Analysis of Municipal Water Quality Data

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EXECUTIVE SUMMARY

Water quality data from ambient monitoring programs were analyzed for four municipalities in the DFW Metroplex region: Arlington, Fort Worth, Grand Prairie and Irving. The analyses addressed status and trends for selected water quality parameters, regional patterns of variation, and possible impacts of storm water on these parameters. Less extensive analyses were applied to data on metals concentrations. Data analyzed came from locations whose watersheds ranged from small streams with watershed areas less than one square mile, to sites on forks of the Trinity River with watershed areas exceeding 1000 square miles. The data analyzed were obtained between the years 2000 and 2006.

Conclusions

- Measurements of *E. coli* often exceeded the screening level at many locations in all municipalities, especially in small- to medium-sized streams, making this the parameter raising greatest concerns.
- Measurements of Chlorophyll *a* frequently exceed the screening level at several sites, which tended to have broad channels and open surroundings (i.e. no riparian forest), circumstances where *in situ* growth of algae should be expected.
- Concentrations of nutrients were generally below screening levels established by the Texas Commission on Environmental Quality, with a few exceptions.
- Significant increases in Total Kjeldahl Nitrogen or Total Phosphorus were found at several sampling stations in Arlington, Grand Prairie and Irving.
- There were significant decreases in NO_3/NO_2 at many sampling stations in Grand Prairie.
- *E. coli* displayed significantly decreasing trends at several sites, and only one significant increase was noted for a site in Arlington.
- Chlorophyll *a* displayed significantly increasing trends at several sites in Grand Prairie and Irving.
- In Principal Components Analyses the first five factors accounted for more than 70% of the variation in selected water quality parameters, implying that adequate characterization of ambient variations in water quality can be achieved with as few as five well-selected sampling locations. Monitoring plans with 20 – 30 sites include many sites that provide redundant data.
- Discharge data from four gauged stations in the Metroplex region are highly correlated due to shared variations in weather patterns, making it possible to compute a synthetic variable to represent the typical variations in discharge expected at locations that were not gauged.
- Flow-concentration relationships based on this synthetic discharge variable were generally positive and relatively strong for NO_3/NO_2, suggesting potential storm water impacts and watershed sources that are mobilized by runoff and stream flow.
- Flow-concentration relationships were also positive, but variable among sampling stations, for *E. coli*, suggesting that storm water and runoff events mobilize watershed sources that vary in strength among locations.

- Flow-concentration relationships were positive but weaker and more variable for Total Kjeldahl Nitrogen, Total Phosphorus, and Turbidity, suggesting a mix of *in situ* sources and watershed sources of variable strength.
- Flow-concentration relationships were generally negative for Chlorophyll *a* suggesting that storm water events flush out populations of algae that grow *in situ*.
- Metals concentrations were less extensively analyzed but are generally far below concentrations that would raise concerns.

Recommendations

- Some of the monitoring programs analyzed here probably have more sampling stations than necessary to adequately characterize ambient variation in water quality. Number and location of stations should be evaluated.
- Given high levels of *E. coli* at many locations and indications that storm water and runoff events mobilize watershed sources, source typing of *E. coli* by genetic means should be considered for selected locations.
- Dissolved metals concentrations are often undetectable, and metals are more likely to occur in particulate form, so determination of total concentrations would both give more useful data and be more protective of water quality.
- Many organic contaminants likely to be present in urban surface waters raise concerns for human or wildlife health, including “emerging contaminants” such as endocrine disruptors and pharmaceuticals. Obtaining data on such substances would be desirable.

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1. Overview

This report begins with an overview of the data and the analyses conducted (section 1). There are six subsequent sections parts, the first five of which focus on the selected water quality parameters listed in Table 1.1: (section 2) the analysis of location statistics to characterize water quality status; (section 3) the analysis of trends in water quality; (section 4) the analysis of temporal coherence; (section 5) principal components analysis; (section 6) the analysis of flow-concentration relationships; and (section 7) an evaluation of additional parameters, focusing on metals concentrations. The analyses reported address three goals:

I. To evaluation the status and trends of water quality in municipalities of the metroplex (sections 2, 3 and 7).
II. To evaluate the strength correlations among variations in water at different sampling stations (sections 5 and 6). This analysis contributes to the understanding of localized versus broader regional factors affecting water quality. It also contributes to evaluating whether an appropriate number of sampling stations have been monitored to characterize ambient variation in water quality.
III. To explore potential causes of variation in water quality, in particular whether stormflow events mobilize constituents from watershed sources, thus contributing to contaminant loading.

Municipalities in the metroplex have been collecting ambient water quality samples from several streams for several years. The resulting data could shed light on status of stream water quality in the region, and trends in water quality. Additionally, this monitoring could provide insight into impacts of storm water flow on receiving waters, since an ambient sampling program ideally obtains samples representing the variety of flow conditions characteristic of a stream. This report presents analyses of status and trends in water quality, regional correlations in water quality across multiple sampling stations, and relations of water quality with stream flow to illuminate the impact of storm water. Data were provided from monitoring programs run by Arlington, Fort Worth, Grand Prairie, and Irving.

Watershed areas associated with the upstream areas of the sampling stations used by these municipalities are presented in tables in Appendix 3, along with land use data. Watershed areas range 1.2 – 183 mi^2 for stations in Arlington. Watershed areas range 21.7 - 36.8 mi^2 for two stations in Fort Worth on small streams. Watershed areas were not provided for stations in Fort Worth on the West Fork of the Trinity River, though they likely exceed 1000 mi^2. Watershed areas range 0.2 – 3010 mi^2 for stations in Grand Prairie, including one on the West Fork of the Trinity River. Watershed areas range 0.8 – 3040 mi^2 for stations in Irving, including stations on the West and Elm Forks of the Trinity River.

Land use types follow the NLCD 2001 Land Cover Class Definitions (http://www.mrlc.gov/nlcd_definitions.asp, see also Appendix 3). Land use in all the watersheds involved in this study is dominated by developed open space or low density development (<50% impervious surfaces). These two land use types accounted for about half of watershed area for stations in Arlington, Fort Worth, and Irving, and about one-third of the watershed area for stations in Grand Prairie. Medium and high density development (>50% impervious surfaces) accounted for about 20% - 50% of watershed area for stations across all municipalities. Other common land use types included grassland, deciduous forest, and pasture in all municipalities, and cultivated crops in Grand Prairie.

For the data made available for this study, sampling frequencies and periods of observation differed among municipalities. In Arlington, water quality samples were taken monthly from May 2000 to February 2006. In Fort Worth, water quality samples were taken from January 2001 to March 2006. In Grand Prairie, water quality samples were taken monthly from December 2001 to March 2006, though many parameters were determined only on a quarterly basis. In Irving, water quality samples were taken monthly from July 2001 to October 2004. Data sets generally contained missing values, and not all parameters were measured over the entire period of observations. Each municipality chose a different set of water quality parameters to measure from their samples, and therefore this study focused primarily on parameters that were measured by two or more municipalities. Parameters to be analyzed were selected based upon completeness and comparability of data sets, and in consultation with municipal personnel and TRA personnel.

Analyses undertaken to address the issues of water quality status and trends are relatively straightforward. Water quality status over a period of time can be judged from conventional “location statistics” such as the mean or median. Dispersion statistics, such as standard deviations and percentiles, are helpful in assessing variation in water quality and the likelihood of exceedances of standards. Trends can be judged from linear regression or log-linear regression versus time. Identification and interpretation of significant trends is guided by standard statistical procedures such as *t*-tests on the slopes of such regressions. Therefore these analyses were focused on selected water quality parameters prioritized by relevance to water quality issues and coverage and quality of the data, selected in consultation with TRA and other interested parties at an early stage of the project (Table 1.1).

Table 1.1 Water quality parameters selected for analysis

STORET Code	Parameter
00010	Water Temperature
00625	Total Kjeldahl Nitrogen (TKN)
00630	NO_3 / NO_2
00665	Total Phosphorus (TP)
01351	Flow Severity
31699	*E. coli*
32211	Chlorophyll *a* (Chl-*a*)
82078	Turbidity

Analysis of regional patterns and storm water impacts is more complicated. To characterize regional patterns of variation in water quality, two statistical analyses were conducted for the selected water quality parameters: an analysis of temporal coherence, and a Principal Components Analysis. For a selected parameter, the analysis of temporal coherence focuses on correlations over time between stations. For each pair of stations available, the correlation coefficient is calculated for observations taken at the same time. The average of all these pairwise correlations is a quantity called the temporal coherence.

When it is high (near 1 in value), there are regionally coherent patterns of variation among the stations in the data set. Such coherent patterns are usually the result of seasonal and weather-related variation. For example, the analyses done in this report demonstrate that water temperature has high coherence, which is expected due to strong seasonal heating and cooling of surface waters. When coherence is moderate to low in value, regionally coherent patterns of variation are weaker, and single stations or sets of stations tend to display idiosyncratic patterns of variation as a result of site-specific factors such as local channel and watershed characteristics, or in situ biological processes. For data sets displaying low to moderate coherence, the Principal Components Analysis further dissects the patterns of correlations among sites, to identify patterns of variation that might be held in common among all or some sites. The procedures of coherence analysis and Principal Components Analysis are illustrated below, as applied to variations in discharge at gauged stations in the metroplex region. These procedures are further explained in the sections of the report presenting their results.

Analysis of storm water impacts has generally been a challenge in water quality studies. When appropriate data are available, a common procedure for analyzing the impact of stream flow, including storm flows, is to plot concentration of a parameter versus flow. Regression analysis is then used to identify increasing or decreasing relationships. The former indicates that events of high flow (e.g. storms) produce loading of a parameter, while the latter indicates that events of high flow dilute a parameter with sources other than storm water. Unfortunately, most of the monitoring stations where water quality samples for this study were obtained are not gauged for discharge. Therefore techniques of temporal coherence and Principal Components Analysis were applied to construct a synthetic variable called “Reconstructed Discharge” that represents the generalized, regional patterns of stream flow variation in the metroplex region over a time span encompassing the periods of observation for the data analyzed here.

Discharge data from the four available gauged sites within the region (Table 1.2) displays regionally coherent variation, reflecting patterns of dry and rainy periods shared among all four locations (Fig. 1.1). The temporal coherence is 0.60, as measured by the average pairwise correlation between time series in the data set (i.e. the average of the correlations in Table 1.3). From these correlations, a synthetic variable representing regional variation in discharge was constructed as the first factor from a Principal Components Analysis applied to the natural logarithms of discharge (Fig. 1.2). Principal Components Analysis uses the correlations in a data set to construct synthetic variables called “factors”. The first such factor represents patterns of variation held in common among all sites in the analysis, and is constructed to account for as much of the total variation in the data as possible. This synthetic variable is later used as a surrogate for discharge (which was not measured at most sites in this study) to create “reconstructed” flow-concentration analyses for the selected water quality parameters. This procedure assumes that streams in the metroplex undergo similar variations in discharge over time, due to shared seasonal and meteorological patterns. Given that this assumption is imperfect and given the noise in the available data, these analyses are primarily exploratory, identifying parameters and sites where storm water loading might be problematic, without being definitive. The analyses could thus focus attention where continued monitoring might be most valuable.

Table 1.2 Sites gauged for discharge				
Watershed	**USGS No.**	**TCEQ No.**	**Location**	**Description**
Main Stem	08048543	10938	Lat 32°45'06", long 97°17'21", Tarrant County	W Fk Trinity Rv at Beach St, Ft Worth, TX
Village Creek	08048970	10786	Lat 32°36'12", long 97°15'53", Tarrant County	Village Ck at Everman, TX
Main Stem	08049500	11081	Lat 32°45'46", long 96°59'42", Dallas County	W Fk Trinity Rv at Grand Prairie, TX
Main Stem	08050100	10815	Lat 32°44'51", long 96°55'32", Dallas County	Mountain Ck at Grand Prairie, TX

Table 1.3 Pairwise correlations for discharge time series (ln transformed data)			
	10786	**11081**	**10815**
10938	0.514	0.733	0.471
10786		0.657	0.520
11081			0.692

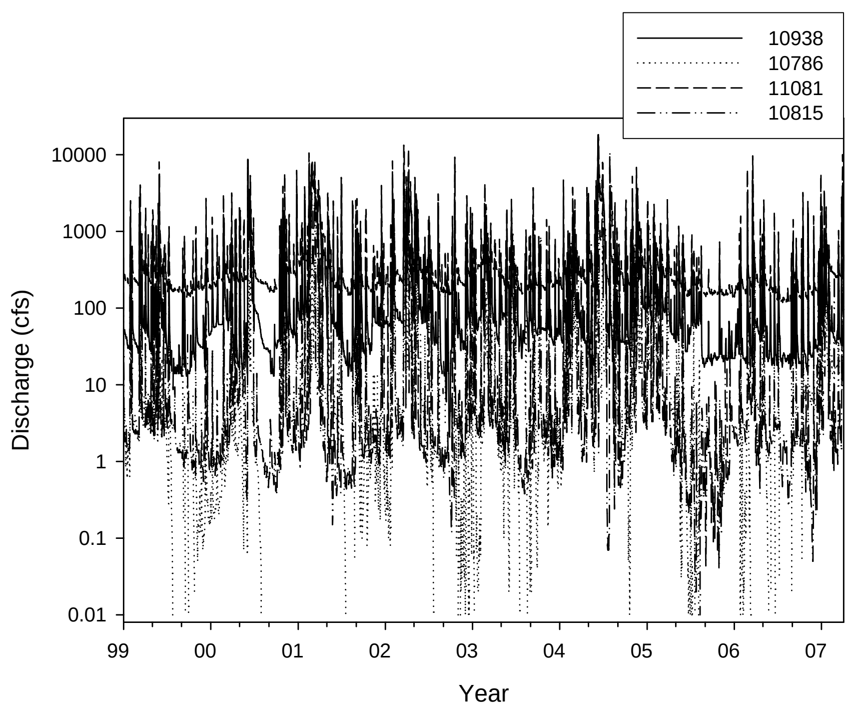

Fig. 1.1 Discharge at gauged stations, Jan. 1, 1999 to Apr. 4, 2007.

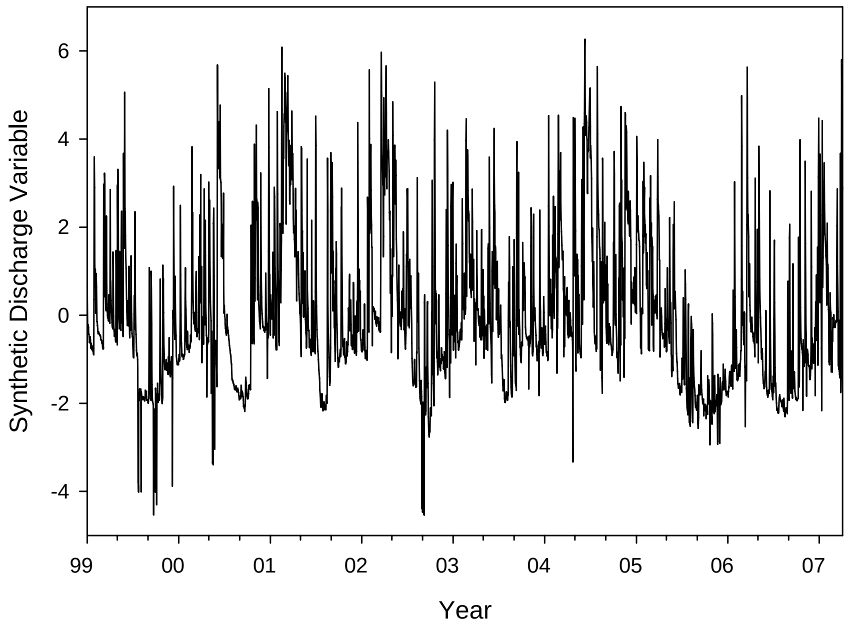

Fig. 1.2 Synthetic discharge variable, calculated by Principal Components Analysis to represent regionally coherent patterns of discharge variation.

2. Analysis of Location Statistics.

Location statistics calculated for all selected parameters at all stations included the mean, median, standard deviation, minimum, maximum and quartiles. The extensive tables summarizing these results are presented in Appendix 1. In this narrative, attention is called to those stations where either the mean or the median of the parameter exceeds levels of concern. The corresponding entries in the tables in the Appendix are highlighted, and the statistics are also reported in this narrative for convenience. The 2006 Draft Guidance for Assessing and Reporting Surface Water Quality in Texas (TCEQ) provides screening levels for four of the parameters analyzed here (Table 2.1). For turbidity and TKN, high values indicate concern, but there are no established screening levels. For these parameters, sites with notably high mean or median values are noted. Two remaining parameters (temperature and flow severity) are included in this report primarily to enhance the characterization of the sites from which data were obtained, and are not generally quantities for which there is direct water quality concern. Although summary statistics are provided in the appendix, they are not discussed in this section.

Table 2.1 Screening levels for selected water quality parameters

Parameter	**Screening Level**
00630 NO_3/NO_2*	1.95 mg / liter
00665 TP	0.69 mg / liter
31699 *E. coli*	126 colonies / 100 ml
32211 Chl-*a*	14.1 μg / liter

*Screening level for NO_3 was used.

For NO_3/NO_2, all sites in Arlington had mean and median values below the screening level of 1.95 mg / liter. This parameter was not measured for sites in Fort Worth, and insufficient data were available from sites in Irving. In Grand Prairie, all but one site had mean and median values below the screening level. Station 17669 was the exception, with mean and median values well above the screening level (Table 2.2). That the lower quartile also exceeds the screening level indicates that NO_3/NO_2 concentrations exceeding levels of concern are very frequent at this site.

Station 17669 in Grand Prairie is on the lower West Fork of the Trinity River at Roy Orr Boulevard. All of the other sites for which NO_3/NO_2 data are available are from much smaller streams with smaller watersheds. While Ft. Worth and Irving both have stations on the West Fork of the Trinity River, no or insufficient data are available to confirm the high values reported from station 17669.

Table 2.2 Sites of concern for NO_3/NO_2	
Station →	**Grand Prairie 17669**
N	15
Mean	6.96
SD	5.15
Min	0.04
Lo Quart	2.72
Median	6.76
Hi Quart	10.58
Max	18.00

For TP, all sites in Arlington had mean and median values below the screening level of 0.69 mg / liter. This parameter was not measured for sites in Fort Worth. In Grand Prairie, all but one site had mean and median values below the screening level. Station 17669 was the exception, with mean and median values above the screening level (Table 2.3). Likewise, in Irving all but one site had mean and median values below the screening level. Station 11080 was the exception, with mean and median values above the screening level (Table 2.3). That the lower quartile is near or exceeds the screening level at these sites indicates that TP concentrations exceeding levels of concern are very frequent at both sites.

Station 17669 in Grand Prairie is on the lower West Fork of the Trinity River, as is station 11080 (at MacArthur Boulevard). Station 17669 is downstream of the Village Creek WWTP and station 11080 is further downstream. Most of the other sites for which TP data are available are from much smaller streams with smaller watersheds. In Irving, there are two stations on the Elm Fork of the Trinity River (17162 and 17163) which also have large watersheds. However, TP levels at these two stations are comparable to those found at smaller streams. This result suggests that high TP is likely restricted to the West Fork.

Table 2.3 Sites of concern for TP		
Station →	**Grand Prairie 17669**	**Irving 11080**
N	19	31
Mean	1.12	0.91
SD	0.54	0.40
Min	0.34	0.22
Lo Quart	0.72	0.60
Median	1.03	0.90
Hi Quart	1.54	1.15
Max	1.99	1.67

For *E. coli*, the screening level of 126 colonies / 100 ml is conventionally used with the geometric mean due to the high skew of such data. Here the median was used, which has similar statistical properties for skewed data. Many sites in all municipalities had median values above the screening level (Table 2.4).

In Arlington and Grand Prairie, there are no obvious characteristics that distinguish sites with medians that exceed the screening level. These sites have a wide range of stream and watershed sizes, but none are on the West Fork of the Trinity River. Likewise, in Irving, all but one of the stations with medians exceeding the screening level are in small to medium watersheds with varying land use. The one station in Fort Worth with a median exceeding the screening level is on a small stream. Only one station on either the West or the Elm Fork of the Trinity River had a median exceeding the screening level, station 11080 in Irving. By comparison, many of the smaller stream sites have much larger and more frequent exceedances of the screening level. High *E. coli* levels thus appear to be a greater concern in small to medium streams than at the large river sites analyzed here.

Table 2.4 Sites of concern for *E. coli*

Station →	Arlington 10719	Arlington 10721	Arlington 10722	Arlington 10723	Arlington 10724
N	15	15	15	15	15
Mean	623	630	441	920	357
SD	889	1283	900	2000	377
Min	81	4	17	34	8
Lo Quart	193	116	37	96	60
Median	245	158	134	242	207
Hi Quart	644	263	242	651	568
Max	3470	4840	3470	7940	1160

Table 2.4 Sites of concern for *E. coli* (cont.)

Station →	Arlington 10791	Arlington 10792	Arlington 17190	Arlington 17191	Fort Worth 17369
N	15	15	15	14	70
Mean	496	531	656	593	1796
SD	1215	1200	1276	1305	9741
Min	2	4	45	6	4
Lo Quart	66	138	61	72	92
Median	139	182	158	130	229
Hi Quart	314	371	497	162	597
Max	4840	4840	4840	4840	81640

Table 2.4 Sites of concern for *E. coli* (cont.)

Station →	Grand Prairie 10867	Grand Prairie 13621	Grand Prairie 17671	Grand Prairie 17672	Grand Prairie 17674
N	53	53	45	50	53
Mean	803	593	1700	1008	904
SD	1365	1131	2549	1458	1416
Min	6	24	43	13	22
Lo Quart	70	111	198	48	140
Median	160	198	651	230	271
Hi Quart	520	387	1540	1705	821
Max	4838	4840	12000	4840	4840

Table 2.4 Sites of concern for *E. coli* (cont.)					
Station →	**Grand Prairie 17675**	**Grand Prairie 17677**	**Grand Prairie 17679**	**Grand Prairie 17683**	**Irving 10866**
N	54	54	51	53	36
Mean	1289	625	907	1735	875
SD	2312	1067	2605	1853	1455
Min	51	37	6	8	10
Lo Quart	177	134	81	280	65
Median	372	232	159	922	144
Hi Quart	1003	341	359	3110	911
Max	12000	4840	17300	6490	4840

Table 2.4 Sites of concern for *E. coli* (cont.)					
Station →	**Irving 10871**	**Irving 11080**	**Irving 15624**	**Irving 17165**	**Irving 17166**
N	12	33	36	35	34
Mean	2727	417	2813	1531	1442
SD	2896	696	4021	1573	1556
Min	17	13	76	19	99
Lo Quart	125	62	719	313	412
Median	2675	216	2025	651	733
Hi Quart	4188	409	3588	2830	1855
Max	9700	3470	24200	4840	4840

Table 2.4 Sites of concern for *E. coli* (cont.)					
Station →	**Irving 17172**	**Irving 17174**	**Irving 17175**	**Irving 17176**	**Irving 17177**
N	37	37	35	36	34
Mean	682	1208	2168	1222	1620
SD	1321	1663	1784	2022	1899
Min	1	17	76	1	2
Lo Quart	42	82	604	97	183
Median	215	344	1730	356	447
Hi Quart	498	1230	3810	1254	2983
Max	4840	4840	4840	9700	4840

Table 2.4 Sites of concern for *E. coli* (cont.)					
Station →	**Irving 17178**	**Irving 17179**	**Irving 17938**	**Irving 17939**	**Irving 18314**
N	38	34	25	26	25
Mean	970	2248	346	1301	1075
SD	1466	4317	434	1430	1565
Min	1	6	19	48	32
Lo Quart	24	90	78	477	167
Median	149	415	172	821	242
Hi Quart	1175	3200	449	1413	959
Max	4840	24200	1540	4838	4840

For Chl-*a*, all sites in Arlington had mean and median values below the screening level of 14.1 μg / liter. This parameter was not measured for sites in Fort Worth. In Grand Prairie, three sites had mean and median values above the screening level, and in Irving nine sites had mean and median values above the screening level (Table 2.5). Only four of the sites with mean values above the screening level also had median values above the screening level. Thus for 75% of the sites with high Chl-*a*, values exceeding the screening level occurred for less than 50% of the observations.

One of the stations in Grand Prairie (17684) with high Chl-*a* is in the Mountain Creek Arm of Joe Pool Lake, and applying the higher screening level of 26.7 mg / liter for reservoirs would not designate this as a high Chl-*a* site. Two of the stations in Irving with high Chl-*a* are on the Elm Fork of the Trinity River (17163 and 17164). An additional site on the West Fork in Grand Prairie (17669) has relatively high Chl-*a*, although only the maximum exceeds the screening level. These observations suggest that sites on larger rivers with broad channels are especially prone to high Chl-*a*, possibly as a result of better light conditions for algal growth than narrow, shaded channels. Unfortunately, Chl-*a* was not measured at the West Fork sites in Fort Worth. The remaining stations with high Chl-*a* represent a mix of small to medium watersheds. Some have high proportions of grassland, though some are highly developed, but all appear from satellite photos to have relatively open surroundings and little shading. These observations again suggest that favorable light conditions are required for the development of high Chl-*a*.

Table 2.5 Sites of concern for Chl-*a*

Station →	Grand Prairie 10867	Grand Prairie 17680	Grand Prairie 17684	Irving 17163	Irving 17164
N	20	19	20	33	17
Mean	15.3	14.6	17.7	29.6	14.3
SD	25.1	22.9	12.6	78.2	9.8
Min	2.2	0.2	3.6	3.4	2.5
Lo Quart	4.8	3.1	9.0	7.8	7.6
Median	6.2	4.8	14.4	14.2	10.1
Hi Quart	10.5	16.6	22.7	22.9	18.7
Max	90.9	94.1	44.7	461.1	33.5

Table 2.5 Sites of concern for Chl-*a* (cont.)

Station →	Irving 17168	Irving 17170	Irving 17173	Irving 17177	Irving 17178
N	31	33	32	30	33
Mean	17.4	16.1	22.4	20.9	14.6
SD	14.3	10.5	105.1	21.1	19.3
Min	3.3	2.2	0.2	0.5	0.6
Lo Quart	7.0	9.6	1.3	8.0	4.4
Median	14.8	13.1	2.2	12.8	10.1
Hi Quart	24.2	22.6	3.8	26.4	16.0
Max	71.1	49.0	597.6	95.5	106.6

Table 2.5 Sites of concern for Chl-*a* (cont.)

Station →	Irving 17179	Irving 18359
N	31	25
Mean	15.5	19.1
SD	24.5	13.5
Min	0.2	0.2
Lo Quart	2.6	11.2
Median	5.6	16.2
Hi Quart	13.6	22.4
Max	101.9	57.5

For TKN, there is no established screening level. Both TP and TKN are often interpreted as representing organic nutrients bound in microbial biomass. Since microbial, especially algal, biomass often has a molar N:P ratio of about 16, the screening level for TP (0.69 mg / liter) is the biomass equivalent of about 5 mg / liter of TKN. This conversion is calculated by noting that 0.69 mg TP / liter is equivalent to 0.022 mmol P / liter. If the microbial N:P ratio of 16 applies, biomass with this amount of P would contain 0.36 mmol N / liter, which is equivalent to 4.99 mg N / liter. Using the criterion of 5 mg / liter, no stations were characterized by high TKN. That is, the amounts of TKN found at these sites are not at the high levels that would be associated with undesirable amounts of algal or microbial biomass.

For Turbidity, there is no established screening level. High Turbidity can inhibit feeding of fish, detracts from the aesthetic value of water, and can be correlated to high bacterial contamination or algal abundance. Turbidity levels that can inhibit fish feeding vary widely in a range of about 30 – 100 NTU. Therefore, a value of 50 NTU, roughly in the middle of this range associated with effects on fish, was adopted as a screening level here. Turbidity was measured only for stations in Fort Worth and Grand Prairie. Only one site was found to have mean and median Turbidity exceeding the screening level adopted here (Table 2.6). This site is in the Mountain Creek Arm of Joe Pool Lake. It had high Chl-*a*, a potential cause of Turbidity, and given that it is in a shallow part of a reservoir, events of sediment resuspension are also likely. Among all other sites where both Turbidity and Chl-*a* were measured, there was a significant positive correlation among station means for these parameters ($r = 0.63$, $P = 0.002$). This relationship supports the suggestion that algal abundance contributes to Turbidity.

Table 2.6 Sites of concern for Turbidity

Station →	**Grand Prairie 17684**
N	54
Mean	68.8
SD	48.8
Min	0.0
Lo Quart	39.2
Median	59.8
Hi Quart	85.8
Max	303.0

3. Analysis of Trends.

Trends were calculated for all selected parameters at all stations with sufficient data for such an analysis. Simple linear regression was used for Water Temperature, Flow Severity, and Turbidity, while regression of natural logarithms was used for the remaining parameters. Transformation to natural logarithms has been found necessary for analyzing trends in these parameters in similar studies, such as the most recent Basin Summary Report, and the data analyzed here had sufficient skew and heteroscedasticity to warrant such a transformation. ("Heteroscedasticity" refers to any change in the variance of a parameter with the mean of the parameter. In regression modeling to detect trends, the mean of a parameter is represented as a linear function of time, either increasing or decreasing. Regression calculations assume that variance of the data around this trend line is the same at all times. For some water quality parameters, this is not case. Skewed data commonly have higher variance around the trend line for higher values of the parameter. For example, an increasing trend for skewed data is usually accompanied by an increasing spread of the data points. Transformation to natural logarithms is a common statistical procedure to eliminate this problem, since logarithms of the data are typically less skewed than the original data.)

Transformation to natural logarithms changes the interpretation of the slope of a trend. Without such a transformation, the slope measures the rate of trend, in parameter units per unit time. After transformation, the slope indicates the proportional rate of change in the parameter per unit time. For these regression calculations, time was indexed in months. For interpretation, it is convenient to convert a slope for ln-transformed data to the corresponding monthly percentage rate of increase or decrease, calculated as [exp(slope) – 1] X 100. A corresponding doubling time (for increases) or half-life (for decreases) can also be calculated as ln 2 / slope. The doubling time (or half-life) conveys how long it would take for a two-fold change to occur, if the current trend in a parameter persisted. A short time indicates a rapid trend. The extensive tables summarizing the results of trend analyses are presented in Appendix 2. In this narrative, attention is called to those stations where a statistically significant ($P < 0.05$) trend was detected. The corresponding entries in the tables in the Appendix are highlighted, and the statistics are also reported in this narrative for convenience.

Trends in Water Temperature and Flow Severity were analyzed primarily to determine the potential meteorological and hydrological changes occurring during the period of observations. No statistically significant trends were found for Water Temperature. Two stations in Arlington and five in Fort Worth had significant decreases in Flow Severity (Table 3.1). In contrast, two stations in Grand Prairie and one in Irving had significant increases in Flow Severity. The stations with significant decreases are all medium to large streams in the western metroplex with watershed areas exceeding 20 square miles. Discharge data summarized above indicate drier conditions in the later part of the time periods involved, from about the middle of 2005, possibly accounting for these reductions in flow severity. The stations with significant increases are in the central-eastern metroplex, and two have small watershed areas (< 20 square miles). Possibly, the general reduction in rainfall and discharge over time is stronger in the western metroplex than the eastern, and is more evident in larger watersheds that integrate over many localized variations. Flow Severity could also change due to hydrological alterations such as channelization or construction in the watershed. Flow Severity is judged subjectively relative to “normal” conditions and thus could also vary due to changes in personnel or their experience. One station with a statistically significant increase is the one in the Mountain Creek Arm of Joe Pool Lake (Grand Prairie 17684). Personnel sampling this site apparently assigned flow severity as an index relative to the normally expected lake level, but the resulting data likely are not comparable to stream data.

Table 3.1 Significant trends in Flow Severity

Station →	Arlington 10780	Arlington 17189	Forth Worth 10938	Fort Worth 16120	Fort Worth 17368
Slope	-0.022	-0.025	-0.016	-0.013	-0.013
Std Error	0.008	0.010	0.005	0.005	0.005
T	2.749	2.349	3.181	2.536	2.739
df	20	18	65	65	65
P	0.012	0.030	0.002	0.014	0.008

Table 3.1 Significant trends in Flow Severity (cont.)

Station →	Fort Worth 17369	Fort Worth 17370	Grand Prairie 17673	Grand Prairie 17684	Irving 17170
Slope	-0.012	-0.009	0.011	0.029	0.019
Std Error	0.006	0.004	0.005	0.007	0.009
T	2.024	2.072	2.054	4.472	2.115
df	67	67	53	51	37
P	0.047	0.042	0.045	<0.001	0.041

NO_3/NO_2 was not measured for stations in Fort Worth and Irving. No significant trends were detected for NO_3/NO_2 at stations in Arlington. Significant decreases were detected for several stations in Grand Prairie, and a significant increase was found at one station (Table 3.2).

Because regression with natural logarithms was used, the rates of these trends can be characterized by the monthly percentage increase (or decrease) and the corresponding doubling time (or half-life). Stations in Grand Prairie with decreasing NO_3/NO_2 display monthly percentage decreases of 6-16%, corresponding to half-lives of 4-11 months. These trends are in the direction of improving water quality. The station with an increase displays an monthly percentage increase of 16%, corresponding to a doubling time of 4.6 months. This trend is of greater concern, because it is in the direction of declining water quality. Station 17672 in Grand Prairie is a small, intermittent stream with a small watershed in a highly developed industrial/military area. NO_3/NO_2 represents highly mobile ions likely to be transported from watershed sources. The small size of the stream in question likely makes it sensitive to such transport. Although NO_3/NO_2 increased at this site, the average over the period of record was relatively low, and no observations exceeded the screening level used above.

Table 3.2 Significant trends in NO_3/NO_2					
Station →	**Grand Prairie 10815**	**Grand Prairie 10867**	**Grand Prairie 13621**	**Grand Prairie 17663**	**Grand Prairie 17672**
Slope	-0.166	-0.137	-0.119	-0.113	0.151
Std Error	0.051	0.043	0.036	0.043	0.047
T	3.238	3.182	3.340	2.612	3.215
df	15	14	15	14	13
P	0.006	0.007	0.004	0.020	0.007

Table 3.2 Significant trends in NO_3/NO_2 (cont.)					
Station →	**Grand Prairie 17676**	**Grand Prairie 17677**	**Grand Prairie 17679**	**Grand Prairie 17680**	**Grand Prairie 17681**
Slope	-0.111	-0.098	-0.152	-0.169	-0.064
Std Error	0.036	0.042	0.044	0.072	0.030
T	3.066	2.357	3.470	2.347	2.163
df	15	15	14	14	15
P	0.008	0.032	0.004	0.034	0.047

Table 3.2 Significant trends in NO_3/NO_2 (cont.)	
Station →	**Grand Prairie 17682**
Slope	-0.096
Std Error	0.031
T	3.128
df	14
P	0.007

TKN was not measured for stations in Fort Worth. No significant trends were detected for TKN at stations in Arlington or Grand Prairie. Significant increases were detected for several stations in Irving (Table 3.3). Stations in Grand Prairie with increasing TKN display monthly percentage increases of 1.0-3.3%, corresponding to doubling times of 21-46 months. None of these stations had mean, median or maximum levels of TKN that exceeded the value of 5 mg / liter taken above as a suggested screening level. These trends are of concern, however, because they are in the direction of declining water quality. Sites with increasing TKN represent a mix of watershed sizes from very small intermittent streams to the Elm Fork of the Trinity River. Many are near major highways.

Table 3.3 Significant trends in TKN					
Station →	**Irving 10866**	**Irving 17162**	**Irving 17164**	**Irving 17168**	**Irving 17173**
Slope	0.027	0.027	0.032	0.020	0.025
Std Error	0.007	0.006	0.007	0.007	0.007
T	3.672	4.384	4.710	2.941	3.686
df	28	29	12	30	29
P	0.001	<0.001	0.001	0.006	0.001

Table 3.3 Significant trends in TKN (cont.)			
Station →	**Irving 17174**	**Irving 17175**	**Irving 17178**
Slope	0.015	0.021	0.019
Std Error	0.007	0.007	0.006
T	2.164	2.878	2.994
df	31	26	26
P	0.038	0.008	0.006

TP was not measured for stations in Fort Worth. Significant increases were detected for one station in Arlington, four stations in Grand Prairie, and two stations in Irving (Table 3.4). Stations in Arlington and Grand Prairie with increasing TP display monthly percentage increases of 1.1-1.9%, corresponding to doubling times of 36-63 months. Stations in Irving with increasing TP display more rapid trends, with monthly percentage increases of 4.1-5.7%, corresponding to doubling times of 13-17 months. None of these stations had mean, median or maximum levels of TP that exceeded the screening level for TP (except station 18314 in Irving, where the maximum value was 0.70 mg / liter, just above the screening level of 0.69 mg / liter). These trends are of concern, however, because they are in the direction of declining water quality.

Many of the sites with increasing TP have small watersheds (<8 square miles) with substantial commercial or industrial development (Arlington 10725, Grand Prairie 17673, 17676, 17678, and Irving 18314). Most have had recent construction or commercial development. These observations suggest erosion and sediment loading might have increased, and contributed to rising TP. One station with increasing TP is on the Elm Fork of the Trinity River (Irving 17164), and thus could potentially be affected by trends far upstream. However, stations 17162 and 17163, further upstream on the Elm Fork, displayed weak declines in TP. Between stations 17163 and 17164, the Elm Fork passes through a heavily developed industrial and commercial area, with some evidence of disturbed land or recent construction in satellite photos. The final station with increasing TP is on Mountain Creek just downstream of the Joe Pool Dam (Grand Prairie 17681). Thus it could be influenced by trends within the lake. However, satellite photos show evidence of construction just west of the station, so that again, recent land disturbance and erosion could explain increasing TP.

Table 3.4 Significant trends in TP					
Station →	**Arlington 10725**	**Grand Prairie 17673**	**Grand Prairie 17676**	**Grand Prairie 17678**	**Grand Prairie 17681**
Slope	0.011	0.019	0.019	0.018	0.013
Std Error	0.004	0.007	0.006	0.007	0.005
T	2.881	2.729	3.058	2.609	2.677
df	20	16	17	17	17
P	0.009	0.015	0.007	0.018	0.016

Table 3.4 Significant trends in TP (cont.)		
Station →	**Irving 17164**	**Irving 18314**
Slope	0.040	0.055
Std Error	0.017	0.021
T	2.385	2.660
df	19	20
P	0.028	0.015

For *E. coli*, significant decreases were detected at two stations in Forth Worth, six in Grand Prairie, and one in Irving (Table 3.5). Among all these stations, monthly percentage decreases ranged 2.2-7.3%, corresponding to half-lives of 10-32 months. Most of these stations had mean and median *E. coli* values below the screening level. Three stations with significant decreases had mean and median *E. coli* values exceeding the screening level (Grand Prairie 17677, 17679, Irving 17177), indicating an improvement in water quality with respect to this parameter. A significant increase was detected for one station in Arlington. This station displays an monthly percentage increase of 5.7%, corresponding to a doubling time of 13 months. This station also has mean and median *E. coli* values exceeding the screening level, making the further decline in water quality a concern. In section 2, 35 sites were identified as having high *E. coli*, because median levels exceeded the screening criterion. Most of these sites had no significant trends, while three showed decreases and one showed an increase.

The site in Arlington with increasing *E. coli* (10724) has a small watershed mostly with low density development or open developed land, but also with a small amount of forest. Because the watershed is small and beaver activity has been noted in the area, it is possible that this or other wildlife activity is responsible for the high *E. coli* levels. Grand Prairie stations 17677 and 17679 lie further downstream in this drainage (Fish Creek), both of which had high *E. coli* levels but decreasing trends. The areas immediately upstream of these stations have relatively high proportions of forest, suggesting again that wildlife activity might be responsible for high and variable *E. coli* levels. Station 17177 in Irving is the remaining high *E. coli* site with a significant decrease. It has a relatively small watershed (6.5 square miles) that is fully developed, but which has parkland immediately adjacent to the upstream stream banks, again suggesting wildlife activity. The remaining sites with significant trends in *E. coli* were all sites with relatively low levels that displayed further declines. Watershed sizes and characteristics are highly variable for these sites, which range from small streams (Grand Prairie 17672) to the West Fork of the Trinity River (Forth Worth 10938 and 16120).

Table 3.5 Significant trends in *E. coli*					
Station →	**Arlington 10724**	**Fort Worth 10938**	**Fort Worth 16120**	**Grand Prairie 10867**	**Grand Prairie 13621**
Slope	0.055	-0.026	-0.056	-0.031	-0.022
Std Error	0.025	0.013	0.010	0.015	0.011
T	2.213	2.064	5.330	2.069	2.100
df	13	65	68	51	51
P	0.045	0.043	<0.001	0.044	0.041

Table 3.5 Significant trends in *E. coli*					
Station →	**Grand Prairie 17663**	**Grand Prairie 17666**	**Grand Prairie 17672**	**Grand Prairie 17677**	**Grand Prairie 17679**
Slope	-0.032	-0.042	-0.038	-0.026	-0.031
Std Error	0.015	0.021	0.016	0.010	0.015
T	2.110	2.054	2.374	2.585	2.081
df	51	52	48	52	49
P	0.040	0.045	0.022	0.013	0.043

Table 3.5 Significant trends in *E. coli* (cont.)	
Station →	**Irving 17177**
Slope	-0.070
Std Error	0.025
T	2.838
df	32
P	0.008

Chl-*a* was not measured for stations in Fort Worth. Significant increases were detected for four stations in Grand Prairie, and one in Irving (Table 3.6). Stations in Grand Prairie with increasing Chl-*a* display monthly percentage increases of 2.7-4.6%, corresponding to doubling times of 15-26 months. The station in Irving with increasing Chl-*a* displays a slower trend, with an monthly percentage increase of 1.0%, corresponding to a doubling time of 69 months. For most of these stations the mean and median levels of Chl-*a* were below the screening level. These trends are of concern, however, because they are in the direction of declining water quality. One station, Grand Prairie 17684, had mean and median levels of Chl-*a* exceeding the screening level, along with an increasing trend.

Three of the sites with increasing Chl-*a* (Grand Prairie 17673, 17676, 17679) have small to medium watersheds with substantial grassland or open developed space (>20% of area). Though not characterized as high Chl-*a* sites by the screening level used above, these sites could have sufficient light to develop high algal biomass. One of the sites with increasing Chl-*a* is on the Mountain Creek Arm of Joe Pool Lake (Grand Prairie 17684) and is characterized as a high Chl-*a* site using the screening level for streams, but would not be so characterized by the higher screening level for reservoirs. Nevertheless, the increasing trend suggests that eutrophication may be occurring in this lake. The remaining site with an increasing trend for Chl-*a* is on the West Fork of the Trinity River (Irving 11080), which is not a high Chl-*a* site based on the screening level, but whose broad channel likely provides sufficient light to develop high algal biomass.

Table 3.6 Significant trends in Chl-*a*					
Station →	**Grand Prairie 17673**	**Grand Prairie 17676**	**Grand Prairie 17679**	**Grand Prairie 17684**	**Irving 11080**
Slope	0.032	0.045	0.042	0.027	0.010
Std Error	0.014	0.010	0.016	0.007	0.004
T	2.259	4.627	2.712	3.631	2.320
df	17	18	17	18	28
P	0.037	<0.001	0.015	0.002	0.028

Turbidity was not measured for stations in Arlington and Irving. A significant increase was detected for one station in Fort Worth (Table 3.7). This site had mean and median Turbidity levels below the screening level used above, and this trend is in the direction of improving water quality. The station in question is on the West Fork of the Trinity River.

Table 3.7 Significant trends in Turbidity	
Station →	**Fort Worth 10938**
Slope	-0.269
Std Error	0.081
T	3.333
df	62
P	0.001

4. Analysis of Coherence.

This analysis was undertaken to assess whether variations in selected water quality parameters are coherent. Coherence is a measure of the strength of correlation among variables measured over time at different locations. The available data are for a parameter aligned by sampling time, and the correlation coefficient is calculated for all possible pairs of locations. Coherence is then computed as the average of these pairwise correlations. Mathematically, coherence can vary from -1 to +1, but in practice most values vary from near zero to +1. When coherence approaches the upper limit of +1, variations in the data from different locations are highly correlated, and the time series from each location resemble each other strongly. For regions the size of the DFW metroplex, coherence is usually high for meteorological and geophysical parameters, such as water temperature that are strongly related to regional climate and seasonal variations. When coherence is near zero, this indicates that the parameter varies independently at each location, suggesting that localized factors unique to each location influence the parameter. Biological parameters such as Chl *a* often show such low coherence. Intermediate values of coherence indicate that some locations behave similarly, while others display different patterns.

A coherence analysis was conducted separately for data from each municipality, because municipalities had varying sampling schedules for the various parameters. The analysis assumes that data from different locations have been sampled at the same time. Sampling was monthly or quarterly, and it was straightforward to align data from different stations by sampling time. In some cases, samples were taken a few days apart, but all data were collected within the span of one week. Where data was sufficient, a coherence analysis was also conducted for all data pooled, to extend the regional coverage across multiple municipalities. For this pooled analysis, sampling times were aligned by month, and samples aligned at the same month were in some cases up to three weeks apart. This deviates from the assumptions of coherence analysis, in a fashion that is most likely to reduce calculated coherence below its true value. Many of the data series contained missing values, so the number of samples involved in each pairwise correlation entering the coherence analysis varied. For this reason, the range of sample sizes (N) is presented for each coherence.

Coherences were high for Water Temperature (Table 4.1), 0.88 or higher, which is expected because this parameter is strongly influenced by regional meteorology and seasonality. Essentially, all stations showed the same variation over time in water temperature. Coherences were intermediate Flow Severity. Although this parameter is also influenced by regional meteorology and seasonality, there are differences among stations in their patterns of variation. Possibly, these differences result from differences in watershed and channel characteristics that affect flow. Turbidity was measured in two municipalities and were found to be rather low. This indicates a high degree of independent variation among stations due to localized factors. Turbidity is potentially influenced by flow, erosion, and biological productivity. Thus it is not surprising that localized variations are found.

Table 4.1 Coherence for geophysical parameters						
	00010 Temperature		01351 Flow Severity		82078 Turbidity	
City	**Coherence**	**N-range**	**Coherence**	**N-range**	**Coherence**	**N-range**
Arlington	0.881	17 – 22	0.463	18 – 22	Not done	Not done
Ft. Worth	0.972	19 – 66	0.535	18 – 67	0.221	19 – 65
Grand Prairie	0.937	17 – 56	0.431	17 – 56	0.183	17 – 55
Irving	0.905	3 – 37	0.215	3 – 40	Not done	Not done
All	0.874	10 - 63	0.198	3 – 65	0.125	8 – 62

Data for nutrient parameters were moderately to highly skewed, and so were transformed to natural logarithms for the trend analysis. It is less clear whether such transformation is appropriate for coherence analysis. Mathematically, the transformation reduces the influence of extreme observations in the calculation of coherence. For nutrient parameters, coherences are presented for both raw data and transformed data (Table 4.2), and values were generally similar for both analyses. Coherences for nitrogen parameters (TKN and NO_3/NO_2) were intermediate (0.2-0.6), as was coherence for TP in Arlington. In the other municipalities, coherence for TP was low (<0.18). These results indicate that localized factors influence variations in nutrients, especially for TP. Wastewater or other discharges could be a local source of both nitrogen and phosphorus. For nitrogen, atmospheric deposition is another likely source, and because it is likely to be similar across the metroplex region, atmospheric deposition could act to raise the coherence of nitrogen parameters. For phosphorus, erosion and sediments are a likely source, and this factor is more localized and likely to reduce the coherence of TP.

Table 4.2 Coherence for nutrient parameters												
	00625 TKN (raw)		00265 TKN (ln)		00630 NO_3/NO_2 (raw)		00630 NO_3/NO_2 (ln)		00665 TP (raw)		00665 TP (ln)	
City	**Coherence**	**N-range**	**Coherence**	**N-range**	**Coherence**	**N-range**	**Coherence**	**N-range**	**Coherence**	**N-range**	**Coherence**	**N-range**
Arlington	0.436	18 – 22	0.527	18 – 22	0.600	19 – 22	0.522	19 – 22	0.216	19 – 22	0.275	19 – 22
Ft. Worth	Not done	Not done	Not done	Not done	Not done	Not done	Not done	Not done	Not done	Not done	Not done	Not done
Grand Prairie	0.304	6 – 18	0.308	6 – 18	0.224	5 – 17	0.300	5 – 17	0.112	6 – 19	0.183	6 – 19
Irving	0.202	3 – 22	0.255	3 – 22	Not done	Not done	Not done	Not done	0.057	3 – 37	0.065	3 – 37
All	0.169	3 – 30	0.197	3 – 30	Not done	Not done	Not done	Not done	0.024	3 – 37	0.048	3 - 37

Data for biological parameters were also moderately to highly skewed, and thus coherences are presented for both raw data and transformed data (Table 4.3). Coherences for *E. coli* were intermediate (0.12-0.51), which is unexpected for biological parameters since there are usually many localized factors that affect biological dynamics. Growth and survival of bacteria is strongly temperature dependent, and thus regional variations in meteorology and seasonality could tend to synchronize bacterial dynamics sufficiently to produce moderate coherences. Coherences for Chl *a* were generally low (<0.22), indicated a strong influence of localized factors, as expected for biological parameters.

Table 4.3 Coherence for biological parameters

	31699 *E. coli* (raw)		**31699 *E. coli* (ln)**		**32211 Chl *a* (raw)**		**32211 Chl *a* (ln)**	
City	**Coherence**	**N-range**	**Coherence**	**N-range**	**Coherence**	**N-range**	**Coherence**	**N-range**
Arlington	0.463	14 – 15	0.370	14 – 15	-0.045	19 – 22	0.035	19 – 22
Ft. Worth	0.414	18 – 71	0.506	18 – 71	Not done	Not done	Not done	Not done
Grand Prairie	0.260	17 – 54	0.325	17 – 54	0.134	7 – 20	0.216	7 – 20
Irving	0.122	8 – 38	0.204	8 – 38	0.052	4 – 33	0.078	4 – 33
All	0.118	5 – 65	0.153	5 - 65	0.121	3 – 35	0.149	3 – 35

5. Principal Components Analysis (PCA)

Principal components analysis calculates synthetic variables, called factors, that summarize the variation in the data set, constructed to that the largest percentage of variation is represented by the first factor. Then, under the constraint that the second factor must be uncorrelated with the first, the second factor is constructed to represent the largest percentage of the remaining variation possible. Under the constraint that the third factor must be uncorrelated with the first and second factors, the third factor is constructed to represent the largest percentage of the remaining variation possible. Subsequent axes are constructed in a similar fashion. As a result, the total variation in the data is partitioned among the factors so that the first factor represents the largest proportion of total variation, with each successive factor representing lower proportions.

The first few factors usually account for a majority of total variation, and scores along these factors can be calculated for each site, so that when these scores are plotted, clusters of points represent sites with similar patterns of variation. When successful, these clusters of sites share patterns of variation that can be interpreted and perhaps related to local characteristics or historical events shared among sites. For the analyses reported here, plots of scores for the first two factors were examined. The identification of clusters on such graphs is necessarily subjective. This is a potential disadvantage of the method, as is the subjectivity of interpreting the basis for such clusters.

This analysis requires a matrix of time-by-site data without missing values. This was constructed with a stepwise procedure to eliminate sites (columns) and times (rows) with high proportions of missing values: (1) calculate the proportion of missing values in each row and column; (2) remove the row or column with the highest proportion; and (3) repeat until the matrix has no missing values. The principal components analysis was then calculated from the correlations among sites.

Principal components analysis was conducted for the selected water quality parameters (Table 1.1) within each municipality. Differences in sampling schedules among municipalities made it impossible to assemble pooled data sets, due to the requirement of no missing values explained above.

The results of these analyses are very extensive and are contained in electronic appendices, in the form of Excel spreadsheets. For the sake of brevity, two examples of PCA results are presented in detail, while results for the remaining parameters and municipalities are presented much more concisely. Computations for the PCA analyses were conducted using the program Statistica (StatSoft, Tulsa, OK, version 6), and results tables and graphs are embedded in the Excel spreadsheets provided as electronic appendices with some additional graphs and commentary. Those results are then briefly summarized in this report. PCA is a correlation based method, and as such it can be influenced by the extreme values likely in skewed data sets. For this reason, parameters showing skew were transformed to natural logarithms prior to PCA, and those results are summarized in this report. For such data sets, PCA was also conducted on raw data, and those results are available in the electronic appendices to this report.

Example 1. Parameter 00010 (Water Temperature) in Grand Prairie

This example illustrates the application of PCA to data that are highly coherent, and for which all sites vary in a highly correlated manner. The main advantage of a PCA in such a situation is that it can provide a way of identifying errors not caught by other checks of data quality. After eliminating missing values, the data matrix for this example had 19 sites and 42 times, and the PCA calculated 19 factors. Table 5.1 reports the percentage of total variation represented by the first 5 factors, and the cumulative percentage represented by a given factor and all the previous ones. The proportion of variation represented by the first factor is very high, and subsequent factors add little to the proportion of variation represented by the analysis. This is directly related to the strong coherence among sites, which in turn results directly from the strong correlations between pairs of sites. This behavior is expected for temperature, due to strong seasonal variations that are essentially the same among all sites.

Table 5.1 Variance partitioning for Water Temperature in Grand Prairie

Factor	% Variation	Cumulative % Variation
1	93.4	93.4
2	2.5	95.9
3	1.1	97.0
4	1.0	98.0
5	0.5	98.5

A plot of scores for Factor 1 versus Factor 2 shows one station that differs from all the remaining sites that cluster closely together (Fig. 5.1). All sites are tightly clustered at the left end of the graph, with only one site (17679) in another location. This result suggests that all sites but one share a very similar pattern of variation. Plotting the data for all sites shows immediately that site 17679 has an unusually high initial value that is virtually certain to be a recording error not caught at an earlier stage (Fig. 5.2). When this sampling time is removed from the data set, the analysis is virtually the same, except that site 17679 clusters with all others, showing the very similar variations of temperature among all sites. When the coherence among sites is high, as it is for all these data, the PCA is not very informative, though it does serve as an additional check on data quality, capable of flagging anomalous results.

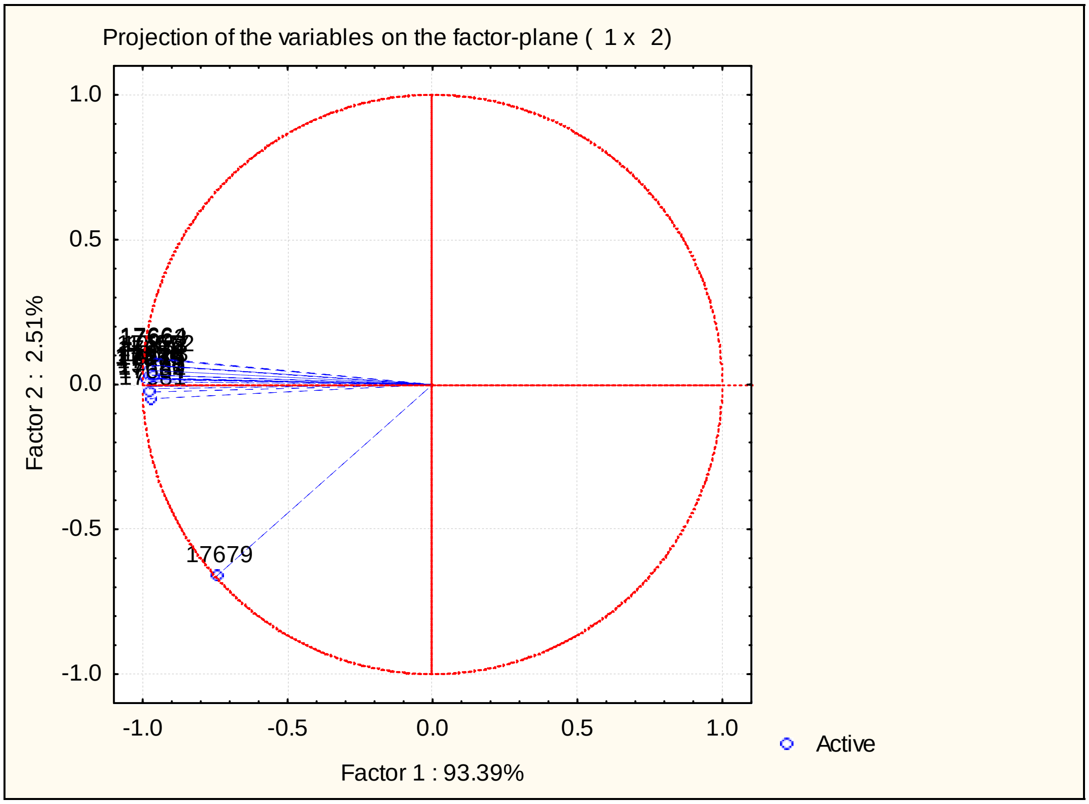

Figure 5.1 PCA scores for Factor 1 vs. Factor 2, Water Temperature in Grand Prairie.

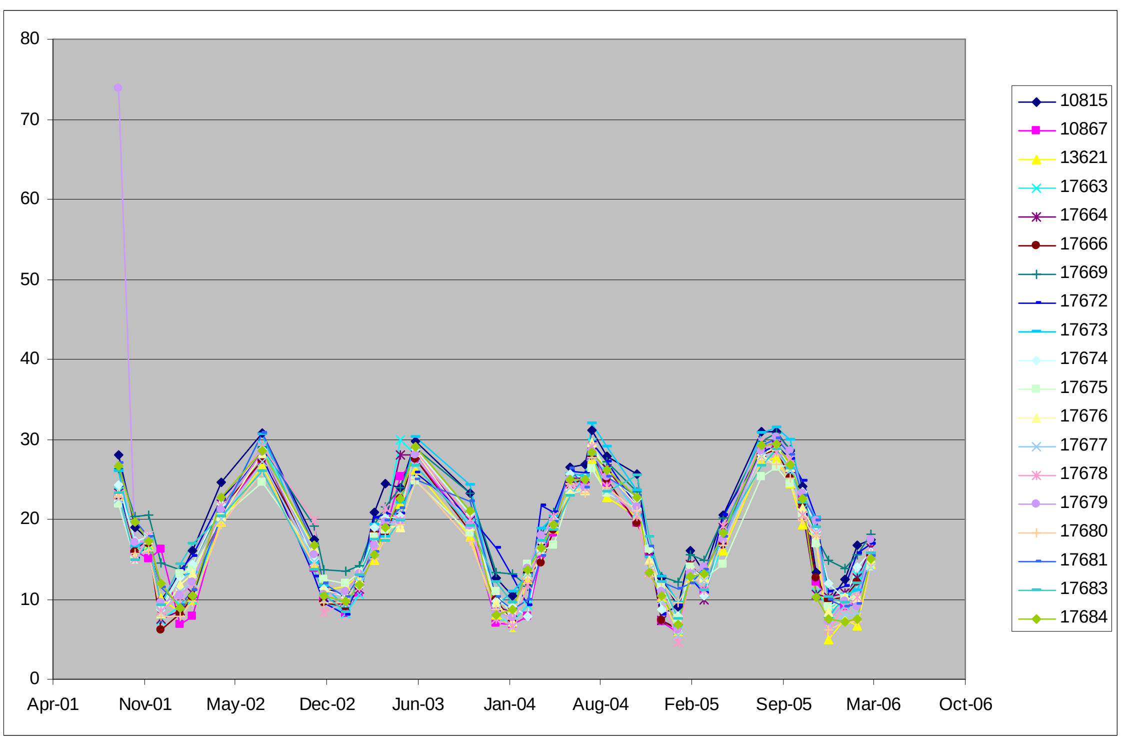

Figure 5.2 Time series of Water Temperature at all sites in Grand Prairie.

Example 2. Parameter 00665 (Total Phosphorus) in Grand Prairie, using natural logarithms

After eliminating missing values, the data matrix for this example had 17 sites and 17 times, and the PCA calculated 17 factors. Table 5.2 reports the percentage of total variation represented by the first 5 factors, and the cumulative percentage represented by a given factor and all the previous ones. In this case, the first factor represents just over a third of the total variation, the first two represent just over half the total variation, and the first five factors represent over 80% of the total variation. Unlike temperature, which had high coherence (>0.9) and highly correlated variations among sites, TP had lower coherence (<0.2) implying weaker correlations among sites. This latter situation implies that the first several factors calculated in the PCA will represent relatively low proportions of total variation.

Table 5.2 Variance partitioning for TP in Grand Prairie

Factor	% Variation	Cumulative % Variation
1	36.9	36.9
2	18.4	55.2
3	11.3	66.5
4	9.2	75.7
5	8.2	83.9

Scores for the first two factors were plotted (Fig. 5.3), and this plot allows identification of four clusters of sites (Table 5.3). The interpretations listed arise from inspecting time series of the parameter value for the sites in the clusters (Figs. 5.4-5.7). Sites in Cluster A all show a decrease during the first year to a period of low values around August 2002, followed by an increase and high variability until about August 2004, followed by a period of lower variability (Fig. 5.4). These sites are spread throughout the region sampled by Grand Prairie. Sites in Cluster B show parallel variations (Fig. 5.5), and are the two northernmost sites in Grand Prairie, located on Bear Creek. Sites in Cluster C show parallel variations (Fig. 5.6), and are both located on tributaries of Mountain Creek Lake. For cluster D the interpretation of their grouping is unclear (Fig. 5.7). Site 17669 is on the Trinity River, and obviously has higher levels than the other three, which are in the Mountain Creek Watershed.

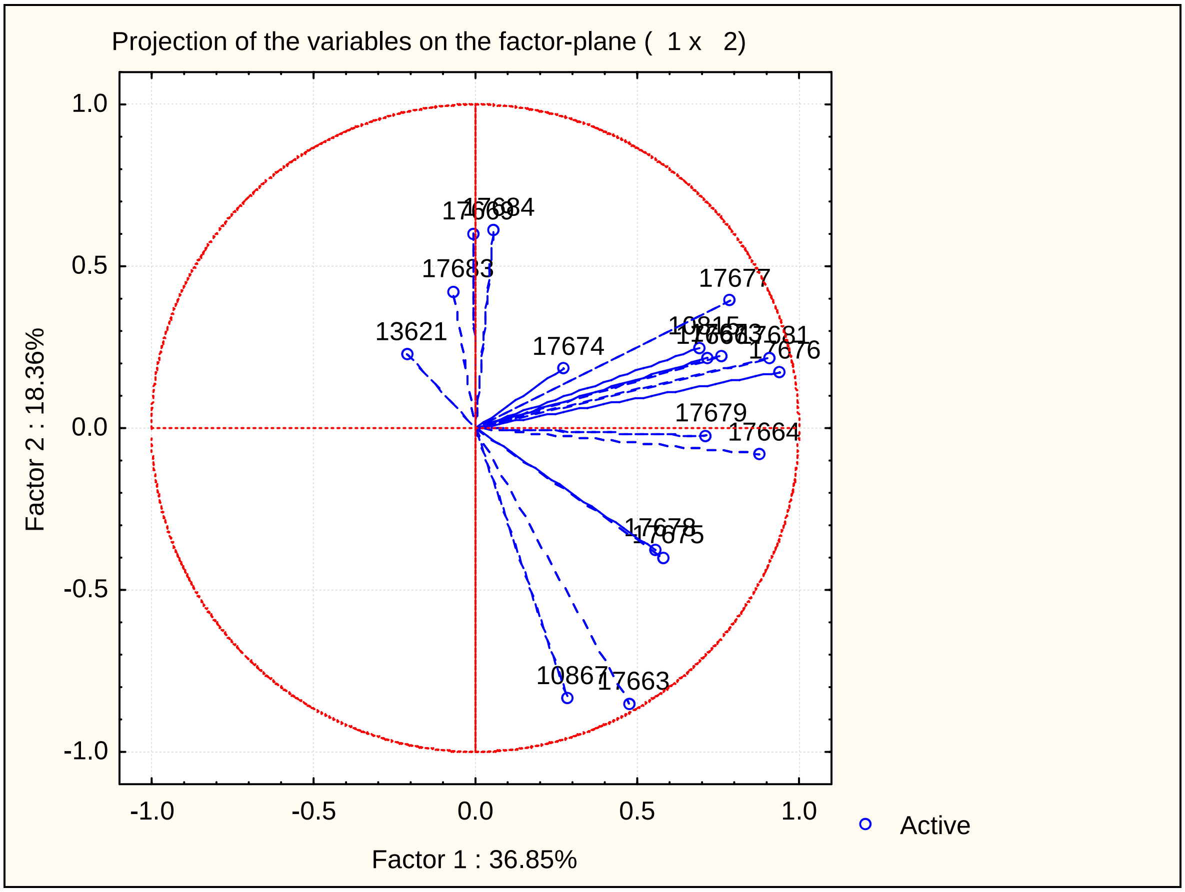

Figure 5.3 PCA scores for Factor 1 vs. Factor 2, TP in Grand Prairie.

Table 5.3 Clusters of sites with similar variation in TP for Grand Prairie		
Cluster	Sites	Interpretation
A	17674, 17677, 10815, 17666, 17673, 17681, 17676, 17679, 17664	Phase of low values around Aug 2002, followed by high variation until Aug 2004, then lower variation.
B	10867, 17663	Parallel variations in the two northernmost sites on Bear Creek.
C	17678, 17675	Parallel variations in the two sites on tributaries of Mountain Creek Lake.
D	13621, 17683, 17669, 17684	Unclear.

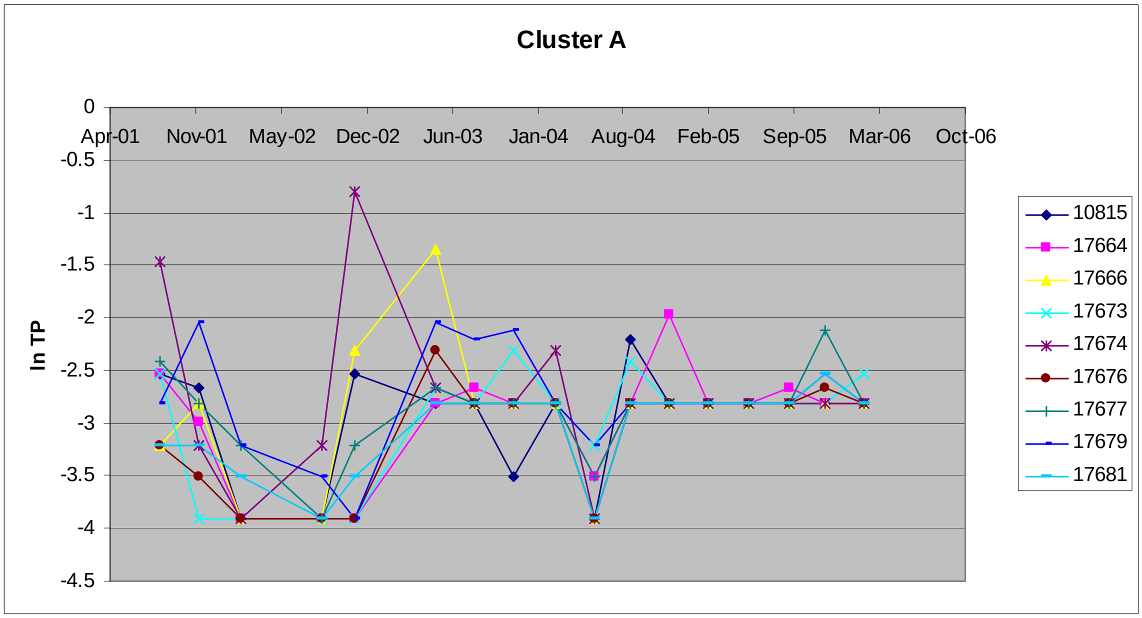

Figure 5.4 Time series of the natural logarithm of TP for sites in Cluster A as identified by PCA for Grand Prairie.

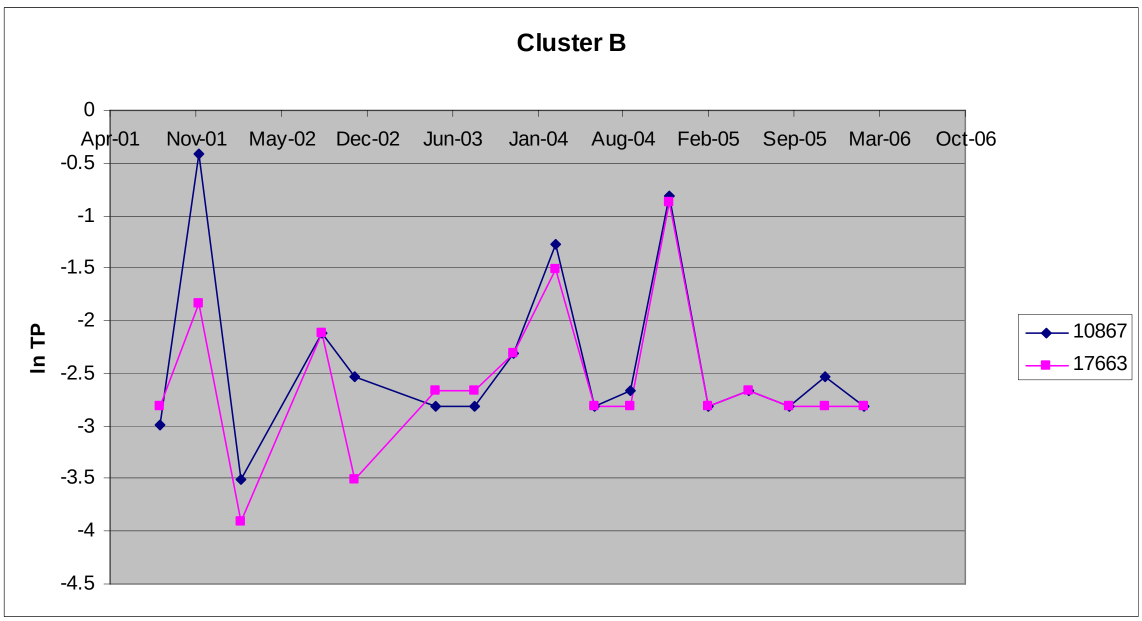

Figure 5.5 Time series of the natural logarithm of TP for sites in Cluster B as identified by PCA for Grand Prairie.

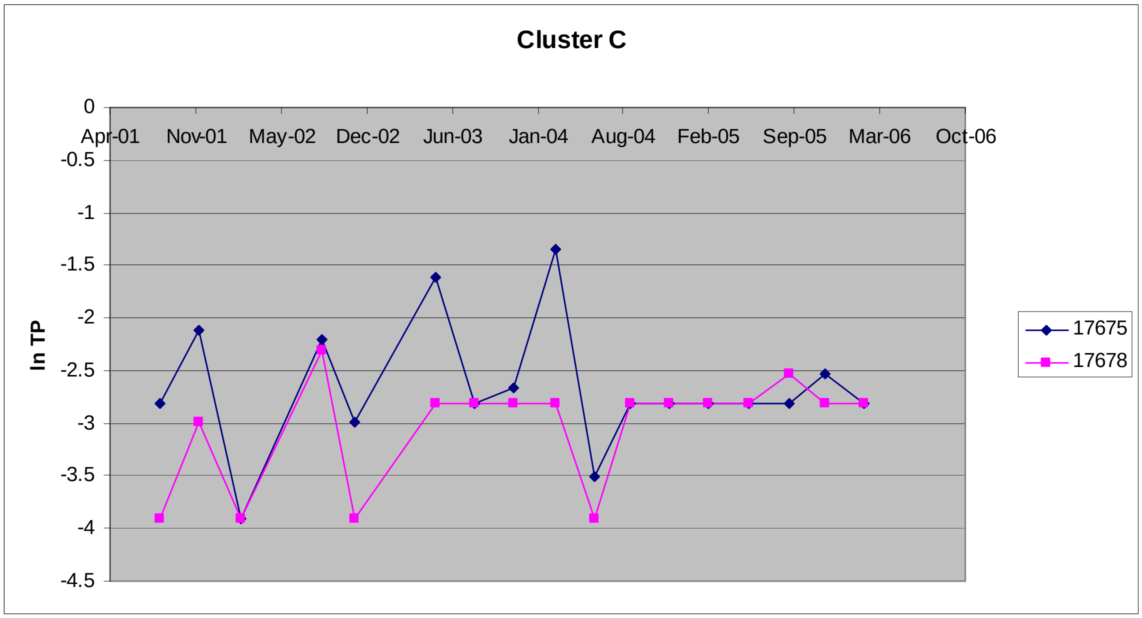

Figure 5.6 Time series of the natural logarithm of TP for sites in Cluster C as identified by PCA for Grand Prairie.

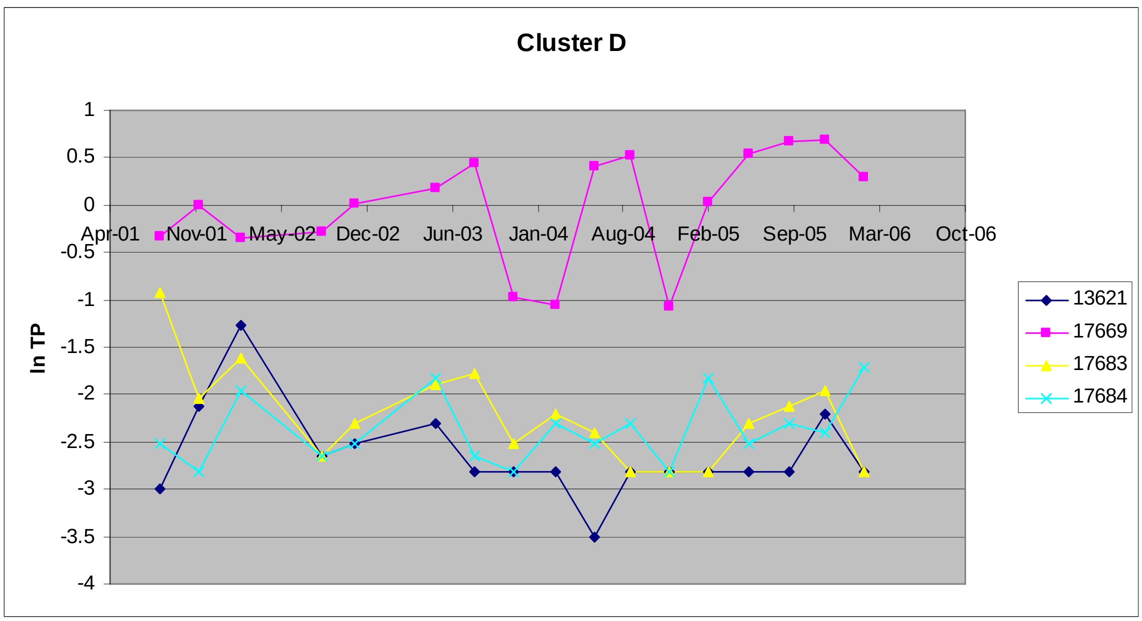

Figure 5.7 Time series of the natural logarithm of TP for sites in Cluster D as identified by PCA for Grand Prairie.

Summary of PCA for parameter 00010 Water Temperature

The number of sites available for this analysis ranged 5-22 among municipalities, and the number of sampling times ranged 16-65 (Table 5.4, note that these samples sizes are smaller than the total data sets, due to the need to remove sites and times with missing values). As noted in Example 1 above, temperature variations are highly coherent, showing essentially the same seasonal and meteorological variations at all sites. Consequently, most of this variation can be summarized by the first factor derived by the PCA, and no meaningful variation is summarized by remaining factors (Table 5.5). Another consequence of high coherence is that no clusters of sites can be delineated within municipalities – all sites essentially form one cluster of sites that share essentially the same variations over time. In all four PCA analyses conducted for temperature, the only exception to this pattern was the single site in Grand Prairie found to have an erroneous observation (as explained in Example 1 above).

Table 5.4 Sample sizes for PCA for 00010 Water Temperature

	Arlington	Ft. Worth	Grand Prairie	Irving
No. Sites	12	5	19	22
No. Times	16	65	42	23

Table 5.5 Variance partitioning for 00010 Water Temperature

	Arlington		Ft. Worth		Grand Prairie		Irving	
Factor	% Var	Cum % Var	% Var	Cum % Var	% Var	Cum % Var	% Var	Cum % Var
1	88.7	88.7	97.6	97.6	93.4	93.4	91.8	91.8
2	3.6	92.3	1.3	98.9	2.5	95.9	2.6	94.4
3	2.8	95.1	0.7	99.6	1.1	97.0	1.4	95.8
4	1.6	96.7	0.3	99.9	1.0	98.0	1.1	96.9
5	1.0	97.8	0.1	100.0	0.5	98.5	0.7	97.6

Summary of PCA for parameter 00625 Total Kjeldahl Nitrogen

This parameter was not measured in Fort Worth. The number of sites available for this analysis ranged 4-21 among remaining municipalities, and the number of sampling times ranged 17-19 (Table 5.6). Cumulatively, the first two factors summarized 49-84% of the variation in TKN for different municipalities (Table 5.7). The first five factors summarized over 70% of the variation in TKN (only four factors could be computed for Arlington, since only four sites were available).

Table 5.6 Sample sizes for PCA for 00625 TKN

	Arlington	Ft. Worth	Grand Prairie	Irving
No. Sites	4	-	15	21
No. Times	18	-	17	19

Table 5.7 Variance partitioning for 00625 TKN

	Arlington		Ft. Worth		Grand Prairie		Irving	
Factor	% Var	Cum % Var	% Var	Cum % Var	% Var	Cum % Var	% Var	Cum % Var
1	64.1	64.1	-	-	36.5	36.5	33.0	33.0
2	19.7	83.7	-	-	16.6	53.1	15.9	48.9
3	10.4	94.2	-	-	10.7	63.8	9.3	58.1
4	5.8	100.0	-	-	8.4	72.2	7.2	65.3
5	-	-	-	-	6.7	78.9	6.5	71.8

In Arlington, a shared pattern of variation characterized all sites, with low and high phases of about 1 yr duration separated by increases and decreases (Table 5.8). A distinct cluster consisting of a single site (10722) was identified, which was the result of a single very high observation in the data from this site. Possibly, this observation is erroneous, because its value of about 2 mg / liter is about 4X the value of the next highest observation. Apart from this one observation, TKN at site 10722 showed similar variations over time to those at other sites in Arlington.

Table 5.8 Clusters of sites with similar variation in TKN for Arlington

Cluster	Sites	Interpretation
A	10719, 10725, 17181	Shared pattern of variation, with low phase Nov. 2001 – Apr. 2002, high phase Apr. 2003 – Apr. 2004, low phase July 2004 – July 2005
B	10722	Possible erroneous observation

In Grand Prairie, four clusters of sites were identified (Table 5.9), which appeared to have geographic patterns. Cluster A consisted of sites mostly north of I-30 which exhibited a phase of high TKN from November, 2003 to February, 2004. Cluster B consisted of sites mostly south of I-30 which had variable values until about 2004, and declines after that. Cluster C consisted of two sites on tributaries of Mountain Creek Lake, which both exhibited a strong increase in TKN until 2004, followed by a strong decline. Cluster D was a single site located on Walnut Creek, distant from other sites, which had a single high observation early in the data series, followed more recently by lower values.

Table 5.9 Clusters of sites with similar variation in TKN for Grand Prairie

Cluster	Sites	Interpretation
A	17664, 17663, 17666, 17678, 10867, 17675	Mostly north of I-30, high phase around Nov. 2003 – Feb. 2004
B	17676, 17673, 17677, 17684, 10815, 17683	Mostly south of I-30, generally declining since 2004, and variable prior to that
C	17674, 17679	Tributaries of Mtn Creek Lake, strong increase prior to 2004, strong decrease after 2004
D	13621	Walnut Creek, high value in Feb. 2003, followed by lower values

In Irving, three clusters of sites were identified (Table 5.10), which some tendency toward a geographic pattern. Cluster A consisted of sites in the Bear Creek watershed which exhibited increasing TKN prior to 2003, high and variable values until June 2004, with decreasing values afterwards. Despite this later decline, significant increases were found for three sites in this cluster (10866, 17173, 17174) in the trend analysis presented above. Cluster B consisted of two upstream sites on Delaware Creek which had variable but generally declining values until March 2003, with increasing values afterwards. One of these sites (17175) had a significant increase in the trend analysis presented above. Cluster C consisted of a mix of sites on Elm Fork tributaries and downstream reaches of Bear Creek and Delaware Creek. These sites were characterized by high variability in TKN since December 2003. Three of them (17162, 17168, 17178) had significant increases in the trend analysis presented above.

Table 5.10 Clusters of sites with similar variation in TKN for Irving		
Cluster	Sites	Interpretation
A	18315, 10866, 18313, 17173, 17174	All in Bear Creek watershed, increasing prior to 2003, variable and high until June 2004, then declining
B	17175, 17176	Delaware Creek upstream sites, variable but generally declining until Mar. 2003, increasing since
C	11080, 17162, 17163, 17165, 17166, 17168, 17170, 17172, 17177, 17178, 17179, 17938, 17938, 18314	Mix of sites on Elm Fork tributaries, downstream Bear Creek, and downstream Delaware Creek, characterized by high variability since Dec. 2003

Summary of PCA for parameter 00630 NO_3/NO_2

This parameter was not measured in Fort Worth and too few observations were available from Irving. The number of sites available for this analysis ranged 4-19 among remaining municipalities, and the number of sampling times ranged 12-19 (Table 5.11). Cumulatively, the first two factors summarized 55-79% of the variation in NO_3/NO_2 for different municipalities (Table 5.12). The first five factors summarized over 70% of the variation in NO_3/NO_2 (only four factors could be computed for Arlington, since only four sites were available).

Table 5.11 Sample sizes for PCA for 00630 NO_3/NO_2				
	Arlington	Ft. Worth	Grand Prairie	Irving
No. Sites	4	-	19	-
No. Times	19	-	12	-

Table 5.12 Variance partitioning for 00630 NO_3/NO_2								
	Arlington		Ft. Worth		Grand Prairie		Irving	
Factor	% Var	Cum % Var	% Var	Cum % Var	% Var	Cum % Var	% Var	Cum % Var
1	60.7	60.7	-	-	38.3	38.3	-	-
2	18.5	79.2	-	-	16.4	54.7	-	-
3	11.6	90.8	-	-	11.3	66.0	-	-
4	9.2	100.0	-	-	10.8	76.8	-	-
5	-	-	-	-	6.2	83.0	-	-

In Arlington, two clusters of sites were identified (Table 5.13), but their interpretation is unclear. All sites in Arlington displayed roughly seasonal variations in NO_2/NO_3, with high values tending to occur in the first two quarters of the year.

Table 5.13 Clusters of sites with similar variation in NO_3/NO_2 for Arlington		
Cluster	Sites	Interpretation
A	10722, 17191	Unclear
B	10719, 10725	Unclear

In Grand Prairie, four clusters of sites were identified (Table 5.14). As noted in the trend analysis, NO_3/NO_2 decreased at many sites in Grand Prairie, and the clusters of sites appeared to differ in their variations around these trends. Cluster A consisted of sites where decreasing trends became evident only after February 2004. Cluster B consisted of sites with two phases of high values, from May 2003 to February 2004 and from February to May of 2005. Cluster C consisted of sites with relatively constant variation around the decreasing trend, while Cluster D consisted of sites with variability that increased over time.

Table 5.14 Clusters of sites with similar variation in NO_3/NO_2 for Grand Prairie		
Cluster	Sites	Interpretation
A	10867, 17663, 17664, 17674, 17683	Various locations, variable before Feb. 2004 and generally declining since
B	17666, 17676	Small but perennial creeks, high phases from May 2003 - Feb. 2004, and Feb. – May 2005, low otherwise
C	17673, 17675, 17678, 17679, 17680, 17681, 17682, 17684	Various locations, variable but generally decreasing
D	10815, 13621, 17669, 17677	Various locations, declining over time but becoming more variable.

Summary of PCA for parameter 00665 Total Phosphorus

This parameter was not measured in Fort Worth. The number of sites available for this analysis ranged 4-17 among remaining municipalities, and the number of sampling times ranged 17-26 (Table 5.15). Cumulatively, the first two factors summarized 35-78% of the variation in TP for different municipalities (Table 5.16). The first five factors summarized over 50% of the variation in TKN (only four factors could be computed for Arlington, since only four sites were available).

Table 5.15 Sample sizes for PCA for 00665 TP				
	Arlington	Ft. Worth	Grand Prairie	Irving
No. Sites	4	-	17	16
No. Times	19	-	17	26

Table 5.16 Variance partitioning for 00665 TP								
	Arlington		Ft. Worth		Grand Prairie		Irving	
Factor	% Var	Cum % Var	% Var	Cum % Var	% Var	Cum % Var	% Var	Cum % Var
1	51.6	51.6	-	-	36.9	36.9	19.6	19.6
2	26.5	78.1	-	-	18.4	55.2	15.1	34.6
3	12.6	90.7	-	-	11.3	66.5	13.5	48.1
4	9.3	100.0	-	-	9.2	75.7	10.5	58.7
5	-	-	-	-	8.2	83.9	7.7	66.4

In Arlington, three clusters of sites were identified (Table 5.17). Cluster A consisted of two sites on different creeks characterized by variations in TP without a consistent trend. Cluster B consisted of site 10722, in a central Arlington location which had occasional high values of TP exceeding those observed at other sites. Cluster C consisted of site 10725 on Fish Creek, whose watershed has commercial and industrial development, including the Arlington Airport, and which had a significant increase in the trend analysis presented above.

Table 5.17 Clusters of sites with similar variation in TP for Arlington		
Cluster	Sites	Interpretation
A	10719, 17191	Rush and Johnson Creeks, variation without trend
B	10722	Characterized by occasional high values
C	10725	Fish Creek, developed area with increasing trend

In Grand Prairie, four clusters of sites were identified (Table 5.18). Cluster A consisted of sites all showing a decrease during the first year to a period of low values around August 2002, followed by an increase and high variability until about August 2004, followed by a period of lower variability. Three of the sites in Cluster A had significant increasing trends, as noted in the trend analysis above. Cluster B consisted of the two northernmost sites in Grand Prairie on Bear Creek show parallel variations but no trend. Cluster C consisted of two sites on tributaries of Mountain Creek Lake that again showed parallel variations. One of these sites (17678) had a significant increase in the trend analysis presented above. Cluster D consisted of sites whose grouping is unclear. Site 17669 is on the Trinity River, and has higher levels than the other three, which are in the Mountain Creek Watershed. Time series data for TP at all sites in Grand Prairie were presented in Example 2 above.

Table 5.18 Clusters of sites with similar variation in TP for Grand Prairie		
Cluster	Sites	Interpretation
A	17674, 17677, 10815, 17666, 17673, 17681, 17676, 17679, 17664	Various locations, phase of low values around Aug. 2002, followed by high variation until Aug. 2004, then lower variation
B	10867, 17663	Bear Creek, parallel variations with no trend
C	17678, 17675	Tributaries of Mtn Creek Lake, parallel variations
D	13621, 17683, 17669, 17684	Unclear

In Irving, six clusters of sites were identified (Table 5.18). Cluster A consisted of sites in various locations exhibiting high variability in TP until June 2003, followed by a period of low variability. Clusters B, C, D each consisted of two sites, one of which was on a fork of the Trinity River while the others were on downstream reaches of its tributaries. Differing patterns of variability appeared to be shared among the pairs in these clusters, involving short-term trends, changes in variability, or conspicuous peaks in TP concentration. Cluster E consisted of two sites in central Irving which shared a conspicuous peak of TP in December 2002 followed by a period of low variability. Cluster F consisted of several sites on upstream reaches of different streams, which displayed a period of high variability in TP prior to June 2003, then a period of low variability until June 2004, followed by recent increases. Despite the difficulty of interpreting these various patterns of variation in TP, it is interesting that sites on high order streams (Trinity River and downstream reaches of its tributaries) formed one set of clusters (B, C, D) distinct from sites on smaller, lower order streams.

Table 5.19 Clusters of sites with similar variation in TP for Irving

Cluster	Sites	Interpretation
A	17170, 17173, 17174	Various locations, high variability until June 2003, then lower variability
B	11080, 17178	Downstream Delaware Creek and West Fork Trinity River, increase after July 2002 with higher variability
C	17162, 17168	Cottonwood Branch and Elm Fork Trinity River, parallel variations with conspicuous peak in June 2003
D	17163, 17166	Cottonwood Branch and Elm Fork Trinity River, unclear interpretation
E	15624, 17177	Central Irving, conspicuous peak in Dec. 2002, then lower variability
F	17165, 17172, 17175, 17176	Upstream reaches of several streams, high variability until June 2003, then a period of low variability until June 2004, then a recent increase

Summary of PCA for parameter 01351 Flow Severity

The number of sites available for this analysis ranged 5-18 among municipalities, and the number of sampling times ranged 15-67 (Table 5.20). Cumulatively, the first two factors summarized 51-89% of the variation in Flow Severity for different municipalities (Table 5.21). The first five factors summarized over 65% of the variation in Flow Severity.

Table 5.20 Sample sizes for PCA for 01351 Flow Severity

	Arlington	Ft. Worth	Grand Prairie	Irving
No. Sites	12	5	18	16
No. Times	15	67	35	28

Table 5.21 Variance partitioning for 01351 Flow Severity								
	Arlington		Ft. Worth		Grand Prairie		Irving	
Factor	% Var	Cum % Var	% Var	Cum % Var	% Var	Cum % Var	% Var	Cum % Var
1	56.1	56.1	79.6	79.6	43.3	43.3	36.0	36.0
2	15.9	72.1	9.4	88.9	10.6	53.9	15.4	51.4
3	10.5	82.5	5.2	94.1	8.2	62.1	11.0	62.4
4	7.4	89.9	3.4	97.6	6.7	68.9	9.2	71.6
5	4.5	94.4	2.4	100.0	5.5	74.3	7.1	78.7

In Arlington, three clusters of sites were identified (Table 5.22). Cluster A consisted of sites on Johnson and Rush Creeks characterized by generally decreasing flow severity until July 2002, followed by increases. These sites have mostly natural stream bottoms upstream of sampling locations. Cluster B consisted of sites in various locations characterized by relatively low Flow Severity after October 2002. One of these sites (10780) had a significant decrease in the trend analysis presented above. Cluster C consisted of sites in various locations characterized by high values with high variability prior to August 2002, and lower values with lower variability after that. One of these sites (17189) had a significant decrease in the trend analysis presented above. The sites in cluster C have variable characteristics, but most have significant commercial, industrial or construction activities, or channelized bottoms. Thus the distinction between clusters A and C suggests that development and channelization of streams affects patterns variation in Flow Severity.

Table 5.22 Clusters of sites with similar variation in Flow Severity for Arlington		
Cluster	Sites	Interpretation
A	10719, 10721, 10791, 17190	Johnson and Rush Creeks, decrease until July 2002, then an increase
B	10722, 10780, 17191	Various locations, relatively low values after Oct. 2003
C	10723, 10724, 10725, 10792, 17189	Various locations, high values and high variability until Aug. 2002, then lower values and lower variability

In Ft. Worth, two clusters of sites were identified (Table 5.23). Cluster A consisted of three sites on the West Fork of the Trinity River and one on Sycamore Creek. These sites all had high variability with many high values before July 2003, followed by lower and less variable values. One of these sites (17369) had a significant decrease in the trend analysis presented above. Cluster B consisted of one site on Marine Creek which had few high values, and many low ones after April 2003. It also had a significant decrease in the trend analysis presented above. Site 17370 thus appears to differ from the rest in consistently having lower values of Flow Severity. All of these sites are in central Ft. Worth in areas with significant commercial, residential or industrial development.

Table 5.23 Clusters of sites with similar variation in Flow Severity for Ft. Worth		
Cluster	Sites	Interpretation
A	10938, 16120, 17368, 17469	West Fork Trinity River and Sycamore Creek, variable with many high values prior to July 2003, then lower and less variable
B	17370	Marine Creek, few high values overall, and many low values since Apr. 2003

In Grand Prairie, six clusters of sites were identified (Table 5.24). Cluster A consisted of several sites mostly in the Mountain Creek watershed, which were characterized by high variability in Flow Severity throughout the period of observations. Cluster B consisted of three sites in the Mountain Creek watershed with low values from July 2002 to March 2003, but higher values at other times. Cluster C consisted of two sites on Bear Creek and one on the West Fork of the Trinity River, which had high values in October 2001, then low values until March 2003, and higher values and higher variability thereafter. These are the three northernmost sites sampled in Irving, and are all high order streams with relatively large undeveloped floodplain areas adjacent to the channel. Cluster D consisted of sites in the Mountain Creek Watershed which had low values of Flow Severity from July 2002 to March 2003, and then higher and more variable values. Cluster E was the single site on the shore of Joe Pool Lake, which displayed a significant increase in the trend analysis presented above. However, the interpretation of Flow Severity for this lake site is uncertain. Cluster F was a site on Cottonwood Creek which also had a significant increase in Flow Severity in the trend analysis presented above.

Table 5.24 Clusters of sites with similar variation in Flow Severity for Grand Prairie		
Cluster	Sites	Interpretation
A	10815, 17666, 17672, 17674, 17675, 17677, 17678	Mostly in Mtn Creek watershed, characterized by high variability throughout period of observations
B	13621, 17676, 17683	Mtn Creek watershed, low values from July 2002 to Mar. 2003, higher otherwise
C	10867, 17663, 17669	Bear Creek and West Fork Trinity River, high values in Oct. 2001, then low values until Mar. 2003, then higher and more variable
D	17680, 17681, 17682	Mtn Creek watershed, low values from July 2002 to Mar. 2003, then higher and more variable
E	17684	Joe Pool Lake, Mtn Creek arm, uncertain interpretation
F	17673	Cottonwood Creek

In Irving, four clusters of sites were identified (Table 5.25). Cluster A consisted of several sites in various locations, all of which had low values from November 2001 to August 2002, followed by high variability of Flow Severity. These sites were the most variable in Irving, and all have some amount of development, including residential, commercial and industrial, impoundments, nearby major highways, and DFW airport for one site. Cluster B consisted of four sites in the Bear Creek and Delaware Creek watersheds, which had normal Flow Severity without any variability until September 2003, after which there was higher variability. Cluster C consisted of a site on the Elm Fork of the Trinity River and a site on Hackberry Creek, which both had normal Flow Severity without any variability until July 2003, then higher variability. Cluster D consisted of a single site on Delaware Creek which had normal Flow Severity on every sampling date except for two.

Table 5.25 Clusters of sites with similar variation in Flow Severity for Irving

Cluster	Sites	Interpretation
A	11080, 17162, 17166, 17168, 17172, 17175, 17176, 17178, 17179	Various locations, low values from Nov. 2001 – Aug. 2002, then high variability
B	10866, 15624, 17173, 17174	Bear and Delaware Creek watersheds, normal prior to Sep. 2003, then highly variable
C	17163, 17170	Hackberry Creek and Elm Fork Trinity River, normal prior to July 2003, then highly variable
D	17177	Delaware Creek, always normal except for two observations

Summary of PCA for parameter 31699 E. coli

The number of sites available for this analysis ranged 5-22 among municipalities, and the number of sampling times ranged 14-66 (Table 5.26). Cumulatively, the first two factors summarized 43-80% of the variation in *E. coli* for different municipalities (Table 5.21). The first five factors summarized over 70% of the variation in *E. coli*.

Table 5.26 Sample sizes for PCA for 31699 *E. coli*

	Arlington	Ft. Worth	Grand Prairie	Irving
No. Sites	12	5	20	22
No. Times	14	66	43	22

Table 5.27 Variance partitioning for 31699 *E. coli*

	Arlington		Ft. Worth		Grand Prairie		Irving	
Factor	% Var	Cum % Var	% Var	Cum % Var	% Var	Cum % Var	% Var	Cum % Var
1	46.8	46.8	65.8	65.8	36.1	36.1	25.9	25.9
2	12.6	59.4	13.7	79.5	11.8	47.9	17.1	43.1
3	11.2	70.7	10.8	90.3	8.7	56.6	12.4	55.5
4	10.2	80.8	6.0	96.3	7.3	63.9	9.2	64.7
5	6.9	87.7	3.7	100.0	6.6	70.5	6.5	71.2

In Arlington, three clusters of sites were identified (Table 5.28). Cluster A consisted of several sites in various locations, which had moderate variability in *E. coli* values, without any apparent trend until October 2004, after which there was a strong increase to a conspicuous peak in May 2005. Cluster B consisted of two sites on Johnson Creek and Village Creek that also had the large peak of *E. coli* in May 2005, but which had highly variable *E. coli* prior to that. Cluster C consisted of two sites on Fish Creek and one on Johnson Creek which did not display a conspicuous peak in May 2005, otherwise their interpretation is uncertain.

Table 5.28 Clusters of sites with similar variation in *E. coli* for Arlington

Cluster	Sites	Interpretation
A	10722, 10723, 10780, 10791, 10792, 17190, 17191	Various locations, moderate variability without trend until Oct. 2004, then increasing to a large peak in May 2005
B	10721, 17189	Johnson and Village Creeks, peak in May 2005 with large variations prior
C	10724, 10725, 10719	Fish and Johnson Creeks, uncertain interpretation

In Fort Worth, three clusters of sites were identified (Table 5.29). Cluster A consisted of two sites on the West Fork of the Trinity River, which had high and variable values of *E. coli* until 2004, after which there was a general decline. One of these sites (10938) had a significant decrease in the trend analysis presented above. Cluster B consisted of one site on the West Fork of the Trinity River and one on Marine Creek characterized by high variability throughout the period of observations. Cluster C consisted of a single site on Sycamore Creek which had higher values of *E. coli* than other sites and a very high value in June 2003.

Table 5.29 Clusters of sites with similar variation in *E. coli* for Ft. Worth

Cluster	Sites	Interpretation
A	10938, 16120	West Fork Trinity River, high and variable until 2004, then generally declining
B	17368, 17370	West Fork Trinity River and Marine Creek, high variability throughout period of observations
C	17369	Sycamore Creek, high values with one very high peak in June 2004

In Grand Prairie, five clusters of sites were identified (Table 5.30). Cluster A consisted of several sites in the Mountain Creek watershed and one on the West Fork of the Trinity River. These sites had parallel variations in *E. coli*, with peaks tending to occur in winter or spring, and generally decreasing values from 2005 to 2006. One of these sites (17679) had a significant decrease in the trend analysis presented above. Cluster B consisted of sites in various watersheds, but all in the northern part of the region sampled in Grand Prairie. These sites had parallel variations in *E. coli*, with peaks occurring in all seasons, and generally decreasing values from 2004 to 2006. Four of these sites (10867, 17663, 17666, 17672) had significant decreases in the trend analysis presented above. Cluster 3 consisted of several sites in the Mountain Creek watershed which had highly variable *E. coli* values and a general decrease since April 2005. One of these sites (17677) had a significant decrease in the trend analysis presented above. Cluster D consisted of two sites in the southern part of the Mountain Creek watershed that had a period of low values from April 2002 to February 2003 and generally high and variable values at other times. Cluster E consisted of two sites in the northern part of the Mountain Creek watershed (downstream of Mountain Creek Lake) which had periods of high *E. coli* values from April to December 2002 and from October 2004 to April 2005.

Table 5.30 Clusters of sites with similar variation in *E. coli* for Grand Prairie

Cluster	Sites	Interpretation
A	17669, 17674, 17675, 17676, 17679	Mountain Creek watershed and West Fork Trinity River, parallel variations with peaks in winter or spring, decreasing 2005-2006
B	10867, 17663, 17664, 17666, 17672, 17673	Various northerly locations, parallel variations with peaks occurring in all seasons, decreasing 2004-2006
C	13621, 17677, 17678, 17683, 17684	Mountain Creek watershed, high variability but generally declining after Apr. 2005
D	17680, 17681	Mountain Creek watershed (south), low values from Apr. 2002 – Feb. 2003
E	10815, 17682	Mountain Creek watershed (north), high values from Apr. – Dec. 2002 and Oct. 2004 – Apr. 2005

In Irving, five clusters of sites were identified (Table 5.31). Cluster A consisted of several sites in various locations which all had high variability in *E. coli* throughout the period of observations. Cluster B consisted of two sites on the Elm Fork of the Trinity River and two on Cottonwood Branch. These sites had relatively low values of *E. coli* with low to moderate variability. These sites are downstream of DFW airport or near major highways. Cluster C consisted of three sites on Delaware Creek that displayed parallel variations in *E. coli*, with periods of high values from June to November 2003 and March to October 2004. Cluster D consisted of a single site on Delaware Creek that lacked the two periods of high values seen for sites in Cluster C, and which had a significant decrease in the trend analysis presented above. Cluster E likewise consisted of a single site on Delaware Creek that lacked the two periods of high values seen for sites in Cluster C. This site had low values of *E. coli*, low variability, and no apparent trend.

Table 5.31 Clusters of sites with similar variation in *E. coli* for Irving

Cluster	Sites	Interpretation
A	10866, 11080, 17170, 17172, 17173, 17174, 17179, 17938, 17939, 18313, 18315	Various locations, high variability throughout period of observation
B	17162, 17163, 17165, 17168	Elm Fork Trinity River and Cottonwood Branch, low values and low to moderate variability
C	17176, 17178, 18314	Delaware Creek, parallel variations with high values from June – Nov. 2003 and Mar. – Oct. 2004
D	17177	Delaware Creek, decreasing trend
E	17175	Delaware Creek, low values with low variability

Summary of PCA for parameter 32211 Chl-a

This parameter was not measured in Fort Worth. The number of sites available for this analysis ranged 4-22 among remaining municipalities, and the number of sampling times ranged 17-22 (Table 5.32). Cumulatively, the first two factors summarized 34-66% of the variation in Chl-*a* for different municipalities (Table 5.16). The first five factors summarized over 60% of the variation in Chl-*a* (only four factors could be computed for Arlington, since only four sites were available).

Table 5.32 Sample sizes for PCA for 32211 Chl-*a*				
	Arlington	Ft. Worth	Grand Prairie	Irving
No. Sites	4	-	18	22
No. Times	19	-	17	22

Table 5.33 Variance partitioning for 32211 Chl-*a*								
	Arlington		Ft. Worth		Grand Prairie		Irving	
Factor	% Var	Cum % Var	% Var	Cum % Var	% Var	Cum % Var	% Var	Cum % Var
1	35.9	35.9	-	-	32.5	32.5	18.7	18.7
2	30.4	66.3	-	-	16.1	48.7	15.6	34.4
3	18.2	84.4	-	-	11.9	60.5	11.1	45.5
4	15.6	100.0	-	-	9.4	70.0	10.2	55.6
5	-	-	-	-	6.8	76.8	8.5	64.2

In Arlington, two clusters of sites were identified (Table 5.34). Cluster A consisted of one site on Johnson Creek and one on Fish Creek, which displayed parallel variations in Chl-*a*, with periods of high values from January to April 2002, in October 2003, and from July 2004 to July 2005. Cluster B consisted of one site on Rush Creek and one on a small unnamed creek in East Arlington. These sites displayed high variability in Chl-*a*, with very low values occasionally occurring in winter.

Table 5.34 Clusters of sites with similar variation in Chl-*a* for Arlington		
Cluster	Sites	Interpretation
A	10719, 10725	Johnson and Fish Creeks, parallel variations with high values Jan. – Apr. 2002, Oct. 2003, July 2004 – July 2005
B	10722, 17191	Rush Creek and a small unnamed creek, high variability with occasional low values in winter

In Grand Prairie, six clusters of sites were identified (Table 5.35). Cluster A consisted of several sites in various locations characterized by a generally increasing trend. Three of these sites (17676, 17679, 17684) had significant decreases in the trend analysis presented above. Increasing trends in Chl-*a* during recent years characterized most of the other clusters identified. Cluster B consisted of several sites in the Mountain Creek watershed, which were variable without apparent trend until August 2004, but increasing since then. Cluster C consisted of one site in Bear Creek on one on the North Fork of Cottonwood Creek which had low values at the start of observations, increased until May 2003, then had high and variable values until August 2004, and a decrease since. This was the only group of sites displaying a recent decrease in Chl-*a*. Cluster D consisted of one site on Johnson Creek and one on Mountain Creek which decreased to low values in May 2004, but increased since then. Cluster E consisted of one site on Cottonwood Creek and one on the South Fork of Fish Creek which had seasonal variations in Chl- with high values occurring in January or February, then very low values in May 2004, but increased since then. Cluster F consisted of a single site on Crockett Branch which was highly variable until November of 2003 but increased since then.

Table 5.35 Clusters of sites with similar variation in Chl-*a* for Grand Prairie

Cluster	Sites	Interpretation
A	10815, 17663, 17666, 17672, 17676, 17679, 17684	Various locations, generally increasing throughout the period of observations
B	13621, 17675, 17678, 17681	Mtn Creek watershed, variable prior to Aug. 2004, then increasing
C	10867, 17673	Bear Creek and North Fork of Cottonwood Creek, increasing until May 2003, variable and high until Aug. 2004, then decreasing
D	17664, 17680	Johnson and Mountain Creeks, declining to low values in May 2004, the increasing
E	17674, 17677	Cottonwood Creek and South Fork Fish Creek, seasonal variations until low value in May 2004, then increasing
F	17683	Crockett Branch, highly variable, but increasing since Nov. 2003

In Irving, six clusters of sites were identified (Table 5.36). Cluster A consisted of several sites in various locations with highly variable Chl-*a* throughout the period of observations, but otherwise having no clear interpretation. Cluster B consisted of several sites in various locations with highly variable Chl-*a* but all sharing a period of relatively high values in April to September 2003. Cluster C consisted of several sites in various locations that also shared the period of relatively high values in April to September 2003 and another period of relatively high values from February to May of 2004. Cluster D consisted of several sites in various locations with no clear interpretation of their variation in Chl-*a*. Cluster E consisted of a single site on Delaware Creek with a tendency for seasonal variations in Chl-*a*, with high values in winter or spring.

Table 5.36 Clusters of sites with similar variation in Chl-*a* for Irving		
Cluster	Sites	Interpretation
A	17168, 17172, 17175, 17176, 18315, 18359	Various locations, highly variable throughout period of observations
B	10866, 17174, 17177, 17178, 17179, 17938, 17939	Various locations, high values from Apr. – Sep. 2003
C	11080, 17166, 17173, 18313	Various locations, high values from Apr. – Sep. 2003 and Feb. – May 2004
D	17162, 17163, 17165, 17170	Various locations, unclear
E	18314	Delaware Creek, tendency for high values in winter and spring

Summary of PCA for parameter 82078 Turbidity

This parameter was not measured in Arlington or Irving. The number of sites available for this analysis ranged 5-20 among remaining municipalities, and the number of sampling times ranged 42-64 (Table 5.37). Cumulatively, the first two factors summarized 41-68% of the variation in Turbidity for different municipalities (Table 5.38). The first five factors summarized over 70% of the variation in Turbidity (note – when there are only five sites, the PCA creates only five factors which mathematically must account for 100% of the variation).

Table 5.37 Sample sizes for PCA for 82078 Turbidity				
	Arlington	Ft. Worth	Grand Prairie	Irving
No. Sites	-	5	20	-
No. Times	-	64	42	-

Table 5.38 Variance partitioning for 82078 Turbidity								
	Arlington		Ft. Worth		Grand Prairie		Irving	
Factor	% Var	Cum % Var	% Var	Cum % Var	% Var	Cum % Var	% Var	Cum % Var
1	-	-	45.5	45.5	26.0	26.0	-	-
2	-	-	22.9	68.4	14.7	40.7	-	-
3	-	-	19.6	88.0	11.9	52.5	-	-
4	-	-	11.3	99.2	9.7	62.2	-	-
5	-	-	0.8	100.0	7.7	70.0	-	-

In Fort Worth, four clusters of sites were identified (Table 5.39). Cluster A consisted of one site on Marine Creek and one on Sycamore Creek characterized by high variability and several peak values that occurred simultaneously at both sites, the two largest occurring in February 2001 and April 2003. Cluster B consisted of a single site on the West Fork of the Trinity River with one very large peak value in October 2002 (this was observed as one of the smaller peaks at sites 17369 and 17370), and other large peaks in January 2001 and July 2005. Cluster C consisted of a single site on the West

Fork of the Trinity River where variable Turbidity was observed without conspicuous peaks or apparent trends. Cluster D consisted of a single site on the West Fork of the Trinity River with a decreasing trend of Turbidity, which was significant in the trend analysis presented above. The occurrence of conspicuous peaks in Turbidity could result from events of high discharge that mobilize sediments. The smaller creek sites appear more susceptible to such events than the West Fork sites, and shared several simultaneous peak values of Turbidity. Only the West Fork site that was furthest downstream (16120) showed conspicuous peaks indicating such events, while the others did not. Localized differences in channel morphology and flow at these sites could explain such differences.

Table 5.39 Clusters of sites with similar variation in Turbidity for Fort Worth

Cluster	Sites	Interpretation
A	17369, 17370	Marine and Sycamore Creeks, highly variable with several shared peaks
B	16120	W. Fork Trinity River, one very large peak and several smaller ones
C	17368	W. Fork Trinity River, variation without large peaks or apparent trends
D	10938	W. Fork Trinity River, decreasing trend

Conclusions of PCA analyses

The PCA analyses produced a wealth of detail concerning variations in water quality parameters. In some cases clusters of sites with similar variations were identified, and in a few of these instances, these clusters represented sites in the same watershed or in close proximity. However, in other cases such geographical grouping was not evident. In many cases the shared pattern of variation could be characterized in terms of periods of high or low values shared among sites, or shared trends, though in some cases no such interpretation was evident.

Perhaps more important than these details is the observation that the first five factors calculated by PCA usually accounted for 70% or more of the total variation in the data. For those municipalities monitoring large numbers of sampling stations (Grand Prairie, Irving), this result implies that data from many of the stations are redundant, and that approximately five well-chosen stations might be sufficient to achieve the same characterization of ambient variations water quality parameters.

6. Flow-Concentration Analysis

In this section selected water quality parameters are regressed against flow (discharge) to identify positive or negative relationships. Positive relationships indicate that events of high flow (e.g. storms) produce loading of a parameter. Such a situation could arise when a constituent has watershed sources that are easily dissolved and mobilized by runoff. For example, nitrate salts are highly soluble and occur naturally in soils and in some fertilizers. They would easily leach from the landscape, entering runoff and stream water, and thus a positive flow-concentration would be expected for NO_3/NO_2. Negative flow-concentration relationships indicate that events of high flow dilute a parameter that has sources within a stream. For example, production by algae residing in a stream can an important source of Chl-*a*, and events of high discharge would tend to wash out resident algal populations, reducing Chl-*a*. Unfortunately, most of the monitoring stations where water quality samples were taken are not gauged for discharge. As explained in the introduction above (section 1, Overview), a “reconstructed discharge” was computed for these analyses using Principal Components Analysis. The first factor from a PCA of the natural logarithms of discharge was computed from the four stations where gauged discharge data were available. This first factor accounted for 70.1% of the variation in discharge among the four stations involved. It was taken to represent regional variations in discharge across the metroplex region and used as a surrogate measure of flow for all stations in this study. Values of reconstructed discharge from this factor were calculated for every date from January 1, 1999 to April 4, 2007 and were paired by date with observations of selected water quality parameters from the monitoring stations analyzed in this study.

Values of reconstructed discharge used as predictor variables for these regression analyses are unitless, since they were derived from natural logarithms of raw data. In exploratory analyses, a simple linear regression was applied to the raw values of each water quality parameter, and the residuals of these regressions were examined. In many cases, skew and heteroscedasticity of the residuals indicated that the water quality data should be transformed to natural logarithms. When displaying fitted regression models graphically, fitted values were back-transformed to arithmetic scales. To increase the power of the regression analyses, all stations within a municipality with sufficient data were analyzed simultaneously, using a regression model with separate slope and intercept terms for each station. That is, a distinct regression relationship was computed for each station, to account for possible localized factors affecting water quality parameters, but pooling increased the sensitivity of the overall analysis. This regression model was then compared to three hierarchically related, simpler regression models using partial-*F* tests with a significance level of 0.05: (1) A model in which all stations have flow-concentration relationships with a common slope, but differing intercepts. (2) A model in which all stations have a single flow-concentration relationship with a common slope and intercept. (3) A null model with no significant flow-concentration relationship at all. Regressions were computed with the General Linear Models module of Statistica version 6. Simpler regression models with common slopes or slopes and intercepts were accepted in preference to more complex ones when the partial-*F* test indicated that differences among stations were not significant.

In this report, these analyses are briefly summarized and more complete statistical reports are contained in the Excel spreadsheets provided as electronic appendices. When the analysis indicated that the most complex regression model with different slopes and intercepts for all station could not be rejected in favor of a simpler regression model, the different slope terms for each station are presented. The fitted regression model and data for each such station are also presented graphically for each station whose slope term is significantly ($P < 0.05$) different from zero. When more than four stations had significant flow-concentration relationships, only the stations with the two highest and two lowest significant slope terms are shown graphically, for brevity. When the analysis indicated accepting the simpler regression model with a common slope but differing intercepts for each station, only the shared slope term is reported, and graphs display data from all stations together with fitted models for the stations with the highest and lowest intercepts. When the analysis indicated accepting the simpler regression model with both a common slope and a common intercept for all stations, the shared slope is reported and all data are again displayed, with the fitted regression model that applies to all stations. When the analysis indicates the null model of no significant flow-concentration, the data are displayed, but no fitted regression model is reported.

Flow-concentration analysis for 00625 TKN

TKN was measured in Arlington, Grand Prairie, and Irving. All regressions used data transformed to natural logarithms. For TKN in Arlington, 83 observations from 4 stations were analyzed. The null model of no significant flow-concentration relationship was accepted (Fig. 6.1).

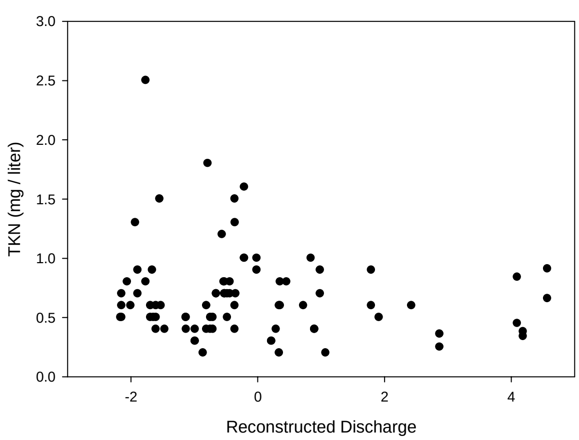

Fig. 6.1 Flow-concentration data for TKN in Arlington.

For TKN in Grand Prairie, 383 observations from 23 stations were analyzed. The model with a common slope (Table 6.1) for all stations but differing intercepts was accepted ($R^2 = 0.20$, $P < 0.001$). The fitted model represents TKN as a weakly increasing function of discharge that differs in elevation for different stations (Fig. 6.2). Note that when a linear model on the natural logarithm scale is back-transformed to an arithmetic scale, it becomes curvilinear. The model fits for the stations with highest and lowest intercept are shown (those for other stations lie between the curves illustrated).

Table 6.1 Flow-concentration relationship for TKN in Grand Prairie				
Station	Slope	Std. Error	*T*	*P*
All stations	0.071	0.014	4.948	<0.001

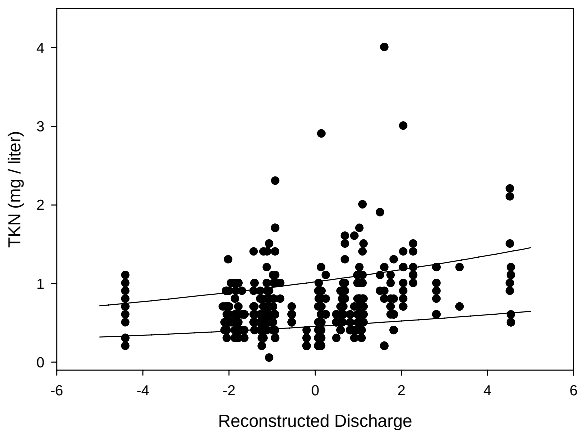

Fig. 6.2 Flow-concentration data for TKN in Grand Prairie; lines show the fitted regression model for the stations with highest and lowest intercepts.

For TKN in Irving, 709 observations from 30 stations were analyzed. The model with a common slope (Table 6.2) for all stations but differing intercepts was accepted (R^2 = 0.18, $P < 0.001$). The fitted model represents TKN as a weakly increasing function of discharge that differs in elevation for different stations (Fig. 6.3).

Table 6.2 Flow-concentration relationship for TKN in Irving				
Station	Slope	Std. Error	*T*	*P*
All stations	0.048	0.012	4.130	<0.001

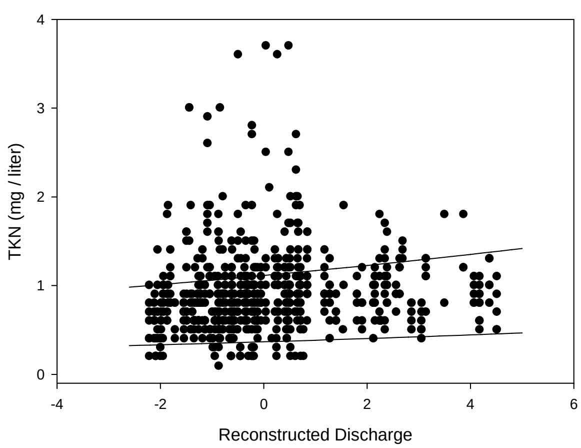

Fig. 6.3 Flow-concentration data for TKN in Irving; lines show the fitted regression model for the stations with highest and lowest intercepts.

In general, for TKN flow-concentration relationships were either non-significant (Arlington) or weakly positive (Grand Prairie and Irving). The latter results suggest that there may be sources of TKN in these watersheds that are mobilized by events of high discharge. However, the weakness of the regression relationships and the high scatter around the fitted lines in Figs. 6.2 and 6.3 suggest that the influence of such sources is generally weak. The scatter in the data, together with the significance of the differences in elevation for regressions in Grand Prairie and Irving suggest that localized factors are important in determining the levels of TKN in these streams. In situ processes of biological nitrogen fixation and nitrogen recycling could have contributed to TKN, reducing the influence of watershed sources mobilized by discharge.

Flow-concentration analysis for 00630 NO_3/NO_2

NO_3/NO_2 was measured in Arlington, and Grand Prairie. All regressions used data transformed to natural logarithms. For NO_3/NO_2 in Arlington, 85 observations from 4 stations were analyzed. The model with a common slope (Table 6.3) for all stations but differing intercepts was accepted (R^2 = 0.39, P < 0.001). The fitted model represents NO_3/NO_2 as an increasing function of discharge that differs in elevation for different stations (Fig. 6.4).

Table 6.3 Flow-concentration relationship for NO_3/NO_2 in Arlington				
Station	Slope	Std. Error	*T*	*P*
All stations	0.272	0.058	4.718	<0.001

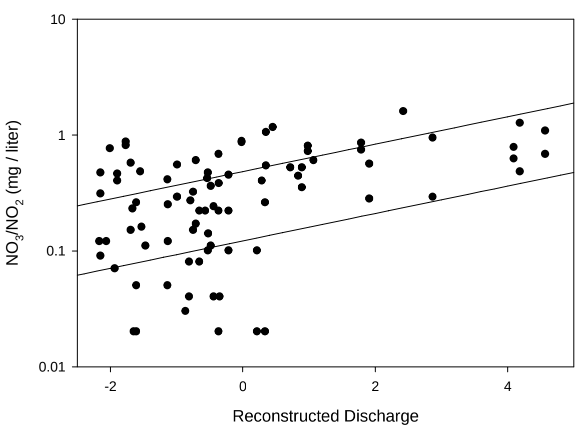

Fig. 6.4 Flow-concentration data for NO_3/NO_2 in Arlington; lines show the fitted regression model for the stations with highest and lowest intercepts.

For NO_3/NO_2 in Grand Prairie, 354 observations from 23 stations were analyzed. The model with a common slope (Table 6.4) for all stations but differing intercepts was accepted (R^2 = 0.44, P < 0.001). The fitted model represents NO_3/NO_2 as an increasing function of discharge that differs in elevation for different stations (Fig. 6.5).

Table 6.4 Flow-concentration relationship for NO_3/NO_2 in Grand Prairie				
Station	Slope	Std. Error	*T*	*P*
All stations	0.200	0.031	6.499	<0.001

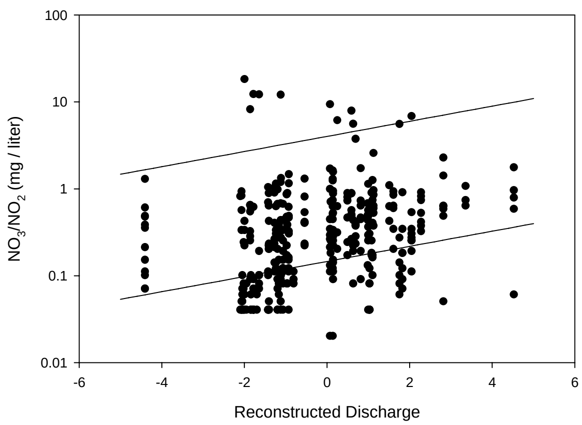

Fig. 6.5 Flow-concentration data for NO_3/NO_2 in Grand Prairie; lines show the fitted regression model for the stations with highest and lowest intercepts.

In general, for NO_3/NO_2 flow-concentration relationships were positive, suggesting that there are sources of NO_3/NO_2 in these watersheds that are mobilized by events of high discharge. This is not surprising, since these ions are highly soluble and sometimes poorly retained by soils. The significance of the differences in elevation for these regressions suggests that localized factors are also important in determining the levels of NO_3/NO_2 in these streams.

Flow-concentration analysis for 00665 TP

TP was measured in Arlington, Grand Prairie, and Irving. All regressions used data transformed to natural logarithms. For TP in Arlington, 85 observations from 4 stations were analyzed. The model with a common slope (Table 6.5) for all stations but differing intercepts was accepted (R^2 = 0.12, P = 0.035). The fitted model represents TP as an increasing function of discharge that differs in elevation for different stations (Fig. 6.5). Although the overall model is statistically significant, the slope term for the flow-concentration relationship is not, indicating a weak relationship.

Table 6.5 Flow-concentration relationship for TP in Arlington				
Station	Slope	Std. Error	*T*	*P*
All stations	0.059	0.048	1.234	0.221

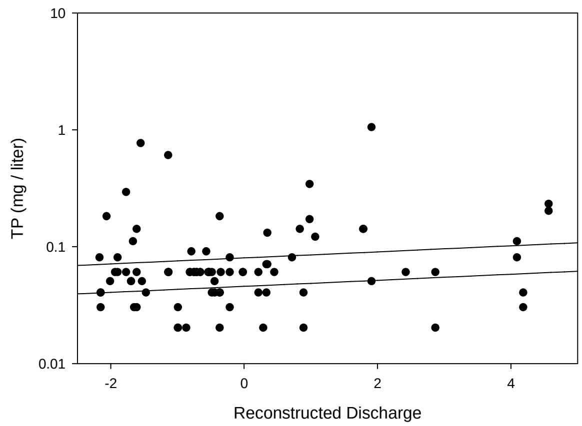

Fig. 6.6 Flow-concentration data for TP in Arlington; lines show the fitted regression model for the stations with highest and lowest intercepts.

For TP in Grand Prairie, 503 observations from 23 stations were analyzed. The model with different slopes (Table 6.6) for different stations was accepted ($R^2 = 0.58$, $P < 0.001$). The slopes of flow-concentration relationships were statistically significant for four stations, for which the fitted models represent TP as an increasing function of discharge for three stations, and a decreasing function for one (Fig. 6.7).

Table 6.6 Flow-concentration relationships for TP in Grand Prairie				
Station	Slope	Std. Error	*T*	*P*
18311	0.047	0.019	2.513	0.012
10815	0.036	0.083	0.431	0.666
10867	0.244	0.077	3.180	0.002
13621	0.147	0.086	1.708	0.088
17663	0.217	0.072	2.995	0.003
17664	0.071	0.079	0.902	0.368
17665	-0.092	0.166	-0.556	0.579
17666	0.013	0.075	0.178	0.859
17669	-0.200	0.073	-2.751	0.006
17671	-0.026	0.076	-0.339	0.735
17672	-0.001	0.093	-0.011	0.992
17673	0.080	0.087	0.918	0.359
17674	-0.028	0.092	-0.300	0.765
17675	0.109	0.081	1.345	0.179
17676	0.089	0.084	1.050	0.294
17677	0.062	0.088	0.706	0.481
17678	-0.049	0.089	-0.548	0.584
17679	0.138	0.085	1.632	0.104
17680	0.010	0.089	0.115	0.908
17681	0.098	0.085	1.150	0.251
17682	0.022	0.081	0.277	0.782
17683	-0.073	0.099	-0.736	0.462
17684	0.023	0.086	0.269	0.788

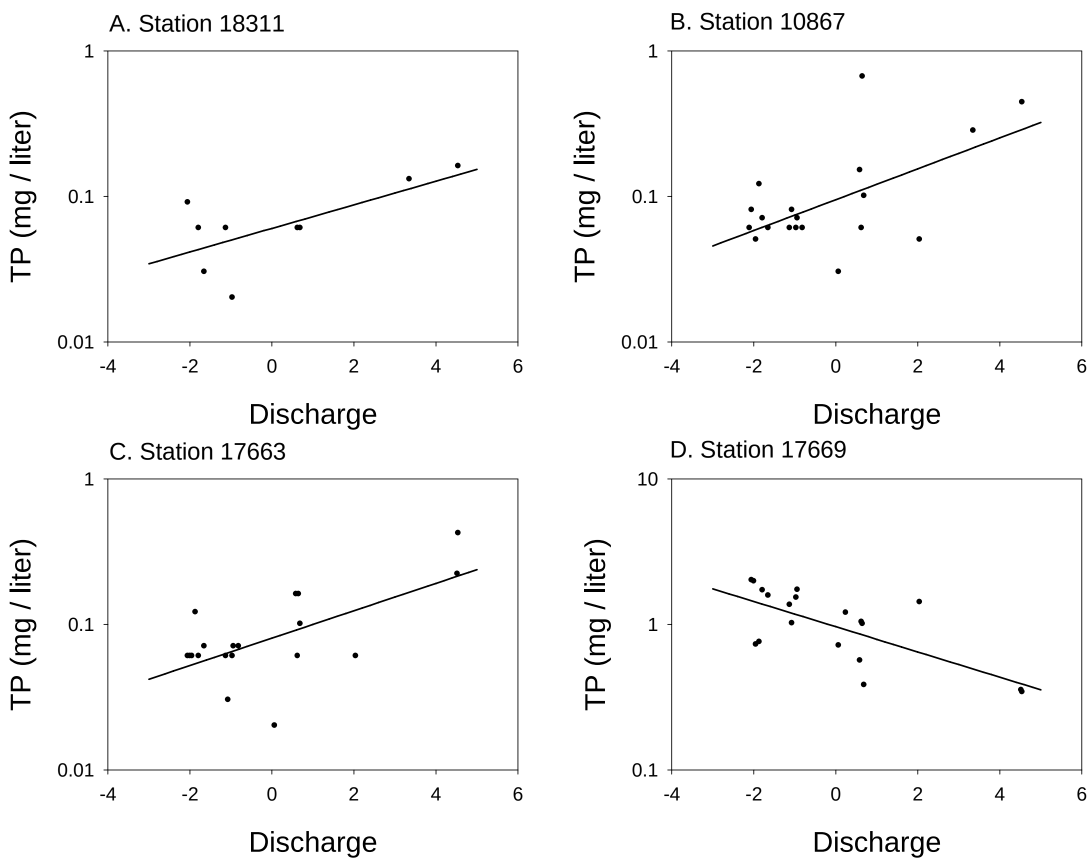

Fig. 6.7 Flow-concentration data for TP in Grand Prairie for stations with significant flow-concentration relationships; lines show the fitted regression models.

For TP in Irving, 795 observations from 30 stations were analyzed. The model with a common slope (Table 6.7) for all stations but differing intercepts was accepted (R^2 = 0.40, P < 0.001). The fitted model represents TP as an increasing function of discharge that differs in elevation for different stations (Fig. 6.8).

Table 6.7 Flow-concentration relationship for TP in Arlington

Station	Slope	Std. Error	*T*	*P*
All stations	0.121	0.017	7.118	<0.001

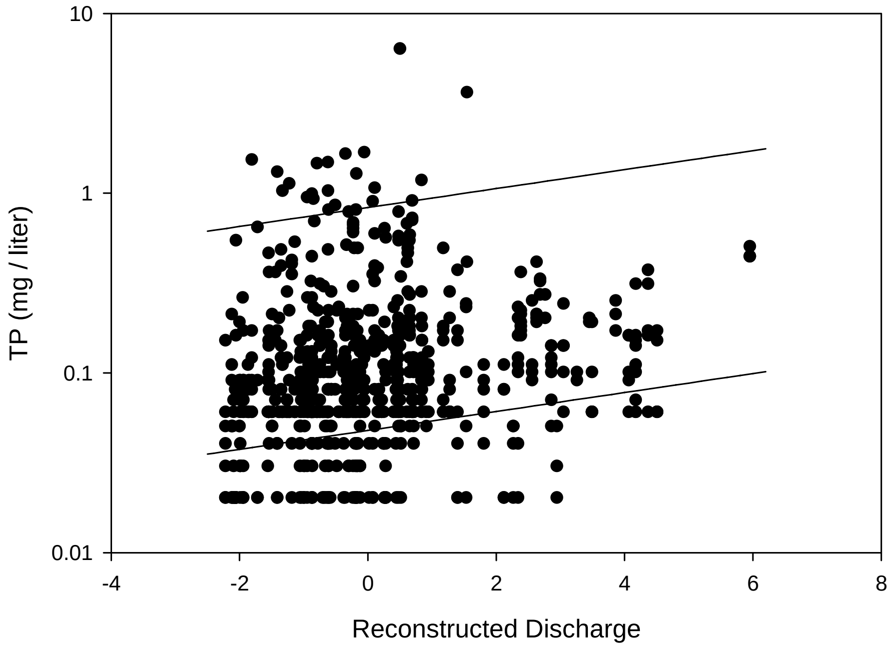

Fig. 6.8 Flow-concentration data for TP in Irving; lines show the fitted regression model for the stations with highest and lowest intercepts.

For TP flow-concentration relationships were either weakly positive (Arlington and Irving and Irving), or variable in sign among stations (Grand Prairie). Positive relationships suggest sources of TP in these watersheds that are mobilized by events of high discharge. Since the phosphate ion is relatively immobile in soils, it is likely that such sources are particulate, and sediments containing TP could be transported by high discharge either from the watershed landscape or from upstream stream bottoms. In Arlington and Irving, the weakness of the regression relationships and the high scatter around the fitted lines in Figs. 6.6 and 6.8 suggest that the influence of such sources is generally weak. The scatter in the data, together with the significance of the differences in elevation for regressions in Arlington and Irving suggest that localized factors are important in determining the levels of TP in these streams. In Grand Prairie, local differences are apparently strong enough to produce both positive and negative flow-concentration relationships that are statistically significant. The significant positive relationships are from stations on relatively high order streams (Bear Creek and Johnson Creek), for which sediments from either the landscape or upstream reaches could be mobilized during high discharge. The significant negative flow-concentration relationship is from a station on the West Fork of the Trinity River. Negative relationships suggest that in situ sources are diluted by events of high discharge. These could include recycling of P from sediments or decaying aquatic vegetation. While such sources are usually weak in flowing water environments, they could be present in those with broad channels and slow-flowing pools or backwaters.

Flow-concentration analysis for 01351 Flow Severity

Flow Severity was measured in all municipalities. For Flow Severity in Arlington, 254 observations from 12 stations were analyzed. The model with a common slope (Table 6.5) and a common intercept for all stations was accepted ($R^2 = 0.19$, $P < 0.001$). The fitted model represents Flow Severity as an increasing function of discharge (Fig. 6.9).

Table 6.8 Flow-concentration relationship for Flow Severity in Arlington				
Station	Slope	Std. Error	*T*	*P*
All stations	0.238	0.031	7.610	<0.001

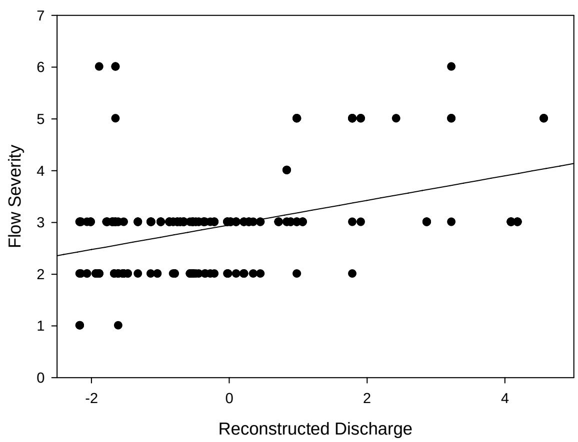

Fig. 6.9 Flow-concentration data for Flow Severity in Arlington; the line shows the fitted regression model for all stations.

For Flow Severity in Fort Worth, 366 observations from 6 stations were analyzed. The model with a common slope (Table 6.9) and a common intercept for all stations was accepted ($R^2 = 0.42$, $P < 0.001$). The fitted model represents Flow Severity as an increasing function of discharge (Fig. 6.10).

Table 6.9 Flow-concentration relationship for Flow Severity in Fort Worth				
Station	Slope	Std. Error	*T*	*P*
All stations	0.318	0.020	16.177	<0.001

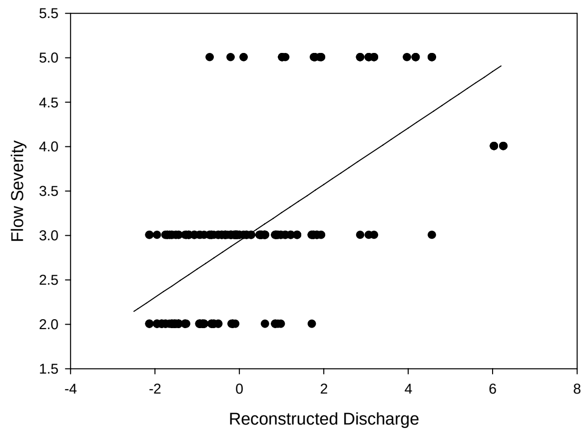

Fig. 6.10 Flow-concentration data for Flow Severity in Fort Worth; the line shows the fitted regression model for all stations.

For Flow Severity in Grand Prairie, 1165 observations from 23 stations were analyzed. The model with a common slope (Table 6.10) for all stations but differing intercepts was accepted ($R^2 = 0.22$, $P < 0.001$). The fitted model represents Flow Severity as an increasing function of discharge that differs in elevation for different stations (Fig. 6.11).

Table 6.10 Flow-concentration relationship for Flow Severity in Grand Prairie				
Station	Slope	Std. Error	*T*	*P*
All stations	0.199	0.013	15.897	<0.001

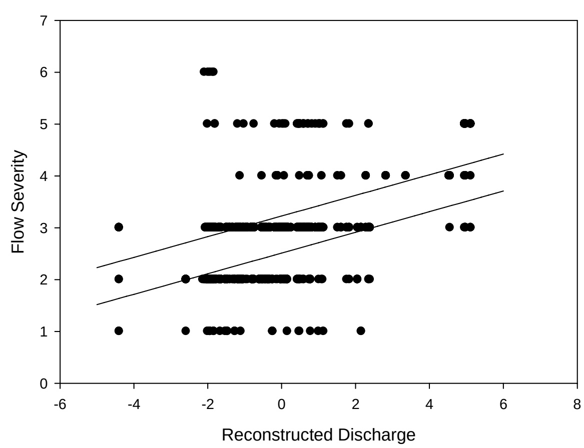

Fig. 6.11 Flow-concentration data for Flow Severity in Grand Prairie; lines show the fitted regression model for the stations with highest and lowest intercepts.

For Flow Severity in Irving, 870 observations from 31 stations were analyzed. The statistical situation for these data was complex. The model with a common slope was rejected (partial $F = 2.47$, $P < 0.001$), indicating significant differences in slopes among stations. However, no individual station had a significant slope term for the flow-concentration relationship, leaving such relationships weakly characterized by regression modeling. Therefore, the regression model with a common slope (Table 6.11) for all stations but differing intercepts was accepted, and was itself significant ($R^2 = 0.17$, $P < 0.001$). Although this model provided a significant estimate for the slope of an overall flow-concentration relationship, it must be qualified by noting that some stations might deviate from this relationship. The fitted model that was accepted represents Flow Severity as an increasing function of discharge that differs in elevation for different stations (Fig. 6.12).

Table 6.11 Flow-concentration relationship for Flow Severity in Irving

Station	Slope	Std. Error	*T*	*P*
All stations	0.137	0.012	11.548	<0.001

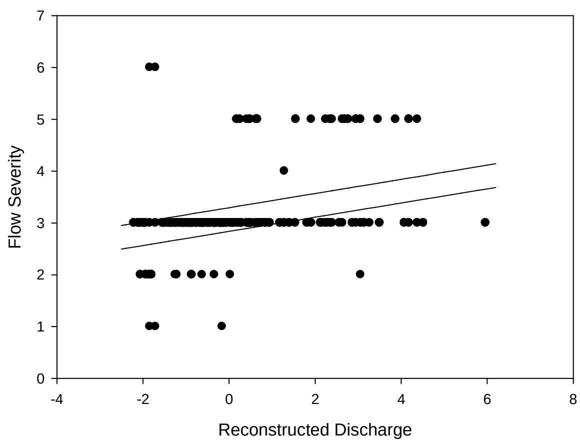

Fig. 6.12 Flow-concentration data for Flow Severity in Irving; lines show the fitted regression model for the stations with highest and lowest intercepts.

In general, for Flow Severity flow-concentration relationships were positive. This is expected because the Flow Severity scale should be related to discharge by definition, at least for index values of 1-5. Note that although the highest index value of 6 indicates dry conditions that would be associated with low discharge across the region, such values were relatively rare in the data analyzed here and thus had little influence. The Flow Severity scale is subjective, and requires judging current conditions relative to those deemed normal. Thus the expected positive relationship with discharge is not a foregone conclusion, especially when discharge is not directly determined from a nearby gauging station, but is a synthetic variable computed from regional discharge data, as was done here. The finding of positive relationships indicates that Flow Severity could be a meaningful measurement despite its subjectivity. The finding of a single relationship with a common slope and intercept for all stations in two municipalities (Arlington and Fort Worth) further suggests that consistent judgments of Flow Severity can be made for multiple stations under some circumstances. In two other municipalities, Grand Prairie and Irving, the intercepts of Flow Severity versus discharge differed significantly among stations, and there was some statistical evidence that slopes also differed among stations in Irving. These results could arise from particular features of individual stations affecting the judgment of Flow Severity, or could indicate changes in personnel or their judgments during the course of the data collection.

Flow-concentration analysis for 31699 E. coli

E. coli was measured in all municipalities. All regressions used data transformed to natural logarithms. For *E. coli* in Arlington, 179 observations from 12 stations were analyzed. The model with a common slope (Table 6.12) and a common intercept for all stations was accepted ($R^2 = 0.06$, $P < 0.001$). The fitted model represents Flow Severity as an increasing function of discharge (Fig. 6.13).

Table 6.12 Flow-concentration relationship for *E. coli* in Arlington				
Station	Slope	Std. Error	*T*	*P*
All stations	0.287	0.083	3.454	0.001

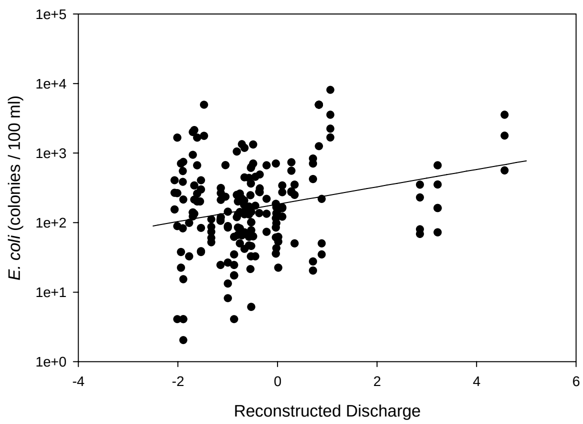

Fig. 6.13 Flow-concentration data for *E. coli* in Arlington; the line shows the fitted regression model for all stations.

For *E. coli* in Fort Worth, 365 observations from 6 stations were analyzed. The model with a common slope (Table 6.13) for all stations but differing intercepts was accepted ($R^2 = 0.35$, $P < 0.001$). The fitted model represents *E. coli* as an increasing function of discharge that differs in elevation for different stations (Fig. 6.14).

Table 6.13 Flow-concentration relationship for *E. coli* in Fort Worth				
Station	Slope	Std. Error	*T*	*P*
All stations	0.608	0.052	11.778	<0.001

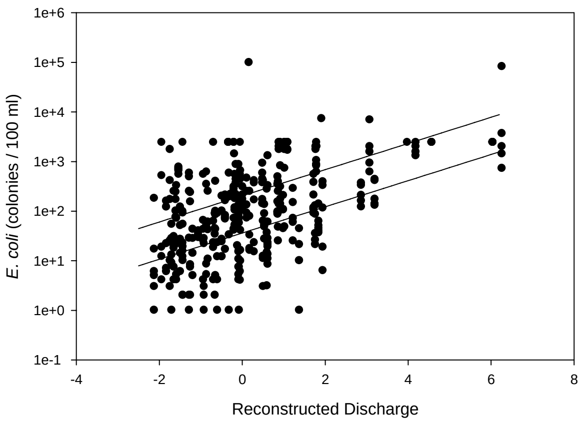

Fig. 6.14 Flow-concentration data for *E. coli* in Fort Worth; lines show the fitted regression model for the stations with highest and lowest intercepts.

For *E. coli* in Grand Prairie, 1150 observations from 23 stations were analyzed. The model with a common slope (Table 6.14) for all stations but differing intercepts was accepted ($R^2 = 0.41$, $P < 0.001$). The fitted model represents *E. coli* as an increasing function of discharge that differs in elevation for different stations (Fig. 6.15).

Table 6.14 Flow-concentration relationship for *E. coli* in Grand Prairie				
Station	Slope	Std. Error	*T*	*P*
All stations	0.458	0.029	16.023	<0.001

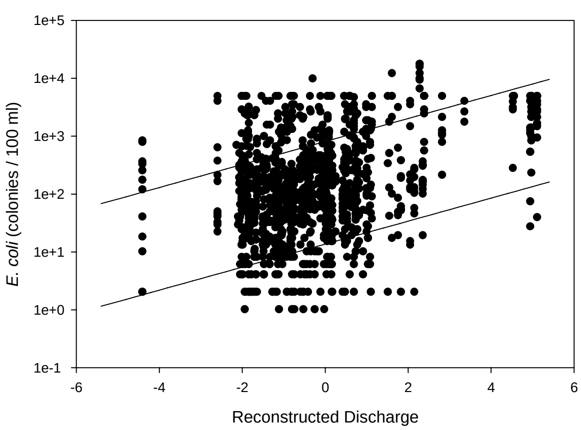

Fig. 6.15 Flow-concentration data for *E. coli* in Grand Prairie; lines show the fitted regression model for the stations with highest and lowest intercepts.

For *E. coli* in Irving, 861 observations from 30 stations were analyzed. The model with different slopes (Table 6.15) for different stations was accepted ($R^2 = 0.37$, $P < 0.001$). The slopes of flow-concentration relationships were statistically significant for ten stations, for which the fitted models represent *E. coli* as an increasing function of discharge. Figure 5.16 shows data together with the fitted models for the two stations with the highest significant slopes for flow-concentration relationships, and the two stations with the lowest significant slopes.

Table 6.15 Flow-concentration relationships for *E. coli* in Irving

Station	Slope	Std. Error	*T*	*P*
18359	0.332	0.047	7.009	0.000
10864	0.154	0.696	0.221	0.825
10866	0.642	0.203	3.168	0.002
10868	0.071	0.395	0.180	0.857
10871	0.538	0.234	2.301	0.022
11080	0.453	0.242	1.868	0.062
15624	0.320	0.190	1.689	0.092
17162	0.276	0.182	1.513	0.131
17163	0.503	0.187	2.692	0.007
17164	0.445	0.267	1.667	0.096
17165	0.173	0.161	1.075	0.283
17166	0.102	0.199	0.510	0.610
17167	0.367	0.277	1.327	0.185
17168	0.447	0.183	2.435	0.015
17170	0.333	0.204	1.633	0.103
17171	1.288	0.394	3.267	0.001
17172	0.231	0.211	1.096	0.273
17173	0.451	0.188	2.400	0.017
17174	0.218	0.188	1.162	0.245
17175	-0.169	0.190	-0.888	0.375
17176	0.292	0.165	1.773	0.077
17177	-0.233	0.196	-1.191	0.234
17178	0.630	0.187	3.360	0.001
17179	0.603	0.200	3.010	0.003
17938	-0.096	0.243	-0.396	0.692
17939	0.013	0.232	0.055	0.956
18310	0.302	0.289	1.043	0.297
18313	0.671	0.214	3.136	0.002
18314	0.022	0.215	0.100	0.920
18315	0.643	0.214	3.005	0.003

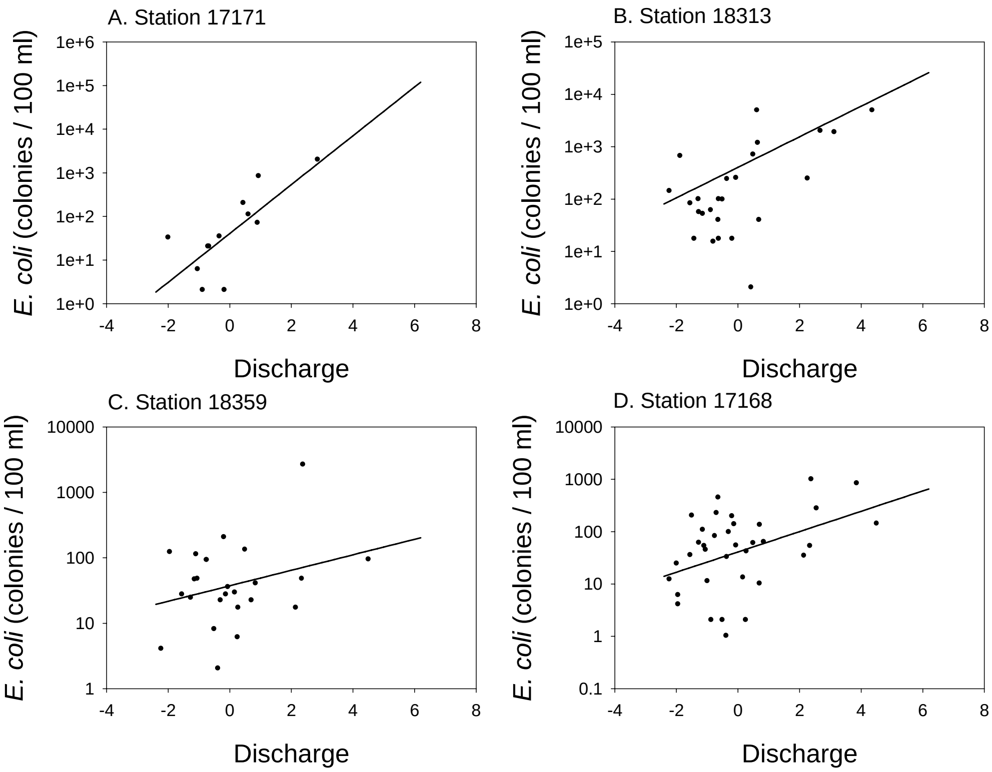

Fig. 6.16 Flow-concentration data for *E. coli* in Irving for four stations with significant flow-concentration relationships; lines show the fitted regression models.

In general, for *E. coli* flow-concentration relationships were positive, suggesting that there are sources of *E. coli* in these watersheds that are mobilized by events of high discharge. Such sources could include wildlife, domestic pets and animals, or encampments of the homeless. The significance of the differences in elevation for these regressions found in Forth Worth and Grand Prairie, along with the high scatter in all relationships, suggest that localized factors are also important in determining the levels of *E. coli* in these streams. The importance of localized differences among stations is highlighted by the significant differences among stations in Irving for the slopes of flow-concentration relationships. All statistically significant relationships are positive, suggesting sources within the watersheds, but at some stations such sources are apparently stronger than at others.

Flow-concentration analysis for 32211Chl-a

Chl-*a* was measured in Arlington, Grand Prairie, and Irving. All regressions used data transformed to natural logarithms. For Chl-*a* in Arlington, 83 observations from 4 stations were analyzed. The null model of no significant flow-concentration relationship was accepted (Fig. 6.17).

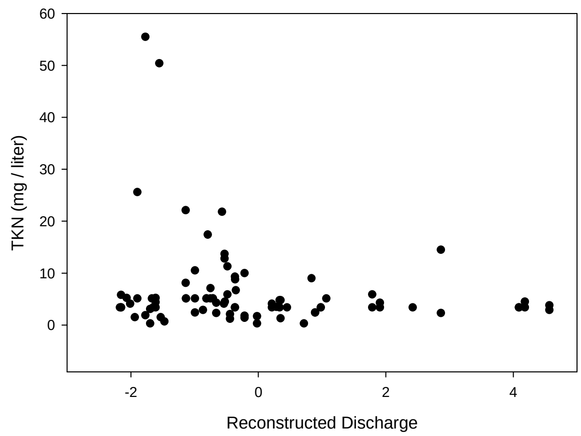

Fig. 6.17 Flow-concentration data for Chl-*a* in Arlington.

For Chl-*a* in Grand Prairie, 426 observations from 23 stations were analyzed. The model with different slopes (Table 6.16) for different stations was accepted ($R^2 = 0.25$, $P < 0.001$). The slopes of flow-concentration relationships were statistically significant for two stations, one for which Chl-*a* was an increasing function of discharge, and one for which it was a decreasing function. Figure 5.18 shows data together with the fitted models for the two stations with slopes for flow-concentration relationships.

Table 6.16 Flow-concentration relationships for Chl-*a* in Grand Prairie				
Station	Slope	Std. Error	*T*	*P*
18311	-0.005	0.034	-0.134	0.894
10815	0.017	0.149	0.113	0.910
10867	-0.058	0.137	-0.424	0.672
13621	-0.190	0.153	-1.238	0.216
17663	0.035	0.129	0.274	0.784
17664	0.105	0.140	0.745	0.456
17665	0.621	0.299	2.076	0.039
17666	0.014	0.134	0.106	0.916
17669	0.133	0.161	0.821	0.412
17671	-0.109	0.136	-0.798	0.425
17672	-0.129	0.169	-0.764	0.446
17673	0.129	0.155	0.830	0.407
17674	0.083	0.167	0.497	0.619
17675	-0.052	0.145	-0.355	0.723
17676	0.069	0.152	0.452	0.651
17677	0.203	0.157	1.292	0.197
17678	-0.005	0.160	-0.029	0.977
17679	-0.214	0.152	-1.405	0.161
17680	-0.216	0.153	-1.410	0.160
17681	0.008	0.188	0.044	0.965
17682	0.227	0.145	1.570	0.117
17683	-0.768	0.179	-4.296	<0.001
17684	0.023	0.154	0.151	0.880

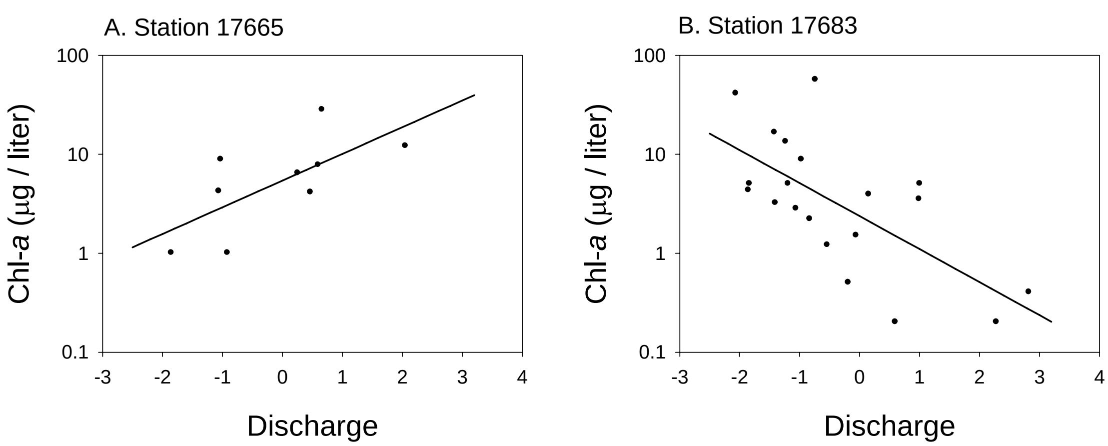

Fig. 6.18 Flow-concentration data for Chl-*a* in Grand Prairie for two stations with significant flow-concentration relationships; lines show the fitted regression models.

For Chl-*a* in Irving, 755 observations from 30 stations were analyzed. The model with a common slope (Table 6.17) for all stations but differing intercepts was accepted ($R^2 = 0.27$, $P < 0.001$). The fitted model represents Chl-*a* as a decreasing function of discharge that differs in elevation for different stations (Fig. 6.19).

Table 6.17 Flow-concentration relationship for Chl-*a* in Irving				
Station	Slope	Std. Error	*T*	*P*
All stations	-0.104	0.024	-4.275	<0.001

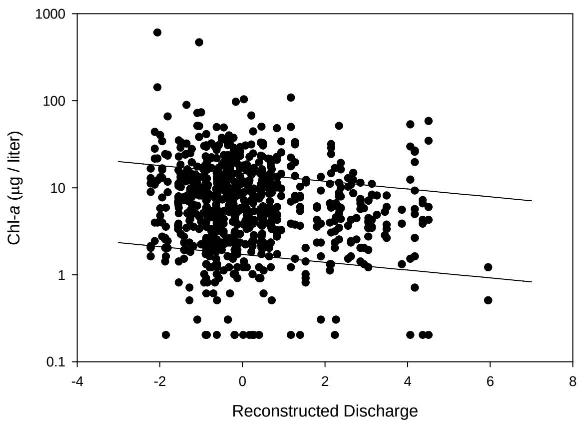

Fig. 6.19 Flow-concentration data for Chl-*a* in Irving; lines show the fitted regression model for the stations with highest and lowest intercepts.

For Chl-*a* flow-concentration relationships were often negative, suggesting that events of high discharge dilute Chl-*a* produced by in situ sources. In flowing water environments, Chl-*a* could be produced by in situ growth of suspended algae or sloughing of attached algae. Both processes are most likely to produce substantial Chl-*a* in streams with broad channels or shallow pools. Alternatively, Chl-a can be advected to a site from upstream sources, in which case a positive flow-concentration relationship might be found. One significant positive flow-concentration relationship was found for Chl-*a*, at station 17683 in Grand Prairie. This is a small stream (Crockett Branch) where strong in situ growth of algae is perhaps unlikely. Although flow-concentration relationships were found for Chl-*a*, there is evidence that localized factors influence this parameter: No significant flow-concentration relationship was found for Arlington, the elevation of the relationships in Irving varied among stations, the slopes of the relationships varied among stations in Grand Prairie, and there was considerable scatter of the data around the fitted regression models.

Flow-concentration analysis for 81078 Turbidity

Turbidity was measured in Fort Worth and Grand Prairie. All regressions used data transformed to natural logarithms. For Turbidity in Fort Worth, 356 observations from 6 stations were analyzed. The model with a common slope (Table 6.18) for all stations but differing intercepts was accepted ($R^2 = 0.31$, $P < 0.001$). The fitted model represents Turbidity as an increasing function of discharge that differs in elevation for different stations (Fig. 6.20).

Table 6.18 Flow-concentration relationship for Chl-*a* in Irving				
Station	Slope	Std. Error	*T*	*P*
All stations	0.159	0.031	5.139	<0.001

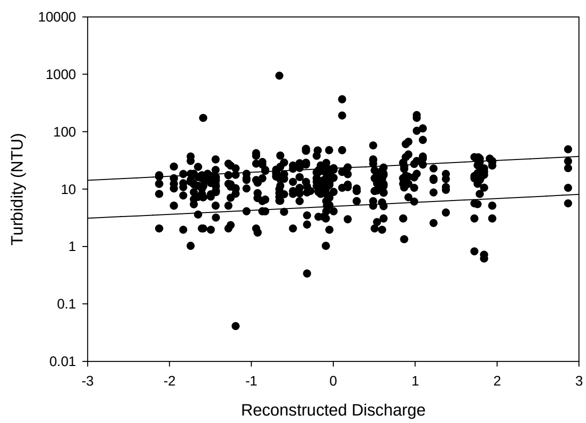

Fig. 6.20 Flow-concentration data for Turbidity in Fort Worth; lines show the fitted regression model for the stations with highest and lowest intercepts.

For Turbidity in Grand Prairie, 1168 observations from 23 stations were analyzed. The model with different slopes (Table 6.18) for different stations was accepted (R^2 = 0.46, $P < 0.001$). The slopes of flow-concentration relationships were statistically significant for sixteen stations. For all of these, Turbidity was an increasing function of discharge. Figure 5.21 shows data together with the fitted models for the two stations with the highest significant slopes for flow-concentration relationships, and the two stations with the lowest significant slopes.

Table 6.16 Flow-concentration relationships for Chl-*a* in Grand Prairie

Station	Slope	Std. Error	*T*	*P*
18311	0.182	0.015	12.309	<0.001
10815	0.150	0.067	2.235	0.026
10867	0.216	0.071	3.050	0.002
13621	0.143	0.070	2.039	0.042
17663	0.281	0.069	4.104	<0.001
17664	0.286	0.066	4.362	<0.001
17665	0.310	0.096	3.219	0.001
17666	0.223	0.064	3.475	0.001
17669	0.284	0.063	4.486	<0.001
17671	0.150	0.066	2.269	0.023
17672	0.184	0.071	2.605	0.009
17673	0.176	0.070	2.530	0.012
17674	0.255	0.070	3.630	<0.001
17675	0.188	0.067	2.790	0.005
17676	0.122	0.069	1.759	0.079
17677	0.237	0.070	3.411	0.001
17678	0.114	0.070	1.629	0.104
17679	0.119	0.070	1.715	0.087
17680	0.160	0.072	2.212	0.027
17681	-0.019	0.070	-0.277	0.782
17682	0.036	0.066	0.550	0.582
17683	0.095	0.070	1.358	0.175
17684	0.054	0.070	0.776	0.438

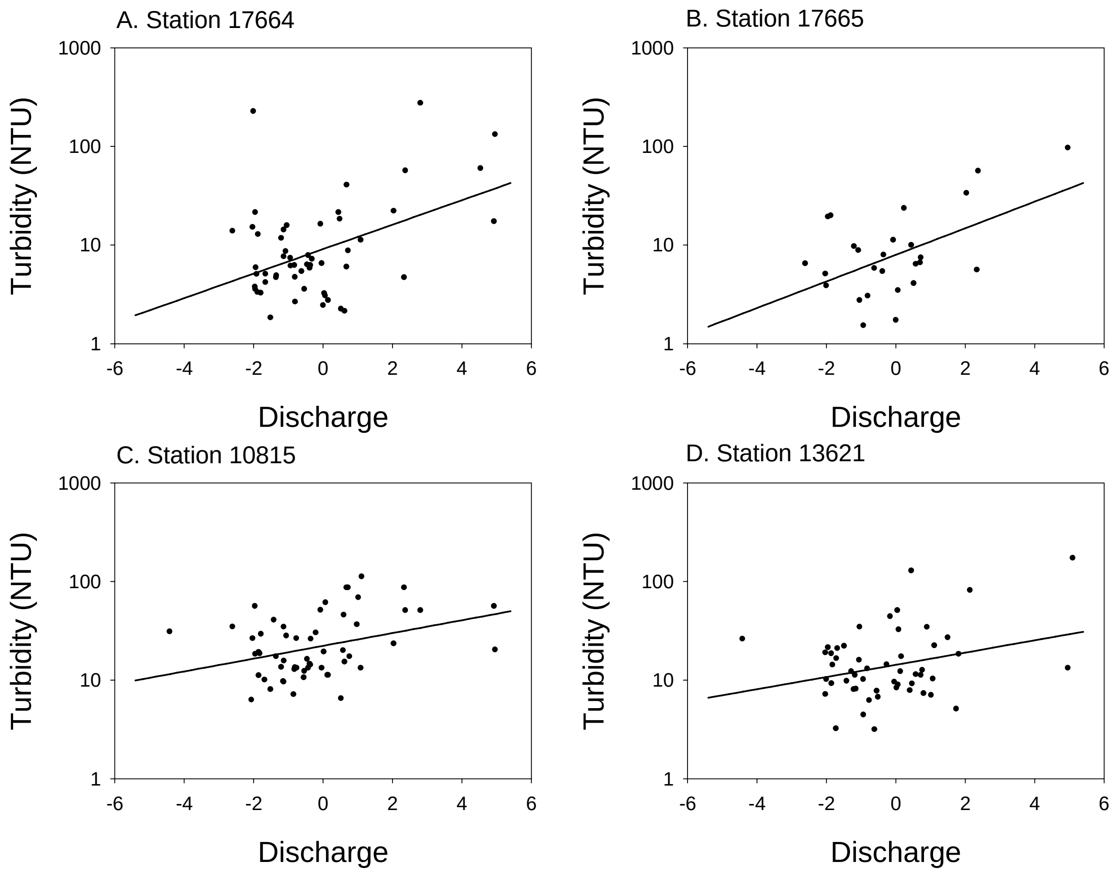

Fig. 6.21 Flow-concentration data for Turbidity in Grand Prairie for four stations with significant flow-concentration relationships; lines show the fitted regression models.

In general, for Turbidity flow-concentration relationships were positive. Turbidity is a complex parameter and both watershed and in situ sources are possible. Erosion and downstream transport of particulates contributes to turbidity, as potentially does in situ growth of algae. The positive flow-concentration relationships found here suggest that watershed sources (erosion and transport) are more important than in situ sources. The significance of the differences in elevation for these regressions found in Forth Worth, the differences in slopes found in Grand Prairie, and the high scatter in all relationships suggest that localized factors are important in determining Turbidity in these streams. All statistically significant relationships are positive, suggesting sources within the watersheds, but at some stations such sources are apparently stronger than at others. Within Grand Prairie, there is a tendency for the stations with the highest slopes for flow-concentration relationship to occur in the Johnson Creek watershed, suggesting that sources of particulates are high in this watershed. Lower slopes or non-significant relationships tend to occur in the Mountain Creek watershed.

Summary of flow-concentration analyses

These analyses were conducted to provide information on possible causes of variation in the selected water quality parameters. In general, positive flow-concentration relationships imply that there are watershed or upstream sources for a parameter, so that events of high discharge increase the transport of substances to a sampling station. Negative relationships indicate that there are in situ sources producing a substance at the sampling location, and that events of high discharge thus dilute the substance.

There are several reasons why the flow-concentration relationships in this analysis should be noisy. Among other factors, the impact of a rainfall event on both flow and concentration of water quality parameters varies in relation to watershed size, stream size, and the amount, extent, and location of rainfall within the watershed. Beyond this inherent variability, methodological factors that introduce errors include the variation in timing between a recent rainfall event and the collection of a sample, and in this study, the use of a "Reconstructed Discharge" variable based on regional discharge patterns. This approach neglects significant localized variation in rainfall, and does not account for the differing relationships between rainfall events and the discharges of large and small streams. Essentially, all streams are treated as if they have the same magnitude of variation in discharge.

The differences among flow-concentration relationships for the parameters analyzed here imply that the balance between external and in situ sources differs. Among nutrient parameters, flow-concentration relationships were usually positive. Those for NO_3/NO_2 were strongest, which is likely a result of the high solubility and mobility of these ions. Natural and urban dust, fertilized landscapes, and natural soils and sediments can all contain varying amounts of NO_3/NO_2, which is mostly available for mobilization by rainfall and runoff. Thus it is not surprising that positive flow-concentration relationships were relatively strong for this parameter. TKN also has potential watershed sources, primarily in the form of organic particulates that can transported during events of high discharge, although ammonia N can also have watershed sources such as livestock wastes or fertilizer. Although positive flow-concentration relationships were found for TKN, they were relatively weak, which possibly indicates that in situ sources also contribute to TKN. Such in situ sources could include biological N-fixation and N-recycling from decaying organic matter. For TP, the most likely watershed or upstream sources are particulates eroded from the landscape or resuspended from the stream bottom, and events of high discharge are likely to transport such particles to a given location. Thus positive flow-concentration relationships were expected, and were found. As for TKN, these relationships were relatively weak and variable. In situ sources of TP are possible, in the form of recycling from decaying organic matter, but are likely to be weak. The variability of flow-concentration relationships for TP probably reflects local variation in factors affecting erosion and sediment transport, including watershed topography and land use, and channel morphology.

For two biological parameters, *E. coli* and Chl-*a*, flow-concentration analysis suggests opposing conclusions. For *E. coli*, moderately to strongly positive flow-concentration relationships were found, implicating watershed sources that are mobilized by events of high discharge. *E. coli* and similar bacteria are unlikely to grow rapidly outside their host animals, but once deposited in feces they are subject to transport in runoff and stream water. A number of sources are possible, including wildlife, domestic pets and animals, homeless encampments, and leaking sewers or septic tanks. Genetic techniques for identifying sources (i.e. host animals) of *E. coli* are becoming available, though they are still expensive. In contrast to *E. coli*, Chl-*a* generally had negative flow-concentration relationships, indicating that in situ sources are diluted by events of high discharge. This is not surprising, since both in situ growth of suspended algae and sloughing of attached algae are likely. As with most biological processes, algal dynamics are highly variable, which likely accounts for the weakness and variability seen in flow-concentration relationships for Chl-*a*.

Turbidity is a complex parameter, and the particles composing it can include both inorganic and detrital particles originating from the landscape, and algae that have grown within stream water. Thus a mix of watershed and in situ sources is possible. Flow-concentration relationships for turbidity were generally positive, indicating that watershed sources dominate. Such relationships were also variable in strength, probably as a consequence of the large number of processes that contribute to Turbidity.

Finally, flow-concentration relationships were analyzed for the Flow Severity index. This exercise is primarily of methodological interest. A positive relationship is expected between a regional discharge index (the flow measure used here) and the Flow Severity index, at least for data dominated by index levels 1 – 5, which was the case here. (Index level 6 is “dry”, an observation likely only when regional discharge is low). Such positive relationships were found in these analyses, verifying this expectation. Few stream sites in the metroplex region are gauged for discharge, so Flow Severity is an easily obtained metric providing a surrogate for information that is unavailable. The disadvantage of Flow Severity is that subjective judgments are required of flow conditions relative to what is considered normal at a site. A single flow-concentration relationship with a common slope and intercept characterized Flow Severity within two municipalities. This finding suggests that it is possible to make consistent judgments of this index among multiple sites. However, site-to-site variations in flow-concentration relationships were found for Flow Severity in two other municipalities. This latter finding suggests that judgments of Flow Severity are either affected by local characteristics of the streams involved, or that the personnel or judgments changed in the course of data collection. Although the Flow Severity index obtains information about flow conditions at little expense, its interpretation requires caution.

7. Examination of metals data

Results for metals concentrations were not available for Fort Worth. For other municipalities, most of the data for many metals were coded undetectable (Tables 7.1-7.3). For most metals, the frequency of detectable values was less than 50%, which implies that the median concentration is below the detection limit. The frequency of detectable values exceeds 50% for only three metals in three municipalities. Summary statistics for these data sets were computed, coding undetectable values to one-half the detection limit (Table 7.4).

For Manganese, which had more 50% detectable values in Arlington, there is no screening criterion established by TCEQ.

For Copper, which had more than 50% detectable values in Grand Prairie, TCEQ has established chronic and acute screening criteria to protect aquatic life, which are increasing functions of hardness. The lowest hardness in Grand Prairie is just above 100 mg / liter. Using this value of hardness leads to a chronic screening level of 12.3 μg / liter for Copper. The maximum concentration of Copper observed in Grand Prairie is below this level.

For Total Zinc, which had more than 50% detectable values in Irving, TCEQ has established chronic and acute screening criteria to protect aquatic life, which are increasing functions of hardness. The lowest hardness in Irving is just above 100 mg / liter. Using this value of hardness leads to a chronic screening level of 105 μg / liter for Zinc. Although the maximum concentration of Total Zinc observed in Irving exceeds this level, both the mean and median are well below it.

Trends and spatial patterns were not examined for metals, given that the proportion of undetectable values is usually large, and given that even when detectable, metals concentrations appear to be below levels that would raise concerns.

Table 7.1 Total sample size and frequency detectable for metals in Arlington

Metal	Total N	Detectable N	% Detectable
Arsenic, Dissolved	12	3	25.0%
Cadmium, Dissolved	245	1	0.4%
Chromium, Dissolved	221	3	1.4%
Copper , Dissolved	234	50	21.4%
Iron, Dissolved	257	21	8.2%
Lead, Dissolved	221	0	0%
Manganese, Dissolved	245	130	53.1%
Nickel, Dissolved	179	7	3.9%
Selenium, Dissolved	12	0	0%
Silver, Dissolved	12	0	0%
Zinc, Dissolved	175	0	0%

Table 7.2 Total sample size and frequency detectable for metals in Grand Prairie			
Metal	Total N	Detectable N	% Detectable
Cadmium, Dissolved	82	1	1.2%
Chromium, Dissolved	85	7	8.2%
Copper, Dissolved	81	41	50.6%
Lead, Dissolved	80	1	1.3%
Selenium, Dissolved	58	5	8.6%
Zinc, Dissolved	65	14	21.5%

Table 7.3 Total sample size and frequency detectable for metals in Irving			
Metal	Total N	Detectable N	% Detectable
Cadmium, Dissolved	817	5	0.6%
Cadmium, Total	482	10	2.1%
Chromium, Dissolved	752	21	2.8%
Chromium, Total	231	51	22.1%
Copper, Dissolved	793	175	22.1%
Copper, Total	396	98	24.7%
Lead, Dissolved	758	0	0%
Lead, Total	459	45	9.8%
Zinc, Dissolved	486	69	14.2%
Zinc, Total	357	342	95.8%

Table 7.4 Summary statistics for metals data with > 50% detectable (µg / liter)			
Metal	Manganese	Copper	Zinc, Total
Municipality	Arlington	Grand Prairie	Irving
N	245	81	357
Mean	110	1.86	23.1
SD	167	1.26	10.5
Min	12.5	1.0	5
Lo Quart	25	1.5	16
Median	56	1.5	22
Hi Quart	140	2.0	28
Max	1700	10.0	108

8. Conclusions

- Measurements of *E. coli* often exceeded the screening level at many locations in all municipalities, especially in small- to medium-sized streams, making this the parameter raising greatest concerns.
- Measurements of Chlorophyll *a* frequently exceed the screening level at several sites, which tended to have broad channels and open surroundings (i.e. no riparian forest), circumstances where *in situ* growth of algae should be expected.
- Concentrations of nutrients were generally below screening levels established by the Texas Commission on Environmental Quality, with a few exceptions.
- Significant increases in Total Kjeldahl Nitrogen or Total Phosphorus were found at several sampling stations in Arlington, Grand Prairie and Irving.
- There were significant decreases in NO_3/NO_2 at many sampling stations in Grand Prairie.
- *E. coli* displayed significantly decreasing trends at several sites, and only one significant increase was noted for a site in Arlington.
- Chlorophyll *a* displayed significantly increasing trends at several sites in Grand Prairie and Irving.
- In Principal Components Analyses the first five factors accounted for more than 70% of the variation in selected water quality parameters, implying that adequate characterization of ambient variations in water quality can be achieved with as few as five well-selected sampling locations. Monitoring plans with 20 – 30 sites include many sites that provide redundant data.
- Discharge data from four gauged stations in the Metroplex region are highly correlated due to shared variations in weather patterns, making it possible to compute a synthetic variable to represent the typical variations in discharge expected at locations that were not gauged.
- Flow-concentration relationships based on this synthetic discharge variable were generally positive and relatively strong for NO_3/NO_2, suggesting potential storm water impacts and watershed sources that are mobilized by runoff and stream flow.
- Flow-concentration relationships were also positive, but variable among sampling stations, for *E. coli*, suggesting that storm water and runoff events mobilize watershed sources that vary in strength among locations.
- Flow-concentration relationships were positive but weaker and more variable for Total Kjeldahl Nitrogen, Total Phosphorus, and Turbidity, suggesting a mix of *in situ* sources and watershed sources of variable strength.
- Flow-concentration relationships were generally negative for Chlorophyll *a* suggesting that storm water events flush out populations of algae that grow *in situ*.
- Metals concentrations were less extensively analyzed but are generally far below concentrations that would raise concerns.

Recommendations

- Some of the monitoring programs analyzed here probably have more sampling stations than necessary to adequately characterize ambient variation in water quality. Number and location of stations should be evaluated.
- Given high levels of *E. coli* at many locations and indications that storm water and runoff events mobilize watershed sources, source typing of *E. coli* by genetic means should be considered for selected locations.
- Dissolved metals concentrations are often undetectable, and metals are more likely to occur in particulate form, so determination of total concentrations would both give more useful data and be more protective of water quality.
- Many organic contaminants likely to be present in urban surface waters raise concerns for human or wildlife health, including “emerging contaminants” such as endocrine disruptors and pharmaceuticals. Obtaining data on such substances would be desirable.

Discussion

Water quality data from ambient monitoring programs were analyzed for four municipalities in the DFW Metroplex region: Arlington, Fort Worth, Grand Prairie and Irving. The analyses addressed status and trends for selected water quality parameters, regional patterns of variation, and possible impacts of storm water on these parameters. Less extensive analyses were applied to data on metals concentrations. Data analyzed came from locations whose watersheds ranged from small streams with watershed areas less than one square mile, to sites on forks of the Trinity River with watershed areas exceeding 1000 square miles. The data analyzed were obtained between the years 2000 and 2006.

A comparison of selected water quality parameters to screening levels established by the Texas Commission on Environmental Quality yielded mixed results concerning water quality status during the time period involved. Concentrations of NO_3/NO_2 were generally below the screening level, though frequent exceedances occurred at one site on the West Fork of the Trinity River in Grand Prairie. This finding occurred at the only site on the Trinity River where NO_3/NO_2 was determined, and thus confirmation other locations would be helpful. Total Phosphorus also frequently exceeded the screening level at this site on the West Fork, but not at other sites in this study including some on the Elm Fork.

Measurements of *E. coli* often exceeded the screening level at many locations in all municipalities, making this the parameter raising greatest concerns. While high values of *E. coli* characterized a variety of locations, there was some tendency for relatively small streams to have high values.

Measurements of Chlorophyll *a* frequently exceed the screening level at several sites, which tended to have broad channels and open surroundings (i.e. no riparian forest), circumstances where *in situ* growth of algae should be expected.

There is no established screening level for Total Kjeldahl Nitrogen, but it is argued that the amounts measured in this study are lower than those that would be associated with undesirable biomass of algae or other microbes.

Likewise, there is no established screening level for Turbidity, but except for one site measured levels were generally lower than those thought to affect fish feeding. The one exception is a site on one arm of Joe Pool Lake (not a stream site) where suspension of lake sediments by wind is likely.

The trend analysis also produced mixed results, with both increasing and decreasing trends occurring. There were significant decreases in NO_3/NO_2 at many sampling stations in Grand Prairie, with the exception of one small stream in a highly developed area with a significant increase. Significant increases in Total Kjeldahl Nitrogen or Total Phosphorus were found at several sampling stations in Arlington, Grand Prairie and Irving. The increases in Total Phosphorus tended to occur in small streams, and in some cases recent land disturbance or erosion may have occurred.

E. coli displayed significantly decreasing trends at several sites, and only one significant increase was noted for a site in Arlington. Chlorophyll *a* displayed significantly increasing trends at several sites in Grand Prairie and Irving, including some sites with relatively open surroundings that would likely permit high algal growth, though excessive Chlorophyll *a* levels were not yet observed at these particular sites.

As expected, variations in Water Temperature were highly coherent across the Metroplex region due to synchronized, seasonal heating and cooling of surface waters. Other water quality parameters displayed lower coherence, meaning that observations from different locations were less strongly correlated. Principal Components Analyses generally found that clusters of locations displayed parallel variations in various water quality parameters. Thus there are sets of locations that have highly correlated variations among themselves, and sets of locations that have different patterns of variation. In some cases there were tendencies for sites in the same watershed to show parallel variations in a particular water quality parameter (e.g. TKN increased at several sites in the Bear Creek watershed in Irving increased until 2003, then leveled off and decreased).

A more important finding of the Principal Components Analyses is that in many cases the first five factors accounted for more than 70% of the variation in a selected water quality parameter. This result implies that adequate characterization of ambient variations in water quality can be achieved with as few as five well selected sampling locations. Monitoring plans such as those of Grand Prairie and Irving with 20 – 30 sites include many sites that provide redundant data. The monitoring plans of Arlington and Fort Worth are closer in number of stations to what appears adequate. However, it is also important to select stations that represent the variety of watersheds within a region. In Fort Worth, for example, sites on the West Fork of the Trinity River are over-represented, as are locations near the city center. In contrast, a similar number of sites was sampled in Arlington, but these cover a greater range of smaller stream sizes and are better spread across this municipality.

Discharge data from four gauged stations in the Metroplex region are highly correlated due to shared variations in weather patterns. For this reason, it is possible to compute a synthetic variable called Reconstructed Discharge which represents the typical variations in discharge expected at locations that were not gauged. This Reconstructed Discharge variable was used as surrogate data to analyze changes in concentration of selected water quality parameters at sampling stations that were not gauged.

Reconstructed Discharge was positively related to the Flow Severity index in a manner consistent with the definition of the index. This result suggests that despite its subjective nature, the Flow Severity index provides information relating to discharge. Late in the period of observations analyzed here, from about April of 2005 to February of 2006, there was a period of distinctly low discharge across the region. Consistent with this, decreasing trends in the Flow Severity index were found at several sampling stations. Most of these decreases were on larger streams in the western region of the Metroplex. Increasing trends for the Flow Severity index were found for some sampling stations on smaller and in the eastern Metroplex. These observations suggest that there are regional differences in discharge variation across the Metroplex. Such regional differences are not incorporated into the synthetic variable Reconstructed Discharge, so that flow-concentration relationships based on this synthetic variable are at best approximations to the true relationships.

Flow-concentration relationships were generally positive and relatively strong for NO_3/NO_2. This result suggests potential storm water impacts, with watershed sources of these ions that are mobilized by runoff and stream flow. This result is also expected, because NO_3 and NO_2 are highly soluble and easily leached from soils. Flow-concentration relationships were also positive, but generally weaker or more variable among sites for Total Kjeldahl Nitrogen. Storm water impacts involving mobilization of watershed sources, such as organic detritus, are possible for this parameter, but *in situ* sources such as biological nitrogen fixation and recycling of ammonia are also possible. Flow-concentration relationships were positive, but variable among sampling stations, for Total Phosphorus. This result suggests that there are watershed sources that can be mobilized by storm flow events, but that such sources vary among localities. Phosphorus is not easily leached from soils, so watershed sources likely involve erosion and downstream transport of sediments. These processes probably vary greatly depending on watershed and channel characteristics. Flow-concentration relationships were similarly positive but variable among sampling stations for Turbidity, another parameter likely to be influenced by erosion and downstream transport of sediments.

Flow-concentration relationships were also positive, but variable among sampling stations, for *E. coli*. This result suggests that storm water and runoff events mobilize watershed sources that vary in strength among locations. A number of sources are possible, including wildlife, domestic pets and animals, homeless encampments, and leaking sewers or septic tanks, and local variation in such sources is likely. Given that high *E. coli* concentrations are a possible concern at several sites, more conclusively determining the sources of *E. coli* may be worthwhile. Molecular genetic techniques for doing so are becoming available, and might soon be worth considering, though they are expensive.

Flow-concentration relationships were generally negative for Chlorophyll *a*, but also variable among sampling stations. The negative relationships suggest that storm water events flush out *in situ* populations of algae. The presence of growing, *in situ* algal populations subject to washout is consistent with the finding that high Chlorophyll *a* occurs primarily at sites with broad channels and open surroundings where light conditions would be favorable for such growth.

Metals concentrations were less extensively analyzed for two reasons: first, most data sets were dominated by undetectable measurements and second, there were many differences in choices of specific metals measured by different municipalities. The first finding here is encouraging, and suggests that metals are generally far below concentrations that would raise concerns. Even those data sets with more than half of the measurements indicating detectable concentrations were generally well below screening levels established by the Texas Commission on Environmental Quality. Despite these encouraging results, it should be noted that most of the measurements involved are for dissolved metals. The solubilities of the metals involved are generally low under oxidizing, surface water conditions, so dissolved concentrations would be expected to be low. Total concentrations including suspended particulates could be larger, however. Only Irving routinely determined total concentrations of metals, with results again indicating concentrations below levels of concern. Nevertheless, given the possible health effects of metals for humans and wildlife, and the fact that metals in oxidizing surface waters are likely to be in particulate form, it would be worthwhile to consider more extensive determinations of total metals concentrations.

As noted above, it appears that some of the monitoring plans used by municipalities in the Metroplex region are more extensive than necessary for characterizing ambient variation in water quality. Of course, there reasons to monitor specific sites, such as permit requirements and Illicit Discharge Detection and Elimination. Nevertheless, if a reduction in number of stations were entertained, resources might be freed for other purposes. Genetically typing the sources of *E. coli* at selected locations appears to deserve consideration given the high levels noted at many sites. Though there is little evidence of problems involving metals concentrations, determinations of total metals concentrations would probably be more protective of human and wildlife health than determination of only dissolved concentrations. No data on organic contaminants were analyzed in this study, though many substances likely to be present in urban surface waters raise concerns for human or wildlife health, including “emerging contaminants” such as endocrine disruptors and pharmaceuticals. Data on such substances would be desirable.

9. Guide to electronic appendices

Electronic appendices consist of several Excel workbooks containing all data used in this study, all calculations done directly in Excel, and all output saved from Statistica, the program used for some of the statistical analyses.

The bulk of the water quality data analyzed are contained in files coded with the following names: a city code (ARRT - Arlington, FWRT – Fort Worth, GPRT – Grand Prairie, IRRT - Irving) followed by a STORET parameter. Thus the file ARRT 00010.xls contains data on Water Temperature from Arlington.

In these workbooks, there are six or seven worksheets, organized as follows.

Sheet 1	A data table with Tag ID used to match the "events" query from the data base, with the "results" query, which accomplishes matching the data on sampling station and date with the measurement value for a parameter.
Sheet 2	A data matrix of measured parameter values in which columns are stations and rows are dates (month-year). If transformation to natural logarithms was used for trend analysis, a data matrix of natural logs of measurements also appears on this sheet. Summary statistics for each station appear below the corresponding column.
Sheet 3	Data and results for the trend analysis. XY-pairs for a trend regression are constructed with Y = measured parameter value or natural logarithm (when this was used) and X = number of months since the earliest sample.
Sheet 4	Results of coherence analysis. The data matrix in sheet 2 was input to Statistica to calculate a correlation matrix among all pairs of stations. This matrix was pasted into the worksheet and all values averaged to obtain coherence.
Sheet 5(6)	Data and results for Principal Components Analysis, consisting of edited data to eliminate missing values, and output from the Statistica reports of the analysis. Output saved included a table of eigenvalues (calculating the percent of variance explained by the first five factors), and a plot of factor scores for the first two factors. Notes were made concerning the delineation of clusters of stations on these plots, and time series of the underlying data were plotted to aid interpretation of clusters.
Last Sheet	Analysis of flow-concentration relationships, including data edited to include stations with at least five observations and output from Statistica. The output included regression reports and calculations of partial F statistics to compare the different regression models explained in the text.

An Excel workbook named USGS sites.xls contains discharge data from gauged stations and its analysis. Sheet 1 lists the web links used to obtain the data and information on the stations involved. Sheet 2 has the data as downloaded, from 1-1-1999 to 4-4-2007. Sheet 3 has the results of the Principal Components Analysis of the discharge data, transformed to natural logarithms. Sheet 4 is a table of dates and values for the Reconstructed Discharge variable.

Excel workbooks with a city code and the term "events" or "results" in the file name contain the results of the corresponding database queries. That is, ARRT events.xls has the table constructed by the events query, and ARRT results has the table constructed by the results query. The Tag ID entries of these tables were used to construct the data sets individual parameters.

Excel workbooks with a city code and the term "metals" in the file name contain data and analyses for metals. That is, ARRT metals.xls contains the data and analyses for metals in Arlington. Sheet 1 of these workbooks lists the metals data organized by Tag ID, with calculations of the percent of detectable measurements for each metal parameter. Sheet 2 contains calculations of summary statistics for any metals with > 50% detectable measurements.

The Excel workbook Station info.xls has one sheet for each city, in which each row contains all the information on location, watershed characteristics, etc., provided for a given sampling station. Additional worksheets contain edited versions of these very large data tables.

Appendix 1. Analysis of location statistics.

Arlington 00010 Water Temperature (° C):

Station →	10719	10721	10722	10723	10724	10725	10780	10791	10792	17189
N	22	20	21	22	21	22	22	20	22	21
Mean	21.3	18.3	22.9	20.2	23.5	20.9	22.7	19.7	20.9	19.9
SD	7.1	7.3	7.7	7.3	9.0	7.6	7.2	6.7	8.2	7.2
Min	7.4	5.6	9.7	8.1	7.4	5.9	8.8	7.8	7.8	8.1
Lo Quart	19.1	13.7	19.5	16.2	18.4	19.3	17.6	15.8	15.0	14.0
Median	21.8	19.2	23.2	19.0	23.0	21.5	21.7	19.6	20.5	19.6
Hi Quart	28.3	24.4	29.0	26.9	29.0	27.6	30.4	25.9	27.5	25.6
Max	31.6	29.0	39.5	33.0	40.2	30.0	32.2	30.0	38.0	33.0

Arlington 00010 Water Temperature (cont.):

Station →	17190	17191	10778	10788	10790
N	18	19	1	1	1
Mean	18.0	17.8	26.0	28.0	24.0
SD	7.6	7.0			
Min	5.0	7.5	26.0	28.0	24.0
Lo Quart	10.7	11.7	26.0	28.0	24.0
Median	19.3	17.5	26.0	28.0	24.0
Hi Quart	22.6	22.4	26.0	28.0	24.0
Max	32.5	28.6	26.0	28.0	24.0

Arlington 00625 Total Kjeldahl Nitrogen (mg / liter):

Station →	10719	10722	10725	17191
N	22	22	22	18
Mean	0.60	1.10	0.57	0.76
SD	0.19	1.41	0.26	0.32
Min	0.30	0.20	0.20	0.30
Lo Quart	0.50	0.50	0.40	0.53
Median	0.60	0.60	0.50	0.75
Hi Quart	0.70	1.23	0.70	0.90
Max	1.00	6.90	1.30	1.60

Arlington 00630 NO_3 / NO_2 (mg / liter):

Station →	10719	10722	10725	17191
N	22	22	22	19
Mean	0.40	0.59	0.24	0.38
SD	0.23	0.35	0.32	0.33
Min	0.05	0.02	0.02	0.02
Lo Quart	0.24	0.39	0.04	0.13
Median	0.34	0.50	0.11	0.22
Hi Quart	0.56	0.74	0.27	0.65
Max	0.87	1.59	1.16	1.08

Arlington 00665 Total Phosphorus (mg / liter):

Station →	10719	10722	10725	17191
N	22	22	22	19
Mean	0.08	0.17	0.05	0.10
SD	0.05	0.27	0.02	0.07
Min	0.03	0.02	0.02	0.02
Lo Quart	0.04	0.04	0.04	0.06
Median	0.06	0.06	0.06	0.08
Hi Quart	0.10	0.11	0.06	0.13
Max	0.23	1.04	0.07	0.34

Arlington 01351 Flow Severity:

Station →	10719	10721	10722	10723	10724	10725	10780	10791	10792	17189
N	22	22	21	22	21	20	22	21	22	20
Mean	3.2	2.8	3.0	2.6	3.1	2.7	3.0	2.9	3.0	2.8
SD	0.8	1.1	0.8	0.7	0.7	0.5	0.8	1.1	1.0	0.9
Min	2.0	1.0	2.0	2.0	2.0	2.0	2.0	1.0	2.0	2.0
Lo Quart	3.0	2.0	3.0	2.0	3.0	2.0	3.0	2.0	3.0	2.0
Median	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Hi Quart	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Max	5.0	6.0	5.0	5.0	5.0	3.0	5.0	6.0	6.0	5.0

Station →	17190	17191
N	20	21
Mean	3.0	3.0
SD	1.1	1.2
Min	1.0	1.0
Lo Quart	2.0	2.0
Median	3.0	3.0
Hi Quart	3.0	3.0
Max	5.0	6.0

Arlington 31699 *E. coli* (colonies / 100 ml):

Station →	10719	10721	10722	10723	10724	10725	10780	10791	10792	17189
N	15	15	15	15	15	15	15	15	15	15
Mean	623	630	441	920	357	393	225	496	531	261
SD	889	1283	900	2000	377	613	319	1215	1200	431
Min	81	4	17	34	8	4	24	2	4	4
Lo Quart	193	116	37	96	60	52	56	66	138	24
Median	245	158	134	242	207	117	87	139	182	99
Hi Quart	644	263	242	651	568	391	220	314	371	203
Max	3470	4840	3470	7940	1160	1960	1230	4840	4840	1640

Station →	17190	17191
N	15	14
Mean	656	593
SD	1276	1305
Min	45	6
Lo Quart	61	72
Median	158	130
Hi Quart	497	162
Max	4840	4840

Arlington 32211 Chlorophyll *a* (µg / liter):

Station →	10719	10722	10725	17191
N	22	22	22	19
Mean	4.6	10.4	4.2	6.0
SD	3.0	14.9	3.5	6.0
Min	1.1	0.2	0.2	0.2
Lo Quart	3.3	3.3	2.2	3.1
Median	3.5	4.5	3.3	4.4
Hi Quart	5.0	8.5	4.9	5.5
Max	13.6	55.4	14.4	22.0

Arlington 82078 Turbidity: this parameter was not done.

Fort Worth 00010 Water Temperature (° C):

Station →	10938	16120	17368	17369	17370	18456
N	66	66	66	65	66	19
Mean	20.70	20.83	20.22	20.45	21.09	20.79
SD	7.40	7.49	7.27	7.27	7.43	7.00
Min	7.40	8.10	6.40	7.60	7.70	10.80
Lo Quart	14.65	15.03	14.08	14.60	14.23	14.10
Median	21.25	21.30	21.00	20.30	21.75	21.70
Hi Quart	27.93	27.83	26.68	26.50	27.70	25.75
Max	32.70	33.70	31.70	33.70	34.50	31.50

Fort Worth 00625 Total Kjeldahl Nitrogen (mg / liter): this parameter was not done.

Fort Worth 00630 NO_3 / NO_2 (mg / liter): this parameter was not done.

Fort Worth 00665 Total Phosphorus (mg / liter): this parameter was not done.

Fort Worth 01351 Flow Severity:

Station →	10938	16120	17368	17369	17370	18456
N	67	67	67	69	69	18
Mean	3.0	3.1	3.1	3.0	2.8	2.9
SD	0.9	0.9	0.8	1.0	0.7	0.2
Min	2.0	2.0	2.0	2.0	2.0	2.0
Lo Quart	2.0	3.0	3.0	2.0	2.0	3.0
Median	3.0	3.0	3.0	3.0	3.0	3.0
Hi Quart	3.0	3.0	3.0	3.0	3.0	3.0
Max	5.0	5.0	5.0	5.0	5.0	3.0

Fort Worth 31699 *E. coli* (colonies / 100 ml):

Station →	10938	16120	17368	17369	17370	18456
N	68	70	68	70	71	19
Mean	327	2019	329	1796	525	166
SD	661	11700	738	9741	820	162
Min	0	1	1	4	3	5
Lo Quart	7	22	9	92	26	53
Median	37	87	36	229	104	96
Hi Quart	181	690	156	597	564	205
Max	2419	98040	3640	81640	2419	579

Fort Worth 32211 Chlorophyll *a* (µg / liter): this parameter was not done.

Fort Worth 82078 Turbidity:

Station →	10938	16120	17368	17369	17370	18456
N	64	65	65	65	65	19
Mean	16.7	42.5	19.4	12.8	19.9	11.6
SD	13.3	113.3	10.8	31.0	48.1	5.4
Min	6.0	0.3	6.0	0.0	2.3	0.8
Lo Quart	10.0	15.7	12.1	2.0	7.1	8.5
Median	13.0	23.0	17.7	4.0	10.8	11.0
Hi Quart	18.6	33.0	21.9	8.0	15.0	13.9
Max	101.0	920.0	70.0	185.8	356.0	27.0

Grand Prairie 00010 Water Temperature (° C):

Station →	**10815**	**10867**	**13621**	**17663**	**17664**	**17665**	**17666**	**17669**	**17671**	**17672**
N	56	56	55	54	55	26	56	55	46	51
Mean	21.0	18.1	17.7	18.5	18.8	18.2	18.2	21.0	18.1	19.0
SD	7.3	7.4	6.7	7.7	7.3	7.4	6.9	6.0	6.7	6.8
Min	9.0	5.8	4.9	6.2	6.4	7.4	6.1	11.7	7.3	8.0
Lo Quart	14.5	10.9	12.8	10.8	12.0	10.8	12.5	14.9	11.9	12.8
Median	20.7	17.8	17.2	18.2	19.7	17.8	18.2	20.6	18.2	20.2
Hi Quart	27.8	24.7	23.8	25.8	25.7	24.1	24.7	25.9	23.5	25.3
Max	32.4	29.2	28.3	32.2	29.2	29.8	28.7	30.8	28.7	30.3

Station →	**17673**	**17674**	**17675**	**17676**	**17677**	**17678**	**17679**	**17680**	**17681**	**17682**
N	53	53	55	55	55	53	52	51	55	53
Mean	19.8	18.9	17.9	18.7	18.0	18.3	19.7	17.3	19.5	20.6
SD	7.4	7.0	5.5	6.8	6.8	7.5	10.4	6.5	7.0	7.6
Min	7.7	7.8	7.5	6.3	5.5	4.7	6.2	6.1	8.8	8.6
Lo Quart	13.0	13.1	13.6	13.1	12.6	11.8	13.2	12.3	12.6	13.8
Median	18.8	18.5	17.8	18.2	18.5	19.1	18.6	17.3	19.8	20.2
Hi Quart	26.0	25.5	23.3	24.4	24.0	24.0	25.6	23.6	25.9	27.2
Max	32.1	30.5	26.5	29.6	28.8	34.7	73.8	27.7	30.7	32.0

Station →	**17683**	**17684**	**18311**
N	54	55	24
Mean	18.6	19.1	18.5
SD	6.2	7.6	6.8
Min	7.5	6.8	8.2
Lo Quart	13.6	12.4	13.7
Median	18.1	19.0	17.9
Hi Quart	23.9	25.6	23.8
Max	30.3	30.8	30.1

Grand Prairie 00625 Total Kjeldahl Nitrogen (mg / liter):

Station →	**10815**	**10867**	**13621**	**17663**	**17664**	**17665**	**17666**	**17669**	**17671**	**17672**
N	18	18	18	18	18	7	18	17	15	16
Mean	0.74	0.75	0.80	0.80	0.59	0.90	0.64	1.09	0.97	0.69
SD	0.34	0.33	0.58	0.45	0.19	0.94	0.37	0.42	0.49	0.30
Min	0.20	0.30	0.30	0.20	0.20	0.40	0.30	0.60	0.30	0.30
Lo Quart	0.45	0.53	0.60	0.50	0.50	0.40	0.40	0.90	0.55	0.55
Median	0.80	0.65	0.60	0.70	0.60	0.60	0.60	0.90	1.00	0.70
Hi Quart	0.90	1.00	0.78	0.98	0.70	0.75	0.70	1.20	1.30	0.80
Max	1.70	1.30	2.90	2.10	0.90	3.00	1.90	2.20	2.00	1.40

Station →	**17673**	**17674**	**17675**	**17676**	**17677**	**17678**	**17679**	**17680**	**17681**	**17682**
N	17	18	18	18	18	18	17	17	17	17
Mean	0.67	0.62	0.61	0.56	0.51	0.47	0.69	0.84	0.75	0.75
SD	0.40	0.20	0.32	0.27	0.18	0.18	0.37	0.52	0.86	0.31
Min	0.05	0.30	0.20	0.20	0.20	0.20	0.30	0.20	0.30	0.30
Lo Quart	0.40	0.43	0.40	0.40	0.40	0.40	0.50	0.60	0.40	0.60
Median	0.50	0.65	0.60	0.50	0.50	0.50	0.60	0.60	0.50	0.60
Hi Quart	0.90	0.70	0.85	0.70	0.60	0.50	0.70	1.00	0.70	1.00
Max	1.40	1.00	1.20	1.20	0.90	1.00	1.70	2.30	4.00	1.40

Station →	**17683**	**17684**	**18311**
N	18	18	9
Mean	0.63	0.89	0.66
SD	0.24	0.28	0.22
Min	0.20	0.40	0.30
Lo Quart	0.50	0.70	0.60
Median	0.60	0.95	0.60
Hi Quart	0.68	1.10	0.70
Max	1.20	1.40	1.00

Grand Prairie 00630 NO_3 / NO_2 (mg / liter):

Station →	10815	10867	13621	17663	17664	17665	17666	17669	17671	17672
N	17	16	17	16	16	6	16	15	13	15
Mean	0.50	0.28	0.26	0.26	0.18	0.42	0.26	6.96	0.31	0.37
SD	0.44	0.31	0.24	0.27	0.14	0.18	0.28	5.15	0.27	0.35
Min	0.04	0.04	0.04	0.04	0.02	0.12	0.04	0.04	0.04	0.02
Lo Quart	0.06	0.07	0.09	0.08	0.08	0.37	0.11	2.72	0.10	0.12
Median	0.43	0.15	0.21	0.14	0.16	0.46	0.14	6.76	0.25	0.24
Hi Quart	0.61	0.31	0.30	0.30	0.22	0.53	0.32	10.58	0.31	0.49
Max	1.31	1.06	0.95	0.87	0.48	0.62	1.08	18.00	0.95	1.18

Station →	17673	17674	17675	17676	17677	17678	17679	17680	17681	17682
N	16	16	17	17	17	17	16	16	17	16
Mean	0.39	0.38	0.93	0.30	0.32	0.34	0.40	1.05	0.16	0.13
SD	0.21	0.18	0.34	0.21	0.22	0.30	0.31	1.43	0.10	0.08
Min	0.10	0.04	0.20	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Lo Quart	0.22	0.30	0.84	0.15	0.10	0.14	0.11	0.08	0.08	0.04
Median	0.40	0.37	0.97	0.29	0.38	0.22	0.34	0.40	0.14	0.11
Hi Quart	0.51	0.52	1.14	0.38	0.47	0.62	0.66	1.58	0.19	0.18
Max	0.86	0.67	1.40	0.79	0.72	0.89	0.88	5.48	0.37	0.27

Station →	17683	17684	18311
N	17	17	8
Mean	0.78	0.36	0.26
SD	0.49	0.30	0.24
Min	0.20	0.04	0.04
Lo Quart	0.56	0.07	0.07
Median	0.66	0.40	0.19
Hi Quart	0.85	0.48	0.39
Max	2.25	0.98	0.73

Grand Prairie 00665 Total Phosphorus (mg / liter):

Station →	10815	10867	13621	17663	17664	17665	17666	17669	17671	17672
N	19	19	19	19	19	7	19	19	16	17
Mean	0.06	0.13	0.22	0.10	0.06	0.11	0.06	1.12	0.10	0.12
SD	0.03	0.16	0.52	0.09	0.03	0.09	0.05	0.54	0.07	0.14
Min	0.02	0.03	0.03	0.02	0.02	0.04	0.02	0.34	0.02	0.02
Lo Quart	0.05	0.06	0.06	0.06	0.04	0.06	0.04	0.72	0.06	0.06
Median	0.06	0.07	0.06	0.06	0.06	0.06	0.06	1.03	0.06	0.06
Hi Quart	0.07	0.11	0.11	0.11	0.06	0.12	0.06	1.54	0.14	0.10
Max	0.15	0.66	2.31	0.42	0.14	0.29	0.26	1.99	0.28	0.60

Station →	17673	17674	17675	17676	17677	17678	17679	17680	17681	17682
N	18	19	18	19	18	19	18	17	19	18
Mean	0.06	0.09	0.08	0.05	0.06	0.05	0.07	0.07	0.05	0.08
SD	0.03	0.10	0.06	0.02	0.02	0.02	0.03	0.05	0.02	0.05
Min	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Lo Quart	0.03	0.05	0.06	0.03	0.05	0.02	0.06	0.05	0.04	0.06
Median	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Hi Quart	0.07	0.07	0.08	0.06	0.06	0.06	0.08	0.08	0.06	0.08
Max	0.10	0.45	0.26	0.10	0.12	0.10	0.13	0.25	0.08	0.21

Station →	17683	17684	18311
N	19	19	9
Mean	0.12	0.10	0.07
SD	0.08	0.04	0.05
Min	0.04	0.06	0.02
Lo Quart	0.07	0.07	0.06
Median	0.10	0.08	0.06
Hi Quart	0.14	0.10	0.09
Max	0.40	0.18	0.16

Grand Prairie 01351 Flow Severity:

Station →	10815	10867	13621	17663	17664	17665	17666	17669	17671	17672
N	56	54	54	53	48	22	54	54	47	51
Mean	2.6	2.9	2.8	2.8	2.9	2.6	2.8	3.0	2.9	2.7
SD	0.7	0.7	0.7	0.7	0.8	0.7	0.6	0.8	0.7	0.8
Min	2.0	2.0	1.0	2.0	2.0	2.0	2.0	2.0	2.0	1.0
Lo Quart	2.0	2.3	3.0	2.0	2.0	2.0	2.3	3.0	3.0	2.0
Median	2.5	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Hi Quart	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Max	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	6.0	5.0

Station →	17673	17674	17675	17676	17677	17678	17679	17680	17681	17682
N	55	55	55	55	53	54	50	51	55	56
Mean	2.8	3.0	3.1	2.9	2.6	3.2	3.0	3.0	3.0	2.9
SD	0.6	0.6	0.7	0.6	0.7	0.9	0.8	1.0	0.7	1.1
Min	1.0	2.0	2.0	2.0	1.0	1.0	1.0	1.0	2.0	1.0
Lo Quart	3.0	3.0	3.0	3.0	2.0	3.0	3.0	3.0	3.0	2.0
Median	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Hi Quart	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Max	5.0	5.0	5.0	5.0	5.0	5.0	5.0	6.0	5.0	6.0

Station →	17683	17684	18311
N	51	53	24
Mean	2.6	2.5	2.9
SD	0.5	0.9	0.7
Min	2.0	1.0	2.0
Lo Quart	2.0	2.0	3.0
Median	3.0	3.0	3.0
Hi Quart	3.0	3.0	3.0
Max	4.0	4.0	5.0

Grand Prairie 31699 *E. coli* (colonies / 100 ml):

Station →	**10815**	**10867**	**13621**	**17663**	**17664**	**17665**	**17666**	**17669**	**17671**	**17672**
N	54	53	53	53	54	24	54	53	45	50
Mean	167	803	593	762	467	542	1159	634	1700	1008
SD	663	1365	1131	1290	1122	1337	2724	1325	2549	1458
Min	1	6	24	8	6	8	1	17	43	13
Lo Quart	16	70	111	41	47	26	21	58	198	48
Median	32	160	198	109	98	110	91	89	651	230
Hi Quart	69	520	387	615	265	261	713	210	1540	1705
Max	4840	4838	4840	4838	4840	4838	17300	4838	12000	4840

Station →	**17673**	**17674**	**17675**	**17676**	**17677**	**17678**	**17679**	**17680**	**17681**	**17682**
N	52	53	54	53	54	53	51	51	53	52
Mean	628	904	1289	1024	625	325	907	489	165	256
SD	1664	1416	2312	2500	1067	846	2605	895	760	856
Min	1	22	51	1	37	2	6	2	2	1
Lo Quart	10	140	177	60	134	19	81	21	4	8
Median	40	271	372	106	232	56	159	61	10	23
Hi Quart	246	821	1003	313	341	143	359	575	22	120
Max	9800	4840	12000	15500	4840	4840	17300	4840	4838	4840

Station →	**17683**	**17684**	**18311**
N	53	53	24
Mean	1735	237	395
SD	1853	694	1096
Min	8	1	2
Lo Quart	280	4	8
Median	922	22	18
Hi Quart	3110	89	41
Max	6490	3470	4838

Grand Prairie 32211 Chlorophyll *a* (µg / liter):

Station →	10815	10867	13621	17663	17664	17665	17666	17669	17671	17672
N	20	20	20	20	20	9	20	18	17	18
Mean	7.7	15.3	6.1	10.7	4.0	8.1	3.2	9.2	5.6	6.3
SD	5.6	25.1	5.8	11.9	5.3	8.3	2.3	3.8	7.6	8.7
Min	0.3	2.2	1.1	0.3	0.2	1.0	0.2	1.6	0.8	0.7
Lo Quart	4.5	4.8	3.4	4.4	1.3	4.1	1.5	7.5	1.8	1.4
Median	6.4	6.2	5.0	7.0	2.3	6.4	2.4	9.6	2.9	3.8
Hi Quart	10.0	10.5	5.5	10.9	5.0	8.8	5.0	11.2	5.1	5.4
Max	22.0	90.9	26.6	54.0	24.3	28.0	7.5	15.2	32.1	30.0

Station →	17673	17674	17675	17676	17677	17678	17679	17680	17681	17682
N	19	20	20	20	20	20	19	19	19	19
Mean	7.7	3.6	5.7	4.0	3.3	3.7	8.4	14.6	4.8	9.7
SD	6.9	2.7	7.1	3.8	2.2	2.1	8.6	22.9	1.8	9.4
Min	0.2	1.0	0.8	0.2	0.2	0.2	0.2	0.2	1.3	0.0
Lo Quart	2.2	1.8	1.5	1.1	1.5	2.1	1.9	3.1	3.7	4.2
Median	6.1	3.1	2.9	3.0	2.7	3.6	5.6	4.8	4.7	7.0
Hi Quart	10.1	5.0	5.0	5.1	5.0	5.0	10.5	16.6	5.5	14.2
Max	23.4	12.1	25.1	13.5	8.8	7.3	28.6	94.1	10.0	42.2

Station →	17683	17684	18311
N	20	20	9
Mean	8.7	17.7	5.1
SD	14.5	12.6	5.1
Min	0.2	3.6	0.2
Lo Quart	1.4	9.0	0.3
Median	3.7	14.4	3.0
Hi Quart	6.0	22.7	11.0
Max	56.2	44.7	12.4

Grand Prairie 82078 Turbidity:

Station →	10815	10867	13621	17663	17664	17665	17666	17669	17671	17672
N	56	54	53	54	54	26	55	55	46	52
Mean	28.3	33.4	20.7	32.7	21.4	13.8	11.2	47.8	16.4	27.7
SD	23.4	51.2	29.1	57.4	49.0	20.3	30.0	80.9	17.3	78.3
Min	6.2	5.4	0.0	5.4	1.8	1.5	1.4	6.1	2.3	2.5
Lo Quart	13.0	12.7	8.0	11.2	4.2	4.3	2.7	17.8	5.3	6.6
Median	18.5	17.6	12.0	15.6	6.2	6.4	4.8	22.7	10.9	11.2
Hi Quart	34.6	31.8	20.6	25.8	14.7	10.7	9.8	28.7	19.6	17.5
Max	110.0	298.0	170.0	313.0	270.0	95.0	224.0	381.0	83.0	559.0

Station →	17673	17674	17675	17676	17677	17678	17679	17680	17681	17682
N	54	55	55	55	55	54	51	51	55	54
Mean	34.7	31.5	15.3	10.1	16.3	7.2	28.3	40.7	21.6	45.8
SD	61.4	54.7	16.6	12.4	45.2	10.3	35.3	107.1	11.2	26.8
Min	5.6	3.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.0
Lo Quart	8.3	8.0	5.6	3.9	4.2	2.1	13.8	8.5	14.2	25.1
Median	12.0	15.0	9.4	5.4	6.1	4.3	18.3	17.0	20.0	38.0
Hi Quart	31.1	22.6	14.4	9.2	11.5	8.6	26.0	35.4	26.7	62.8
Max	295.0	290.0	85.0	60.0	330.0	66.8	233.0	750.0	69.5	118.0

Station →	17683	17684	18311
N	54	54	24
Mean	10.1	68.8	6.8
SD	16.3	48.8	9.8
Min	1.6	0.0	0.5
Lo Quart	3.0	39.2	1.5
Median	4.5	59.8	2.6
Hi Quart	10.0	85.8	4.9
Max	104.0	303.0	36.3

Irving 00010 Water Temperature (° C):

Station →	10864	10866	10868	10871	11080	15624	17162	17163	17164	17165
N	10	34	12	12	34	35	39	38	21	36
Mean	23.1	20.1	20.0	22.9	21.8	22.1	19.3	20.2	21.9	18.8
SD	8.2	7.8	8.8	9.3	7.0	6.1	7.2	7.5	8.6	7.7
Min	10.4	6.8	8.6	8.1	10.2	12.2	7.4	7.6	8.2	5.3
Lo Quart	18.2	13.1	11.7	13.7	16.4	17.1	13.0	14.2	15.4	12.9
Median	23.5	19.9	18.2	27.4	23.0	22.1	21.4	22.8	25.1	19.6
Hi Quart	29.9	27.2	28.0	29.5	27.8	27.4	25.7	27.1	29.6	24.8
Max	33.4	33.4	33.6	35.7	33.0	32.3	30.8	30.1	32.1	33.0

Station →	17166	17167	17168	17170	17171	17172	17173	17174	17175	17176
N	35	12	35	38	12	37	37	37	36	36
Mean	20.6	22.5	20.9	20.5	21.8	18.7	20.3	19.6	20.2	20.4
SD	8.1	9.0	8.5	8.0	8.5	8.2	7.4	7.6	8.9	8.2
Min	5.7	6.5	4.1	7.7	9.3	2.6	1.5	5.2	4.3	7.3
Lo Quart	14.0	15.9	13.2	13.4	13.1	11.3	14.9	12.8	12.2	13.6
Median	21.6	24.9	22.6	22.4	25.0	18.3	21.0	20.2	23.6	21.4
Hi Quart	27.0	29.8	27.9	27.2	27.2	24.6	26.8	27.0	27.9	27.2
Max	31.9	33.3	33.2	33.3	32.5	33.5	30.1	33.2	32.4	34.7

Station →	17177	17178	17179	17938	17939	18310	18313	18314	18315	18359
N	33	36	34	25	26	16	25	25	25	25
Mean	23.3	21.6	20.2	19.3	18.4	20.2	19.8	19.9	19.5	20.4
SD	9.1	8.6	7.3	7.6	7.6	7.0	7.8	7.4	7.6	8.0
Min	7.2	7.1	8.7	7.6	4.7	8.6	5.6	5.8	7.5	8.1
Lo Quart	16.2	13.5	13.2	12.3	11.6	14.5	14.5	15.3	12.6	13.8
Median	24.1	23.3	20.1	20.6	19.0	23.5	21.2	20.1	21.0	22.5
Hi Quart	30.8	29.0	27.0	26.3	25.4	26.3	26.4	25.9	25.6	26.9
Max	38.8	34.8	29.9	29.5	29.1	28.1	31.0	30.8	30.6	32.1

Note: two sites with only two observations each are not reported.

Irving 00625 Total Kjeldahl Nitrogen (mg / liter):

Station →	10864	10866	10868	10871	11080	15624	17162	17163	17164	17165
N	5	30	7	5	30	31	31	28	14	32
Mean	0.40	0.76	0.53	0.88	1.15	0.84	0.80	0.88	0.66	1.03
SD	0.21	0.40	0.66	0.66	0.33	0.71	0.39	0.43	0.22	0.61
Min	0.20	0.20	0.20	0.30	0.50	0.20	0.20	0.50	0.40	0.20
Lo Quart	0.20	0.50	0.20	0.60	0.90	0.40	0.60	0.68	0.43	0.68
Median	0.40	0.70	0.30	0.60	1.10	0.60	0.80	0.80	0.65	1.00
Hi Quart	0.50	0.90	0.40	0.90	1.38	0.80	1.00	1.00	0.88	1.13
Max	0.70	1.90	2.00	2.00	1.90	3.00	1.90	2.90	1.00	3.60

Station →	17166	17167	17168	17170	17171	17172	17173	17174	17175	17176
N	32	10	32	32	6	30	31	33	28	25
Mean	0.97	0.65	0.99	0.76	0.73	0.64	0.80	0.89	1.18	0.95
SD	0.60	0.35	0.36	0.27	0.14	0.28	0.45	0.37	0.54	0.35
Min	0.20	0.20	0.20	0.09	0.50	0.20	0.20	0.20	0.40	0.20
Lo Quart	0.68	0.35	0.78	0.60	0.70	0.50	0.60	0.70	0.80	0.80
Median	0.90	0.65	1.00	0.80	0.75	0.60	0.70	0.80	1.10	0.90
Hi Quart	1.00	0.90	1.13	0.90	0.80	0.78	0.90	1.00	1.40	1.10
Max	3.60	1.20	1.80	1.60	0.90	1.60	2.70	1.90	2.80	1.90

Station →	17177	17178	17179	17938	17939	18310	18313	18314	18315	18359
N	25	28	29	23	24	15	23	21	23	23
Mean	0.97	0.81	1.07	0.77	0.90	1.07	0.83	0.94	0.90	1.14
SD	0.34	0.32	0.72	0.22	0.70	0.52	0.40	0.32	0.39	0.42
Min	0.30	0.20	0.50	0.30	0.20	0.60	0.40	0.40	0.40	0.60
Lo Quart	0.70	0.60	0.60	0.65	0.50	0.80	0.60	0.70	0.60	0.90
Median	1.00	0.80	0.90	0.80	0.65	0.90	0.80	0.90	0.90	1.10
Hi Quart	1.10	1.00	1.10	0.90	1.20	1.10	0.80	1.10	1.00	1.25
Max	1.80	1.60	3.70	1.30	3.70	2.50	2.30	1.70	2.00	2.60

Note: two sites with only two observations each are not reported.

Irving 00630 NO_3 / NO_2 (mg / liter): the only data available were single observations made on one date at several stations, and thus they were not suitable for this analysis.

Irving 00665 Total Phosphorus (mg / liter):

Station →	10864	10866	10868	10871	11080	15624	17162	17163	17164	17165
N	10	33	12	12	31	33	37	35	21	34
Mean	0.05	0.16	0.10	0.12	0.91	0.09	0.16	0.13	0.09	0.21
SD	0.02	0.36	0.17	0.13	0.40	0.14	0.08	0.04	0.05	0.61
Min	0.02	0.02	0.02	0.02	0.22	0.02	0.08	0.07	0.02	0.02
Lo Quart	0.03	0.05	0.03	0.04	0.60	0.03	0.12	0.11	0.05	0.05
Median	0.05	0.06	0.04	0.06	0.90	0.06	0.14	0.12	0.10	0.07
Hi Quart	0.06	0.11	0.06	0.17	1.15	0.06	0.17	0.15	0.11	0.10
Max	0.09	2.09	0.63	0.44	1.67	0.78	0.48	0.27	0.21	3.60

Station →	17166	17167	17168	17170	17171	17172	17173	17174	17175	17176
N	32	12	32	35	12	34	34	34	33	33
Mean	0.11	0.11	0.12	0.12	0.10	0.09	0.08	0.13	0.14	0.10
SD	0.12	0.11	0.08	0.11	0.10	0.11	0.11	0.13	0.17	0.10
Min	0.02	0.02	0.02	0.03	0.04	0.02	0.02	0.02	0.02	0.02
Lo Quart	0.06	0.03	0.07	0.06	0.06	0.02	0.02	0.06	0.06	0.06
Median	0.06	0.08	0.11	0.09	0.07	0.06	0.06	0.09	0.06	0.06
Hi Quart	0.08	0.11	0.15	0.12	0.10	0.07	0.06	0.12	0.11	0.12
Max	0.63	0.41	0.46	0.67	0.41	0.51	0.60	0.66	0.78	0.50

Station →	17177	17178	17179	17938	17939	18310	18313	18314	18315	18359
N	31	35	32	22	23	13	22	22	22	21
Mean	0.20	0.09	0.20	0.07	0.11	0.11	0.40	0.10	0.10	0.09
SD	0.15	0.08	0.13	0.02	0.13	0.05	1.32	0.14	0.11	0.05
Min	0.02	0.02	0.02	0.02	0.02	0.06	0.02	0.02	0.02	0.02
Lo Quart	0.11	0.06	0.14	0.06	0.06	0.08	0.06	0.05	0.06	0.06
Median	0.17	0.07	0.17	0.06	0.06	0.08	0.06	0.06	0.06	0.07
Hi Quart	0.22	0.10	0.21	0.08	0.10	0.14	0.15	0.10	0.10	0.10
Max	0.80	0.42	0.59	0.12	0.57	0.20	6.30	0.70	0.53	0.21

Note: two sites with only two or three observations each are not reported.

Irving 01351 Flow Severity:

Station →	10864	10866	10868	10871	11080	15624	17162	17163	17164	17165
N	11	35	14	12	35	36	40	37	22	36
Mean	3.2	3.2	3.1	3.0	3.2	3.1	3.1	3.1	3.2	3.1
SD	0.6	0.7	0.5	0.0	0.7	0.6	0.6	0.6	0.8	0.6
Min	3.0	2.0	3.0	3.0	2.0	2.0	2.0	2.0	2.0	2.0
Lo Quart	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Median	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Hi Quart	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Max	5.0	5.0	5.0	3.0	5.0	5.0	5.0	5.0	5.0	5.0

Station →	17166	17167	17168	17170	17171	17172	17173	17174	17175	17176
N	36	12	37	39	12	37	36	36	35	37
Mean	3.0	3.2	3.2	3.2	3.0	3.0	3.1	3.1	2.8	2.9
SD	0.4	1.0	0.8	0.8	0.0	0.2	0.7	0.5	0.4	0.3
Min	2.0	1.0	2.0	1.0	3.0	2.0	2.0	2.0	2.0	2.0
Lo Quart	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Median	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Hi Quart	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Max	5.0	5.0	6.0	5.0	3.0	3.0	5.0	5.0	3.0	3.0

Station →	17177	17178	17179	17938	17939	18310	18313	18314	18315	18359
N	37	36	39	34	23	26	16	25	25	25
Mean	2.9	3.1	3.0	3.1	3.0	3.1	3.3	3.3	3.0	3.2
SD	0.3	0.6	0.5	0.5	0.2	0.6	0.7	0.8	0.5	0.7
Min	2.0	2.0	1.0	2.0	2.0	2.0	3.0	2.0	2.0	2.0
Lo Quart	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Median	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Hi Quart	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Max	3.0	6.0	5.0	5.0	3.0	5.0	5.0	5.0	5.0	5.0

Note: one site with only three observations is not reported.

Irving 31699 *E. coli* (colonies / 100 ml):

Station →	**10864**	**10866**	**10868**	**10871**	**11080**	**15624**	**17162**	**17163**	**17164**	**17165**
N	10	36	12	12	33	36	40	38	21	35
Mean	249	875	335	2727	417	2813	396	245	452	1531
SD	243	1455	596	2896	696	4021	669	398	925	1573
Min	37	10	1	17	13	76	10	15	1	19
Lo Quart	85	65	30	125	62	719	49	28	17	313
Median	116	144	72	2675	216	2025	84	62	76	651
Hi Quart	378	911	338	4188	409	3588	492	186	333	2830
Max	690	4840	2090	9700	3470	24200	3460	1630	3970	4840

Station →	**17166**	**17167**	**17168**	**17170**	**17171**	**17172**	**17173**	**17174**	**17175**	**17176**
N	34	11	35	38	12	37	37	37	35	36
Mean	1442	768	126	86	273	682	960	1208	2168	1222
SD	1556	1154	215	97	579	1321	4015	1663	1784	2022
Min	99	3	1	4	2	1	1	17	76	1
Lo Quart	412	30	13	21	17	42	6	82	604	97
Median	733	106	52	45	33	215	46	344	1730	356
Hi Quart	1855	961	134	108	130	498	181	1230	3810	1254
Max	4840	3460	977	413	1960	4840	24200	4840	4840	9700

Station →	**17177**	**17178**	**17179**	**17938**	**17939**	**18310**	**18313**	**18314**	**18315**	**18359**
N	34	38	34	25	26	16	25	25	25	25
Mean	1620	970	2248	346	1301	316	701	1075	722	154
SD	1899	1466	4317	434	1430	619	1358	1565	1352	512
Min	2	1	6	19	48	2	2	32	4	2
Lo Quart	183	24	90	78	477	34	39	167	19	22
Median	447	149	415	172	821	87	97	242	35	35
Hi Quart	2983	1175	3200	449	1413	165	651	959	731	91
Max	4840	4840	24200	1540	4838	2407	4840	4840	4840	2600

Note: sites with only two observations each are not reported.

Irving 32211 Chlorophyll *a* (µg / liter):

Station →	**10864**	**10866**	**10868**	**10871**	**11080**	**15624**	**17162**	**17163**	**17164**	**17165**
N	5	31	9	7	30	31	35	33	17	32
Mean	5.3	6.4	4.4	12.2	12.7	13.3	9.4	29.6	14.3	6.8
SD	2.6	5.0	3.2	13.2	6.4	27.6	4.6	78.2	9.8	9.5
Min	2.2	0.5	0.8	0.8	2.2	0.2	2.3	3.4	2.5	0.2
Lo Quart	4.1	2.3	2.0	1.7	8.3	1.8	6.7	7.8	7.6	1.9
Median	4.1	5.6	5.0	5.0	11.1	4.8	8.4	14.2	10.1	4.0
Hi Quart	7.7	7.3	5.4	23.0	16.6	9.3	11.8	22.9	18.7	8.7
Max	8.2	22.8	9.9	30.2	31.8	140.1	26.7	461.1	33.5	50.1

Station →	**17166**	**17167**	**17168**	**17170**	**17171**	**17172**	**17173**	**17174**	**17175**	**17176**
N	30	7	31	33	7	32	32	32	31	32
Mean	8.2	10.6	17.4	16.1	6.9	2.4	22.4	10.3	5.1	6.3
SD	10.5	6.6	14.3	10.5	3.1	1.8	105.1	13.8	5.5	5.7
Min	0.2	1.3	3.3	2.2	2.8	0.2	0.2	1.1	0.8	0.2
Lo Quart	2.8	6.7	7.0	9.6	4.6	0.9	1.3	3.1	1.6	2.5
Median	4.7	12.1	14.8	13.1	7.5	2.0	2.2	5.1	3.5	5.8
Hi Quart	8.5	12.6	24.2	22.6	9.2	3.9	3.8	11.2	5.3	7.7
Max	43.6	22.0	71.1	49.0	10.4	6.5	597.6	72.2	23.3	30.3

Station →	**17177**	**17178**	**17179**	**17938**	**17939**	**18310**	**18313**	**18314**	**18315**	**18359**
N	30	33	31	25	25	16	25	25	25	25
Mean	20.9	14.6	15.5	5.8	5.4	12.1	5.1	9.0	5.5	19.1
SD	21.1	19.3	24.5	3.5	8.3	5.8	4.6	9.7	4.4	13.5
Min	0.5	0.6	0.2	1.2	0.2	0.2	0.9	2.1	0.2	0.2
Lo Quart	8.0	4.4	2.6	3.7	2.2	8.0	1.9	3.8	2.0	11.2
Median	12.8	10.1	5.6	4.9	2.7	11.4	3.8	5.8	4.5	16.2
Hi Quart	26.4	16.0	13.6	7.9	5.0	14.5	6.5	12.2	9.0	22.4
Max	95.5	106.6	101.9	14.0	39.5	26.3	20.5	48.4	14.6	57.5

Note: sites with only two observations each are not reported.

Irving 82078 Turbidity: this parameter was not done.

Appendix 2. Analysis of trends.

Arlington 00010 Water Temperature (° C):

Station →	10719	10721	10722	10723	10724	10725	10780	10791	10792	17189
Slope	-0.0594	-0.0883	-0.0451	-0.0518	-0.1280	-0.0896	-0.0917	-0.0538	-0.0781	0.0022
Std Error	0.0820	0.0909	0.0906	0.0845	0.1081	0.0867	0.0815	0.0838	0.0942	0.0906
T	0.7245	0.9715	0.4973	0.6124	1.1845	1.0329	1.1244	0.6425	0.8287	0.0239
df	20	18	19	20	19	20	20	18	20	19
P	0.477	0.344	0.625	0.547	0.251	0.314	0.274	0.529	0.417	0.981

Station →	17190	17191
Slope	-0.0039	0.0689
Std Error	0.1065	0.0937
T	0.0371	0.7354
df	16	17
P	0.971	0.472

Arlington 00625 Total Kjeldahl Nitrogen (natural logarithms):

Station →	10719	10722	10725	17191
Slope	0.001	-0.006	0.008	0.009
Std Error	0.004	0.009	0.005	0.007
T	0.285	0.660	1.603	1.307
df	20	20	20	16
P	0.778	0.517	0.125	0.210

Arlington 00630 NO_3 / NO_2 (natural logarithms):

Station →	10719	10722	10725	17191
Slope	-0.002	0.005	-0.002	-0.015
Std Error	0.009	0.010	0.015	0.014
T	0.233	0.474	0.150	1.083
df	20	20	20	17
P	0.818	0.640	0.882	0.294

Arlington 00665 Total Phosphorus (natural logarithms):

Station →	10719	10722	10725	17191
Slope	-0.006	0.004	0.011	-0.007
Std Error	0.007	0.013	0.004	0.009
T	0.951	0.305	2.881	0.738
df	20	20	20	17
P	0.353	0.763	0.009	0.470

Arlington 01351 Flow Severity:

Station →	10719	10721	10722	10723	10724	10725	10780	10791	10792	17189
Slope	-0.017	-0.020	-0.017	-0.004	-0.012	-0.006	-0.022	-0.014	-0.002	-0.025
Std Error	0.008	0.012	0.009	0.008	0.008	0.006	0.008	0.013	0.011	0.010
T	1.988	1.718	1.771	0.427	1.507	0.922	2.749	1.097	0.151	2.349
df	20	20	19	20	19	18	20	19	20	18
P	0.061	0.101	0.093	0.674	0.148	0.369	0.012	0.286	0.881	0.030

Station →	17190	17191
Slope	-0.013	-0.010
Std Error	0.015	0.015
T	0.883	0.634
df	18	19
P	0.389	0.534

Arlington 31699 *E. coli* (natural logarithms):

Station →	10719	10721	10722	10723	10724	10725	10780	10791	10792	17189
Slope	-0.025	-0.005	0.049	0.027	0.055	0.010	0.032	0.053	0.036	0.030
Std Error	0.021	0.033	0.029	0.030	0.025	0.034	0.022	0.033	0.029	0.032
T	1.182	0.138	1.695	0.905	2.213	0.287	1.451	1.634	1.233	0.943
df	13	13	13	13	13	13	13	13	13	13
P	0.258	0.893	0.114	0.382	0.045	0.779	0.171	0.126	0.239	0.363

Station →	17190	17191
Slope	0.030	0.023
Std Error	0.029	0.035
T	1.038	0.657
df	13	12
P	0.318	0.523

Arlington 32211 Chlorophyll *a* (natural logarithms):

Station →	10719	10722	10725	17191
Slope	0.000	0.015	0.006	0.015
Std Error	0.007	0.013	0.011	0.013
T	0.019	1.138	0.513	1.145
df	20	20	20	17
P	0.985	0.269	0.614	0.268

Arlington 82078 Turbidity: this parameter was not done.

Fort Worth 00010 Water Temperature (° C):

Station →	10938	16120	17368	17369	17370	18456
Slope	0.0058	0.0371	0.0021	0.0055	0.0351	0.1944
Std Error	0.0510	0.0514	0.0501	0.0513	0.0511	0.2979
T	0.1140	0.7220	0.0410	0.1063	0.6882	0.6525
df	64	64	64	63	64	17
P	0.9096	0.4729	0.9674	0.9157	0.4938	0.5228

Fort Worth 00625 Total Kjeldahl Nitrogen: this parameter was not done.

Fort Worth 00630 Total NO_3 / NO_2: this parameter was not done.

Fort Worth 00665 Total Phosphorus: this parameter was not done.

Fort Worth 01351 Flow Severity:

Station →	10938	16120	17368	17369	17370	18456
Slope	-0.016	-0.013	-0.013	-0.012	-0.009	0.002
Std Error	0.005	0.005	0.005	0.006	0.004	0.010
T	3.181	2.536	2.739	2.024	2.072	0.206
df	65	65	65	67	67	16
P	0.002	0.014	0.008	0.047	0.042	0.839

Fort Worth 31699 *E. coli* (natural logarithms):

Station →	10938	16120	17368	17369	17370	18456
Slope	-0.026	-0.056	-0.005	-0.013	-0.019	-0.032
Std Error	0.013	0.010	0.012	0.010	0.010	0.046
T	2.064	5.330	0.429	1.328	1.846	0.689
df	65	68	66	68	69	17
P	0.043	<0.001	0.669	0.189	0.069	0.500

Fort Worth 32211 Chlorophyll *a*: this parameter was not done.

Fort Worth 82078 Turbidity:

Station →	**10938**	**16120**	**17368**	**17369**	**17370**	**18456**
Slope	-0.269	-0.906	0.042	-0.380	-0.315	0.239
Std Error	0.081	0.730	0.070	0.197	0.312	0.226
T	3.333	1.241	0.596	1.930	1.012	1.060
df	62	63	63	63	63	17
P	0.001	0.219	0.553	0.058	0.315	0.304

Grand Prairie 00010 Water Temperature (° C):

Station →	10815	10867	13621	17663	17664	17665	17666	17669	17671	17672
Slope	-0.0355	-0.0159	-0.0399	-0.0306	-0.0184	-0.1855	-0.0046	-0.0096	0.0121	0.0170
Std Error	0.0608	0.0616	0.0560	0.0653	0.0607	0.1404	0.0572	0.0507	0.0739	0.0576
T	0.5833	0.2574	0.7118	0.4686	0.3031	1.3219	0.0813	0.1894	0.1633	0.2949
df	54	54	53	52	53	24	54	53	44	49
P	0.5621	0.7978	0.4797	0.6413	0.7630	0.1987	0.9355	0.8505	0.8710	0.7693

Station →	17673	17674	17675	17676	17677	17678	17679	17680	17681	17682
Slope	-0.0142	-0.0119	-0.0269	-0.0172	-0.0248	-0.0281	-0.0924	0.0124	-0.0238	-0.0551
Std Error	0.0633	0.0592	0.0460	0.0566	0.0564	0.0638	0.0886	0.0563	0.0583	0.0656
T	0.2247	0.2018	0.5856	0.3042	0.4390	0.4401	1.0426	0.2202	0.4086	0.8398
df	51	51	53	53	53	51	50	49	53	51
P	0.8231	0.8409	0.5606	0.7621	0.6625	0.6617	0.3021	0.8266	0.6844	0.4049

Station →	17683	17684	18311
Slope	-0.0004	-0.0630	-0.1326
Std Error	0.0520	0.0625	0.1376
T	0.0086	1.0081	0.9640
df	52	53	22
P	0.9932	0.3180	0.3455

Grand Prairie 00625 Total Kjeldahl Nitrogen (natural logarithms):

Station →	**10815**	**10867**	**13621**	**17663**	**17664**	**17665**	**17666**	**17669**	**17671**	**17672**
Slope	-0.003	-0.003	-0.010	-0.003	0.001	0.044	-0.003	0.003	0.011	0.011
Std Error	0.008	0.008	0.007	0.008	0.006	0.045	0.007	0.006	0.011	0.007
T	0.345	0.395	1.437	0.316	0.248	0.978	0.465	0.591	1.012	1.611
df	16	16.00	16	16	16	5	16	15	13	14
P	0.734	0.698	0.170	0.756	0.808	0.373	0.648	0.564	0.330	0.130

Station →	**17673**	**17674**	**17675**	**17676**	**17677**	**17678**	**17679**	**17680**	**17681**	**17682**
Slope	0.018	0.004	-0.002	0.012	-0.008	0.005	0.006	0.003	-0.003	0.013
Std Error	0.013	0.006	0.009	0.007	0.006	0.006	0.007	0.009	0.009	0.006
T	1.431	0.677	0.259	1.719	1.461	0.886	0.840	0.319	0.341	2.033
df	15	16	16	16	16	16	15	15	15	15
P	0.173	0.508	0.799	0.105	0.163	0.389	0.414	0.754	0.738	0.060

Station →	**17683**	**17684**	**18311**
Slope	-0.002	0.009	-0.003
Std Error	0.006	0.005	0.013
T	0.284	1.893	0.215
df	16	16	7
P	0.780	0.077	0.836

Grand Prairie 00630 NO_3 / NO_2 (natural logarithms):

Station →	**10815**	**10867**	**13621**	**17663**	**17664**	**17665**	**17666**	**17669**	**17671**	**17672**
Slope	-0.166	-0.137	-0.119	-0.113	-0.010	-0.024	-0.031	-0.115	-0.084	0.151
Std Error	0.051	0.043	0.036	0.043	0.044	0.159	0.047	0.080	0.063	0.047
T	3.238	3.182	3.340	2.612	0.232	0.148	0.675	1.441	1.344	3.215
df	15	14	15	14	14	4	14	13	11	13
P	0.006	0.007	0.004	0.020	0.820	0.889	0.511	0.173	0.206	0.007

Station →	**17673**	**17674**	**17675**	**17676**	**17677**	**17678**	**17679**	**17680**	**17681**	**17682**
Slope	-0.043	0.003	-0.021	-0.111	-0.098	-0.080	-0.152	-0.169	-0.064	-0.096
Std Error	0.035	0.041	0.027	0.036	0.042	0.048	0.044	0.072	0.030	0.031
T	1.239	0.078	0.775	3.066	2.357	1.648	3.470	2.347	2.163	3.128
df	14	14	15	15	15	15	14	14	15	14
P	0.236	0.939	0.450	0.008	0.032	0.120	0.004	0.034	0.047	0.007

Station →	**17683**	**17684**	**18311**
Slope	-0.029	-0.063	-0.085
Std Error	0.029	0.057	0.114
T	1.010	1.102	0.750
df	15	15	6
P	0.329	0.288	0.482

Grand Prairie 00665 Total Phosphorus (natural logarithms):

Station →	**10815**	**10867**	**13621**	**17663**	**17664**	**17665**	**17666**	**17669**	**17671**	**17672**
Slope	0.003	-0.005	-0.025	0.002	0.014	-0.042	0.030	0.013	-0.004	-0.007
Std Error	0.008	0.011	0.013	0.010	0.007	0.042	0.026	0.008	0.013	0.011
T	0.321	0.471	1.910	0.166	2.065	0.999	1.140	1.662	0.323	0.613
df	17	17	17	17	17	5	17	17	14	15
P	0.752	0.644	0.073	0.870	0.055	0.364	0.270	0.115	0.752	0.549

Station →	**17673**	**17674**	**17675**	**17676**	**17677**	**17678**	**17679**	**17680**	**17681**	**17682**
Slope	0.019	-0.006	-0.001	0.019	0.008	0.018	0.002	0.005	0.013	0.016
Std Error	0.007	0.010	0.009	0.006	0.005	0.007	0.007	0.009	0.005	0.008
T	2.729	0.600	0.164	3.058	1.410	2.609	0.315	0.531	2.677	1.872
df	16	17	16	17	16	17	16	15	17	16
P	0.015	0.557	0.872	0.007	0.178	0.018	0.757	0.603	0.016	0.080

Station →	**17683**	**17684**	**18311**
Slope	-0.013	0.006	0.018
Std Error	0.007	0.005	0.023
T	1.800	1.339	0.799
df	17	17	7
P	0.090	0.198	0.451

Grand Prairie 01351 Flow Severity:

Station →	10815	10867	13621	17663	17664	17665	17666	17669	17671	17672
Slope	0.000	-0.002	0.008	0.001	-0.001	-0.001	0.005	-0.014	0.013	0.011
Std Error	0.006	0.006	0.006	0.006	0.007	0.017	0.005	0.007	0.007	0.007
T	0.046	0.341	1.334	0.195	0.157	0.080	1.064	1.958	1.746	1.594
df	54	52	52	51	46	20	52	52	45	49
P	0.963	0.735	0.188	0.846	0.876	0.937	0.292	0.056	0.088	0.117

Station →	17673	17674	17675	17676	17677	17678	17679	17680	17681	17682
Slope	0.011	-0.001	0.011	0.004	0.006	0.007	0.012	0.002	0.009	0.002
Std Error	0.005	0.005	0.006	0.005	0.006	0.008	0.007	0.009	0.006	0.009
T	2.054	0.164	1.818	0.941	0.996	0.883	1.747	0.258	1.508	0.244
df	53	53	53	53	51	52	48	49	53	54
P	0.045	0.870	0.075	0.351	0.324	0.381	0.087	0.798	0.137	0.808

Station →	17683	17684	18311
Slope	-0.002	0.029	0.003
Std Error	0.005	0.007	0.014
T	0.399	4.472	0.238
df	49	51	22
P	0.692	<0.001	0.814

Grand Prairie 31699 *E. coli* (natural logarithms):

Station →	**10815**	**10867**	**13621**	**17663**	**17664**	**17665**	**17666**	**17669**	**17671**	**17672**
Slope	-0.024	-0.031	-0.022	-0.032	-0.019	-0.045	-0.042	-0.025	-0.008	-0.038
Std Error	0.013	0.015	0.011	0.015	0.013	0.040	0.021	0.013	0.017	0.016
T	1.838	2.069	2.100	2.110	1.445	1.133	2.054	1.888	0.442	2.374
df	52	51	51	51	52	22	52	51	43	48
P	0.072	0.044	0.041	0.040	0.154	0.269	0.045	0.065	0.660	0.022

Station →	**17673**	**17674**	**17675**	**17676**	**17677**	**17678**	**17679**	**17680**	**17681**	**17682**
Slope	-0.024	-0.008	-0.020	-0.017	-0.026	0.000	-0.031	-0.015	0.002	0.013
Std Error	0.021	0.012	0.012	0.017	0.010	0.016	0.015	0.017	0.014	0.018
T	1.164	0.698	1.718	1.059	2.585	0.005	2.081	0.841	0.115	0.691
df	50	51	52	51	52	51	49	49	51	50
P	0.250	0.488	0.092	0.295	0.013	0.996	0.043	0.405	0.909	0.493

Station →	**17683**	**17684**	**18311**
Slope	-0.026	-0.005	-0.007
Std Error	0.014	0.018	0.045
T	1.801	0.251	0.149
df	51	51	22
P	0.078	0.803	0.883

Grand Prairie 32211 Chlorophyll *a* (natural logarithms):

Station →	10815	10867	13621	17663	17664	17665	17666	17669	17671	17672
Slope	0.022	0.008	0.000	0.014	0.001	0.004	0.021	0.005	0.010	0.020
Std Error	0.014	0.013	0.010	0.014	0.017	0.059	0.012	0.009	0.016	0.015
T	1.601	0.605	0.049	1.045	0.038	0.069	1.757	0.603	0.634	1.374
df	18	18	18	18	18	7	18	16	15	16
P	0.127	0.553	0.962	0.310	0.970	0.947	0.096	0.555	0.535	0.188

Station →	17673	17674	17675	17676	17677	17678	17679	17680	17681	17682
Slope	0.032	0.012	0.011	0.045	0.018	0.023	0.042	0.000	0.005	0.033
Std Error	0.014	0.010	0.013	0.010	0.012	0.012	0.016	0.020	0.006	0.020
T	2.259	1.277	0.851	4.627	1.474	1.987	2.712	0.011	0.841	1.636
df	17	18	18	18	18	18	17	17	17	17
P	0.037	0.218	0.406	0.000	0.158	0.062	0.015	0.992	0.412	0.120

Station →	17683	17684	18311
Slope	0.031	0.027	0.083
Std Error	0.020	0.007	0.056
T	1.524	3.631	1.490
df	18	18	7
P	0.145	0.002	0.180

Grand Prairie 82078 Turbidity:

Station →	**10815**	**10867**	**13621**	**17663**	**17664**	**17665**	**17666**	**17669**	**17671**	**17672**
Slope	-0.407	-0.077	-0.446	-0.192	-0.020	-0.247	-0.161	0.112	-0.104	0.928
Std Error	0.187	0.446	0.248	0.499	0.425	0.395	0.255	0.692	0.189	0.653
T	2.181	0.172	1.794	0.385	0.046	0.626	0.631	0.161	0.553	1.422
df	54	52	51	52	52	24	53	53	44	50
P	0.034	0.864	0.079	0.701	0.963	0.537	0.531	0.873	0.583	0.161

Station →	**17673**	**17674**	**17675**	**17676**	**17677**	**17678**	**17679**	**17680**	**17681**	**17682**
Slope	-0.734	-0.208	-0.202	0.108	-0.401	0.055	0.242	0.629	-0.142	0.248
Std Error	0.523	0.461	0.140	0.105	0.384	0.089	0.314	0.956	0.094	0.228
T	1.405	0.452	1.446	1.029	1.043	0.625	0.770	0.658	1.507	1.087
df	52	53	53	53	53	52	49	49	53	52
P	0.166	0.653	0.154	0.308	0.302	0.535	0.445	0.514	0.138	0.282

Station →	**17683**	**17684**	**18311**
Slope	-0.013	0.288	-0.218
Std Error	0.141	0.428	0.197
T	0.092	0.673	1.105
df	52	52	22
P	0.927	0.504	0.281

Irving 00010 Water Temperature (° C):

Station →	**10864**	**10866**	**10868**	**10871**	**11080**	**15624**	**17162**	**17163**	**17164**	**17165**
Slope	0.3670	0.0859	0.0986	-0.1167	0.0854	0.0533	-0.0163	0.0119	-0.1162	-0.0198
Std Error	0.5460	0.1227	0.5921	0.6228	0.1002	0.0911	0.0936	0.1065	0.2444	0.1096
T	0.6722	0.7000	0.1665	0.1874	0.8524	0.5848	0.1745	0.1116	0.4755	0.1805
df	8	32	10	10	32	33	37	36	19	34
P	0.520	0.489	0.871	0.855	0.400	0.563	0.862	0.912	0.640	0.858

Station →	**17166**	**17167**	**17168**	**17170**	**17171**	**17172**	**17173**	**17174**	**17175**	**17176**
Slope	-0.0315	0.0934	0.0214	-0.0347	-0.1745	-0.0022	0.0205	0.0186	0.0347	0.0024
Std Error	0.1202	0.6044	0.1295	0.1062	0.5655	0.1170	0.1053	0.1082	0.1289	0.1213
T	0.2618	0.1546	0.1652	0.3264	0.3086	0.0184	0.1949	0.1716	0.2693	0.0198
df	33	10	33	36	10	35	35	35	34	34
P	0.795	0.880	0.870	0.746	0.764	0.985	0.847	0.865	0.789	0.984

Station →	**17177**	**17178**	**17179**	**17938**	**17939**	**18310**	**18313**	**18314**	**18315**	**18359**
Slope	0.0350	0.0074	0.0381	0.3035	0.1597	0.2062	0.3374	0.3264	0.3565	0.3446
Std Error	0.1422	0.1254	0.1134	0.2051	0.2011	0.3372	0.2084	0.1987	0.2011	0.2146
T	0.2461	0.0588	0.3355	1.4799	0.7941	0.6115	1.6190	1.6429	1.7724	1.6056
df	31	34	32	23	24	14	23	23	23	23
P	0.807	0.953	0.739	0.152	0.435	0.551	0.119	0.114	0.090	0.122

Note: sites with only two observations each are not reported.

Irving 00625 Total Kjeldahl Nitrogen (natural logarithms):

Station →	**10864**	**10866**	**10868**	**10871**	**11080**	**15624**	**17162**	**17163**	**17164**	**17165**
Slope	-0.022	0.027	0.160	0.013	0.005	0.000	0.027	0.011	0.032	0.014
Std Error	0.204	0.007	0.045	0.082	0.005	0.011	0.006	0.005	0.007	0.008
T	0.109	3.672	3.529	0.163	1.016	0.034	4.384	2.007	4.710	1.728
df	3	28	5	3	28	29	29	26	12	30
P	0.920	0.001	0.017	0.881	0.318	0.973	<0.001	0.055	0.001	0.094

Station →	**17166**	**17167**	**17168**	**17170**	**17171**	**17172**	**17173**	**17174**	**17175**	**17176**
Slope	0.015	0.072	0.020	0.019	0.024	0.004	0.025	0.015	0.021	0.014
Std Error	0.008	0.042	0.007	0.006	0.014	0.008	0.007	0.007	0.007	0.008
T	1.800	1.719	2.941	3.031	1.735	0.572	3.686	2.164	2.878	1.819
df	30	8	30	30	4	28	29	31	26	23
P	0.082	0.124	0.006	0.005	0.158	0.572	0.001	0.038	0.008	0.082

Station →	**17177**	**17178**	**17179**	**17938**	**17939**	**18310**	**18313**	**18314**	**18315**	**18359**
Slope	0.009	0.019	0.001	0.000	0.000	0.004	0.005	0.012	0.011	0.012
Std Error	0.008	0.006	0.008	0.009	0.016	0.020	0.011	0.011	0.011	0.009
T	1.121	2.994	0.157	0.037	0.014	0.183	0.402	1.138	1.005	1.299
df	23	26	27	21	22	13	21	19	21	21
P	0.274	0.006	0.877	0.971	0.989	0.857	0.692	0.269	0.326	0.208

Note: sites with only two observations each are not reported.

Irving 00630 NO_3 / NO_2: this parameter was not done.

Irving 00665 Total Phosphorus (natural logarithms):

Station →	**10864**	**10866**	**10868**	**10871**	**11080**	**15624**	**17162**	**17163**	**17164**	**17165**
Slope	0.040	0.022	0.015	-0.024	0.007	0.010	-0.001	-0.005	0.040	0.015
Std Error	0.034	0.015	0.061	0.068	0.008	0.013	0.005	0.005	0.017	0.015
T	1.184	1.441	0.247	0.354	0.898	0.737	0.217	1.180	2.385	0.938
df	8	31	10	10	29	31	35	33	19	32
P	0.270	0.160	0.810	0.731	0.377	0.467	0.830	0.247	0.028	0.355

Station →	**17166**	**17167**	**17168**	**17170**	**17171**	**17172**	**17173**	**17174**	**17175**	**17176**
Slope	0.004	0.024	0.009	-0.005	-0.011	0.010	0.017	-0.006	-0.005	0.006
Std Error	0.012	0.060	0.010	0.008	0.041	0.013	0.012	0.011	0.013	0.012
T	0.379	0.393	0.951	0.716	0.256	0.752	1.331	0.592	0.367	0.510
df	30	10	30	33	10	32	32	32	31	31
P	0.707	0.702	0.349	0.479	0.803	0.458	0.193	0.558	0.716	0.613

Station →	**17177**	**17178**	**17179**	**17938**	**17939**	**18310**	**18313**	**18314**	**18315**	**18359**
Slope	0.006	0.007	0.014	0.017	-0.012	-0.006	0.055	0.055	0.009	0.023
Std Error	0.011	0.008	0.011	0.011	0.023	0.014	0.033	0.021	0.022	0.018
T	0.529	0.864	1.324	1.607	0.524	0.405	1.684	2.660	0.433	1.330
df	29	33	30	20	21	11	20	20	20	19
P	0.601	0.394	0.195	0.124	0.606	0.694	0.108	0.015	0.670	0.199

Note: sites with only two or three observations each are not reported.

Irving 01351 Flow Severity:

Station →	10864	10866	10868	10871	11080	15624	17162	17163	17164	17165
Slope	0.013	0.000	-0.003	0.000	0.008	-0.004	0.004	0.007	0.000	-0.007
Std Error	0.041	0.010	0.008	0.000	0.010	0.009	0.007	0.008	0.021	0.008
T	0.333	0.025	0.444	N/A	0.812	0.442	0.551	0.804	0.007	0.842
df	9	33	12	10	33	34	38	35	20	34
P	0.747	0.980	0.665	N/A	0.423	0.661	0.585	0.427	0.995	0.406

Station →	17166	17167	17168	17170	17171	17172	17173	17174	17175	17176
Slope	-0.006	0.072	-0.020	0.019	0.000	-0.001	-0.010	-0.001	0.001	0.000
Std Error	0.005	0.065	0.011	0.009	0.000	0.002	0.010	0.007	0.006	0.003
T	1.133	1.097	1.918	2.115	N/A	0.401	1.015	0.136	0.151	0.125
df	34	10	35	37	10	35	34	34	33	35
P	0.265	0.298	0.063	0.041	N/A	0.691	0.318	0.892	0.881	0.901

Station →	17177	17178	17179	17938	17939	18310	18313	18314	18315	18359
Slope	0.006	-0.003	-0.009	0.002	-0.028	0.003	0.009	-0.020	-0.003	0.001
Std Error	0.009	0.006	0.008	0.006	0.015	0.023	0.022	0.012	0.020	0.006
T	0.672	0.459	1.218	0.381	1.890	0.146	0.413	1.641	0.154	0.250
df	34	37	32	21	24	14	23	23	23	22
P	0.506	0.649	0.232	0.707	0.071	0.886	0.683	0.114	0.879	0.805

Note: sites with only two or three observations each are not reported; two sites had no variation in flow severity.

Irving 31699 *E. coli* (natural logarithms):

Station →	**10864**	**10866**	**10868**	**10871**	**11080**	**15624**	**17162**	**17163**	**17164**	**17165**
Slope	0.132	0.016	0.165	0.236	-0.031	0.022	-0.016	0.011	0.004	-0.030
Std Error	0.056	0.026	0.125	0.127	0.022	0.019	0.016	0.020	0.062	0.020
T	2.359	0.597	1.321	1.858	1.434	1.167	0.997	0.564	0.064	1.512
df	8	34	10	10	31	34	38	36	19	33
P	0.046	0.555	0.216	0.093	0.162	0.251	0.325	0.576	0.950	0.140

Station →	**17166**	**17167**	**17168**	**17170**	**17171**	**17172**	**17173**	**17174**	**17175**	**17176**
Slope	-0.029	0.088	-0.028	-0.003	0.230	0.038	0.107	0.008	-0.014	-0.012
Std Error	0.016	0.171	0.026	0.014	0.124	0.028	0.032	0.025	0.019	0.033
T	1.867	0.515	1.101	0.208	1.853	1.387	3.302	0.309	0.719	0.363
df	32	9	33	36	10	35	35	35	33	34
P	0.071	0.619	0.279	0.836	0.094	0.174	0.002	0.759	0.477	0.719

Station →	**17177**	**17178**	**17179**	**17938**	**17939**	**18310**	**18313**	**18314**	**18315**	**18359**
Slope	-0.070	0.016	-0.029	0.037	0.003	-0.017	0.069	-0.007	-0.008	0.034
Std Error	0.025	0.028	0.032	0.035	0.030	0.055	0.054	0.041	0.062	0.040
T	2.838	0.568	0.884	1.058	0.108	0.298	1.286	0.175	0.122	0.846
df	32	36	32	23	24	14	23	23	23	23
P	0.008	0.574	0.384	0.301	0.915	0.770	0.211	0.862	0.904	0.406

Note: sites with only two or three observations each are not reported.

Irving 32211 Chlorophyll *a* (natural logarithms):

Station →	**10864**	**10866**	**10868**	**10871**	**11080**	**15624**	**17162**	**17163**	**17164**	**17165**
Slope	0.050	0.002	0.009	-0.041	0.010	0.014	0.006	0.013	-0.014	0.003
Std Error	0.023	0.007	0.007	0.079	0.004	0.012	0.003	0.007	0.013	0.009
T	2.133	0.294	1.291	0.522	2.320	1.179	1.977	1.863	1.063	0.293
df	3	29	7	5	28	29	33	31	15	30
P	0.123	0.771	0.238	0.624	0.028	0.248	0.056	0.072	0.305	0.771

Station →	**17166**	**17167**	**17168**	**17170**	**17171**	**17172**	**17173**	**17174**	**17175**	**17176**
Slope	-0.007	0.010	0.008	0.007	0.033	0.001	0.007	-0.009	0.014	0.006
Std Error	0.010	0.049	0.006	0.005	0.023	0.008	0.012	0.008	0.007	0.009
T	0.716	0.200	1.206	1.314	1.419	0.081	0.559	1.126	1.965	0.645
df	28	5	29	31	5	30	30	30	29	30
P	0.480	0.850	0.238	0.198	0.215	0.936	0.580	0.269	0.059	0.524

Station →	**17177**	**17178**	**17179**	**17938**	**17939**	**18310**	**18313**	**18314**	**18315**	**18359**
Slope	0.009	0.009	0.004	-0.012	-0.005	0.007	0.008	0.014	0.009	0.011
Std Error	0.009	0.007	0.012	0.007	0.012	0.016	0.010	0.009	0.015	0.013
T	1.032	1.306	0.330	1.595	0.404	0.438	0.803	1.549	0.630	0.875
df	28	31	29	23	23	14	23	23	23	23
P	0.311	0.201	0.744	0.124	0.690	0.668	0.430	0.135	0.535	0.391

Note: sites with only two or three observations each are not reported.

Irving 82078 Turbidity: this parameter was not done.

Appendix 3. Station and watershed characteristics.

Information reported by municipal personnel and Trinity River Authority. Blank entries in tables indicate data that were not provided.

Arlington – Station locations and watershed areas:

Site	**Location**	**Stream Flow**	**Area (mi^2)**
10719	Johnson Creek	perennial	15.4
10721	Johnson Creek	perennial?	2.5
10722			3
10723	Cottonwood Creek	perennial?	1.2
10724	Fish Creek	perennial?	3.4
10725	Fish Creek	perennial?	7.6
10780	Village Creek		121.2
10791	Rush Creek		9.3
10792	Kee Branch	perennial?	6.6
17189	Village Creek		182.7
17190	Rush Creek		13.6
17191	Rush Creek		30.5

? Indicates streams classified as perennial for which notes from city personnel indicated that intermittent flow occurred.

Arlington -- percent land use in watersheds:

Site	Open Water	Developed, Open Space	Developed, low (20-49%)	Developed, medium (50-79%)	Developed, high (80-100%)	Barren Land	Deciduous Forest	Evergreen Forest	Mixed Forest	Shrub / Scrub	Grass-lands	Pasture	Cultivated Crops	Woody Wetlands	Emergent Herbaceous Wetlands
10719	0.00%	20.58%	31.81%	21.31%	26.13%	0.00%	0.00%	0.00%	0.00%	0.00%	0.17%	0.00%	0.00%	0.00%	0.00%
10721	0.00%	14.94%	31.59%	28.04%	24.47%	0.00%	0.00%	0.00%	0.00%	0.00%	0.96%	0.00%	0.00%	0.00%	0.00%
10722	0.00%	18.68%	46.59%	18.18%	16.55%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
10723	0.00%	14.65%	26.80%	30.99%	27.57%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
10724	0.00%	12.47%	52.76%	26.16%	5.35%	0.00%	1.22%	0.00%	0.00%	0.00%	2.05%	0.00%	0.00%	0.00%	0.00%
10725	0.12%	15.02%	29.91%	29.75%	6.75%	0.00%	9.12%	0.00%	0.00%	0.00%	8.46%	0.69%	0.00%	0.11%	0.06%
10780	0.41%	9.24%	11.67%	3.79%	2.21%	0.07%	18.19%	0.25%	0.00%	0.26%	37.25%	12.68%	3.88%	0.05%	0.03%
10791	0.11%	15.74%	21.57%	11.60%	2.03%	0.07%	15.90%	0.09%	0.00%	0.00%	26.44%	6.44%	0.00%	0.00%	0.00%
10792	0.04%	19.33%	38.47%	17.23%	5.64%	0.00%	8.03%	0.05%	0.00%	0.00%	9.85%	1.37%	0.00%	0.00%	0.00%
17189	2.04%	14.03%	18.76%	6.77%	3.50%	0.05%	14.86%	0.19%	0.00%	0.17%	27.77%	9.12%	2.57%	0.10%	0.06%
17190	0.10%	17.21%	26.15%	14.12%	4.94%	0.05%	13.18%	0.08%	0.00%	0.00%	19.35%	4.76%	0.00%	0.05%	0.00%
17191	0.15%	21.92%	33.80%	14.84%	5.29%	0.02%	9.71%	0.05%	0.00%	0.00%	11.73%	2.46%	0.00%	0.02%	0.00%

Fort Worth – Station locations and watershed areas:

Site	Location	Stream Flow	Area (mi^2)
10938	W. Fork Trinity River	perennial	
16120	W. Fork Trinity River	perennial	
17368	W. Fork Trinity River	perennial	
17369	Sycamore Creek	perennial	36.8
17370	Marine Creek	perennial	21.7

Fort Worth -- percent land use in watersheds:

Site	Open Water	Developed, Open Space	Developed, low (20-49%)	Developed, medium (50-79%)	Developed, high (80-100%)	Barren Land	Deciduous Forest	Evergreen Forest	Mixed Forest	Shrub / Scrub	Grass-lands	Pasture	Cultivated Crops	Woody Wetlands	Emergent Herbaceous Wetlands
10938								0.40%	0.00%	5.68%	56.20%	5.40%	2.31%	0.14%	0.04%
16120								0.39%	0.00%	5.49%	55.08%	5.48%	2.36%	0.14%	0.04%
17368								0.40%	0.00%	5.77%	56.91%	5.45%	2.34%	0.14%	0.04%
17369	0.07%	16.83%	42.28%	14.17%	9.91%	0.00%	3.31%	0.12%	0.00%	0.05%	11.07%	1.83%	0.36%	0.01%	0.00%
17370	1.86%	13.11%	26.57%	11.50%	6.73%	0.26%	4.55%	0.04%	0.00%	0.00%	31.44%	1.79%	2.14%	0.00%	0.00%

Grand Prairie – Station locations and watershed areas:

Site	**Location**	**Stream Flow Type**	**Area (mi^2)**
10815	Mountain Creek		306.6
10867	Bear Creek	perennial	83.1
13621	Walnut Creek	intermittent w/pools	62.7
17663	Bear Creek	perennial	83.8
17664	Johnson Creek	perennial	18.1
17666	Arbor Creek	perennial	1.7
17669	W. Fork Trinity River	perennial	3010.8
17672	Copart Branch, Mountain Creek (Muck Run)	intermittent w/pools	0.6
17673	North Fork Cottonwood Creek		5.2
17674	Cottonwood Creek	perennial	10.5
17675	Kirby Creek	perennial	2.6
17676	South Fork Cottonwood Creek	perennial	4.5
17677	South Fork Fish Creek	perennial	14.7
17678	North Fork Fish Creek		5.6
17679	Fish Creek	perennial	25.9
17680	North Fork Fish Creek		0.7
17681	Mountain Creek		226.2
17682	Mountain Creek		296.6
17683	Crockett Branch, Cottonwood Creek		0.2
17684	Joe Pool Lake, Mountain Creek Arm		Lake Site

Grand Prairie -- percent land use in watersheds:

Site	Open Water	Developed, Open Space	Developed, low (20-49%)	Developed, medium (50-79%)	Developed, high (80-100%)	Barren Land	Deciduous Forest	Evergreen Forest	Mixed Forest	Shrub / Scrub	Grass-lands	Pasture	Cultivated Crops	Woody Wetlands	Emergent Herbaceous Wetlands
10815	5.10%	8.14%	12.07%	6.79%	2.70%	0.38%	14.26%	3.26%	0.00%	0.09%	28.23%	8.02%	9.96%	0.60%	0.40%
10867	0.28%	17.13%	27.68%	15.97%	5.64%	0.05%	11.73%	0.06%	0.00%	0.11%	18.19%	2.47%	0.58%	0.10%	0.01%
13621	0.55%	8.45%	7.68%	3.36%	0.94%	0.21%	21.67%	0.12%	0.00%	0.06%	38.87%	16.10%	1.71%	0.28%	0.01%
17663	0.28%	17.04%	27.56%	15.88%	5.62%	0.05%	11.82%	0.06%	0.00%	0.11%	18.33%	2.56%	0.57%	0.10%	0.01%
17664	0.00%	20.70%	30.15%	21.86%	25.77%	0.07%	0.98%	0.00%	0.00%	0.00%	0.41%	0.02%	0.00%	0.00%	0.03%
17666	0.00%	16.36%	15.94%	28.81%	38.90%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
17669	2.27%	7.54%	6.20%	2.36%	1.37%	0.31%	14.18%	0.37%	0.00%	5.03%	52.23%	5.57%	2.32%	0.16%	0.09%
17672	0.00%	16.16%	18.53%	32.25%	33.06%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
17673	0.00%	20.20%	39.34%	16.97%	19.40%	0.00%	0.00%	0.00%	0.00%	0.00%	2.89%	1.20%	0.00%	0.00%	0.00%
17674	0.00%	18.73%	30.41%	17.54%	20.41%	0.00%	4.39%	0.00%	0.00%	0.00%	7.32%	1.19%	0.00%	0.00%	0.00%
17675	0.33%	13.65%	22.62%	19.30%	8.59%	0.00%	9.01%	0.13%	0.00%	0.00%	11.94%	0.00%	14.19%	0.23%	0.00%
17676	0.00%	14.19%	19.16%	18.69%	22.69%	0.00%	10.21%	0.00%	0.00%	0.00%	13.67%	1.39%	0.00%	0.00%	0.00%
17677	0.10%	14.16%	28.87%	25.33%	5.85%	0.00%	10.55%	0.06%	0.03%	0.00%	12.00%	1.09%	1.70%	0.24%	0.03%
17678	0.00%	11.34%	39.00%	24.12%	5.17%	0.00%	10.14%	0.12%	0.00%	0.00%	7.06%	0.16%	2.89%	0.00%	0.00%
17679	0.09%	12.58%	31.23%	24.27%	6.08%	0.00%	10.87%	0.07%	0.01%	0.00%	10.49%	0.94%	3.05%	0.27%	0.03%
17680	0.00%	7.84%	5.60%	0.00%	0.00%	0.00%	7.03%	1.22%	0.00%	0.00%	24.44%	4.18%	49.34%	0.36%	0.00%
17681	5.12%	6.02%	7.29%	3.69%	0.83%	0.46%	14.67%	3.06%	0.00%	0.12%	34.95%	10.20%	13.03%	0.35%	0.20%
17682	5.18%	7.74%	11.63%	6.51%	2.31%	0.39%	14.35%	3.35%	0.00%	0.10%	28.93%	8.23%	10.30%	0.60%	0.38%
17683	0.00%	8.17%	29.76%	25.23%	36.84%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Irving – Station locations and watershed areas:

Site	Location	Stream Flow Type	Area (mi^2)
10866	Bear Creek		85.4
11080	W. Fork Trinity River		3039.6
15624	Vilbig Lake at unnamed creek		0.8
17162	Elm Fork Trinity River	perennial	2514.5
17163	Elm Fork Trinity River	perennial	2554.5
17165	Cottonwood Branch		1
17166	Cottonwood Branch		2
17168	Cottonwood Branch		4.6
17170	Hackberry Creek		15.6
17172	Hackberry Creek		5.2
17173	Dry Branch		3.2
17174	Estelle Creek		3
17175	Delaware Creek		0.6
17176	Delaware Creek		3.2
17177	Delaware Creek		6.5
17178	Delaware Creek	intermittent	7.2
17179	West Irving Branch		3
17938	Hackberry Creek		9.5
17939	Grapevine Creek		5.1
18313	Bear Creek		91.2
18314	Delaware Creek		5.7
18315	Bear Creek		77.1
18359	Cottonwood Branch		3.5

Irving -- percent land use in watersheds:

Site	Open Water	Developed, Open Space	Developed, low (20-49%)	Developed, medium (50-79%)	Developed, high (80-100%)	Barren Land	Deciduous Forest	Evergreen Forest	Mixed Forest	Shrub / Scrub	Grass-lands	Pasture	Cultivated Crops	Woody Wetlands	Emergent Herbaceous Wetlands
10866	0.29%	17.14%	27.31%	15.86%	5.82%	0.05%	11.75%	0.06%	0.00%	0.11%	18.29%	2.61%	0.56%	0.11%	0.06%
11080	2.25%	7.64%	6.38%	2.50%	1.55%	0.31%	14.12%	0.36%	0.00%	5.00%	51.79%	5.52%	2.30%	0.17%	0.10%
15624	0.00%	30.10%	54.57%	10.26%	4.27%	0.00%	0.40%	0.00%	0.00%	0.00%	0.08%	0.32%	0.00%	0.00%	0.00%
17162	4.89%	5.54%	4.18%	2.88%	1.03%	0.11%	11.40%	0.26%	0.00%	0.06%	44.69%	13.40%	11.01%	0.33%	0.20%
17163	4.84%	5.68%	4.51%	3.20%	1.34%	0.11%	11.28%	0.26%	0.00%	0.06%	44.12%	13.24%	10.84%	0.33%	0.20%
17165	0.00%	46.46%	18.53%	21.93%	5.06%	0.00%	0.00%	0.00%	0.00%	0.00%	6.62%	1.40%	0.00%	0.00%	0.00%
17166	0.00%	28.76%	19.38%	30.58%	17.39%	0.00%	0.08%	0.00%	0.00%	0.00%	3.31%	0.50%	0.00%	0.00%	0.00%
17168	0.00%	33.01%	24.61%	27.55%	11.88%	0.00%	0.03%	0.00%	0.00%	0.00%	1.84%	1.08%	0.00%	0.00%	0.00%
17170	0.07%	13.81%	17.99%	24.74%	16.49%	0.00%	6.48%	0.09%	0.00%	0.00%	13.88%	6.07%	0.32%	0.02%	0.04%
17172	0.09%	18.40%	13.73%	15.43%	20.12%	0.00%	4.72%	0.00%	0.00%	0.00%	16.17%	11.34%	0.00%	0.00%	0.00%
17173	0.00%	10.94%	38.72%	21.06%	26.45%	0.37%	1.73%	0.00%	0.00%	0.00%	0.73%	0.00%	0.00%	0.00%	0.00%
17174	0.00%	26.10%	19.33%	20.81%	8.62%	0.00%	4.23%	0.00%	0.00%	0.00%	20.92%	0.00%	0.00%	0.00%	0.00%
17175	0.00%	2.22%	67.01%	14.30%	16.47%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
17176	0.00%	5.85%	59.66%	16.67%	17.82%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
17177	0.00%	11.34%	52.39%	18.28%	17.98%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
17178	0.00%	14.29%	51.67%	17.25%	16.63%	0.00%	0.00%	0.00%	0.00%	0.00%	0.16%	0.00%	0.00%	0.00%	0.00%
17179	0.00%	18.18%	51.00%	15.21%	15.61%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
17938	0.12%	16.35%	17.99%	23.04%	16.29%	0.00%	5.12%	0.00%	0.00%	0.00%	12.63%	7.89%	0.50%	0.00%	0.07%
17939	0.00%	18.17%	15.32%	19.87%	23.99%	0.06%	2.12%	0.02%	0.00%	0.00%	15.81%	4.64%	0.00%	0.00%	0.00%
18313	0.76%	16.51%	27.22%	15.67%	6.47%	0.06%	11.57%	0.06%	0.00%	0.10%	17.72%	2.77%	0.52%	0.19%	0.39%
18314	0.00%	9.57%	52.66%	18.98%	18.80%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
18315	0.29%	17.02%	28.52%	15.62%	5.30%	0.06%	11.81%	0.06%	0.00%	0.12%	18.16%	2.31%	0.62%	0.10%	0.01%

NLCD 2001 Land Cover Class Definitions
Note: classes found only in coastal regions excluded.

Open Water - All areas of open water, generally with less than 25% cover of vegetation or soil.
Developed, Open Space - Includes areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20 percent of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes
Developed, Low Intensity - Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20-49 percent of total cover. These areas most commonly include single-family housing units.
Developed, Medium Intensity - Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50-79 percent of the total cover. These areas most commonly include single-family housing units.
Developed, High Intensity - Includes highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80 to100 percent of the total cover.
Barren Land (Rock/Sand/Clay) - Barren areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.
Deciduous Forest - Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75 percent of the tree species shed foliage simultaneously in response to seasonal change.
Evergreen Forest - Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75 percent of the tree species maintain their leaves all year. Canopy is never without green foliage.
Mixed Forest - Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75 percent of total tree cover.
Shrub/Scrub - Areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions.
Grassland/Herbaceous - Areas dominated by graminoid or herbaceous vegetation, generally greater than 80% of total vegetation. These areas are not subject to intensive management such as tilling, but can be utilized for grazing.
Pasture/Hay - Areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20 percent of total vegetation.

Cultivated Crops - Areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20 percent of total vegetation. This class also includes all land being actively tilled.
Woody Wetlands - Areas where forest or shrubland vegetation accounts for greater than 20 percent of vegetative cover and the soil or substrate is periodically saturated with or covered with water.
Emergent Herbaceous Wetlands - Areas where perennial herbaceous vegetation accounts for greater than 80 percent of vegetative cover and the soil or substrate is periodically saturated with or covered with water.