged from approx. 275-850 umhos/cm. Lowest mean level was on the West Fork in Ft. Worth, close to site SDA05-04 (approx. 400 umhos/cm), and highest mean level was on the West Fork upstream of TRA Central, close to site SDA05-06 (approx. 750 umhos/cm). There was an upward trend in specific conductance at Palestine near site SDA05-15. Conductance increased once it reached the middle of the DFW metroplex and slightly decreased with travel downstream to site SDA05-15.

Total phosphorus: levels ranged from 0.02-2.32 mg/l. Lowest mean level was at Catfish Creek between Fairfield and Palestine, between site SDA05-14 and site SDA05-15 (0.08 mg/l), and highest mean level was on the main stem NE of Ennis, near site SDA05-14 (1.18 mg/l). There was an increasing trend in total phosphorus at main stem downstream of confluence with White Rock Creek, close to site SDA05-10. Total phosphorus peaked after confluence of main stem and White Rock Creek, near site SDA05-10, then slowly decreased downstream to site SDA05-15, though the variation in TP conc remained dramatic. (mean in mg/l; listed flowing downstream): 0.09, 0.11, 1.18, 0.08, 0.94.
Chlorophyll a: levels ranged from 0.5-58.3 ug/l. Lowest mean level was on Delaware Creek in Irving, downstream of site SDA05-06 (8.43 ug/l), and highest mean level was on the West Fork in Ft. Worth, close to site SDA05-04 (15.7 ug/l). There was an increasing trend in chlorophyll a on the West Fork upstream of TRA Central, close to site 6, and at Palestine near site SDA05-15. (mean in ug/l; listed flowing downstream): 15.7, 8.43, 14, 0.5, 14.2.
Secchi depth (mean in meters; listed flowing downstream): 0.33, 0.16, 0.58, 0.13.
TSS (mean in mg/l; listed flowing downstream): 182, 7.9, 149, 11.8, 217.
Ammonia (mean in mg/l; listed flowing downstream): 0.12, 0.17, 0.12, 0.26, 0.08.
NO2/NO3 (mean in mg/l; listed flowing downstream): 0.59, 0.18, 6.15, 0.06, 4.76.

<u>Notes</u>:

Seg 841: This segment lies within the DFW metroplex and receives significant WWTP discharges and urban runoff. This is reflected in the data with high PCB and chlordane conc in fish tissue, TP exceeding the screening criteria frequently.

Seg 805: Concern for PCBs and chlordane in fish tissue, and for nutrient concs above screening criteria. Overall, the spatial pattern throughout this segment shows the impact of the DFW metroplex and its non-point and WWTP discharges. Two upstream stations, site SDA05-14 and site SDA05-10, have high TP concentration sand other indications of eutrophication. High and often increasing levels of DO through this segment indicate that eutrophication has not caused oxygen depletion. Sufficient river flow to maintain aeration, combined with advanced wastewater treatment may explain this observation. High TP levels probably originate from WWTP discharges and from urban and agricultural runoff, and declining TP concs downstream suggest that recovery takes place. This segment is downstream of significant discharges, including WWTPs in the DFW metroplex, and it is impacted by ag and urban nonpoint sources.

Seg 804: Is on the concern list because nutrient concentrations and chlorophyll-a concs exceed the screening criteria throughout the segment. Eutrophication could be due to localized factors

Village Creek:

Terrain—Extends from Johnson Co. to Tarrant Co. The smallest of the 10 Trinity River watersheds. Flows northward through iron-rich sandy soils of the Eastern Cross Timbers. Mix of urban and rural with some pastureland. Significant portions downstream have been highly developed and converted into suburban neighborhoods. Upstream portions remain rural with limited row-crop ag. At the end of the subwatershed, contains Lake Arlington, water rsvr for Arlington and much of Tarrant Co. Runs approx 28 river miles.

<u>Negative Assessment Summary (2004 draft 303(d))</u>:
Seg 828A: Village Creek: none
Seg 828: Lake Arlington:
Use concern: temperature in various portions of the rsvr

<u>Water Chemistry</u>:
Dissolved Oxygen: Levels ranged from 60-120% saturated (4-13.4 mg/l). (mean in mg/l; listed flowing downstream): 8.35, 8.93, 9.24
Specific Conductance: (mean in mg/l; listed flowing downstream): Levels ranged from approx. 250-850 umhos/cm. Conductance was high at upstream site, but dramatically decreased in Lake Arlington (probably due to iron-rich soil).
Total Phosphorus: (mean in mg/l; listed flowing downstream): --, 0.05, 0.04
Chlorophyll a: (mean in ug/l; listed flowing downstream): --, 9.96, 28.9
Temperature: (mean in degrees C; listed flowing downstream): 19.8, 20.9, 21.8
Ammonia: (mean in mg/l; listed flowing downstream): --, 0.05, 0.05
Chloride: (mean in mg/l; listed flowing downstream): 48.9, 18.6, 14
NO2/NO3: (mean in mg/l; listed flowing downstream): --, 0.27, 0.15

<u>Notes</u>:
Caution needs to be taken when analyzing the data from this subwatershed because of limited data.

Last TRA sampling site before confluence with main stem: 13904 = Lake Arlington
USGS site AC

Mountain Creek:

Terrain—Located between Dallas and Ft. Worth in the Blackland Prairie ecoregion. Bordered to the east by Austin-chalk escarpment. Flows to the northeast. Largely rural, with abundance of row-crop ag in southern portions. Land use becomes more urban as you go north; development increasing as Mid-Cities grow to the south. Flows from Johnson Co. to Dallas Co. Joe Pool Lake is located in the middle of the subwatershed, and Mountain Creek Lake is at the ed of the subwatershed. Subwatershed runs for approx. 28 river miles.

Negative Assessment Summary (2004 draft 303(d)):
Seg 838: Joe Pool Lake: none

Water Chemistry:
Dissolved Oxygen: Levels ranged from approx. 60-140% saturated (1.01-15.7 mg/l). (mean in mg/l; listed flowing downstream): 9.29, 9.73, 9.75, 9.6, 9.87
TSS (mean in mg/l; listed flowing downstream): 9, --, --, --, --
Specific Conductance: (mean in umhos/cm; listed flowing downstream): 469, 439, 440, 865, 924
Total Phosphorus: (mean in mg/l; listed flowing downstream): 0.11, 0.03, 0.03, 0.27, 0.14
Total Dissolved Solids: (mean in mg/l; listed flowing downstream): 299, 285, 316, 775, 957
Chloride: (mean in mg/l; listed flowing downstream): 58.5, --, --, --
Chlorophyll a: (mean in ug/l; listed flowing downstream): 8.63, --, --, --

Notes:
For 2 upstream sites, TDS exceeded screening levels by 75% of the observations. No known anthropogenic sources so TRA believes this to be a natural condition. Odd monitoring pattern.

Last TRA sampling site before confluence with the main stem: 16434 = Mountain Creek at US287

Richland-Chambers:

<u>Terrain</u>—Chambers Creek starts in Johnson Co., Richland Creek starts in Hill Co., and subwatershed ends in Freestone Co. Primarily rural with row crop ag. Lake Waxahachie and Bardwell Rsvr are located on Waxahachie Creek, a tributary of Chambers Creek; Navarro Mills Lake is on Richland Creek; Richland-Chambers Rsvr, contains 1,136,600 acre ft, the second largest in the basin. From Chambers Creek to R-C dam approx. 100 river miles, and from Richland Creek to R-C dam approx. 79 river miles. Terrain similar to Clear Fork, with flat to gently rolling prairie. During long, dry summers, most creeks in this area become dry or maintain a minimal amount of base flow.

<u>Negative Assessment Summary (2004 draft 303(d))</u>:
Seg 814: Chambers Creek above R-C rsvr:
Aquatic live: partial supporting: depressed DO, confluence with Cummins Creek 16.5 miles upstream
Seg 815: Bardwell Rsvr:
Concern: nutrient enrichment, NO2/NO3, entire rsvr
Seg 816: Lake Waxahachie: none
Seg 817: Navarro Mills Lake
Public water supply threatened: atrazine in entire rsvr
Seg 836: R-C rsvr:
Partially supporting: high pH in lower portions of Chambers Creek arm
Concern: nutrient enrichment: NO2/NO3, confluence of Richland and Chambers Creek arms and lower portion close to dam
Concern: algal growth: lower portion of Richland Creek arm
Seg 837: Richland Creek above R-C rsvr: none

<u>Water Chemistry</u>:
Dissolved oxygen: Levels were relatively constant in CC (approx 100% saturated [ ]), and levels ranged from approx 50-110% saturated ( ) in RC and R-C rsvr. (mean in mg/l; listed flowing downstream, bold means in R-C rsvr):
Chambers Creek (CC): 8.65, 8.73, 8.04, **8.46, 8.29**
Richland Creek (RC): 8.22, **8.85**
Specific Conductance: Levels were relatively constant in CC (approx 300 umhos/cm), and levels in RC ranged from approx. 200-1000 umhos/cm. In RC, the lowest levels were comparable in Navarro Mills rsvr and Richland arm of R-C rsvr (approx 250 umhos/cm), and the highest levels were in RC between the reservoirs (approx 950 umhos/cm). R-C rsvr was at approx 250 umhos/cm. There was an increased trend in RC between the reservoirs, and a decreased trend in Chambers and Richland arms of R-C rsvr. (mean approximated in umhos/cm; listed flowing downstream):
CC: 300, 400, **300, 250**
RC: 300, 900, **250**
Total Phosphorus: Levels ranged from approx. 0.02-0.28 mg/l in CC, from approx. 0.03-0.12 mg/l in RC, and 0.03 mg/l in R-C rsvr. In CC, lowest levels were seen in Lake Waxahachie and Bardwell rsvr, and highest level in Chambers arm of R-C rsvr. Levels

were all low in RC and Richland arm of R-C rsvr. R-C rsvr level was lowest of them all. (mean in mg/l; listed flowing downstream):
CC: 0.05, 0.04, --, **0.18, 0.04**
RC: 0.06, **0.09**
Chlorophyll a: (mean in ug/l; listed flowing downstream):
CC: 7.8, 8.46, --, **42.1, 12.7**
RC: 8.48, **16.3**
Secchi Depth: (mean in m; listed flowing downstream):
CC: 0.68, 0.6, --, **0.19, 1.14**
RC: 0.42, **0.44**
Ammonia: (mean in mg/l; listed flowing downstream):
CC: 0.1, 0.11, --, **0.06, 0.05**
RC: 0.05, **0.05**
NO2/NO3: (mean in mg/l; listed flowing downstream):
CC: 0.4, 0.63, --, **0.18, 0.25**
RC: 0.79, **0.07**
Dissolved orthophosphorus: (mean in mg/l; listed flowing downstream):
CC: 0.08, --, 0.02, **0.01, 0.01**
RC: --, **0.04**

Notes:
Seg 814: R-C rsvr is on the 2004 draft 303(d) list because of depressed DO concs. Most of the measurements below the screening level were collected before noon. Depressed DO may be associated with eutrophication. However, the limited chlorophyll a data do not suggest algal growth to be a concern at this site.

Last TRA sampling site before confluence with Trinity River: 15168 = Richland-Chambers Reservoir, north end of dam

Cedar Creek:

Terrain—Starts in the Blackland Prairies ecoregion (rich, dark soils) and crosses into low, rolling hills of the Post-Oak savannah ecoregion before confluence with main stem. Rsvr constructed for water supply for Fort Worth and Tarrant Co. Completed in 1969 and holds 678,000 acre feet (34,000 surface acres). Subwatershed ranges from Kaufman Co. to Henderson Co. Primarily rural with row crop ag and grazing. From headwaters in Kaufman Co. to Cedar Creek rsvr dam, approx 55 river miles.

Negative Assessment Summary (2004 draft 303(d)):
Seg 818: Cedar Creek Reservoir
Aquatic life: concern: depressed DO in Cedar Creek cove and downstream of Kings Creek
General use: partially supporting/not supporting: high pH in various portions of the rsvr
Use concern: limited data, high pH Prairie Creek cove

Concerns: Nutrient enrichment: OP, TP, and NH3 various portions of rsvr; Algal growth various portions of rsvr

Water Chemistry (means at last sampling point in subwatershed):
Dissolved Oxygen: 8.93 mg/l
Specific Conductance: approx 170 umhos/cm
Total Phosphorus: 0.08 mg/l
Chlorophyll a: 22.9 ug/l
Secchi depth: 1.04 m
Ammonia: 0.08 mg/l
NO2/NO3: 0.18 mg/l
Dissolved orthophosphorus: 0.02 mg/l

Notes:
Seg 818: Cedar Creek rsvr is on the 2004 draft 303(d) list for pH exceeds stream standard throughout the segment. TCEQ lists it as 5c, meaning more data needed prior to scheduling a TMDL. The avg pH in the rsvr is approx 8, and there may be an increasing trend over time. The elevated values are most likely related to algal growth. However, Cedar Creek subwatershed is the only segment in the Trinity Basin that has a max pH stream standard of 8.5; all other subwatersheds have 9.0.

Last TRA sampling site before confluence with Trinity River: 16748 = Cedar Creek Reservoir, south end, south of Bluebird Lane

1992 United States Geological Survey (USGS) Study of the Trinity River

In 1991, the U.S. Congress funded the USGS to begin the National Water-Quality Assessment (NAWQA) Program. The goal of NAWQA was to evaluate the water quality of more than 50 of the nation's river basins and aquifers using existing information from USGS and other water agencies. The river basins and aquifers studied under NAWQA cover approximately half of the U.S. and include drinking water sources for over 70% of the U.S. population. The Trinity River basin was studied between 1992 and 1995.

The NAWQA rivers and aquifers are to be evaluated every decade to evaluate changes in water-quality conditions, so a new NAWQA report on Trinity River basin water quality should be available in the near future.

Nutrients

Nutrients (i.e., nitrogen and phosphorus) were shown to be, in general, much lower than their maximum contaminant levels established by the EPA (10 mg/l and 0.1 mg/l, respectively). The only times nitrogen (in the form of nitrate) exceeded the MCL were in an urbanized stream in Ft. Worth and the Trinity River downstream of Dallas. Total nitrogen concentrations were similar in urban and agricultural streams and were larger in urban and agricultural streams than in streams in rangeland and forest areas. Total phosphorus concentrations were similar in all tributaries, regardless of land use. Nutrient concentrations in streams vary seasonally and are as much as 100% greater during the spring than during the winter.

Pesticides (herbicides, insecticides, and fungicides)

In the Trinity Basin, herbicides were more prevalent than insecticides. Four to six herbicides were detected in streams draining urban and agricultural areas. The most commonly detected herbicide was atrazine. It was mostly detected in agricultural stream samples, with approximately 12% of agricultural streams exceeding the EPA 1996 MCL for atrazine (3 μg/l). This mostly happened during the spring when atrazine was applied to the fields and rains producing runoff was most common. However, atrazine was also detected in stream samples from other land uses, such as forest, rangeland, urban, and the Trinity River downstream of Dallas, though none of the stream samples exceeded the EPA 1996 MCL. Two to four insecticides were commonly detected in streams draining urban areas, and usually no more than one insecticide was detected in streams draining agricultural areas. The most commonly detected insecticide was diazinon. Diazinon was detected in about one-half of the rangeland and forest samples and agricultural samples, in all the urban samples, and in about 90% of the Trinity River downstream of Dallas samples. About 15% of the urban samples exceeded the EPA 1996 lifetime health advisory concentration for diazinon (0.6 μg/l). Diazinon detection did not show any seasonal patterns. Other pesticides were detected in the Trinity River. Twenty-three different herbicides were detected in the rangeland and forest streams, 19 in agricultural streams, and 24 in urban streams. Five different insecticides were detected in rangeland and forest streams, 10 in agricultural streams, and 10 in urban streams.

A concern raised with this study was that streams with pesticides flow into reservoirs, which are drinking water supplies for north central Texas. For example, 1995 samples at Richland-Chambers Reservoir, the water supply for the TRWD and TRA, contained 6-8 pesticides, and Summer 1995 samples, after the spring runoff, had atrazine concentrations at the MCL.

Water Quality Trends

Lead, DDT, and PCB concentrations have decreased, but chlordane, PAH, and zinc concentrations have increased in sediments from urban streams (White Rock Lake, Dallas) since the mid-1960s. Decreases are due to regulatory changes (bans) on leaded gasoline and pesticides, and increases are due to automobile use in the watershed.

Organochlorines

Concentrations of some toxic compounds in sediments commonly exceed Texas Natural Resource Conservation Commission (now called TCEQ) screening concentrations. Concentrations of chlordane, dieldrin, and DDT degradation products DDD and DDE, in bed sediment are larger in streams draining urban areas than in streams draining agricultural areas and exceed TNRCC screening concentrations for these compounds in sediment. Chlordane, DDT, and PCBs are more commonly detected in fish in streams draining urban areas than agricultural areas, though DDD and DDE breakdown products were more commonly detected in tissues at agricultural sites. Aldrin, endrin, and heptachlor and breakdown product heptachlor epoxide exceeded their respective TCEQ screening levels only at agricultural sites in the Trinity River basin. Overall, more organochlorine compounds were detected in sediment than in biological tissues; however, certain organochlorines like chlordane and PCBs were detected more frequently in aquatic biota than sediment.

Stream Habitat Characteristics and Fish Community Degradation

Fish communities are affected by characteristics of stream flow and the structure of physical habitats in the stream channel, in addition to water chemistry. In streams where historical patterns of stream flow have been altered by channelization, degradation in the fish community has occurred. Streams in developed urban and agricultural settings generally have more variable stream flow, more degraded and less diverse physical habitats, and more degraded fish communities than comparable streams in less-developed settings. The urban stream West Fork Trinity River in Ft. Worth has highly variable stream flow, is channelized with little or no meandering, has few woody snags in the stream, and has low woody-species diversity in the riparian zone. As a result, more nonnative and generally more pollutant-tolerant species of fish are in this stream than in comparable natural streams. In the West Fork reach, the % of fish with external anomalies is the greatest among the three examined reaches. The relatively large incident of external anomalies could be related to the quality of water and sediment originating in the urban area.

Fish community changes reflect water-quality improvements

During 1970-1985, 13 fish kills were documented in the Trinity River from a reach just downstream of Dallas to Lake Livingston. The magnitude and frequency of the fish kills resulted in a depleted fish community, particularly in the reach of the Trinity River immediately downstream from Dallas. An estimated 1.04 million fish died in these 13 kills, a result of minor flooding that resulted in resuspension of bottom sediment, an increase in BOD, and a subsequent drop in DO. Improvements in the treatment of wastewater in the DFW area from the early 1970s through the mid-1990s have been beneficial to the water quality of the Trinity River. Ammonia plus organic nitrogen concs in the Trinity River downstream from Dallas have decreased ~95%. DO has improved vastly in the same area. The fish community has improved markedly since the mid-1980s when several fish kills occurred. Now many native species of fish absent in the 1970s have returned to the Trinity River downstream from Dallas, suggesting a return of this reach to a more natural condition.

Comparison of Trinity River basin study unit surface-water results with nationwide NAWQA findings

(Total of 10 sites. Scores for each site in the Trinity River Basin were compared with scores for all sites sampled in the 20 NAWQA Study Units during 1992-1995).

Nutrients: The median nutrient concentration at the Trinity River site downstream from large wastewater discharges is the highest category of all NAWQA stream sites, and one sample from the site exceeded the EPA MCL. Otherwise, all the sites (8) except one in a rural area are less than the national median.

Pesticides: Median pesticide concentrations are greater than the national NAWQA median at all 3 sites for which there were adequate data to make a comparison. Sites with urban watersheds are in the highest category. Exceedence of drinking water standards is due to diazinon in urban streams and atrazine in agricultural streams.

Organochlorines: OC pesticides and PCBs in sediments and biota at 2 sites in DFW are in the highest category. Sites in watershed with little development are in the lowest category.

Trace Elements: Concs in sediment in West Fork site are in the highest category. The next highest conc is in the Trinity River downstream of Dallas. All other sites are below the national median.

Semivolatile Organic Compounds (in stream bed sediments): SOCs, mainly PAHs, in DFW are in the highest category.

Fish Communities: A fish community index is greater than the national median at 4 of 10 sites. The 2 most degrades are on the Trinity River, one downstream of Dallas and the other is south of Lake Livingston.

Stream Habitat: Only 1 site had greater stream habitat degradation than the national median (south of Lake Livingston).

Conclusions: Nutrient concentrations in most streams in the Trinity River Basin were below national median concentrations for NAWQA Study Units. Two exceptions are the Trinity river downstream from Dallas and a rural site. Pesticide concentrations at two urban sites were in the highest category, and concentrations at an agricultural site were in the second highest category, all above the national NAWQA median. In general, concentrations of trace elements, PCBs, organochlorine pesticides, and PAHs in streambed sediments and aquatic biota exceeded national medians (highest 2 categories) or 75^{th} percentiles (highest category) at urban sites and were below national medians at more rural sites. One urban site, one agricultural site, and two sites on the Trinity River downstream from Dallas had fish community indices greater than the national median. One of those sites also had habitat degradation greater than the national median.

1989 UNT Study of Water Quality and Ecological Survey of the Trinity River

Background
-Jointly conducted by IAS at UNT and by Environmental Science Graduate Program at UT-Dallas.
-The purpose of the study was to develop a contemporary understanding of the chemical, physical, and, perhaps more importantly, the biological water quality in strategic reaches above, in, and below the Dallas-Ft. Worth metroplex.
-12 stations were established and sampled every 3 months for the duration of the project.
-Toxicity of Trinity River water and sediment was determined by conducting acute and chronic toxicity tests using fish and invertebrates. Field studies were also conducted to assess the status of the fish and benthic macroinvertebrate communities in the Trinity River.
-Water quality issues from the 1860s to the 1960s resulted in the removal/elimination of municipal and industrial dischargers in the Trinity River. In the 1970s, large regional WWTPs replaced smaller and less-efficient municipal and industrial WWTPs. While this resulted in improved water quality, DFW population boomed and WWTPs could not keep up with the increased waste load. Consequently, the Trinity River experienced periods of reduced water quality.
-From the late 1970s to the late 1980s, considerable effort was put forth by the major WWTPs within the DFW metroplex to increase capacity as well as upgrade operational efficiencies. This was complimented by constant monitoring. The results were improved water quality along the Trinity River.
-The Clean Water Act of 1987 states that toxic chemicals cannot be discharged in toxic amounts into the waters of the U.S.
-Nonpoint source input of pollutants have increased due to the rapid growth of the metroplex, yet little is known about the nonpoint sources contribution to water quality standard violations.
-A U.S. Department of the Interior Fish and Wildlife Service (F&WS) conducted a water quality survey in the Trinity River in 1988. Results showed that the high tissue levels of contaminants (metals, pesticides, and chlorinated organics) in fish and/or turtles warranted concern for fish and wildlife predators (UNT 1989, p.5). That same report also implicated chlorine in WWTP effluent as a major stressor on aquatic life, recommending that effluent chlorination be limited. As a response to chlorinated effluent issues around the country, EPA and TWC mandated that WWTP effluent be dechlorinated before discharge into the Trinity River by 1990.

-Population: 2,930,568 for DFW in 1980. Estimate for 1986 was 3,655,300. Eight cities had populations over 70,000 (Dallas, Ft. Worth, Arlington, Garland, Irving, Richardson, Plano, and Grand Prairie). The year 2010 population for DFW was estimated to be 5 million (NCTCOG, 1988—UNT 1989 p.8).

Trinity River Flow Discharge

-Mean annual river flow during the 2 year study differed: 1987 had much higher flows than 1988. Annual mean daily flows were slightly higher than normal and were significantly below normal in 1988 (lowest annual mean daily flow recorded for the past 10 years at all the gauge stations).

Sampling stations	**River Mile**	**USGS gauging stations**
TR1	533.9	08048000
TR2	509.1	08048543
TR3	488.6	08049500
TR4	481.0	08057000
Elm Fork	8.5	08055500
TR5	471.0	08057000
TR6	466.1	08057410
TR7	436.0	08062500
East Fork	3.9	08062000
TR8	408.5	08062500
TR9	371.2	08062700
TR10	294.9	08065000

River miles based on those used by the Trinity River Authority (TRA)

-At the time of the first collection in Aug 1987, flow was low (as is normal during late summer) near the 7Q2 low flows for the Trinity River at stations TR2, TR6, and TR9. At the June 1988 collection, flow was much higher, especially in upstream sampling stations, but this was not noticed at far downstream stations. By September 1988, flow at all sampling stations was back at 7Q2 low flow conditions. In summary, river flows at all sampling stations were generally low compared to historical discharge data during each quarterly survey.

Materials and Methods

Water Chemistry

-Water chemistry: Samples were collected quarterly at the 12 stations. Samples were collected in triplicate and analyzed for dissolved oxygen, temperature, conductivity, pH, total and free chlorine, alkalinity, hardness, turbidity, chloride, ammonia, nitrite, nitrate, organic nitrogen, sulfate, total phosphorus, chemical oxygen demand (COD), organic carbon, biochemical oxygen demand (BOD), orthophosphate, chlorophyll a, dissolved solids, suspended solids. Single samples were collected and analyzed for pesticides, metals, acid and base-neutral organics, extractable organics, and purgeable volatile organics. Accuracy of analytical measurements was derived from field replicates and performance spikes. Precision of analyses was determined by triplicate analysis of a single field replicate.

Sediment Chemistry

-Sediment chemistry: Sediment samples were collected quarterly and analyzed for particle size, total phosphate, organic carbon, oxidation reduction potential, chemical oxygen demand (COD), sediment oxygen demand (SOD), pH, pesticide scan, and metals scan.

Biological Exposure Tests

-Chemical analysis of Trinity River fish samples: In Aug 1987 and Aug 1988, sunfish were collected from each sampling station to determine body burdens of metals and pesticides and selected organic compounds: Cd, Cu, Ni, Cr, Pb, Zn, aldrin, DDD, DDE, DDT, chlordane, hepatchlor epoxide, heptachlor, total PCBs, endrin, lindane, dieldrin, endrin aldehyde. Whole body residue levels were determined where possible.

Ambient Toxicity Tests

-Ambient toxicity: River water samples were collected from each collection station, then brought back to the lab for *C. dubia* survival and reproduction assays, fathead minnow larval survival and growth assays, and the Microtox assay.

-*In situ* ambient toxicity assay: Performed studies during summers 1987 and 1988 to see if Trinity River at select sampling sites impaired the growth of the Asiatic clam *Corbicula c.f. fluminea*. Juvenile clams (4>x>5 cm) were collected from Clear Creek; 6 were added per cage and suspended in the water column for 30 days and measured mortality rates.

Sediment Toxicity Tests

-Acute sediment toxicity test: conducted with whole sediments and used *D. magna*. Used sediment from the UNT Water Research Field Station (WRFS) and from Cross Lake, LA, as reference sediments. Ran in triplicates. Observed 24 and 48h mortality. Also performed acute tox tests on interstitial water from sediment by centrifugation. *D. magna* neonates and *Chironomus tentans* larvae were tested in the same vessel. Observed 24 and 48h mortality.

-Chronic sediment toxicity test: Sub-chronic partial live cycle tests were conducted with whole sediment on *D. magna* and *Hyalella azteca*, tested together in the same vessel. The endpoints were survival, growth inhibition, and daphnid production. Done in triplicates for 10 days. Used sediment from the WRFS as control and sediment from Cross Lake, LA, as reference sediments.

A long-term partial life cycle test was conducted on *C. tentans* to measure survival and growth. Used sediment from the UNT Water Research Field Station (WRFS) and from Cross Lake, LA, as reference sediments. Test was run for 10 days. *C. tentans* were also used for a long-term life cycle test using interstitial water. The endpoints were mortality and growth inhibition. Used interstitial water from WRFS sediment as controls.

-Sediment toxicity analysis using the fathead minnow early life stage assay: Sample sediments were aliquoted, equal volumes of sediment and dechlorinated tap water were used per glass container. Samples from each station were run in triplicate plus a control sediment. Twenty fathead minnow embryos were exposed for 12 d in stainless steel baskets placed on the sediment. Larvae were fed newly-hatched *Artemia nauplii* three times daily. Surviving larvae were sacrificed and inspected for gross abnormalities. Larvae were dried at 100 C for at least 2 hrs and then weighed.

Benthic Macroinvertebrates

-Collection: Benthic macroinvertebrates were collected quarterly using a Petite Ponar grab sampler (0.023 m2) and a D-frame net. Three ponar grabs were collected at each station for sediment dwellers. Invertebrates inhabiting littoral area snags and vegetation were collected with sweeps of a D-frame net. Riffle areas, if present, were sampled using a D-frame net.

-Processing: All ponar samples were field washed through a 150 um mesh screen. The sample was then transferred to jars and preserved in 10% formalin. In the lab, samples were stained with rose Bengal to facilitate sorting and IDing. Samples were again washed through a 150 um mesh screen to remove fine particles, rose Bengal stain, and preservative. Organisms were separated from the substrate and sorted into major taxonomic groups by using a dissecting microscope at 10 diameters magnification. After sorting, 70% ethanol was used as the storage preservative. Oligochaetes and chironomid larvae were mounted on slides and later identified.

D-frame samples were preserved in Kahles solution in the field. In the lab, samples were washed through a mesh sieve, and organisms were picked from the debris and sorted into major taxonomical groups. After sorting, samples were preserved in 70% ethanol and stored until identified.

-Analysis of benthic macroinvertebrate data:
Estimates of diversity (Brillouin Index)
Similarity of taxa composition between benthic communities (Morisita's Index)

Fish

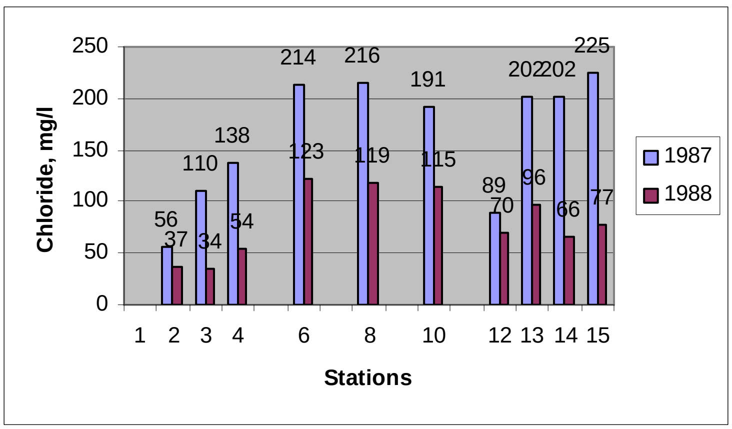
-Fish were collected quarterly by seine, electroshock, and gill nets at the 12 stations. Seines were used to sample 50 m of shoreline at each station. Specimens captured in the field by seine and electroshock were fixed in the field and returned to the lab for identification and enumeration. Gill net specimens were identified, measured for standard and total maximum length, weight, and released. All fish were identified to the lowest possible taxon, examined for parasites, physical abnormalities, and evidence of hybridizations.

RESULTS

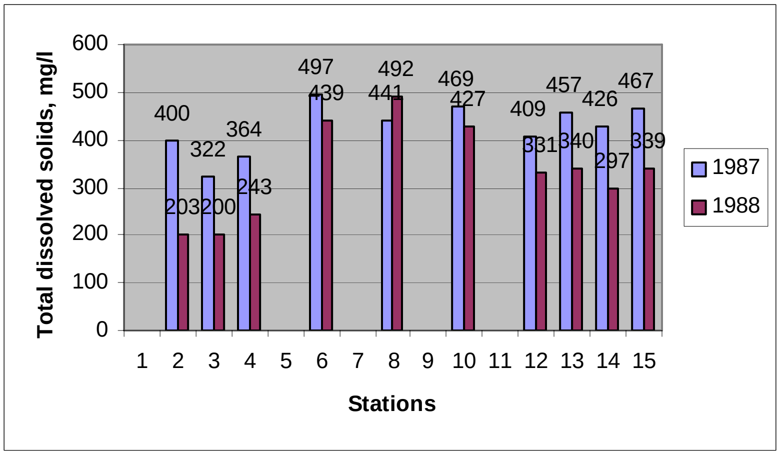
Flow:
TR1 – SDA03
TR2 – SDA04
Aug 1987: 0.2124 m/s, Sept 1988: 0.1586 m/s (7Q2: 0.2379 m/s)
TR3 – SDA06
TR4
Elm Fork – SDA02
TR5 – SDA08
TR6 – SDA10
Aug 1987: 18.2664 m/s, Sept 1988: 16.0008 m/s (7Q2: 12.6956 m/s)
TR7 – SDA13
East Fork – SDA12
TR8 – SDA14
TR9
Aug 1987: 22.2878 m/s, Sept 1988: 14.4432 m/s (7Q2: 13.1484 m/s)
TR10 – SDA15

Water Chemistry:

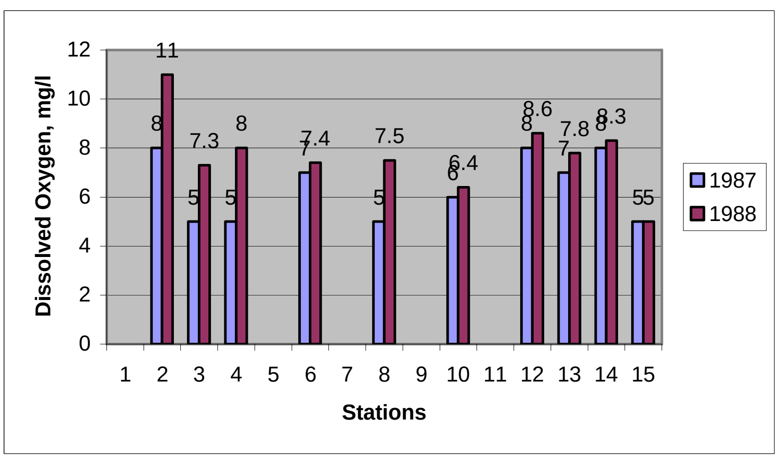
Chloride: Chloride concentrations were higher at the August 1987 collection, approximately twice the concentrations detected in September 1988. However, the same general trend was seen for both years. Chloride concentrations were relatively low at the Lake Lewisville dam site (SDA05-02; 56 mg/l (1987) and 37 mg/l (1988)) as well as the less urbanized East Fork site (SDA05-12; 89 mg/l (1987) and 70 mg/l (1988)). Chloride concentrations rapidly increased upstream of the TRA WWTP and remained high throughout DFW. For August 1987, dilution from the East Fork did not decrease chloride concentrations and at the last site, the chloride concentration was at its maximum concentration (225 mg/l) coincident with low flows in the river. Samples from 1988 followed a similar concentration trend, with the exception that chloride concentrations appeared to slowly decrease once the Trinity River left DFW. The chloride standard for this river segment states that the annual average concentration cannot exceed 175 mg/l. This standard was exceeded, though not overly so, at most stations downstream of the Village Creek WWTP collection site.



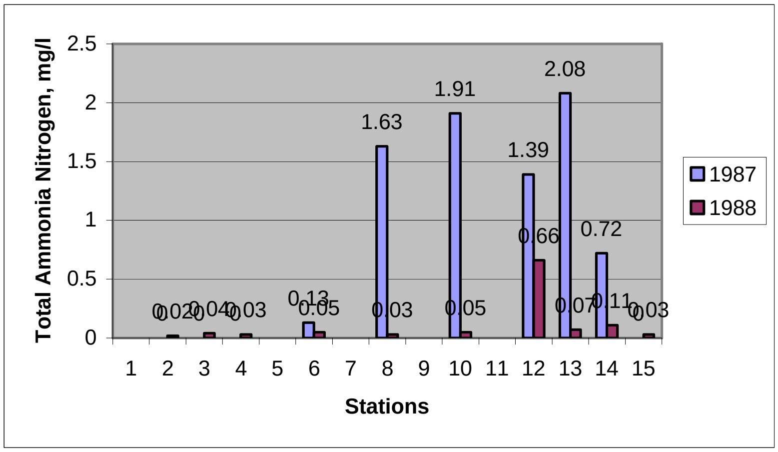
Total dissolved solids: The measure of the amount of organic and inorganic substances dissolved in water. For both August 1987 and September 1988 collection dates, TDS was lower downstream of Lake Worth (SDA05-03) and then increased downstream of the Village Creek WWTP. In August 1987, TDS levels remained higher through DFW and downstream to the last sample site (457-497 mg/l). In September 1988, though, TDS levels gradually decreased downstream of DFW. Even TDS levels in the East Fork (SDA05-12) were high, most likely due to the more natural state of that branch of the Trinity River. TDS levels were higher in August 1987 than September 1988 for all sample sites. The TDS standard for the segment is that of the annual average may not exceed 850 mg/l, and none of the sites exceeded this standard.



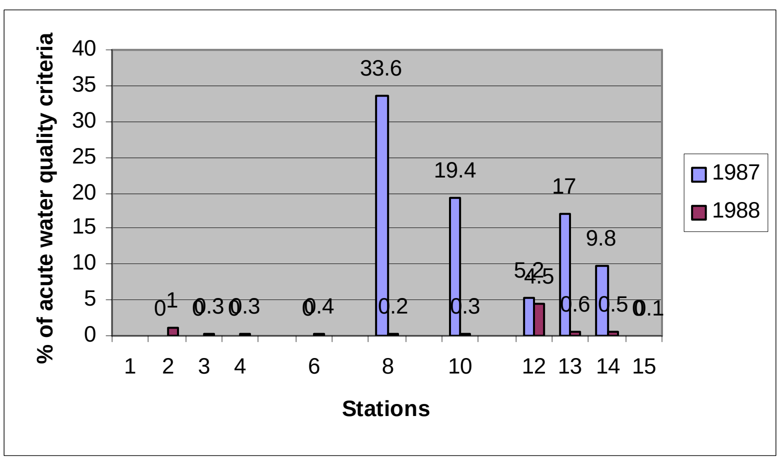
Dissolved oxygen: The water quality standard for DO in Segment 0805 is that the 24-hr average cannot be less than 3.0 mg/l nor less than 2.0 for more than 8 hrs. However, if the discharge at USGS station 08048000 (on the West Fork in Ft. Worth) is less than 80 cubic feet/second, then the standard is 1.0 mg/l. DO levels in this study demonstrate the influence of water temperature on the solubility of oxygen in water. DO levels were high south of the Lake Lewisville dam (SDA05-02; approx. 9.5 mg/l), but DO levels were much lower (approx. 6.5 mg/l) in the Trinity River segments running through DFW. As the Trinity River left DFW, DO concentrations increased to healthier levels (approx. 8 mg/l). Interestingly, DO concentrations at Palestine, TX (SDA05-15) dramatically decreased to levels seen on the Trinity River flowing through DFW. This may be due to sampling time of day as well as influence from upstream WWTPs run by the city of Palestine and the Texas Correctional Facilities.

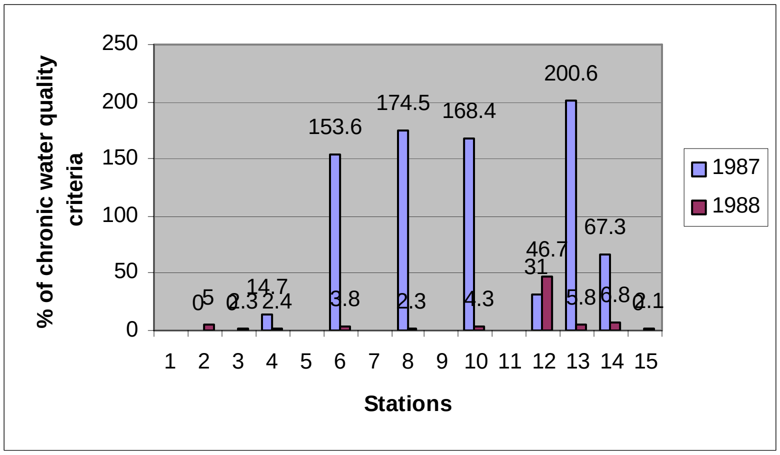


Total ammonia nitrogen: In August 1987, total ammonia levels were low on the Trinity River until after the TRA WWTP. Total ammonia levels then dramatically increased by approximately 12-fold at the site upstream of the Dallas Central WWTP (SDA05-08) and remained high until after the confluence of the Main Stem and the East Fork. Interestingly, the East Fork site (SDA05-12) was also high for a less urbanized area. In September 1988, total ammonia concentrations remained low, even through DFW. Similar to the August 1987 data, the East Fork site had high total ammonia concentrations. This could be due to low water flow, high fertilizer use, or high WWTP input.

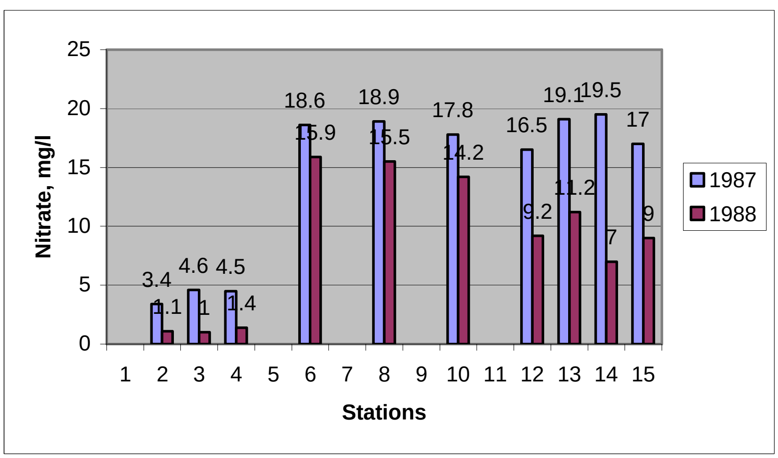


Un-ionized ammonia data were also analyzed for comparison to the national acute and chronic water quality criteria. Ammonia data from all sampling sites were below the acute toxicity criterion for ammonia based on the one-hour average concentration criterion. However, the chronic toxicity criterion was exceeded by several sampling sites in August 1987. Specifically, all sample sites downstream of WWTPs exceeded the four-day average concentration criterion. Further downstream, though, showed attenuation of ammonia levels, resulting in the chronic water quality criterion not being exceeded. These data are likely due to a combination of factors, such as low flow and increased temperature, that raised ammonia concentrations. None of the sites exceeded the chronic water criterion for ammonia in September 1988.

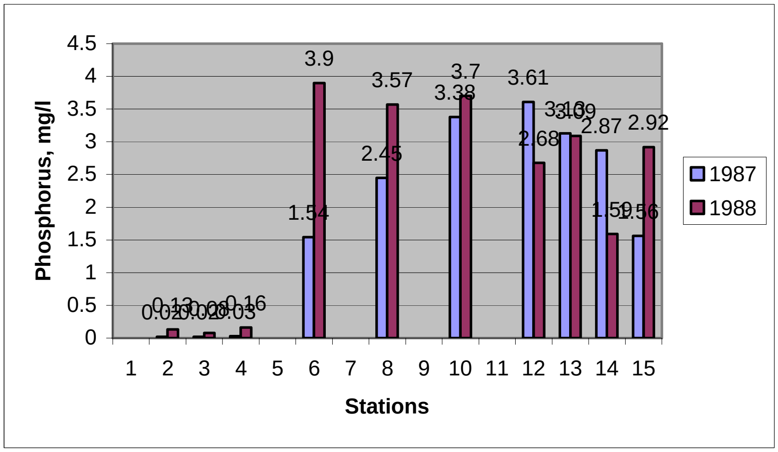


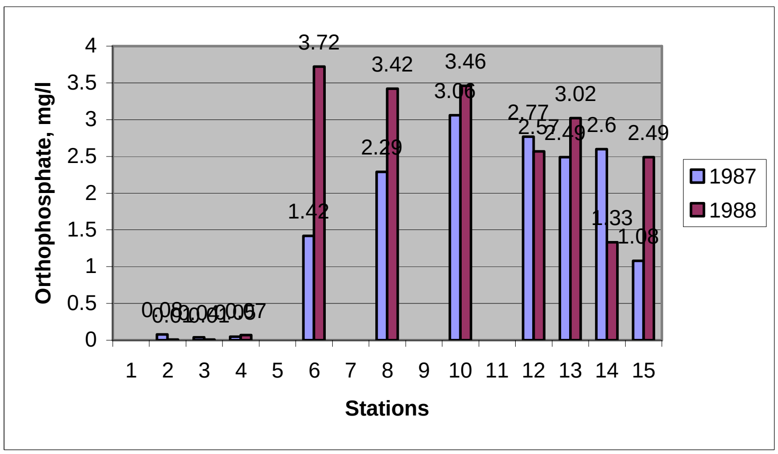


Nitrate nitrogen: Nitrate concentrations were higher in August 1987 than in September 1988, though both years show similar nitrate concentration patterns through DFW. Nitrate levels were low in the West Fork prior to the Village Creek WWTP. In August 1988, all sample sites, including site SDA05-15, after the Village Creek WWTP were approximately 4-fold higher than earlier sample sites. Even the East Fork had high nitrate levels, presumable due to a combination of WWTP effluent and fertilizer run-off. In September 1988, levels were also low on the West Fork prior to the Village Creek WWTP, and levels spiked after the Village Creek WWTP and remained high through the rest of the sample sites. However, nitrate increased approximately 10-fold downstream of Village Creek WWTP and remained that high through DFW. Nitrate levels began to decrease downstream of DFW to lower levels at site SDA05-15, though still approximately 6-fold higher than the West Fork prior to Village Creek WWTP. Elevated concentrations of nitrate (>15 mg/l) in the water supply are known to cause human health effects, though its toxicity to aquatic life is low.

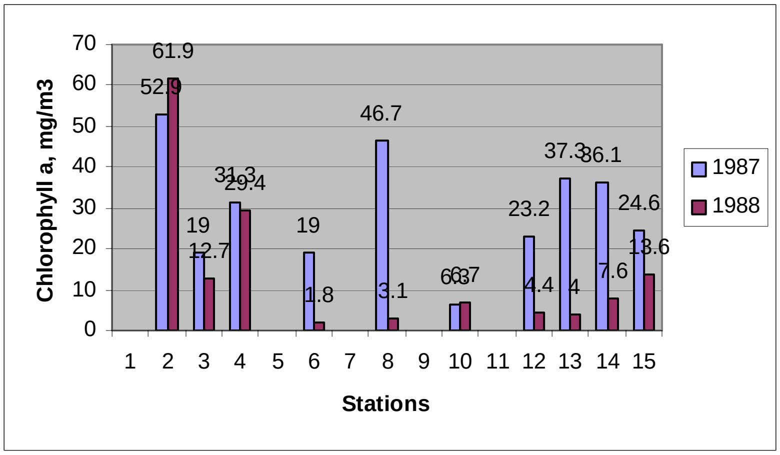


Total phosphate and orthophosphate phosphorus: Total phosphate levels were high downstream of DFW WWTPs. The accumulation of total phosphate through DFW is seen during the August 1987 collection. However, in August 1987, the highest phosphate level of phosphate was at the East Fork sample site, most likely due to fertilizer run-off. Total phosphate levels began to decrease as the Trinity River flowed out of DFW. In September 1988, though, total phosphate levels spiked to the maximum level detected downstream of the Village Creek WWTP. Levels remained high through DFW and then attenuated downstream through site 14. Unexpectedly, total phosphate levels dramatically increased at site SDA05-15. Orthophosphate, a highly biologically available form for uptake by aquatic plants, followed the same pattern as total phosphates for both collection dates.

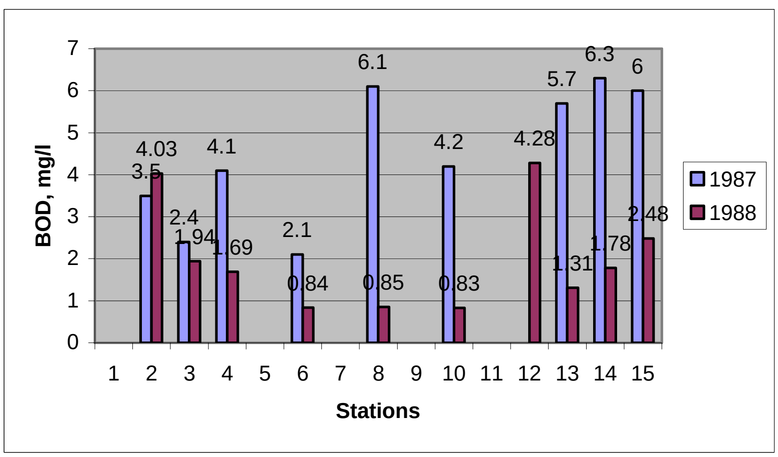




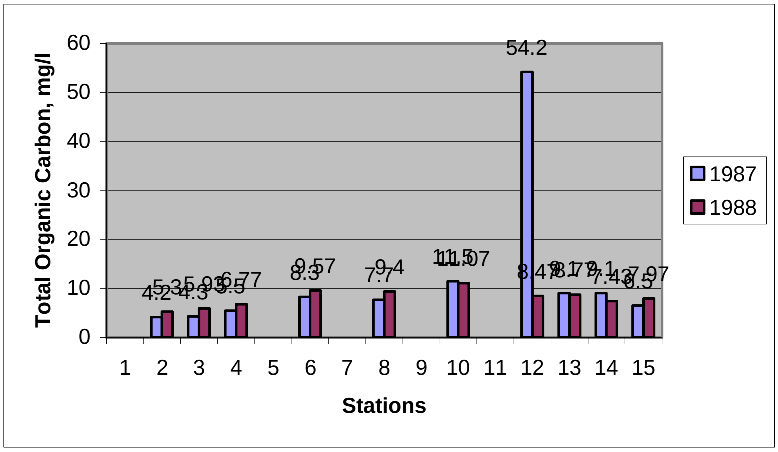
Chlorophyll a: Chlorophyll a was detected at maximum values at the Elm Fork sample site (SDA05-02) for both August 1987 and September 1988. Chlorophyll a levels in August 1987 were lower on the West Fork and Trinity River though DFW except downstream of TRA WWTP which was almost as high as the Elm Fork site. Chlorophyll a levels increased downstream of DFW. The September 1988 sample date saw high levels of chlorophyll a at the Elm Fork sample sites, medium levels on the West Fork, and low levels through DFW. Chlorophyll a levels remained low even downstream of DFW with a slight increase at Palestine, TX (site SDA05-15).



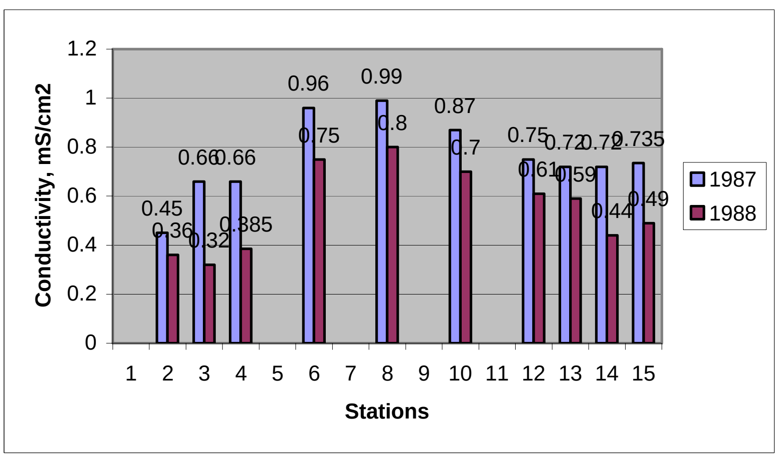
BOD: BOD was a 5-day measurement of oxygen consumption by bacteria metabolizing carbon and nitrogen-based materials. BOD was generally higher on the West Fork upstream of the Village Creek WWTP, on the East Fork, and on the main stem downstream of the Dallas Southside WWTP. In general, BOD levels were relatively low downstream of the 4 major DFW WWTPs, with the exception of upstream of Dallas Central WWTP in August 1987. This may be due to low carbon- and nitrogen-based materials in WWTP effluent or due to increased dilution by effluent discharge with downstream movement through DFW.



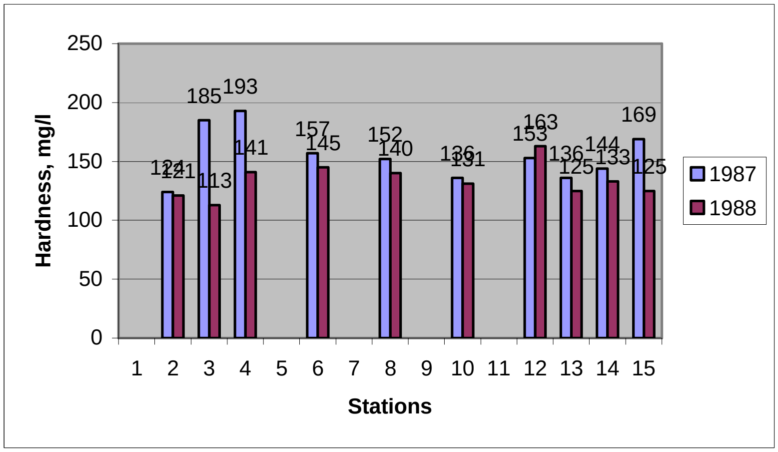
Total organic carbon (TOC) and dissolved organic carbon (DOC): TOC, the measurement of the particulate and the dissolved organic carbon, was generally low for the entire study area. TOC was lowest at the upstream sample sites. TOC slightly increased with each downstream sampling station until reaching a peak downstream of Dallas Central WWTP. TOC levels then slightly decreased with each downstream sample site. The one exception was the East Fork site in August 1987, which was almost 7-fold higher than the same site in September 1988, and almost 5-fold higher than the highest value on the main stem of the Trinity River. The DOC levels followed the same pattern through DFW as did TOC. Results show that the majority of the total organic carbon in the Trinity River samples was dissolved.



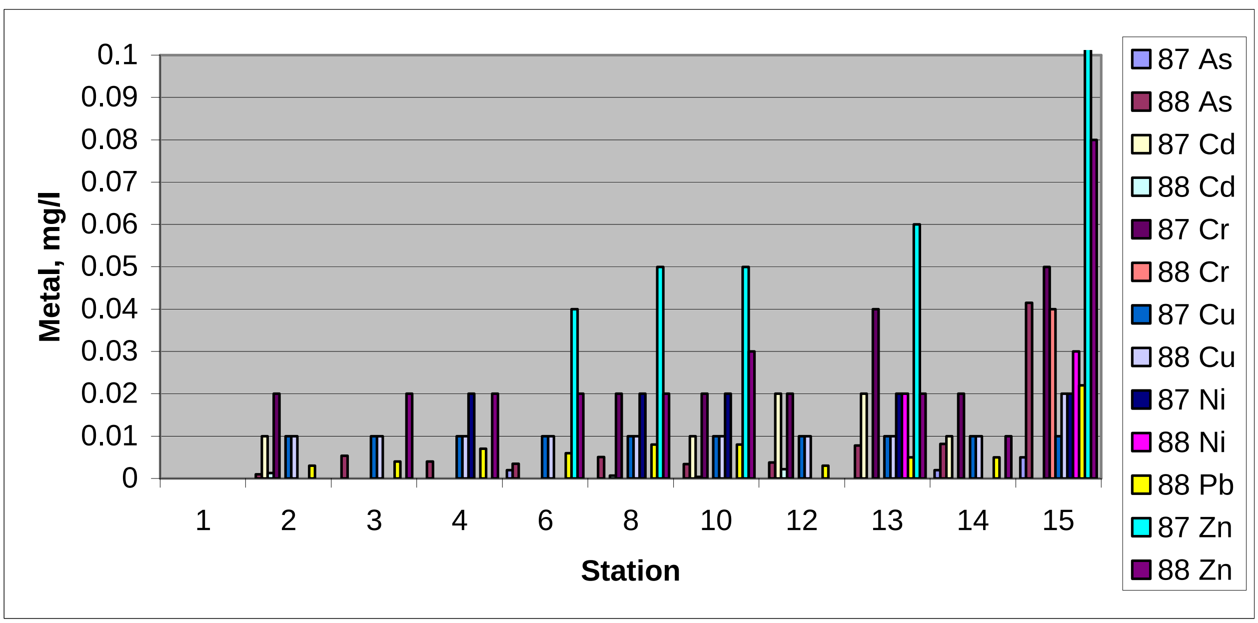
Conductivity: Conductivity is an indirect measurement of the amount of both dissolved inorganic and organic substances in the water. Conductivity was low upstream on the West Fork and the Elm Fork. Conductivity increased rapidly downstream of the WWTPs and remained high through DFW. Conductivity gradually decreased downstream once the Trinity River left DFW. Conductivity in September 1988 was slightly lower than in August 1987, but the pattern through DFW was the same.



Hardness: The Trinity River is considered a hard river, with high levels of calcium and magnesium. Very little change occurred in hardness between upstream and downstream sites and between August 1987 and September 1988.



Metals: Metals were analyzed by atomic absorption spectroscopy. Total and dissolved concentrations were measured for each sample site.
Arsenic: The small amount of As found in the watershed constituted approx. 0.69-1.57% of the acute water quality criteria and 1.32-2.98% of the chronic water quality criteria.
Cadmium: Dissolved Cd was only detected above MDL at a 3 sites in August 1987 and September 1988. However, when considering the MDL as the actual values at those sample sites, 1-23.29% dissolved Cd, as constituted of the acute water quality criteria, was present, and 32.62-744% of dissolved cadmium as percent of the chronic water quality criteria.
Chromium: Cr was only detected above MDL at two sites for both collection periods.



Flow:

TR1 – SDA03
TR2 – SDA04
Aug 1987: 0.2124 m/s, Sept 1988: 0.1586 m/s (7Q2: 0.2379 m/s)
TR3 – SDA06
TR4
Elm Fork – SDA02
TR5 – SDA08
TR6 – SDA10
Aug 1987: 18.2664 m/s, Sept 1988: 16.0008 m/s (7Q2: 12.6956 m/s)
TR7 – SDA13
East Fork – SDA12
TR8 – SDA14
TR9
Aug 1987: 22.2878 m/s, Sept 1988: 14.4432 m/s (7Q2: 13.1484 m/s)
TR10 – SDA15

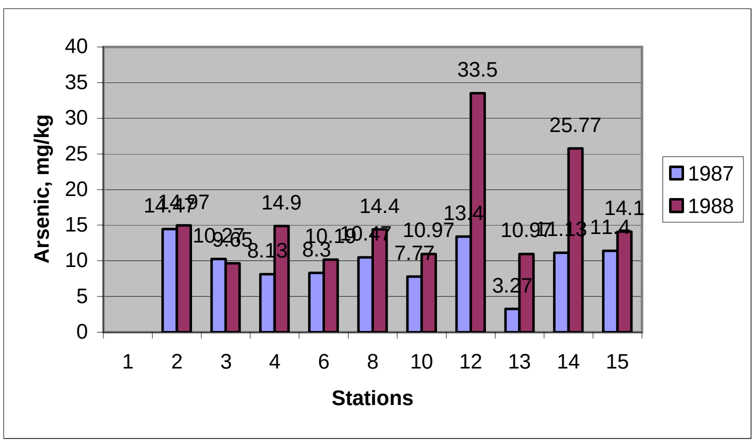
<u>Overall Surface Water Chemistry Summary (directly from 89 report):</u>
-Regulated parameters for Trinity River segment 0805 (chloride, TDS, temperature, DO, and sulfate) in general appear to be in compliance with water quality standards.
-The Trinity River has high nutrient concentrations primarily attributable to discharges from municipal WWTPs. Nitrogen and phosphorus concentrations were significantly elevated at sampling stations downstream of WWTP discharges. Ammonia nitrogen levels were also elevated downstream of WWTPs. Levels of unionized ammonia, the primary cause of ammonia toxicity, exceeded the site specific chronic water quality criterion at stations TR3, TR5, TR6, and TR7 in August 1987 by a factor of 1.5 to 2.0. While duration of these exceedances are not known, results identify ammonia as a possible contributor to chronic toxicity in the river.
-Organic carbon as measured by BOD, TOC, and DOC was lower at sampling stations TR1, TR2, and Elm Fork and higher at sampling stations downstream of WWTPs further demonstrating the influence of WWTP discharges on water quality in the Trinity River.
-Levels of As, Ni, and Zn in the Trinity River did not exceed their acute or chronic site specific water quality criteria at the sampling station.
-Cd, Cu, and Cr concentrations in the Trinity River were below acute and chronic site specific water quality criteria at most stations most of the time. Only twice did these metals exceed the applicable chronic criteria.
-Metals were generally at lower levels at stations TR1, TR2, and Elm Fork as contrasted to the other sampling stations.
-The overall spatial and temporal pattern of pesticides, purgeable volatile organics and acid and base-neutral organic compounds in the Trinity River showed a relationship between the number of detections and location of sampling stations in urban reaches of the Trinity River. The rank

ordering of sampling stations from highest to lowest in terms of number of detections was: TR3 > TR6 > TR5 > TR4 = TR8 > TR1 > Elm Fork > TR2 > TR9 = TR10 > East Fork.
-The following organic priority pollutants were occasionally measured in the Trinity River at concentrations above their acute and/or chronic water quality criteria: lindane, chlordane, 4,4'-DDT, dieldrin, endrin, heptachlor, total PCBs, and hexachlorocyclopentadiene.

Sediment Chemistry:

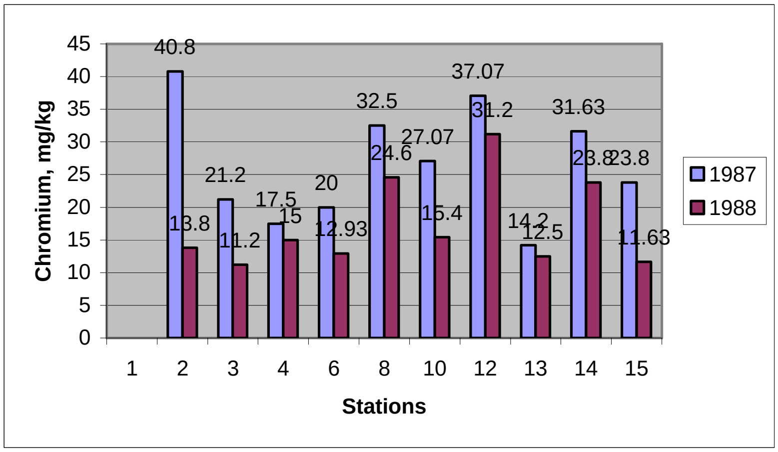
-Unlike surface water samples, sediment samples for all sampling stations at each quarterly survey had above MDL levels of As, Cr, Cu, Pb, Ni, and Zn.
- At the time, there was no existing sediment criteria equivalent to water quality criteria that could be used to evaluate the potential harmful effects of those organic compounds in the sediment.

-Arsenic: Levels were relatively consistent (approximately 8-15 mg/kg) in Trinity River sediment through DFW. The exceptions were two high levels at the East Fork site (SDA05-12) and at the Ennis site (SDA05-14). The TWC's 90th percentile screening level for arsenic was 15.7 mg/kg. This was not exceeded in August 1987, but in September 1988 this was exceeded at two stations.

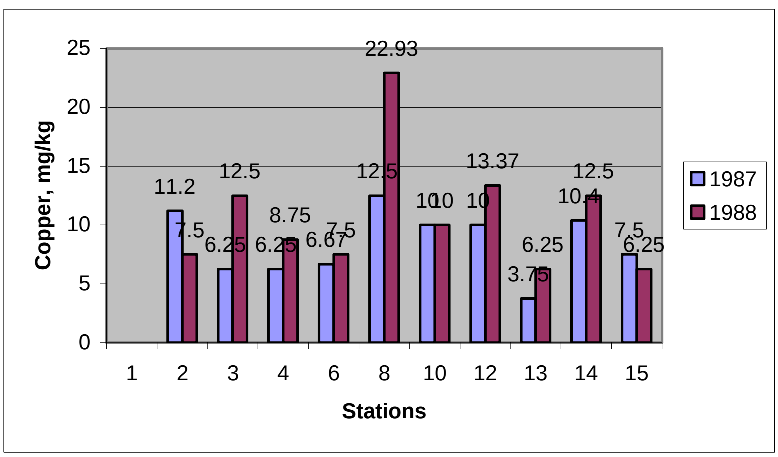


Cadmium: Cd was not detected in sediment samples at most sampling sites. When detected, Cd was found at low levels. Cd levels exceeded the TWC's 90th percentile screening criterion (3.0 mg/kg) at station 1 in September 1988.

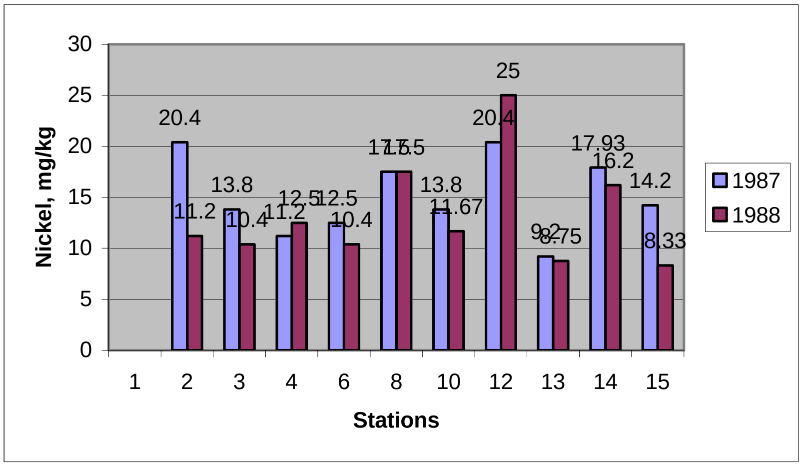
Chromium: Chromium levels generally increased in sediment as the Trinity River flowed through DFW. There was a high level of Cr at the Elm Fork sample site (SDA05-02) in August 1987. Levels peaked in DFW at the sample site downstream of the TRA WWTP. Cr levels were also high at the East Fork sample site (SDA05-12). Cr levels decreased through downstream of Dallas Southside WWTP, but then doubled at the Ennis sample site (SDA05-14) and remained elevated at Palestine (SDA05-15). None of the samples exceeded the TWC's 90th percentile screening criterion (72.1 mg/kg).



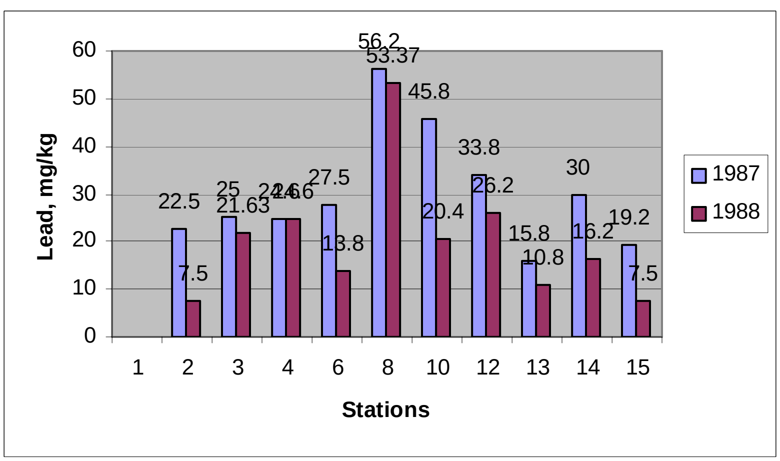
Copper: Copper levels started relatively low and slightly increased as the Trinity River flowed through DFW. There was drop in copper levels downstream of Dallas Southside WWTP (SDA05-13), but then increased to the average concentration at downstream sites. None of the sites exceeded the TWC's 90th percentile screening criterion (40 mg/kg).



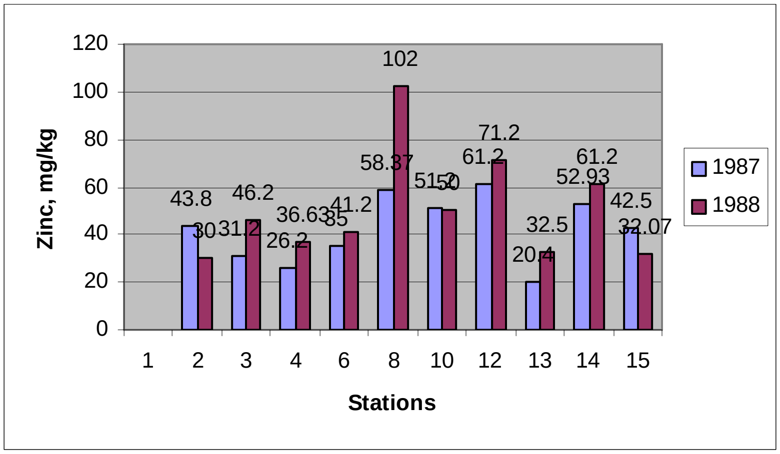
Nickel: Nickel levels followed the same pattern in sample sediments as copper, with the exception of the East Fork sample being much higher than sediment samples downstream of WWTPs. None of the sites exceeded the TWC's 90th percentile screening criterion (31.8 mg/kg).



Lead: Lead levels started low and then rose to maximum levels at the site downstream of TRA WWTP (53-56 mg/kg at SDA05-08). Lead levels slowly decreased back to upstream levels by the last sample site (SDA05-15). Lead concentration pattern was the same for August 1987 and September 1988. None of the samples exceeded the TWC's 90th percentile screening criterion (63 mg/kg).



Zinc: Zinc levels followed the same pattern in sample sediments as copper. None of the sites exceeded the TWC's 90th percentile screening criterion (120 mg/kg).



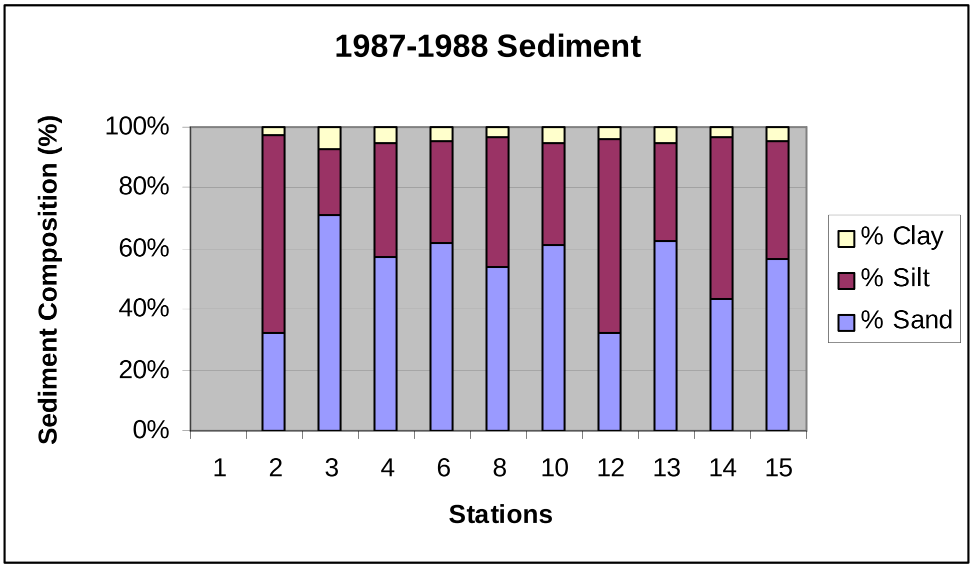
Pesticides: At the time, there was no existing sediment criteria equivalent to water quality criteria that could be used to evaluate the potential harmful effects of those organic compounds in the sediment. Many of the pesticides were below detection limits and those that were above detection limits were infrequent. (review if necessary).

SEDIMENTS

COD
1987:
34502(SDA05-02), 22109(SDA05-03), 6477(SDA05-04), 21333(SDA05-06), 43420(SDA05-08), 28785(SDA05-10), 20903(SDA05-12), 1561(SDA05-13), 21860 (SDA05-14), and 15344(SDA05-15)
1988:
11437(SDA05-02), 24284(SDA05-03), 19067(SDA05-04), 21623(SDA05-06), 16033(SDA05-08), 18503(SDA05-10), 1244(SDA05-12), 13886(SDA05-13), 23850(SDA05-14), and 10415(SDA05-15)
COD is the measure of the presence of chemically oxidizable organic material and other reduced compounds such as hydrogen sulfide in sediments.

% Organic Carbon:
1987:
0.64+0.01(SDA05-02), 0.42+0.07(SDA05-03), 0.82+0.04(SDA05-04), 0.59+0.03(SDA05-06), 0.70+0.02(SDA05-08), 0.84+0.03(SDA05-10), 0.60+0.04(SDA05-12), 0.58+0.08(SDA05-13), 0.62+0.02(SDA05-14), and 0.41+0.01(SDA05-15)
1988:
0.38+0.02(SDA05-02), 0.86+0.06(SDA05-03), 0.81+0.15(SDA05-04), 0.44+0.02(SDA05-06), 1.15+0.15(SDA05-08), 0.56+0.03(SDA05-10), 0.73+0.14(SDA05-12), 0.33+0.03(SDA05-13), 0.58+0.04 (SDA05-14), and 0.32+0.03(SDA05-15)

Sediment particle size: Fifty-eight percent had greater than 50% sand, 61% had less than 50% silt, and 99% had less than 20% clay. In general, Elm Fork and East Fork sediments contained higher percentages of silt than the other sampling stations which were higher in coarse-grained sand. Clay did not comprise a significant portion of the particle size distribution observed during the study.



FISH

General Results: Twelve families, 46 species, and 52,490 fish were collected during the 6 sampling periods. The three most prevalent families, based on number of species collected, were sunfish (Centrarchidae, 11 species), minnows (Cyprinidae, 10 species), and catfish (Ictaluridae, 7 species). The 4 most abundant species were red shiners (Notropis lutrensis, 71%), mosquitofish (Gambusia affinis, 12%), bullhead minnows (Pimephales vigilax, 8%), and longear sunfish (Lepomis megalotis, 2%).

Number of fish species collected: 26(SDA05-02), 31(SDA05-03), 26(SDA05-04), 19(SDA05-06), 18(SDA05-08), 11(SDA05-10), 23(SDA05-12), 24(SDA05-13), 20(SDA05-14), and 24(SDA05-15). The amount of fish species collected decreased as the river flowed through DFW with the lowest amount of species collected occurring upstream of the Dallas-Central WWTP. But then number of fish species collected increased downstream of Dallas and remained elevated through the rest of the river studied.

Species richness:
1987:
13(SDA05-02), 13(SDA05-03), 17(SDA05-04), 11(SDA05-06), 10(SDA05-08), 6(SDA05-10), 14(SDA05-12), 12(SDA05-13), 13(SDA05-14), and 13(SDA05-15)
1988:
20(SDA05-02), 19(SDA05-03), 12(SDA05-04), 7(SDA05-06), 9(SDA05-08), 1(SDA05-10), 10(SDA05-12), 9(SDA05-13), 10(SDA05-14), and 11(SDA05-15)
Decreases in species richness, from that of reference stations, frequently occurred from stations SDA05-06 to SDA05-10. Species richness generally increased at stations SDA05-13 through SDA05-15 and lowest species richness consistently occurred at Station SDA05-10.

Species Evenness and Species Diversity: Evenness is a unitless measure which indicates how equally the number of individuals collected were distributed among the species collected. Values range between zero and one, where a value of one indicated that individuals are equally distributed among all species and values approaching zero indicate an extremely unequal distribution of individuals among the species captures. Evenness values, historically, have been presented in conjunction with diversity indices for the interpretation of biological data.
Evenness 1987:
0.78(SDA05-02), 0.50(SDA05-03), 0.36(SDA05-04), 0.58(SDA05-06), 0.50(SDA05-08), 0.27(SDA05-10), 0.53(SDA05-12), 0.52(SDA05-13), 0.41(SDA05-14), and 0.55(SDA05-15).
Evenness 1988:
0.53(SDA05-02), 0.67(SDA05-03), 0.15(SDA05-04), 0.54(SDA05-06), 0.44(SDA05-08), 0(SDA05-10), 0.46(SDA05-12), 0.42(SDA05-13), 0.21(SDA05-14), and 0.22(SDA05-15).
Brillouin's Species Diversity Index (log2) 1987:
2.90(SDA05-02), 1.87(SDA05-03), 1.47(SDA05-04), 2.01(SDA05-06), 1.65(SDA05-08), 0.70(SDA05-10), 2.02(SDA05-12), 1.87(SDA05-13), 1.53(SDA05-14), and 2.02(SDA05-15).
Brillouin's Species Diversity Index (log2) 1988:
2.29(SDA05-02), 2.84(SDA05-03), 0.54(SDA05-04), 1.52(SDA05-06), 1.39(SDA05-08), 0(SDA05-10), 1.54(SDA05-12), 1.33(SDA05-13), 0.70(SDA05-14), and 0.75(SDA05-15).

Index of Biotic Integrity
Biotic integrity was defined by Karr and Dudley (1981) as "the ability to support and maintain a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of the region." The index of Biotic Integrity (IBI) uses 12 assemblage attributes (metrics) which, based on professional judgment, are considered to be essential for biotic integrity in the region where applied. Scores of 5, 3, or 1 are assigned to each metric depending on whether data approximate, deviate, or greatly deviate from values which are indicative of biotic integrity in the region. Texas Parks and Wildlife used the following IBI scores for determining the aquatic life use subcategories for the Trinity River: exceptional= >49, high= 41-48, intermediate= 36-40, limited= <35. By this classification, 2 sites in '87 and 3 sites in '88 were exceptional, 6 sites in '87 and 4 sites in '88 were high, 2 site2 in '87 and 2 in '88 were limited, and 1 site in '88 was limited.

1987:
44(SDA05-02), 50(SDA05-03), 52(SDA05-04), 46(SDA05-06), 40(SDA05-08), 38(SDA05-10), 46(SDA05-12), 46(SDA05-13), 46(SDA05-14), and 46(SDA05-15).
1988:
52(SDA05-02), 54(SDA05-03), 46(SDA05-04), 42(SDA05-06), 40(SDA05-08), 20(SDA05-10), 42(SDA05-12), 40(SDA05-13), 44(SDA05-14), and 54(SDA05-15).

Reference sites (SDA05-02, SDA05-03, and SDA05-12) had either high or exceptional scores, whereas scores ranged from poor to high downstream of WWTPs in DFW. IBI scores increased to exceptional and high levels downstream of DFW.

MACROINVERTEBRATE Survey Results Summary

A total of 15 families, 90 taxa, and 25,221 individuals were collected by Ponar grab during the 6 benthic macroinvertebrate surveys. An additional 110 families were collected in the qualitative D-frame net sampling. Oligochaeta (Naididae and Tubificidae) were the dominant groups collected by ponar grab. The most abundant Tubificidae collected were sexually immature individuals without capilliform chaetae. Aulodrilus pigueti was subdominant. Polypedilum was the most abundant chironomid taxon with Chironomus and Cryptochironomus subdominant.

Proportionalities of all invertebrates collected by ponar grab: Immature Tubificid (23%), Polypedilum (16%), 69 others (15%), Aulodrilus pigueti (13%), Dero (7%), Cryptochironomus (5%), Nematoda (5%), Limnodrilus cervix (4%), Stephansoniana triv (2%), Procladius (2%), Pristina breviseta (2%).

Taxa richness (total number of taxa collected at each station):
1987:
8(SDA05-02), 19(SDA05-03), 19(SDA05-04), 28(SDA05-06), 12(SDA05-08), 9(SDA05-10), 17(SDA05-12), 13(SDA05-13), 20(SDA05-14), 6(SDA05-15)
1988:
29(SDA05-02), 16(SDA05-03), 18(SDA05-04), 26(SDA05-06), 19(SDA05-08), 23(SDA05-10), 22(SDA05-12), 14(SDA05-13), 14(SDA05-14), 15(SDA05-15)

Combined ranking of all biological indices:
9(SDA05-02), 20(SDA05-03), 18.5(SDA05-04), 17.5(SDA05-06), 33(SDA05-08), 46(SDA05-10), 37(SDA05-12), 46.5 (SDA05-13), 37(SDA05-14), 47(SDA05-15)

Site specific results:
Reference stations:
SDA05-02 (Elm Fork): The Elm Fork ranked first when considering Brillouin diversity, taxa richness, and total number of taxa collected in shoreline sweep net samples. It also ranked first when considering all biotic indices.

SDA05-03 (TR1): Flow, in the reach where ponar grabs were takes, was restricted by a low water dam. The slow water column velocity upstream of the dam provided an extensive areas of soft sediment. Collections at TR1 ranked first for the total number of invertebrates collected and ranked fourth when considering all biotic indices. The zoobenthos was generally dominated by naidid and tubificid worms.

SDA05-04 (TR2): This station represented the most natural habitat of any station in the metropolitan area. Collections ranked second for Brillouin diversity and third when considering all biotic indices.

Stations downstream of WWTPs:
SDA05-06 (TR3): TR3 ranked second when considering the ranks of all biotic indices, and it ranked second for taxa richness.

SDA05-08 (TR5): TR5 ranked 6^{th} for taxa richness for both ponar and shoreline sweep samples. Overall, TR5 ranked 6^{th} for collective biotic indices.

SDA05-10 (TR6): TR6 was a highly impacted station ranking 9.5 when all biotic indices were considered. This station ranked last in Brillouin diversity and the lowest (12^{th}) taxa richness.

SDA05-12 (East Fork): The highest ranking for the East Fork (2^{nd}) occurred for taxa richness in the qualitative shoreline sweeps. When all the biotic indices were considered, the East Fork station ranked high.

SDA05-13 (TR7): Benthic communities were highly altered and ranked second to last (11^{th}) when the ranks of all measured biotic indices were considered. Low rankings were obtained at this station for every biotic index. Upstream point and nonpoint source pollution sources were probably influencing benthic communities at this station. However, this section of river has strong currents, has no pool areas, and little shoreline habitat diversity, all factors that also contributed to the poor benthic community structure.

SDA05-14 (TR8): TR8 ranked the same as the East Fork on all combined biotic indices. It's lowest ranking (11^{th}) occurred for number of individuals collected in ponar grabs, resulting in few taxa.

SDA05-15 (TR10): TR10 was ranked 12^{th} when all biotic indices were considered. It ranked last or nearly last for every biotic index except total taxa collected in shoreline sweeps. When compared to control stations, only the Elm Fork station had more shoreline taxa than SDA05-15.

UNT Theses

Spon, Sandra T. "The response of aquatic insect communities and caged *in situ* juvenile Asiatic clams (*Corbicula fluminea*) to dechlorinated municipal effluent in the Trinity River in North Texas." Masters of Science (Environmental Science), **December 1994**, 192 pp., University of North Texas.

Dischargers to the Trinity River in North Texas were required to dechlorinate their effluents in 1990-1991. Field surveys were conducted above and below an outfall (of the Village Creek WWTP) to determine the response of resident immature insects and caged *in situ* juvenile Asiatic clams to chlorinated and dechlorinated effluent. Within 6 months after dechlorination began, insect community composition and *C. fluminea* survival significantly improved at stations below the outfall. Significantly lower clam growth within one mile below the dechlorinated effluent indicated the presence of non-chlorine toxicants. Effects from chlorinated and dechlorinated effluent exposure were comparable between *Ceriodaphnia dubia* lab tests and *in situ C. fluminea*.

Pre-dechlorination baseline study: based on UNT study of the Trinity River in Aug-Oct 1990 prior to dechlorination at Village Creek WWTP. Effluent contained approx 1.0 mg/l total residual chlorine. Chlorine was a major cause of observed ambient toxicity to *C. dubia* and *P. promelas* in laboratory tests.

Bryan, Brynne L. "Plankton community response to dechlorination of a municipal effluent discharged into the Trinity River." Masters of Science (Environmental Science), **December 1994**, 150 pp., University of North Texas.

Chlorine is used by the Village Creek Waste Water Treatment Plant to kill pathogenic microorganisms prior to discharge of the effluent into the Trinity River. The residual chlorine in the river impacted aquatic life prompting the U.S. EPA in December 1990 to require dechlorination using sulfur dioxide.

The purpose of this study was to test the hypothesis that dechlorination had no effect on the integrity of three select communities: periphyton, phytoplankton, and zooplankton. These communities have constituents from different trophic levels, and each level had the potential of being affected in different ways, either directly from the removal of chlorine or indirectly from shifts in the composition of adjacent trophic levels. Within each community there were different aspects, or parameters, evaluated to test the hypothesis that there was no effect on that community from removal of chlorine. Zooplankton were analyzed for total densities, taxa richness, and distribution. Phytoplankton were analyzed for chlorophyll-a concentrations as well as for total densities, taxa richness, and distribution. Periphyton were analyzed for ash-free dry weight and chlorophyll-a concentrations as well as for densities, taxa richness, and distribution. These evaluations were conducted before as well as after dechlorination went into effect. Examination of changes in the zooplankton, phytoplankton, and periphyton communities may give insight into the response of the entire ecosystem to dechlorination.

Dechlorination had no effect on the phytoplankton community. The periphyton community exhibited a shift in species abundance with a more even distribution of organisms among taxa. No change occurred in zooplankton species abundance, however, there was a decrease in zooplankton density following dechlorination.

Samples were taken from 2 upstream sites (upper most site ~SDA05-04 [3.2 mi. upstream]) and 5 downstream sites (furthest downstream ~ SDA05-06 [17.3 mi. downstream]).

Guinn, Richard J. "Biological and toxicological responses resulting from dechlorination of a major municipal wastewater treatment plant discharge to the Trinity River." Doctor of Philosophy (Biology), **August 1995**, 489 pp., University of North Texas.

To control toxicity caused by chlorination of wastewater discharges, the EPA also began requiring some treatment facilities to dechlorinate their wastewater before discharging. This research was funded by the EPA to document the changes that occurred in the Trinity River from the dechlorination of the effluent from Ft. Worth's Village Creek municipal wastewater treatment plant. The main objective of the study was to examine the in-stream biological effects resulting from the removal of a known toxicant (chlorine) from the wastewater discharge. The study occurred over a two year period beginning in August 1990. A wide variety of biological field assessments and toxicological assays were used to measure various responses. Seven river stations, covering approximately 20 river miles, and the treatment plant effluent were assessed. Two of the river stations were upstream from the treatment plant and used as reference sites. The remaining 5 river stations were downstream from the treatment plant, spread out over 17 river miles.

The study evaluated the impact of chlorination prior to dechlorination, which served as a baseline. Responses determined during dechlorination were compared to the baseline data. An overall improvement in species richness and diversity was seen at those river stations which had previously been adversely impacted by chlorine.

Aquatic toxicity tests, such as those required to be used by dischargers, were conducted during this study. Periodic toxicity was observed with these tests in the effluent and river samples after dechlorination was initiated. Those tests, along with *in situ* toxicity assays, proved to be good predictors of biological community responses.

Samples were taken from 2 upstream sites (upper most site ~SDA05-04 [3.2 mi. upstream]) and 5 downstream sites (furthest downstream ~ SDA05-06 [17.3 mi. downstream]). (Note: same sample sites as Bryan dissertation (above)).

Stephenson, Jaynie M. "Macroinvertebrate community structure as an indicator of watershed health in the upper Trinity River basin, North Central Texas." Masters of Science (Biology), **May 2000**, 160 pp., University of North Texas.

This study describes macroinvertebrate community structure and assesses its potential in detecting point and non-point sources of disturbance associated with rural and urban areas in the Upper Trinity River Basin. Geospatial techniques were used to quantify land use within the watershed in a GIS. At rural sites near the headwaters of the Trinity River, collector-gathering burrowers that are adapted in minimal flow comprised the majority of taxa. Densities of taxa compositions at downstream sites increased and shifted toward psammophilic and rheophilic invertebrates, including primarily collector-filtering clingers, that are characteristic of shifting sand habitats in large prairie rivers. Benthic community structure generally benefited from point source impacts including wastewater treatment plant effluents that maintained higher flow. Community indices were negatively associated with forest land use and positively associated with urban land use. Partial CCA determined that flow and land use contributed equally to species dispersion. Comparisons with historical biomonitoring studies in the upper Trinity River Basin indicate improved watershed health.