A Statistical Analysis of TxDOT Highway Storm Water Runoff:

Comparisons with the Existing North Central Texas Municipal Storm Water Database

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Controlling storm water pollution in urban areas and from industrial activity runoff is viewed by the U.S. Environmental Protection Agency (USEPA) as a key to maintaining and improving the quality of the nation's waterways. Historical water quality summaries suggested that many waters were being impacted by storm water runoff. In the *National Water Quality Inventory, 1992 Report to Congress*, USEPA reported that about one third of U.S. waterways are impaired by storm water runoff. The Water Quality Act of 1987 included requirements to control storm water discharges. Water pollution generated during storm events, whether it is referred to as urban storm water or nonpoint source pollution, is now a regulatory focus.

In November 1990, after almost 20 years, the USEPA published final regulations requiring storm water permits. This final rule targets large municipalities and urban areas, plus eleven categories of industry. Large municipalities were required to commence two-part storm water permit applications, and to commit to implement controls to the "maximum extent practicable" or "MEP." Selected industrial activities, including construction projects, as well as certain municipal activities classified as industrial in nature, were also required to apply for storm water permits within the framework of the Nationwide Pollution Discharge Elimination System (NPDES) structure that USEPA uses for point source discharges.

Seven Affected Cities Join Together Through A Regional Strategy

The North Central Texas Council of Governments (NCTCOG), the 16-county regional water quality planning agency, has a record of success in working with its 223-member local governments to address key regional issues of common concern, such as transportation, wastewater treatment, air quality, and solid waste management. Since the cities targeted for storm water permits represent NCTCOG's seven largest member cities, it seemed logical to explore the concept of a cooperative approach for the permit application process. In 1989, NCTCOG prepared and adopted a Regional Strategy for Managing Urban Storm Water Quality, and entered into local agreements with the seven affected cities (Dallas, Fort Worth, Arlington, Irving, Garland, Plano, and Mesquite) and later, in 1993 with the Texas Department of Transportation (TxDOT) (Dallas and Tarrant County Districts), to provide administrative assistance for the permit application process.

The key objectives outlined in the Regional Strategy included:

- Allowing comprehensive characterization of water quality data to support management programs;
- Providing an opportunity to establish unified "Best Management Practices" (BMP) manuals for use by all cities, thereby assuring equity and consistency;
- Allowing a cost-effective and consistent approach to ordinance development;
- Providing sufficient time to give full consideration to funding needs;
- Allowing public information and participation programs to begin well ahead of management efforts, helping to assure public acceptance; and
- Providing the best information on which to base continued monitoring efforts and BMP's.

Under the local agreements, NCTCOG receives approximately $100,000 annually on a formula basis from the regional participants for its administrative work. The U.S. Geological Survey was engaged to monitor wet-weather storm water discharges during the application phase. This was funded locally by the seven cities and TxDOT through NCTCOG, at a cost of $1.9 million. The services of a professional consultant were also secured through NCTCOG for $1.3 million to assist with permit applications and focus on regional opportunities during the application phase.

Regional Monitoring Program Is Successfully Implemented With USGS

Because of the close proximity of the seven cities within the Dallas/Fort Worth Metroplex, the Regional Task Force sought to coordinate the storm water quality monitoring effort. Early on it was decided that 3 events were insufficient to adequately characterize storm water quality at a given site. NCTCOG, in cooperation with the Regional Task Force, the U.S. Geological Survey and regional consultants, designed an alternative program that could more effectively monitor conditions in the Dallas/Fort Worth metropolitan area. A network of 30 sites was selected for the seven Metroplex cities as a whole, in contrast to the range of 35 to 70 sites possible according to USEPA guidance. Each of the 30 sites, however, was sampled for 7 storm events. This provided a firmer statistical base to evaluate storm water quality and provided the opportunity to improve the number of samples on a seasonal basis. A key point was that the total number of site events remained comparable to what USEPA would have required if each city had established individual wet-weather monitoring programs. An additional advantage to pooling monitoring resources was that the seven cities could combine storm event data, particularly by landuse, to obtain a stronger characterization of typical runoff within the Metroplex.

The major focus of the wet-weather monitoring during the Part 2 application process was to characterize typical runoff from three broad landuse classifications - Residential, Commercial and Industrial. These three categories were targeted exclusively in the federal NPDES storm water regulations. In selecting the sites to be monitored, stations were sought in each municipality which provided as even a mix of the three landuse classifications as possible. The final set of monitoring sites included 11 Residential, 6 Commercial, and 9 Industrial basins and 4 highway sites. The 4 highway sites were added to the regional program with funding from the Texas Department of Transportation when EPA Region 6 required them to apply for a storm water permit or co-apply with a municipality. These sites were installed during the summer of 1993 with sampling being conducted from December 1993 to November 1994. A detailed statistical comparison of the data collected from these highway sites is the focus of this report. Of interest is whether this data is similar to any of the three landuse categories of focus during the municipal sampling.

Description ofhighway sites

As with the selection of the municipal storm water monitoring sites, the site selection process began with the identification by TxDOT staff of 6-10 possible candidate sites that adequately matched a limited set of criteria provided by the USGS. From this list, final sites were selected following field inspection by USGS staff who needed to ensure that the site could be appropriately installed with the monitoring equipment. Final approval of sites was determined by EPA Region 6 NPDES storm water permit staff. In some cases, sites were rejected due to low traffic counts and secondary sites had to be used. The final list of sites includes the following:

1. **I-35W/Deer Creek sitein Tarrant County**- This site drains I-35W and some abutting property from just north of Garden Acres to Deer Creek within the Fort Worth city limits. Its drainage area landuse includes both highway and vacant land. The total drainage is 63.13 acres, with pavement comprising 27% and non-highway acreage 40%.

2. **I-635 and Dallas North Tollway**- This site was selected to monitor storm water effluent from both TxDOT and Texas Turnpike Authority's facilities since the Turnpike Authority originally thought they would be required to co-permit with the City of Dallas. Its landuse is listed as highway only, with 33% impervious area. The total drainage area is 12.05 acres. This site is also referred to as the Bachman Branch site

3. **I-20 at Duncanville/Mountain Creek**- This site is located in the median at the bottom of the hill between Duncanville and Cedar Hill. The drainage area is 115.36 acres in the drainage basin of Mountain Creek. The landuse is listed as highway only but impervious area comprises only 10%.

4. **I-20 at Collins St./Fish Creek**- This site has a drainage area of 13.8 acres and drains into Fish Creek. Its landuse is entirely highway usage and includes approximately 40% impervious concrete pavement with some flexible pavement, as well as some grassy median area.

Statistical Analysis of the Highway Data

The focus of this report is to compare the dataset obtained from the highway storm water monitoring sites with the municipal storm water dataset. In the past, EPA regulations have focused on just three landuse categories: Residential, Commercial, and Industrial. Highway runoff data have traditionally been expected to correlate with Commercial runoff data because of the light industrial nature of this landuse type. This report will evaluate whether this is a valid assumption or whether the highway data correlate better with either of the remaining two landuse types. Another hypothesis that will be evaluated is whether highway data actually represents a distinct, fourth landuse category. And finally, there is the possibility that highway runoff data does not correlate with any one pariticular landuse type but simply mimics the surrounding landuse. Evidence for this scenario will be evaluated as well.

In general, storm water data has considerable variability from one sampling to the next which makes it difficult to characterize and to analyze with much certainty. Generalizations and trends must be relied upon to some extent. Furthermore, storm water data and water quality data in general tend to be non-normally distributed, which precludes the use of standard parametric statistical methods of comparison. In this report, nonparametric tests have been used to analyze the data. Nonparametric tests typically rely on ranking the data instead of analyzing the actual data values. The data is usually reorganized into rank order and assigned a rank value. Then, this rank value is tested to arrive at a statistical value and probability. In addition, it is standard practice to focus on the median value of a dataset when using nonparametric statistics rather than the mean. The mean, which is the sum of the values divided by the sample size, is a good indicator of central tendency of a dataset only if the

dataset is relatively normally distributed. The mean can be highly impacted, especially in smaller datasets, by outlying values which can be common in water quality data. The median is the middle value of the sample values when they are sorted in rank order.
This report will be limited to the conventional parameters. These are the parameters commonly used to define the basic water quality in water samples. Conventional parameters typically include: biochemical oxygen demand (BOD), chemical oxygen demand (COD), total organic carbon (TOC), total suspended solids (TSS), total dissolved solids (TDS), nitrogen series, phosphorus series, bacteria, pH, chloride, sulfate, temperature, dissolved oxygen, oil and grease, alkalinity, and specific conductivity. The current dataset also includes additional measurements of hardness, common anion and cations, phenol, and several metals. Measurements of dissolved oxygen were not included. Descriptive statistics are provided for all of the conventional parameters. However, the statistical analyses will focus on 11 of the 12 parameters required by EPA for computation of pollutant loading estimates in the NPDES permit applications. Insufficient data were collected above the detection limit for the metal, cadmium, to include it in the analyses.

A. Comparisons using combined TxDOT data

Descriptive statistics

Descriptive statistics are provided in Table 1 on the next page for most of the conventional parameters measured. The following parameters were not included since more than 93% of the values were below detection limits: antimony, beryllium, cadmium, cyanide, mercury, selenium, silver, and thallium. Furthermore, only the median value for the oil and grease parameter has been included in the table since 66% of its values were below detection limits and consequently, the mean and standard deviation of such a dataset are meaningless.

The Nonparametric Kruskal-Wallis Tests

In the initial statistical analyses, the TxDOT Highway data were combined together and compared to the other three municipal landuse categories. In the first analysis, the Kruskall-Wallis test was used to compare the median values of the data from each landuse category for each individual parameter. This test evaluates the degree of independence among three or more sample means. The Kruskal-Wallis statistic H is determined by

$$H = \left[\frac{12}{n(n+1)}\right] \bullet \sum_{i=1}^{K} \left[\frac{R_i^2}{n_i}\right] - 3(n+1)$$

where n is the sum of sample sizes, $n_1+n_2+\ldots nK$, and R_i is the sum of the ranks of the items from sample $n_{i.}$

The purpose was to determine whether a significant difference could be detected among the four landuse categories. The results of this analysis are shown in Table 2. A statistical difference was found for 10 of the 11 parameters evaluated (12 EPA loading parameters minus cadmium). Only COD and BOD showed no significant difference among the 4 landuse types. The most significant difference was found in the dissolved phosphorus category where a greater than 3 fold range is shown between the medians of the four landuse types with the TxDOT data falling in the middle. The second most significant difference was found for total dissolved solids. The TxDOT median value is approximately three times greater than the other three values in this category. The Kruskall-Wallis test is used to look for significant differences among three or more groups of data; however, it does not indicate which of the included categories are more different from the others. To address this question, the Mann-Whitney test was used and the results are shown in the next section.

Table 1: Descriptive Statistics for TxDOT Highway Storm Water Data

(collected 12/93 - 11/94)

Parameter	Mean	Standard Error	Median	Standard Deviation	Min	Max	Count
Specific Conductivity. (field)	481.82	85.569	329	452.790	77	2240	28
Specific Conductivity: (lab)	383.48	50.416	311	261.971	113	1100	27
Field pH	7.77	0.102	7.8	0.540	6.2	8.6	28
Lab pH	7.34	0.055	7.4	0.285	6.6	7.7	27
Temp	18.39	0.889	19.25	4.705	11	29	28
COD	61.96	6.504	59	34.42	0	140	28
BOD	6.83	0.386	6.45	2.045	2.7	10	28
Fecal coliform	248311.54	125127.255	44000	6.38E+05	100	3200000	26
Fecal streptococcus	79213.57	31145.854	24500	1.65E+05	100	840000	28
Total hardness	107.04	13.991	82	72.698	42	290	27
Dissolved hardness	60.18	14.635	27.5	68.644	1	200	22
Alkalinity	56.11	4.461	56	23.182	25	100	27
Tot. Suspended Solids	100.37	14.516	90	75.427	17	386	27
Dissolved solids	227.78	35.045	168	182.097	57	715	27
Diss. Residue 180°C	240.70	36.526	184	189.794	73	750	27
Calcium	34.74	3.729	28	19.376	16	80	27
Magnesium	4.80	1.250	1.7	6.496	0.49	21	27
Sodium (dissolved)	29.00	5.793	15	30.102	1.4	110	27
Sodium (%)	29.63	3.358	34	17.449	5	64	27
Sodium (adsorp. ratio)	1.07	0.175	1	0.910	0.1	3	27
Potassium	3.33	0.236	3.1	1.228	1.3	6	27
Sulphate	91.71	23.437	27	121.781	9.5	420	27
Chloride	14.47	2.876	7.6	14.943	1.4	62	27
Nitrate + nitrite	0.75	0.075	0.69	0.398	0.16	1.7	28
Total Kjeldahl Nitrogen	1.45	0.146	1.2	0.774	0.4	3.6	28
Total Phosphorus	0.26	0.032	0.21	0.167	0.06	0.68	28
Dissolved Phosphorus	0.15	0.024	0.11	0.127	0.01	0.53	28
Arsenic	2.25	0.249	2	1.316	0.5	6	28
Chromium	4.93	0.725	3	3.839	2	18	28
Copper	11.32	1.050	10.5	5.558	3	23	28
Lead	24.61	6.460	11	34.184	3	140	28
Nickel	9.68	2.360	4	12.487	1	47	28
Zinc	90.71	12.796	60	67.710	20	260	28
Total Organic Carbon	20.43	1.478	19.5	7.821	7.9	42	28
Oil & Grease	NA	NA	0.5	NA	0.5	6	27
Phenols	5.20	0.847	4	4.481	0.5	16	28

Table 2: Kruskal-Wallis Analysis of Landuse Types

Statistical difference is found when H > Hcrit = 7.815 at P = 0.05. Significant results are shaded.

	Median Values				**Kruskal-Wallis**
Parameter	**TxDOT**	**Commercial**	**Industrial**	**Residential**	**Statistic (H)**
COD	59.0	56.5	67.0	70.0	4.46
BOD	6.45	6.55	7.5	7.3	5.47
TSS	90.0	44.0	104.5	78.0	21.57
TDS	184.0	50.0	69.0	59.0	55.10
Total Phosphorus	0.21	0.14	0.21	0.33	47.16
Dissolved Phosphorus	0.11	0.06	0.09	0.21	62.85
Total Nitrogen	1.98	1.22	1.43	1.69	29.63
TKN	1.2	0.8	0.8	1.1	38.20
Copper	10.5	8.0	12.0	8.0	16.52
Lead	11.0	29.5	29.0	13.0	21.34
Zinc	60.0	80.0	140.0	60.0	37.43

The Mann-Whitney Test for Two Groups

The Mann-Whitney test is another nonparametric test that is based on rank-sum. Like the Kruskal-Wallis test, the Mann-Whitney test is used to evaluate if two samples are drawn from the same population. The Mann-Whitney statistic is given by:

$$U = n_1 n_2 + \frac{n_1(n_1+1)}{2} - R_1$$

where R_1 is the sum of the ranks of the items from sample n_1. When both n_1 and n_2 are greater than or equal to ten, a fair approximation of the U-test can be performed with the aid of the normal distribution. In this case, the expected value of U is

$$E(U) = \frac{n_1 \cdot n_2}{2},$$

the standard deviation is estimated by

$$s = \sqrt{\frac{(n_1 n_2)(n_1 + n_2 + 1)}{12}},$$

and a z-score is given by

$$z = \frac{U - E(U)}{s}.$$

The z-score is then compared with the normal distribution at an infinite number of degrees of freedom.

The results are shown in Table 3 where the combined TxDOT data are compared with each other landuse category in turn for each parameter. For this analysis, the actual probabilities are shown instead of the statistic. The probabilities must be less than 0.05 to accept the hypothesis that there is a significant difference between the two samples; otherwise, one must accept the null hypothesis that the two samples are from the same population of data. Significant difference (indicated in the table with **) was found in all comparisons of TDS. As was previously stated, this is clearly the result of the TxDOT TDS data being significantly higher than all other landuse categories as shown in Table 2. Beyond the TDS parameter, the TxDOT data are significantly different from the Commercial data for the parameters TSS, total phosphorus, dissolved phosphorus, TKN, total nitrogen, lead and copper. It is significantly different from the Industrial data for the following parameters: total kjeldahl nitrogen, total nitrogen, zinc, and lead and from the Residential data for the following parameters: dissolved phosphorus, total phosphorus, total nitrogen and copper. The rest of the parameters showed no significant difference. Although not statistically defensible, it is instructive to identify which landuse category appears most similar to the TxDOT data for each parameter by seeking the highest probability, given that the probability value approaches 1.0 as the two data sets become more similar. This was done by shading the highest probability value in each row of the table. Using this technique, the TxDOT data match with Commercial data only once, Industrial data 3 times, and Residential data 6 times. The highway data appears to be most similar to the Residential data. Even though four of the eleven parameters of Residential data show significant differences with the highway data, this fewer than any other landuse category has. In summary, although this analysis does not indicate an exclusive relationship between the highway data and any of the other landuse categories, significantly more similarity is shown for the Residential data.

Table 3: Comparison of TxDOT Data to Each of the Other Landuse Types Using the Mann-Whitney Test

Parameter	TxDOT v Commercial	TxDOT v Industrial	TxDOT v Residential
COD	0.995	0.171	0.139
BOD	0.414	0.611	0.864
TDS	0.0000**	0.0000**	0.0000**
TSS	0.0031**	0.091	0.909
DP	0.044**	0.908	0.0001**
TKN	0.0006**	0.0000023**	0.469
Zn	0.157	0.00004**	0.764
TP	0.021**	0.705	0.001**
Cu	0.179	0.219	0.048**
Pb	0.006**	0.0005**	0.761
TN	0.0004**	0.0002**	0.142

Statistically significant differences (P < 0.05) are indicated with **. The highest probability (i.e. greatest similarity) in each row is shaded.

B. Comparison of individual highway sites

Because of the slight ambiguity of the initial Mann-Whitney analyses, a further step was taken to address the possibility that the highway data does not represent a homogeneous dataset. Past studies have shown that highway runoff can be indicative of its surrounding landuse. Thus, each highway monitoring station was analyzed separately to identify individual characteristics. In Table 4, found on the next page, the results of Mann-Whitney comparisons are shown for all possible combinations within a given parameter, including comparisons between TxDOT sites themselves and between the three landuse categories. To simplify the table, redundant combinations have been omitted. In Table 4, the TxDOT sites are numbered as follows:

1. I-35W/Deer Creek outfall
2. I-20/Mountain Creek outfall
3. I-20/Fish Creek outfall
4. North Tollway/Bachman Branch outfall.

Among the four sites, Sites 1 and 2 are the most dissimilar, with 8 out of 11 parameters showing a significant difference. Sites 2 and 4 appear to be the most similar, having the least number of significantly different parameters. Following the approach that a higher probability value indicates a greater similarity, each TxDOT site pairwise comparison was examined for the greatest similarity for each parameter. For example, for the parameter COD, Site 1 shows the most similarity to Site 3, Site 2 the most similarity to Site 4, Site 3 the most similarity to Site 1, and Site 4 the most similarity to Site 2. The site to site combinations were tabulated for all parameters and are shown in Table 5. The most common combination is identified for each row by shading. Sites 2 and 4 again show the highest degree of similarity overall, with Sites 1 and 3 showing the next highest similarity.

Table 5: Frequency of Occurrence of the Highest Probability Value with each Pairwise Comparison

	TxDOT 1	TxDOT 2	TxDOT 3	TxDOT 4
TxDOT 1	-	2	3	2
TxDOT 2	2.5*	-	1.5*	5
TxDOT 3	4	2	-	3
TxDOT 4	1	5	3	-

* Indicates a tie occurred in this category

Intercomparisons between the three municipal landuse categories show that the Industrial landuse data are significantly different from both Commercial and Residential 64% of the time, while Commercial and Residential data are significantly different from each other 73% of the time (Table 4). Significant differences occur between the Industrial landuse and both Commercial and Residential landuse categories for all three metal parameters and both phosphorus parameters. In contrast, the significant differences found for both the solids parameters in the Commercial-Industrial comparison are replaced by significant differences between the two nitrogen parameters in the Residential-Industrial comparison. As might be expected, Commercial-Residential comparisons reveal significant differences for these same two categories, solids and nitrogen. What is unexpected is the finding of significant differences in the Commercial- Residential comparisons for the same parameters with which they share common significant differences with the Industrial categories (i.e. TP, DP, Pb, and

Zn). Only copper is an exception to this. This suggests that these three categories clearly show distinct differences from each other.

Table 4: Mann-Whitney Probabilities

(P must be at least 0.05 to accept hypothesis that samples are not significantly different)

PARAMETER		TxDOT 1	TxDOT 2	TxDOT 3	TxDOT 4	Ind.	Res.	TxDOT 2	TxDOT 3	TxDOT 4
COD	C	0.061	0.067	0.458	0.424	0.312	0.093			
	I	0.0148	0.141	0.101	0.633		0.444			
	R	0.006	0.241	0.072	0.942					
	TxDOT 1							0.013	0.371	0.055
	TxDOT 2								0.035	0.338
	TxDOT 3									0.125
BOD	C	0.471	0.398	0.950	0.074	0.107	0.217			
	I	0.200	0.912	0.200	0.196		0.277			
	R	0.193	0.670	0.233	0.092					
	TxDOT 1							0.406	0.277	0.084
	TxDOT 2								0.201	0.338
	TxDOT 3									0.064
TSS	C	0.129	0.002	0.091	0.462	0.00003	0.0013			
	I	0.193	0.637	0.204	0.069		0.050			
	R	0.809	0.129	0.822	0.383					
	TxDOT 1							0.142	0.749	0.317
	TxDOT 2								0.142	0.054
	TxDOT 3									0.520
TDS	C	0.0002	0.00004	0.002	0.0010	0.006	0.044			
	I	0.0001	0.00002	0.0087	0.001		0.092			
	R	0.00006	0.00002	0.0013	0.0005					
	TxDOT 1							0.003	0.048	0.391
	TxDOT 2								0.003	0.003
	TxDOT 3									0.317
TP	C	0.086	0.056	0.0007	0.052	0.0007	0.0000			
	I	0.001	0.638	0.030	0.845		0.00007			
	R	0.00001	0.356	0.447	0.008					
	TxDOT 1							0.018	0.002	0.002
	TxDOT 2								0.371	0.482
	TxDOT 3									0.018

PARAMETER		TxDOT 1	TxDOT 2	TxDOT 3	TxDOT 4	Ind.	Res.	TxDOT 2	TxDOT 3	TxDOT 4
DP	C	0.909	0.095	0.0002	0.005	0.002	0.00000			
	I	0.064	0.003	0.0009	0.221		0.00000			
	R	0.00004	0.0002	0.104	0.020					
	TxDOT 1							0.142	0.002	0.005
	TxDOT 2								0.003	0.018
	TxDOT 3									0.004
Cu	C	0.103	0.222	0.605	0.002	0.008	0.826			
	I	0.006	0.747	0.214	0.125		0.0002			
	R	0.103	0.112	0.528	0.0001					
	TxDOT 1							0.030	0.035	0.009
	TxDOT 2								0.443	0.084
	TxDOT 3									0.002
Pb	C	0.0006	0.215	0.034	0.021	0.386	0.004			
	I	0.0004	0.551	0.017	0.010		0.00005			
	R	0.022	0.020	0.768	0.676					
	TxDOT 1							0.006	0.035	0.074
	TxDOT 2								0.035	0.030
	TxDOT 3									0.848
Zn	C	0.012	0.120	0.002	0.501	0.0002	0.022			
	I	0.0001	0.929	0.00006	0.139		0.000			
	R	0.134	0.009	0.022	0.064					
	TxDOT 1							0.013	0.338	0.013
	TxDOT 2								0.011	0.406
	TxDOT 3									0.005
TN	C	0.989	0.002	0.015	0.005	0.180	0.00005			
	I	0.624	0.0006	0.008	0.003		0.0004			
	R	0.074	0.022	0.261	0.097					
	TxDOT 1							0.007	0.035	0.011
	TxDOT 2								0.180	0.277
	TxDOT 3									0.482
TKN	C	0.577	0.0003	0.034	0.003	0.893	0.00006			
	I	0.570	0.00005	0.009	0.0004		0.00000			
	R	0.006	0.004	0.981	0.130					
	TxDOT 1							0.002	0.009	0.002
	TxDOT 2								0.006	0.074
	TxDOT 3									0.009
SUMMARY		**C**	**I**	**R**	**I/R**					

If Table 4 is again examined for the highest probability value within each parameter, but with sites independently compared to the landuse categories, these findings can be summed to indicate to which landuse category each TxDOT site is most similar. These findings are summarized at the bottom of Table 4 with letters representing each landuse category (C = Commercial, I = Industrial and R = Residential). Site 1 had the highest probability for a given parameter more times (7) for the Commercial category, Site 2 had more similarities (7) with the Industrial data, Site 3 had more similarities (6) with the Residential data and Site 4 had an equal number of similarities (4) with the both the Industrial and the Residential data. From an earlier analysis of the municipal dataset it was learned that the constituents characteristic of Residential landuse areas included COD, all nutrients, diazinon and bacteria. Of these, only COD and the nutrients were included in this analysis. For Industrial landuse areas, all of the conventional metals, TSS, phenols and chloride were characteristic. Of these, this analysis included all of the metals and TSS. No particular constituents were characteristic of Commercial landuse areas which tend to be combinations of light industrial, residential and retail activities rather than ony one particular activity.

Combining all of the above analyses, Site 2, which appears to share the most similarities with Industrial landuse data, was also most similar to Site 4, which appears to share characteristics with both Industrial and Residential data. However, Site 1, which was most similar to Site 3 (although not as strongly as the Site 2-Site 4 relationship), was also most similar to Commercial landuse data. Site 3 however, was shown to be most similar to Residential landuse data, which appears to be quite distinct from the Commercial landuse data. Part of the difficulty in elucidating distinct relationships among the TxDOT sites may be due to the limited data set. The Mann-Whitney test requires a sample size of at least ten for making its fair approximation of the normal distribution. Samples were only taken for seven events at each site. The assumptions of similarity are also not statistically robust and can only be used as general indicators. Nevertheless, certain analogies can be made between the apparent affinities of the TxDOT sites to a given landuse.

TxDOT Site 1 is located on I-35, just north of the large Hughely Hospital complex. It is surrounded by relatively vacant pasture land with small pockets of residential and small commercial establishments. Its highway traffic would not be expected to be highly industrial in nature, but it could show some characteristics of commercial areas due to landscaping activities at the hospital. Site 2 was originally chosen to characterize a typical rural highway and to be in contrast to Site 4 which is located on the North Dallas Tollway. Surrounding landuse at Site 2 is primarily vacant land. Reasons for similarities with Industrial landuse areas (i.e. high metals and TSS) are unclear. Site 3 is surrounded by vacant land but is close to dense residential areas, which may explain its correlation with Residential data. Site 4 is located at a major interchange, densely surrounded by retail and commercial enterprises, and some residential areas. It is not too far from a large industrial sector. The statistical analyses supported these characteristics by showing similarities with both the Residential landuse data and the Industrial landuse data. This study suggests that highway runoff does correlate with the surrounding landuse, even outside of the immediate drainage basin.

Included in the appendix is a series of “box and whisker” plots of the data analyzed in this report. These plots use boxes to indicate the percentiles of the data (10, 25, 50, 75, and 90). Lines extending from these boxes indicate the minimum and the maximum values of the dataset. The plots are useful in providing a quick visual impression of the data distribution and illustrating comparisons between distributions. Visual illustrations are often helpful in understanding some of the results of the statistical analyses which reduce dataset comparisons to simple numbers. For example, a study of the total phosphorus plot helps to understand why Site 1 was found to be statistically different from the other three. Its narrower distribution and lower median value is clearly seen in the plot. Furthermore, Site 2 was found to be statistically similar to both Site 3 and Site 4, yet Site 3 was found to be distinct from Site 4. The plot reveals the wide distribution of the Site 2 data, which overlaps both Site 3 and Site 4 data. From these plots, it can also be seen that TxDOT Site 2 has the most variable data of the 4 sites and that the Industrial data is more variable than the other three landuse categories (Comm., Ind., Res.).

Raw data of all the conventional parameters of the TxDOT highway sites are also included in the appendix. The symbol "<" denotes less than values where samples were at levels below the detection limits of the analyses. A "K" notation associated with the bacterial analyses indicates values that were approximated due to unexpectedly high or low counts which exceeded the dilution range of the analyses.

Conclusions

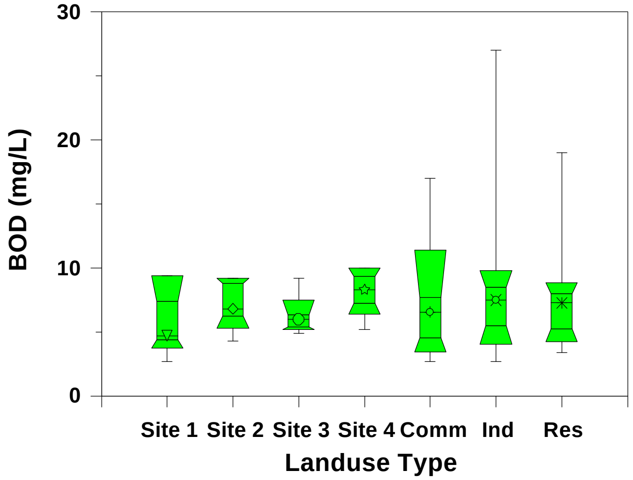
To address the original question of whether highway data represents a distinct landuse type of its own, the results of this report seem to indicate that this is not a valid assumption. Very few significant differences were found between the four landuse types. As to whether the highway data corresponds to any one particular landuse type, the results again do not support this hypothesis. Given the variability of storm water data and the close similarity of the data from each landuse type with each other, it is difficult to extract clear delineations without substantially large datasets. It was expected that highway data would show high levels of metals from the automobile traffic and thus would be most similar to Industrial data. This was not seen. One might also anticipate that highway runoff would have some characteristics of industrial runoff and some of residential runoff and thus might appear similar to commercial runoff (which logically should be a combination of the two). Again, the analyses did not suppport this hypothesis as the greatest number of similarities were found with the Residential landuse data. The source of the pollutants found in the highway runoff is also unclear since expected metals were not found at significant levels.

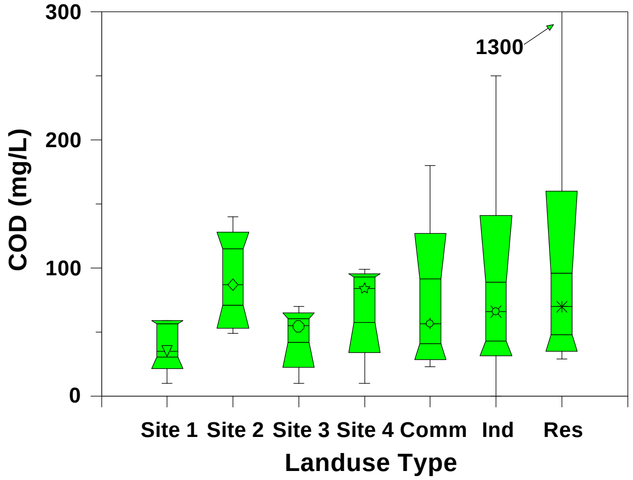
Analyzing the individual highway sites separately proved beneficial. The combined highway dataset showed the strongest affinity to the Residential dataset and a minor affinity to the Industrial dataset with almost no affinity to the Commercial dataset. Site 1 however, clearly has the greatest similarity to the Commercial data. Furthermore, the remaining sites had similarities to other landuse categories, not just to Residential. What seems to be evident, at least in part, is some degree of correlation of the highway data with the surrounding landuse type. This would suggest that the pollutants are either being carried in and deposited by the traffic or there may be airborne transmission. Airborne transport of pollutants away from their source to adjacent land has been suggested in several studies conducted by USEPA. A more extensive dataset and further study is needed to clarify the relationship of the highway data to any one particular landuse category and to identify the pollutant sources.

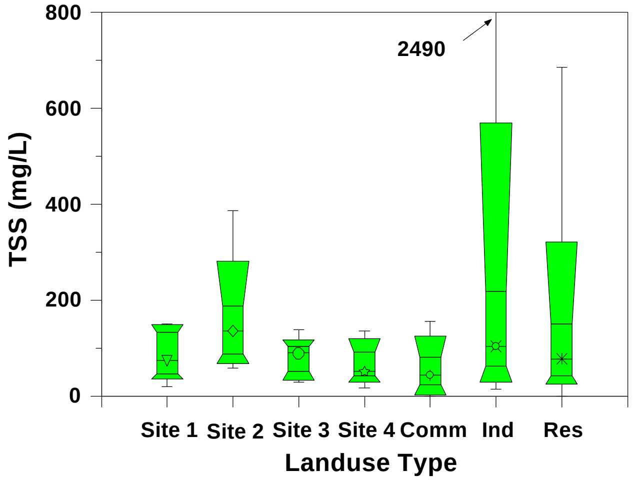
Appendices

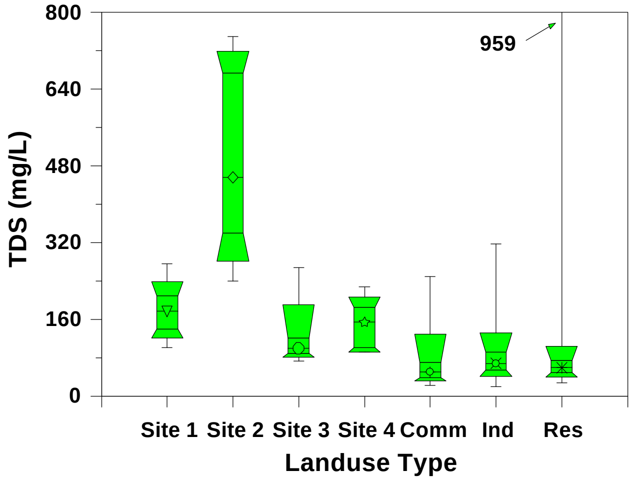
Box and Whisker Plots

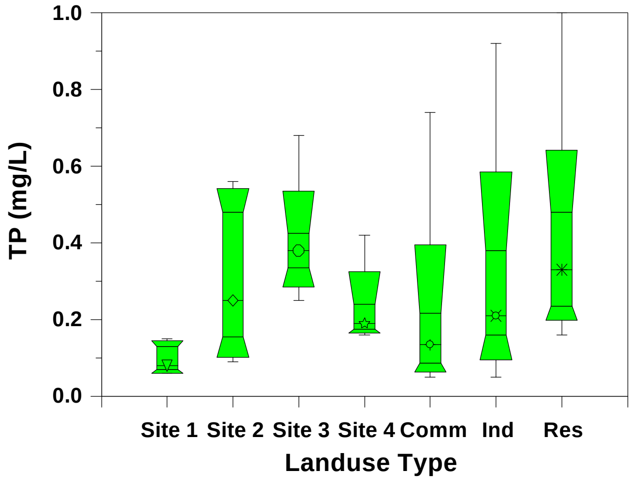
(Shows the distribution of the data with the "whiskers" indicating the minimum and maximum values and the box delineating the 10, 25, 50 (median), 75, and 90th percentiles)

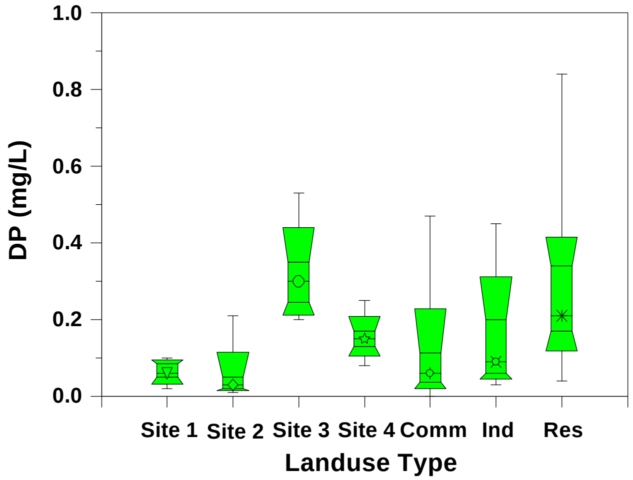

Comparison of Land Use Types
Biochemical Oxygen Demand

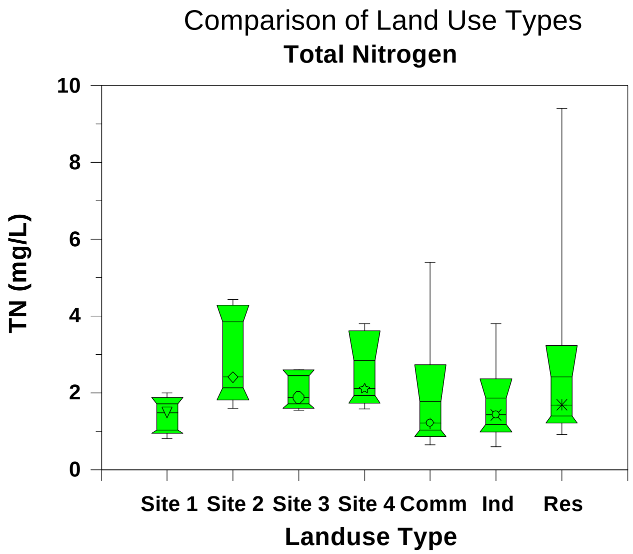

Comparison of Land Use Types
Chemical Oxygen Demand

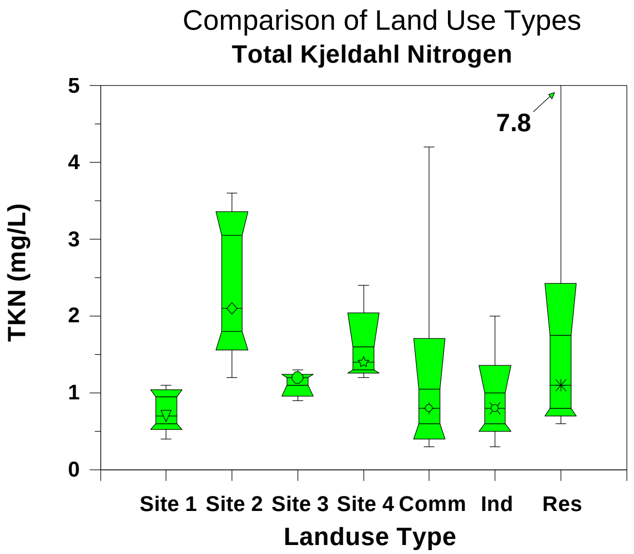

Comparison of Land Use Types
Total Suspended Solids

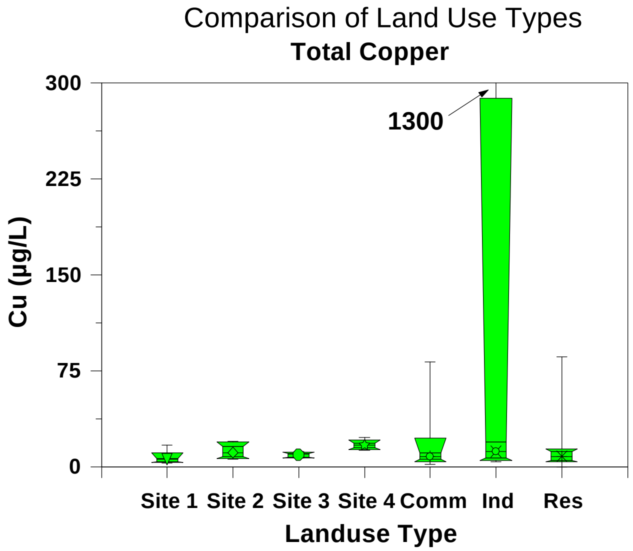

Comparison of Land Use Types
Total Dissolved Solids

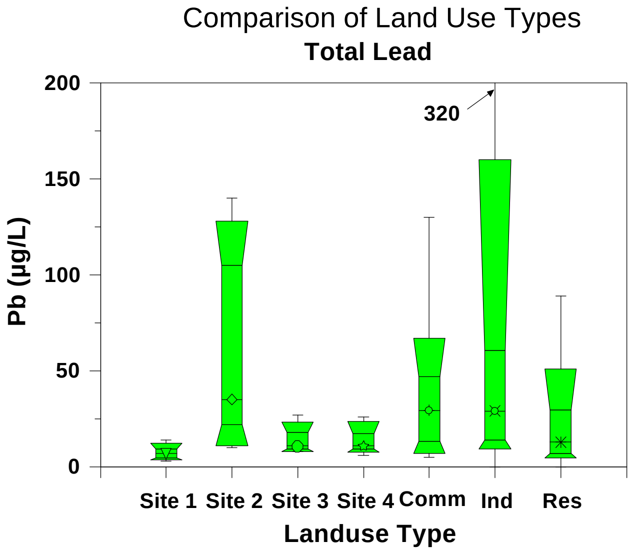

Comparison of Land Use Types
Total Phosphorus

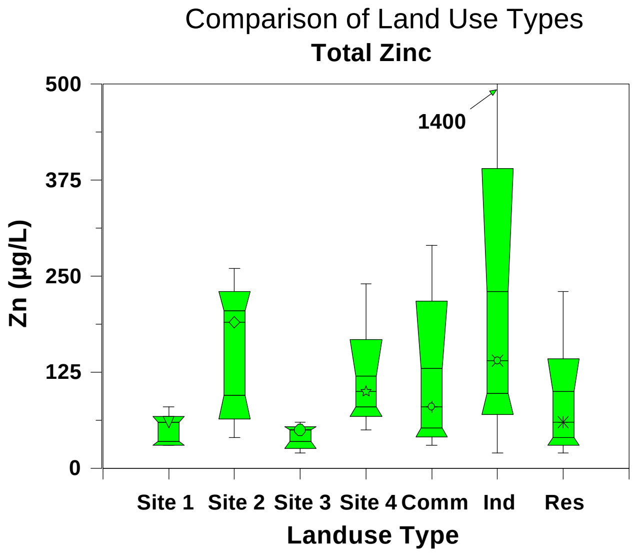

Comparison of Land Use Types
Dissolved Phosphorus


Comparison of Land Use Types
Total Nitrogen
TN (mg/L)
0
2
4
6
8
10
Site 1
Site 2
Site 3
Site 4
Comm
Ind
Res
Landuse Type


Comparison of Land Use Types
Total Kjeldahl Nitrogen
TKN (mg/L)
0
1
2
3
4
5
7.8
Site 1
Site 2
Site 3
Site 4
Comm
Ind
Res
Landuse Type


Comparison of Land Use Types
Total Copper
Cu (µg/L)
0
75
150
225
300
1300
Site 1
Site 2
Site 3
Site 4
Comm
Ind
Res
Landuse Type


Comparison of Land Use Types
Total Lead
Pb (µg/L)
0
50
100
150
200
320
Site 1
Site 2
Site 3
Site 4
Comm
Ind
Res
Landuse Type


Comparison of Land Use Types
Total Zinc
Zn (µg/L)
0
125
250
375
500
1400
Site 1
Site 2
Site 3
Site 4
Comm
Ind
Res
Landuse Type

Conventional parameters - Regional Storm Water Data for TxDOT Sites 12/93 - 11/94

Local	**USGS ID**	**Date**	**Time**	**Sp. Cond.1** **US/CM @ 25C**	**Sp. Cond.2** **µS/CM**	**Field pH** **(STD UNITS)**	**Lab pH** **(STD UNITS)**	**Temp** **(DEGREES)**	**Air Press** **(MM OF HG)**		**COD** **MG/L**	**BOD** **MG/L**
DEER CREEK OUTFALL	08048920	5/2/94	1655	820	311	8	7.7	15			32	4.4
DEER CREEK OUTFALL	08048920	5/9/94	1220	950	236	7.2	7.4	20		<	10	4.4
DEER CREEK OUTFALL	08048920	8/21/94	120	402	515	8.6	7.2	26			54	9.4
DEER CREEK OUTFALL	08048920	8/31/94	1700	757	340	7.8	7.7	24			59	9.4
DEER CREEK OUTFALL	08048920	11/2/94	2344	77	395	7.8	7.4	20			35	4.7
DEER CREEK OUTFALL	08048920	10/7/94	1500	249	204	8	7.7	22.5			59	5.4
DEER CREEK OUTFALL	08048920	11/9/94	525	352	364	7.4	7.5	17.5			29	2.7
MOUNTAIN CREEK OUTF	08049860	4/11/94	1320	252	490	8.6	7.4	19			110	6
MOUNTAIN CREEK OUTF	08049860	1/11/94	550	2240	1100	8.2	7.4	12			140	9.2
MOUNTAIN CREEK OUTF	08049860	5/9/94	1230	513	546	7.5	7.6	20			49	6.5
MOUNTAIN CREEK OUTF	08049860	12/2/93	1532	864	981	8.4	7.6	19			86	6.8
MOUNTAIN CREEK OUTF	08049860	2/28/94	1800	886	664	7.8	7.6	11.5			87	8.4
MOUNTAIN CREEK OUTF	08049860	3/8/94	1145	905	906	7.5	7.5	16			56	4.3
MOUNTAIN CREEK OUTF	08049860	8/20/94	1820	351	443	7.6	7.4	29			120	9.2
FISH CREEK OUTFALL	08049950	5/9/94	1250	139	197	8.4	7.1	20		<	10	4.9
FISH CREEK OUTFALL	08049950	2/28/94	1807	120	152	7.7	7.5	11			59	6
FISH CREEK OUTFALL	08049950	3/8/94	1145	204	399	7.3	7.2	15			70	6.4
FISH CREEK OUTFALL	08049950	11/2/94	2322	842	113	7.6	6.8	20			31	6.3
FISH CREEK OUTFALL	08049950	10/7/94	1525	82	179	8.4	7.4	22			53	5.4
FISH CREEK OUTFALL	08049950	10/24/94	1335	91	139	6.2	7.2	20			55	5.4
FISH CREEK OUTFALL	08049950	11/9/94	707	122	175	7.8	7	18.5			62	9.2
BACHMAN BRANCH OUTF	08055690	1/11/94	142	286	308	7.8	6.9	12			93	8.7
BACHMAN BRANCH OUTF	08055690	5/9/94	1335	261		7.5		19.5		<	10	5.2
BACHMAN BRANCH OUTF	08055690	12/2/93	1652	307	306	8	7.5	18			99	10
BACHMAN BRANCH OUTF	08055690	2/28/94	1828	658	159	7.9	7.6	11.5			50	7.2
BACHMAN BRANCH OUTF	08055690	3/8/94	1145	140	191	8.3	7.3	11.5			65	7.3
BACHMAN BRANCH OUTF	08055690	4/11/94	1327	231	198	7.5	6.6	20			84	10
BACHMAN BRANCH OUTF	08055690	8/5/94	801	390	343	6.7	7.1	24.5			93	8.3
		MEAN -->		481.82	383.48	7.77	7.34	18.39			62.86	6.83
		COUNT -->		28.00	27.00	28.00	27.00	28.00			28.00	28.00

	F. coli.		F. strep	T. hardness	Dis. hard.	Alkalinity	D. solids	T. residue	D. residue	Ca	Mg	Na diss	Na %	Na adsrp
	COLS./100 ML		COLS./100 ML	MG/L	MG/L	MG/L	MG/L	MG/L	MG/L	MG/L	MG/L	(MG/L AS NA)	PERCENT	(RATIO)
K	5000		1600	86		89	168	120	177	30	2.6	27	40	1
K	330	K	100	67	1	66	126	74	134	24	1.7	15	32	0.8
			23000	81		100	259	46	277	26	3.9	69	64	3
	170	K	680	53		64	173	148	145	17	2.1	36	59	2
	250000		31000	83	3	80	208	47	214	28	3.1	41	51	2
	21000		10000	46	3	43	104	151	102	16	1.4	15	41	1
	55000		87000	94		100	194	21	205	32	3.3	35	44	2
	8000		26000	130	100	26	342	211	309	38	7.8	37	38	1
K	100		1200	260	200	61	715	102	750	72	20	110	47	3
	11000		68000	170	110	56	349	58	372	48	11	42	35	1
	4500		28000	290	200	86	659	136	699	80	21	92	41	2
	2200		5100	200	150	44	444	386	456	55	14	57	38	2
	1700		5800	270	190	84	599	73	647	77	20	82	39	2
			18000	85	55	30	263	164	240	24	6.1	39	49	2
	450000		150000	81	24	57	109	30	140	31	0.86	3.6	8	0.2
	2100		3700	55	30	25	83	67	103	21	0.65	3.7	12	0.2
	41000		19000	160	85	71	238	90	267	60	1.5	13	15	0.5
	47000		2800	42	9	33	57	36	73	16	0.49	1.4	6	0.1
	90000		26000	55	25	30	93	105	101	21	0.67	4.6	14	0.3
	170000		51000	45	12	33	69	104	86	17	0.54	1.7	7	0.1
	160000		140000	55	3	52	83	138	93	21	0.74	1.6	5	0.1
K	53000		54000	100	62	41	167	42	185	39	1.3	9.5	16	0.4
K	3200000		840000			64								
	120000		100000	82	12	70	167	136	184	31	1.2	21	34	1
	34000		16000	47	9	38	87	44	94	18	0.61	6.7	22	0.4
K	860000		20000	50	6	44	93	104	92	19	0.63	5.5	18	0.3
K	620000		310000	63	35	28	103	60	125	24	0.8	5.2	14	0.3
	250000	K	180000	140			198	17	229	53	1.7	8.4	11	0.3
	248311.54		79213.57	107.04	60.18	56.11	227.78	100.37	240.70	34.74	4.80	29.00	29.63	1.07
	26.00		28.00	27.00	22.00	27.00	27.00	27.00	27.00	27.00	27.00	27.00	27.00	27.00

K	HCO3	CO3	SO4	Cl	F	Si	NO2	NO2+NO3	N-NH3	TKN	TP	DP		99897		As		Be
MG/L	MG/L	MG/L	MG/L	MG/L	MG/L	MG/L	MG/L	MG/L	MG/L	MG/L	MG/L	MG/L				UG/L		UG/L
1.3			23	24				0.42		0.6	0.06	0.04	<	10		2	<	10
2.1			20	13				0.35		0.7	0.12	0.1	<	10		2	<	10
3.9			24	62				1.1		0.9	0.08	0.08	<	10		4	<	10
2.3			17	35	0.6	4		0.72		1.1	0.14	0.09	<	10		6	<	10
2.4			35	37				0.88		0.6	0.08	0.06	<	20		2	<	10
1.6			14	13				0.6		1	0.15	0.06	<	10		2	<	10
1.7			26	33				0.42		0.4	0.06	0.02	<	20		1	<	10
2.6			170	36				0.31		3.2	0.53	0.05	<	10		4	<	10
4.4			420	11				1.3		2.9	0.25	0.05	<	10		2	<	10
3.4			200	3.6				0.16		1.8	0.11	0.01	<	10	<	1	<	10
5.7			370	23				0.49		1.8	0.2	0.03	<	10		2	<	10
2.8			260	6.6				0.32		2.1	0.43	0.02	<	10		5	<	10
3.1			350	10				0.4		1.2	0.09	0.02	<	10	<	1	<	10
3.4			110	5.2				0.83		3.6	0.56	0.21	<	10		3	<	10
4.6			27	3.3				0.43		1.2	0.31	0.22	<	10		1	<	10
2.6			17	3.7				0.88		1	0.38	0.32	<	10		3	<	10
3.5			100	7.6				1.3		1.3	0.25	0.2	<	10		2	<	10
2.5			9.5	1.4				0.66		0.9	0.44	0.38	<	20		2	<	10
3.4			25	3.3				1.4		1.2	0.36	0.27	<	10		1	<	10
2.5			11	1.7				1.1		1.2	0.41	0.3	<	10		3	<	10
4			9.7	2.9				0.6		1.2	0.68	0.53	<	20		3	<	10
5.4			57	10				1.4		2.4	0.26	0.15	<	10		2	<	10
								0.75		1.3	0.17	0.16	<	10		1	<	10
6			28	24				0.72		1.4	0.42	0.25	<	10		3	<	10
3			18	6.4				0.52		1.3	0.19	0.12	<	10		2	<	10
2.9			18	4				0.38		1.2	0.22	0.08	<	10		2	<	10
4.5			37	4.4				0.8		1.4	0.18	0.18	<	10		1	<	10
4.3			80	5.7				1.7		1.8	0.16	0.14	<	10		1	<	10
3.33			26.00	14.47	0.60	4.00		0.75		1.45	0.26	0.15				2.29		
27.00			27.00	27.00	1.00	1.00		28.00		28.00	28.00	28.00				28.00		

	Cd	Cr	Cu		99896		CN	Pb		Hg	Ni		Se		Ag		Ag EPA		Th	Zn	TOC		O&G		Phenols
	UG/L	UG/L	UG/L				(MG/L AS CN)	UG/L		UG/L	UG/L		UG/L		UG/L		UG/L		UG/L	UG/L	MG/L		MG/L		UG/L
<	1	4	7	<	0.01	<	0.01	8	<	0.1	3	<	1	<	1	<	0.05	<	20	60	11	<	1	<	1
<	1	3	6	<	0.01	<	0.01	7	<	0.1	3	<	1	<	1	<	0.05	<	20	60	12			<	1
<	1	3	4	<	0.01	<	0.01	4	<	0.1	3	<	1	<	1	<	0.05	<	10	30	18	<	1		4
<	1	5	6	<	0.01	<	0.01	11	<	0.1	4	<	1	<	1	<	0.05	<	10	80	20	<	1	<	1
<	1	4	4	<	0.01	<	0.01	5	<	0.1	2	<	1	<	1	<	0.05	<	10	40	12	<	1		3
	5	14	17	<	0.01	<	0.01	14	<	0.1	44	<	1	<	1	<	0.05	<	10	60	14	<	1		2
<	1	2	3	<	0.01	<	0.01	3	<	0.1	1	<	1	<	1	<	0.05	<	5	30	7.9	<	1	<	1
<	1	18	20	<	0.01	<	0.01	120	<	0.1	47	<	1	<	1	<	0.05	<	10	260	31	<	1		10
<	1	5	13	<	0.01	<	0.01	35	<	0.1	21		1	<	1	<	0.05	<	5	190	38	<	1		3
<	1	3	6	<	0.01	<	0.01	10	<	0.1	5	<	1	<	1	<	0.05	<	5	40	16	<	1		5
<	1	3	9	<	0.01	<	0.01	32	<	0.1	11	<	1	<	1	<	0.05	<	10	110	25		6		10
<	1	12	19	<	0.01	<	0.01	90	<	0.1	26	<	1	<	1	<	0.05	<	20	200	29	<	1		1
<	1	3	7	<	0.01	<	0.01	12	<	0.1	8	<	1	<	1	<	0.05	<	5	80	18		1		2
<	1	9	11	<	0.01	<	0.01	140	<	0.1	32	<	1	<	1	<	0.05	<	5	210	42	<	1		14
<	1	2	10	<	0.01	<	0.01	8	<	0.1	3	<	1	<	1		0.74	<	5	30	19	<	1		5
<	1	3	11	<	0.01	<	0.01	15	<	0.1	4	<	1	<	1	<	0.05	<	5	40	18		2		7
<	1	3	12	<	0.01	<	0.01	11	<	0.1	4	<	1	<	1	<	0.05	<	5	50	24	<	1		4
<	1	2	7	<	0.01	<	0.01	8	<	0.1	3	<	1	<	1	<	0.05	<	10	20	13	<	1	<	1
<	1	3	10	<	0.01	<	0.01	11	<	0.1	5	<	1	<	1	<	0.05	<	5	50	18	<	1		4
<	1	3	8	<	0.01	<	0.01	21	<	0.1	5	<	1	<	1	<	0.05	<	5	50	20		2		3
<	1	7	7	<	0.01	<	0.01	27	<	0.1	7	<	1	<	1	<	0.05	<	5	60	21	<	1		3
<	1	4	16	<	0.01	<	0.01	13	<	0.1	4	<	1	<	1		0.71	<	10	100	24		4		12
<	1	3	23	<	0.01		0.01	6	<	0.1	3	<	1	<	1	<	0.05	<	10	50	20	<	1		16
	1	4	20	<	0.01	<	0.01	26	<	0.1	7	<	1	<	1	<	0.05	<	10	240	25	<	1		4
<	1	3	13	<	0.01	<	0.01	11	<	0.1	3	<	1	<	1	<	0.05	<	5	80	13		1		12
<	1	5	17	<	0.01	<	0.01	22	<	0.1	5	<	1	<	1	<	0.05	<	5	120	16		2		2
<	1	3	14		0.01	<	0.01	9	<	0.1	4	<	1	<	1	<	0.05	<	10	80	23		1		8
<	1	5	17	<	0.01	<	0.01	10	<	0.1	4	<	1	<	1	<	0.5	<	5	120	24	<	1		9
	1.14	4.93			0.01		0.01	24.61			9.68		1.00				0.11			90.71	20.43		1.41		5.29
	28.00	28.00			28.00		28.00	28.00			28.00		28.00				28.00			28.00	28.00		27.00		28.00