Stormwater and Urban Water Systems Modeling. In: *Models and Applications to Urban Water Systems*, Vol. 12 (edited by W. James). CHI. Guelph, Ontario, pp. 317 – 338. 2004.

Nonparametric Statistical Tests Comparing First Flush and Composite Samples from the National Stormwater Quality Database

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Abstract
The University of Alabama and the Center of Watershed Protection, as part of an EPA 104(b)3 project, has collected and reviewed phase I NPDES (National Pollutant Discharge Elimination System) MS4 (Municipal Separate Storm Sewer System) stormwater data. The database contains more than 3700 event data sets from 66 municipalities in 17 States. In 1990, communities larger than 100,000 were required to monitor and control the pollutants that reach surface waters from stormwater runoff. Some communities collected grab samples during the first 30 minutes of the event to evaluate the "first flush" effect in contrast to the flow weighted composite samples.

There were 417 paired samples representing both first flush and composite samples from eight communities, mostly located in the southeast USA. Box and probability plots were prepared for 22 constituents including TSS, TDS, BOD5, COD among others. Nonparametric statistical analyses were used to measure differences between sample sets. This paper shows the results of this preliminary analysis, including the effects of storm size and changes in land use. First flush effect was not present in all the land uses, and certainty not for all constituents. More detailed analyses will be performed as additional data are received.

1. INTRODUCTION

The NPDES MS4 Stormwater was developed by EPA in response to the United States Congress to protect United States' receiving waters from contaminated stormwater discharges. In 1972, the Congress passed the Federal Water Pollution Control Act (CWA) expanding the federal role of water pollution control. Some of the effects of the CWA were to increase the federal funding for construction of publicly owned wastewater treatment works (POTW), and to develop community participation and a permit for each point discharge, among other activities. The National Pollutant Discharge Elimination System (NPDES) established effluent guidelines for point discharges that contaminate the nation's water.

The first stormwater regulation was issued in 1973 (38 FR 13530, May 22), but EPA believed that the traditional end-of-pipe controls used for process discharges and treatment works could not be used to control stormwater pollution. In addition, it would require a tremendous effort to issue NPDES permits for each of the stormwater sources in the United States. The initial stormwater regulations were developed for large municipalities (>100,000 population) and for certain industrial categories. Current regulations associated with Phase II of the stormwater permit program now require stormwater management for all urban areas in the US.

The CWA of 1972 provided an important tool for communities. Section 208 provided the capability to implement stormwater management plans at the regional level. The task was welcomed by planning offices, which in some cases received advice from the U.S. Army Corps of Engineers. In 1976, EPA enlarged the planning initiative through the "Section 208: Areawide Assessment Procedures Manual". However, in the late 1970s, some problems arose with the 208 planning projects due to inadequate data and lack of technological development (Whipple, 1980, cited by Pitt et al, 1999).

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Between 1978 and 1983, EPA conducted the National Urban Runoff Program (NURP) that sought to determine water quality from separate storm sewers for different land uses. This program studied 81 outfalls at 28 sites, monitoring approximately 2300 storm events (EPA, 1983).

NURP is still an important reference for water quality characteristics of urban stormwater; however, there are other important studies that characterize stormwater pollutant generation. The USGS created a database with more than 1100 storms at 98 sites in 20 metropolitan areas as part of their monitoring for phase I communities (Smullen and Cave, 2003)

In 1987, the amendments to the CWA established a two-phase program to regulate 13 classes of stormwater discharges. Two of these classifications were discharges from large and medium Municipal Separate Storm Sewer Systems (MS4s). A large MS4 serves an urban population of 250,000 or more, while a medium MS4 serves communities between 100,000 and 250,000. EPA set up a permit strategy for communities complying with NPDES requirements. Monitoring data from this program have been included in some databases. The CDM National Stormwater Quality database included 816 NPDES storm events in a database that includes approximately 3100 total events. The Rouge River National Wet Weather Demonstration Program office in Detroit included their NPDES data in their database (Smullen and Cave, 2003). Recently EPA granted the University of Alabama and the Center of Watershed Protection funding to collect and evaluate NPDES MS4 municipal stormwater permits. By the end of 2002 this project had collected 3757 storm events from 66 agencies and municipalities in 17 states. This database (National Stormwater Quality Database, NSQD) includes geographic and seasonal information that can be useful for various analyses (Pitt et al, 2003).

Sample collection during some of the NPDES MS4 phase I permits required a grab and a composite sample. A grab sample was taken during the first 30 minutes of discharge, and a flow-weighted composite sample for the entire time of discharge. The initial grab sample was used for the analysis of the “first flush effect,” assuming that most of the pollutants are discharged during the first period of runoff. The composite sample was obtained with aliquots collected about every 15 to 20 minutes for at least 3 hours, or until the event ended.

2. FIRST FLUSH

First flush refers to an assumed elevated load of pollutants discharged in the beginning of a runoff event. The first flush effect has been observed more often in small catchments than in large catchments (Thompson et al, 1995, cited by WEF and ASCE 1998). In one case, large catchments (>162 Ha, 400 acres) had the highest concentrations observed at the times of flow peak (Soeur, et al. 1994; Brown et al. 1995). The presence of a first flush also has been reported to be associated with runoff duration by the City of Austin, TX (reported by Swietlik et al., 1995). Peak pollutant concentrations can occur after the peak discharge, thus some pollutant discharges can be significant for events longer than the time of concentration (Ellis, 1986). Adams and Papa (2000), and Deletic (1998) both concluded that the presence of a first flush depends on numerous site and rainfall characteristics.

In this paper, pollutant characteristics are evaluated using the NSQD database for events that include information during the first 30 minutes and the composite sample, using nonparametric statistical methods. A better analysis can be performed by using the M(V) curves that relate the total mass discharge as a function of the total runoff volume; however, this procedure requires high resolution flow and concentration information. The NSQD database only contains concentration data from composite samples (and selected first-flush samples) and few flow data.

3. METHODOLOGY

A total of 417 storm events with paired first flush and composite samples were available from the NPDES MS4 database. The majority of the events were located in North Carolina (76.2%), but some events were also from Alabama (3.1%), Kentucky (13.9%) and Kansas (6.7%). Table 1 shows the events available for this analysis, separated by land use and community. All the events correspond to end-of the pipe samples in separate storm drainage systems.

Table 1. Preliminary number of storm events selected.

State	Community	CO	FW	ID	IS	OP	RE	Total Events	%
AL	**Jefferson County**	5	2	0	0	0	6	13	3.1
NC	**City of Charlotte**	8	0	8	0	3	16	35	8.4
NC	**City of Fayeteville**	18	0	18	18	6	46	106	25.4
NC	**City of Greensboro**	33	0	33	0	15	33	114	27.3
KY	**City of Lexington**	12	3	2	0	2	18	37	8.9
KY	**City of Louisville**	0	0	7	0	0	14	21	5.0
NC	**City of Raleigh**	18	0	18	0	9	18	63	15.1
KA	**City of Wichita**	7	0	7	0	0	14	28	6.7
Total Events		101	5	93	18	35	165	417	
%		24.2	1.2	22.3	4.3	8.4	39.6		100

Note: CO (commercial), FW (freeway), ID (industrial), IS (institutional), OP (Open Space) and RE (residential) land uses

The initial analyses were used to select the constituents and land uses that meet the requirements of the statistical comparison tests. Probability plots, box plots, concentration vs. precipitation and standard descriptive statistic calculations, were performed for 22 constituents for each land use, and all land uses combined. Nonparametric statistical analyses were performed after the initial analyses. Mann Whitney and Fligner-Policello test were most commonly used. Minitab and Systat statistical programs, along with Word and Excel macros, were used during the analysis.

3.1. Initial Analysis

One of the conclusions of the NURP program was that most of the constituents in stormwater generally follow a log-normal distribution, especially between the 5th and 95th percentiles (EPA, 1983). This characteristic was validated using probability plots during the initial analyses. Results from first flush and composite samples were log-transformed, for different pollutant types, in each land use category.

Figure 1 shows initial statistical results for both phosphorus and COD. Elevated first flush concentrations were evident for COD compared to phosphorus. Probability plots provide useful information about the characteristics of the sample population. Figure 1 is an example for total phosphorus observations from the open space land use. Both sample sets follow a log-normal distribution because most of the points lie on a straight line. The slopes of the lines are different, indicating unequal variances. Different methods having different detection limits were used by the different communities. In this case, about 40% of the first flush samples did not have detected concentrations for phosphorus, while about 20% of the composite samples had non-detected phosphorous concentrations. This plot also indicated that the median concentration of the composite samples is almost twice the median value for the first flush samples.

The next initial analysis used box plots. These plots also represent the distribution of the data, but only show the detectable concentrations. The middle line inside the box represents the median of the data. The top of the box represents the third quartile, and the bottom the first quartile. The whiskers are extended from the 5th to the 95th percentile limits. Values outside these limits are represented with asterisks. The exclusion of the non detected values changes the median of the data compared to the probability plots. In this example, both of the medians are similar, in contrast with the results of the probability plot. In this example, the variability of the first flush observations is also seen to be larger than the composite data set.

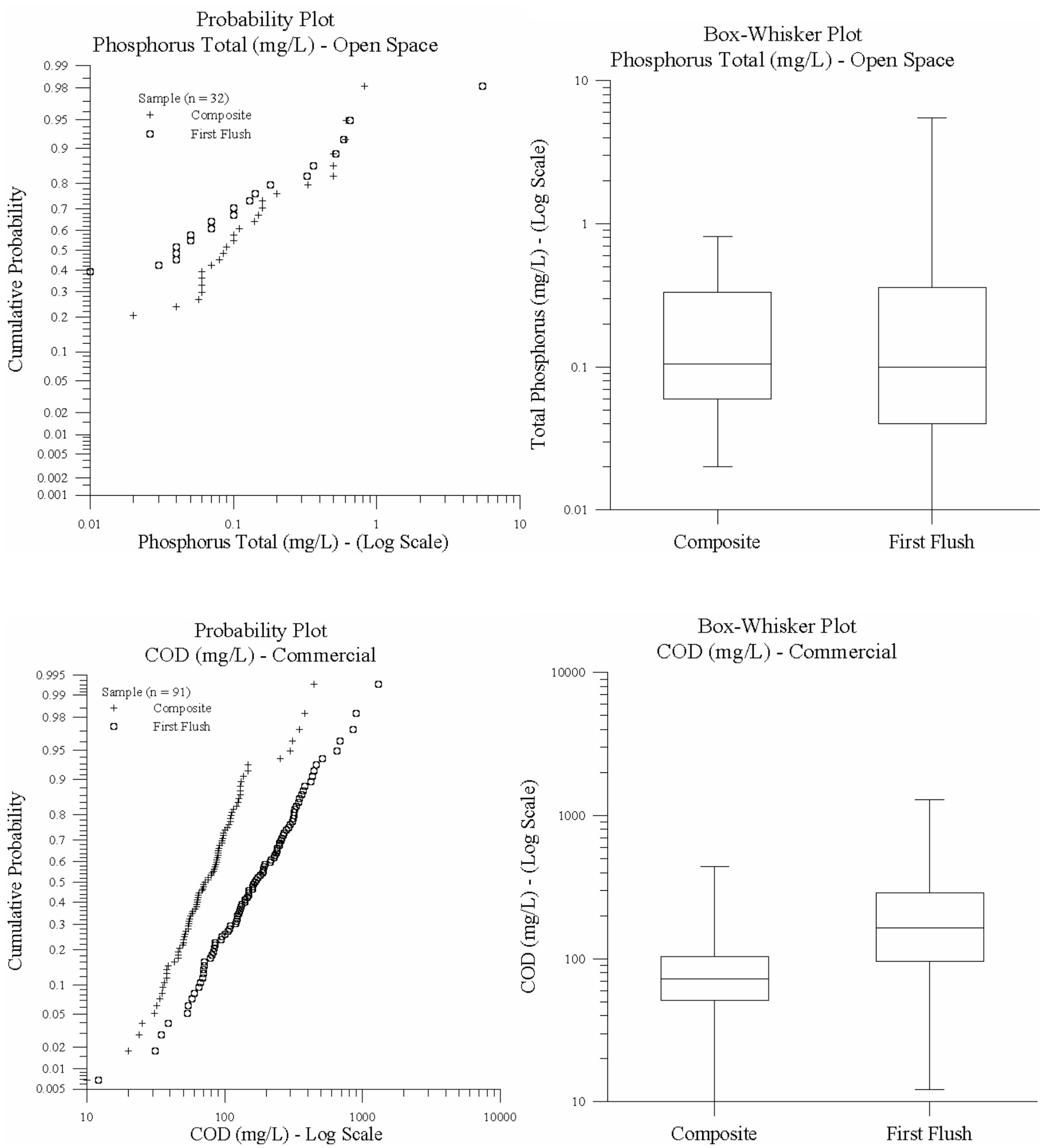

Figure 1. Cumulative Probability and Box-Whisker Plots

Descriptive statistics for each constituent and land use were calculated to determine if the distributions were symmetrical and if they had the same variance (see appendix). This evaluation is needed to select the most appropriate statistical tests. In some conditions, the number of sample pairs was not large enough to allow further analyses. Table 2 shows the results of the initial analysis. Samples having log-normal probability distributions and sufficient data sets were selected for further analyses.

3.2. Nonparametric Statistical Analysis

The last step in the initial analysis was to obtain descriptive statistics of each land use and constituent. The skewness and the standard error of skewness are important for some statistical analyses. A distribution is symmetrical if the skewness divided by the standard error of skewness is smaller than two (Systat, 1997). Another method is to check if the zero value is included in the 95% confidence interval for the skewness. If zero is included the distribution is not skewed.

The Mann-Whitney and Fligner-Policello nonparametric tests were selected to determine if there were statistically significant differences between the first flush and composite data sets for each landuse and constituent. These tests require only data symmetry, or normality, to evaluate the hypothesis. The null hypothesis in the analysis is that the median concentrations of the first flush and composite data sets were the same. The alternative hypothesis is that the medians are different (the first-flush sample median concentrations could be either greater or smaller that the composite sample median concentrations), with a confidence of at least 95%.

Table 2. Initial Analysis.

Constituent	Commercial	Industrial	Institutional	Open Space	Residential	ALL
Turbidity, NTU	Selected	No data	No data	Ned	Selected	Selected
pH, S.U.	Selected	Selected	No data	Ned	Selected	Selected
BOD5, mg/L	Selected	Selected	Box plot FF > Composite	Selected	Selected	Selected
COD, mg/L	Selected	Selected	Selected	Selected	Selected	Selected
TSS, mg/L	Selected	Selected	Selected	Selected	Selected	Selected
TDS, mg/L	Selected	Selected	Selected	Selected	Selected	Selected
O&G, mg/L	Selected	Ned	Ned	Ned	Selected	Selected
Fecal Coliform, col/100mL	Selected	Ned	Ned	Ned	Selected	Selected
Fecal Streptococcus, col/100 mL	Selected	Ned	Ned	Ned	Selected	Selected
Ammonia, mg/L	Selected	Selected	Box plot FF > composite	Ned	Selected	Selected
$NO_2 + NO_3$, mg/L	Selected	Selected	Selected	Selected	Selected	Selected
N Total, mg/L	Selected	Selected	Ned	Selected	Selected	Selected
TKN, mg/L	Selected	Selected	Box plot FF > composite	Selected	Selected	Selected
P Total, mg/L	Selected	Selected	Selected	Selected	Selected	Selected
P Dissolved, mg/L	Selected	Selected	Selected	Selected	Selected	Selected
Ortho-P, mg/L	Ned	Selected	Ned	Ned	Selected	Selected
Cadmium Total, ug/L	Selected	Selected	Ned	Selected	Selected	Selected
Chromium Total, ug/L	Selected	Selected	Ned	Selected	Selected	Selected
Copper Total, ug/L	Selected	Selected	Selected	Selected	Selected	Selected
Lead Total, ug/L	Selected	Selected	Selected	Selected	Selected	Selected
Mercury, ug/L	Ned	Ned	Ned	Ned	Ned	Ned
Nickel, ug/L	Selected	Selected	Ned	Ned	Selected	Selected
Zinc, ug/L	Selected	Selected	Selected	Selected	Selected	Selected

* Ned: Not enough data

Figure 2 shows the steps that were followed during the nonparametric analysis. The most useful test was the Fligner-Policello test. This test requires independent random samples symmetric about the medians for each data set. The advantage of this test is that does not require normality or the same variance in each data set (Fligner and Policello, 1981). The U statistic and the p-value are shown in the attached appendix for some constituents. Chakraborti (2003) presents a definition and explanation of the Mann-Whitney U test. All calculations are included in the extended version posted in the http://www.bama.ua.edu/~maest001/Research/NSQD/NSQDmain.shtml. P-values smaller than five percent (<0.05) indicate that the first flush and composite sample sets have different median concentrations at the 95 percent, or greater, confidence level.

If the number of samples is large, and the distributions are normal and have the same variance, a paired Student's *t*-test is usually a better test to evaluate the hypothesis and support the results of the Fligner-Policello test. To verify that the data distributions are normal, the Anderson-Darling normality test was used (Kottegoda and Rosso, 1997). This method uses an empirical cumulative distribution function to check normality. In the attached appendix, the p-value of the paired difference is shown. P-values larger than five percent (>0.05) indicate that the normality requirement was met, at the 95 percent or greater confidence level.

Finally, if the first flush and composite sample distributions are symmetrical (but not necessarily normal), and if they have the same variance, the Mann-Whitney test can be used. If the p-value is larger than five percent (>0.05), the medians of the sample distribution are assumed to be the same, at the 95 percent or greater confidence level. Results are shown in the attached appendix.

The preferred test would be the Student's *t* test, if the sample characteristics warrant, followed by the Mann-Whitney test and finally the Fligner-Policello test.

The appendix also shows the number of paired samples for each constituent and land use. The selected cases are only for pairs with concentration values above the detection limits. The ratios between the first flush and composite sample medians are also shown. Commercial and residential areas have the highest ratios for most constituents. The smallest ratios were found for open space sites.

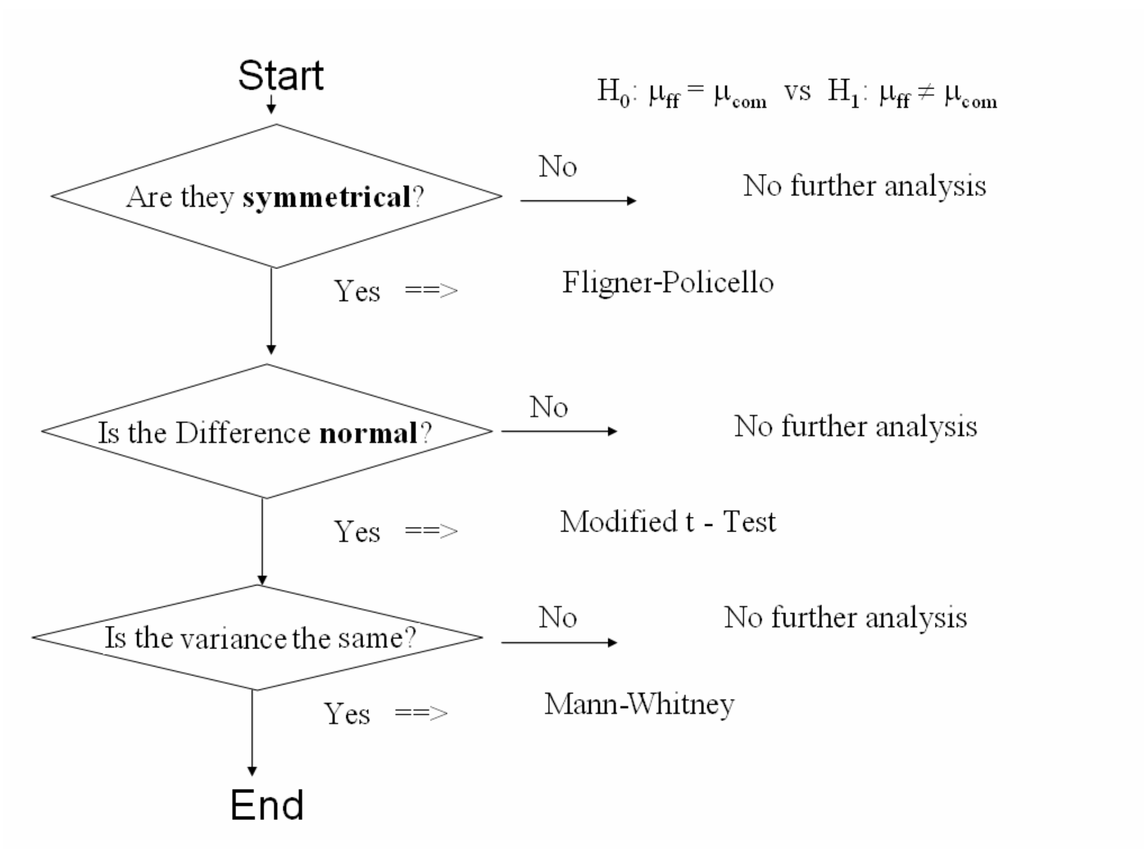

Figure 2. Analysis Flow Chart

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4. RESULTS

Around 83% of the possible paired cases were successfully evaluated; the remaining cannot be evaluated because the data set did not have enough paired data, or were not symmetrical. Table 3 shows the results of the analysis. The "≠" sign indicates that the medians of the first flush and the composite data set are different. The "=" sign indicates that there is not enough information to reject the null hypothesis at the desired level of confidence (at least at the 95 percent level). Events without enough data are represented with an "X".

Table 3. Presence of Significant First Flushes (ratio of first flush to composite median concentrations)

Parameter	Commercial				Industrial				Institutional			
	n	sc	R	ratio	n	sc	R	ratio	n	sc	R	ratio
Turbidity, NTU	11	11	=	1.32			X				X	
pH, S.U.	17	17	=	1.03	16	16	=	1.00			X	
COD, mg/L	91	91	≠	2.29	84	84	≠	1.43	18	18	≠	2.73
TSS, mg/L	90	90	≠	1.85	83	83	=	0.97	18	18	≠	2.12
BOD5, mg/L	83	83	≠	1.77	80	80	≠	1.58	18	18	≠	1.67
TDS, mg/L	82	82	≠	1.83	82	81	≠	1.32	18	18	≠	2.66
O&G, mg/L	10	10	≠	1.54			X				X	
Fecal Coliform, col/100mL	12	12	=	0.87			X				X	
Fecal Streptococcus, col/100 mL	12	11	=	1.05			X				X	
Ammonia, mg/L	70	52	≠	2.11	40	33	=	1.08	18	16	≠	1.66
$NO_2 + NO_3$, mg/L	84	82	≠	1.73	72	71	≠	1.31	18	18	≠	1.70
N Total, mg/L	19	19	=	1.35	19	16	=	1.79			X	
TKN, mg/L	93	86	≠	1.71	77	76	≠	1.35			X	
P Total, mg/L	89	77	≠	1.44	84	71	=	1.42	17	17	=	1.24
P Dissolved, mg/L	91	69	=	1.23	77	50	=	1.04	18	14	=	1.05
Ortho-P, mg/L			X		6	6	=	1.55			X	
Cadmium Total, ug/L	74	48	≠	2.15	80	41	=	1.00			X	
Chromium Total, ug/L	47	22	≠	1.67	54	25	=	1.36			X	
Copper Total, ug/L	92	82	≠	1.62	84	76	≠	1.24	18	7	=	0.94
Lead Total, ug/L	89	83	≠	1.65	84	71	≠	1.41	18	13	≠	2.28
Nickel, ug/L	47	23	≠	2.40	51	22	=	1.00			X	
Zinc, ug/L	90	90	≠	1.93	83	83	≠	1.54	18	18	≠	2.48

Parameter	Open Space				Residential				All Combined			
	n	sc	R	ratio	n	sc	R	ratio	n	sc	R	ratio
Turbidity, NTU			X		12	12	=	1.24	26	26	=	1.26
pH, S.U.			X		26	26	=	1.01	63	63	=	1.01
COD, mg/L	28	28	=	0.67	140	140	≠	1.63	363	363	≠	1.71
TSS, mg/L	32	32	=	0.95	144	144	≠	1.84	372	372	≠	1.60
BOD5, mg/L	28	28	=	1.07	133	133	≠	1.67	344	344	≠	1.67
TDS, mg/L	31	30	=	1.07	137	133	≠	1.52	354	342	≠	1.55
O&G, mg/L			X				X		18	14	≠	1.60
Fecal Coliform, col/100mL			X		10	9	=	0.98	22	21	=	1.21
Fecal Streptococcus, col/100 mL			X		11	8	=	1.30	26	22	=	1.11
Ammonia, mg/L			X		119	86	≠	1.36	269	190	≠	1.54
$NO_2 + NO_3$, mg/L	30	21	=	0.96	121	118	≠	1.66	324	310	≠	1.50
N Total, mg/L	6	6	=	1.53	31	30	=	0.88	77	73	=	1.22
TKN, mg/L	32	14	=	1.28	131	123	≠	1.65	335	301	≠	1.60
P Total, mg/L	32	20	=	1.05	140	128	≠	1.46	363	313	≠	1.45
P Dissolved, mg/L	32	14	=	0.69	130	105	≠	1.24	350	254	=	1.07
Ortho-P, mg/L			X		14	14	=	0.95	22	22	=	1.30
Cadmium Total, ug/L	30	15	=	1.30	123	33	≠	2.00	325	139	≠	1.62
Chromium Total, ug/L	16	4	=	1.70	86	31	=	1.24	218	82	≠	1.47
Copper Total, ug/L	30	22	=	0.78	144	108	≠	1.33	368	295	≠	1.33
Lead Total, ug/L	31	16	=	0.90	140	93	≠	1.48	364	278	≠	1.50
Nickel, ug/L			X		83	18	=	1.20	213	64	≠	1.50
Zinc, ug/L	21	21	=	1.25	136	136	≠	1.58	350	350	≠	1.59

Note: n = number of events. sc = number of selected events with detected values. R = result: not enough data (X); not enough evidence to conclude that median values are different (=); median values are different (≠).

Also shown on this table are the ratios of the medians of the first flush and the composite data sets for each constituent and land use. Generally, a statistically significant first flush is associated with a median concentration ratio of about 1.4, or greater (the exceptions are where the number of samples in a specific category is much smaller). The largest ratios are about 2.5, indicating that for these conditions, the first flush sample concentrations are about 2.5 times greater than the composite sample concentrations. More of the larger ratios are found for the commercial and institutional land use categories, areas where larger paved areas are likely to be found. The smallest ratios are associated with the residential, industrial, and open spaces land uses, locations where there may be larger areas of unpaved surfaces.

Results indicate that for 55% of the evaluated cases, the median of the first flush data set were different than the composite sample set. In the remaining 45% of the cases, both medians were likely the same, or the concentrations were possibly greater later in the events.

About 70% of the constituents in the commercial land use category had elevated first-flush concentrations, while about 60% of the constituents in the residential, institutional and the mixed (mostly commercial and residential) land use categories had elevated first flushes, and about 45% of the constituents in the industrial land use category had elevated first flushes. In contrast, no constituents were found to have elevated first-flushes in the open space category.

COD, BOD_5. TDS, TKN and Zn all had first flushes in all areas (except for the open space category). In contrast, turbidity, pH, fecal coliform, fecal streptococcus, total N, dissolved and ortho-P never showed a statistically significant first flush in any category. The conflict with TKN and total N implies that there may be other factors involved in the identification of first flushes besides land use. If additional paired data becomes available during later project periods, it may be possible to extend this analysis to consider rain effects, drainage area, and geographical location.

5. DISCUSSION

It is expected that peak concentrations generally occur during periods of peak flows (and highest rain energy). On relatively small paved areas, however, it is likely that there will always be a short initial period of relatively high concentrations associated with washing off of the most available material (Pitt, 1987). This peak period of high concentrations may be overwhelmed by periods of high rain intensity that may occur later in the event. In addition, in more complex drainage areas, the routing of these short periods of peak concentrations may blend with larger flows and may not be noticeable. A first flush in a separate storm drainage system is therefore most likely to be seen if a rain occurs at relatively constant intensity over a paved area having a simple drainage system.

If the peak flow (and highest rain energy) occurs later in the event, then there likely will not be a noticeable first flush. However, if the rain intensity peak occurs at the beginning of the event, then the effect is exaggerated. Figure 3 shows an example storm in Lexington, KY. Note that in this event there are two flow peaks, the first occurs one hour after the rain started, the second two hours later. If the concentrations remains the same during the entire event, the maximum load will occur during the later periods of maximum flow (the two peaks), and not during the initial period of the storm.

Another factor that needs to be considered is the source of the contaminants and how fast they travel through the watershed. Streets and pervious areas will contribute flow to the total area discharge before the pervious areas.

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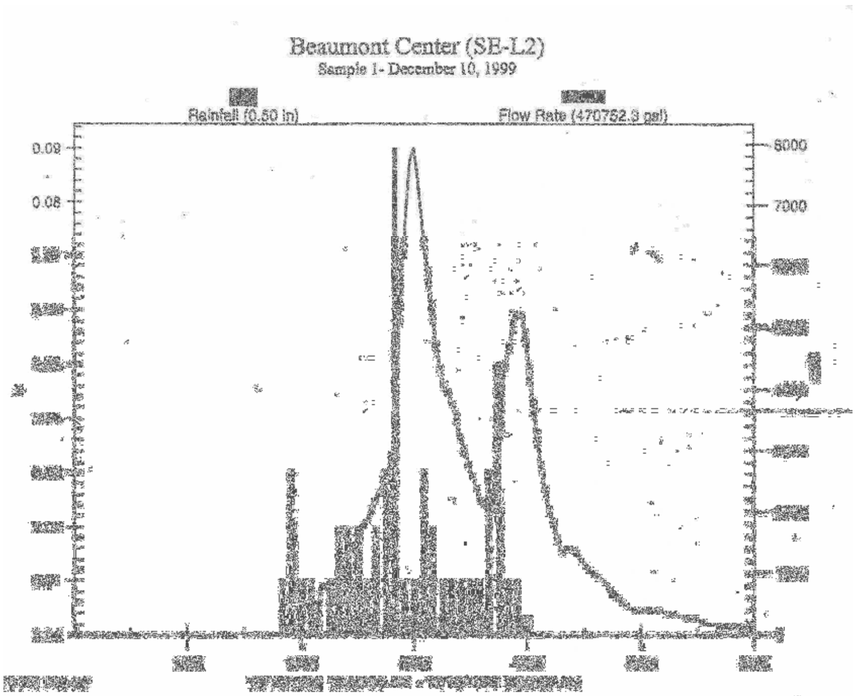


Figure 3. Hydrograph for a storm event. (Source: NPDES permit Lexington–KY 2000). (1 in = 25.4 mm, 1 m^3 = 264.17 gal)

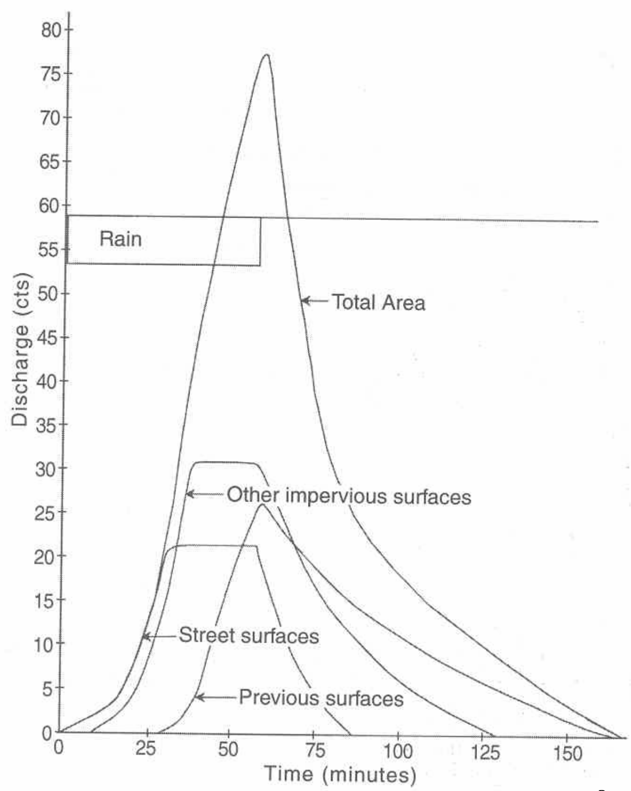


Figure 4. Contributing areas in urban watersheds (Pitt, 1999) (1 m^3/s = 35.32 cfs)

Figure 4 (Pitt, 1999) shows that for an example constant rainfall, the source area flow contribution changes for different rain conditions in a residential area. If the percentage of imperviousness is high, many of the constituents will be discharged faster. This observation agrees with the results observed from the statistical analysis. Commercial areas have a larger frequency of high concentrations at the beginning of the event in contrast to open space areas.

Figure 5 shows that for events (< 12mm, or 0.5 in) in this example medium density residential area, most of the runoff is generated by impervious areas. The average percentage of imperviousness for the monitoring sites was examined. Commercial areas had an average of 83% imperviousness, followed by industrial areas at 70% imperviousness. Institutional and residential land uses were very similar, with 45% and 42% imperviousness respectively. The open space land use category had the smallest imperviousness area, at about 4%. As indicated in Figure 5, larger events can generate more runoff from previous areas than impervious areas. However, it is likely that most of the runoff during the MS4 monitoring activities was associated with the more common small events, and hence, impervious areas were more important.

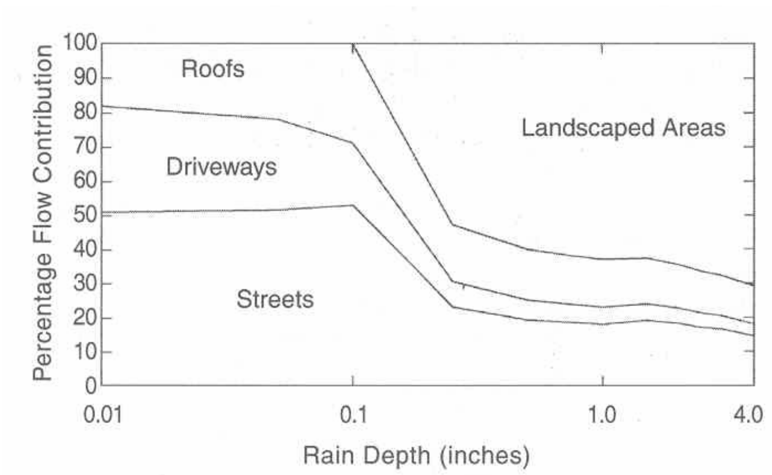
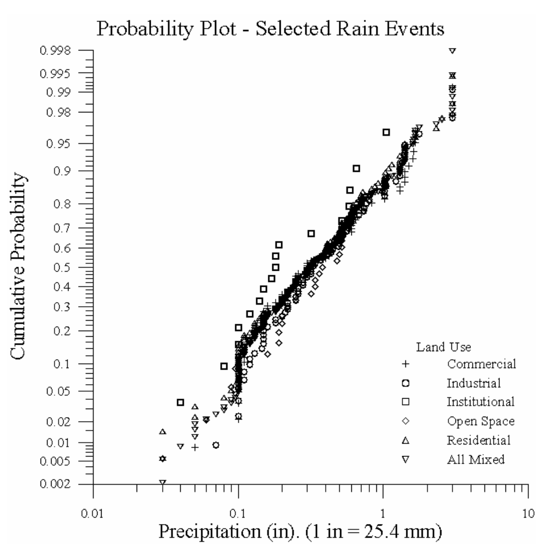


Figure 5. Contributing areas in urban watersheds (Pitt and Voorhees, 1995). (1 in = 25.4 mm)

Probability plots of the precipitation associated with each monitored event for each land use category were prepared to see if there were any significant differences in the ranges of rains observed within each land use category.



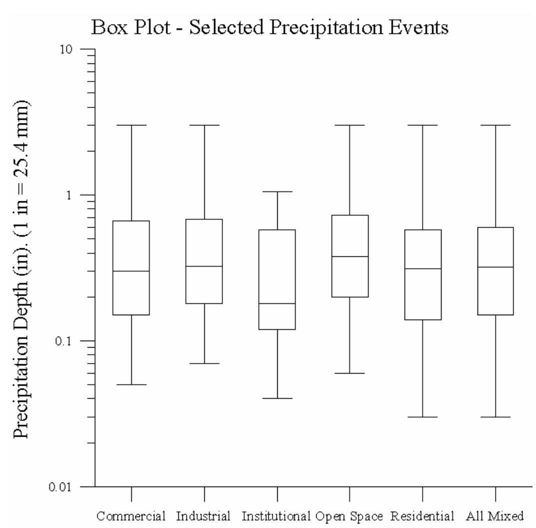


Figure 6. Probability and box plot of selected rain events.

Figure 6 shows that precipitation has the same distribution for almost all the different land uses. The institutional land use shows a slightly smaller median rain, but this is likely because of the small number of events observed in that land use category (18 events). The median precipitation observed during the monitoring at all land uses was about 8 mm (0.3 in), indicating the importance of the runoff from the impervious areas.

Finally another factor that must be considered is the effect of the sampling duration. One of the recommendations during Phase I was to collect a sample during the first 30 minutes of the event, but that the composite only needed to be collected during the first 3 hours or the complete event. Figure 8 shows an example case when these conditions can lead to inappropriate conclusions for longer events.

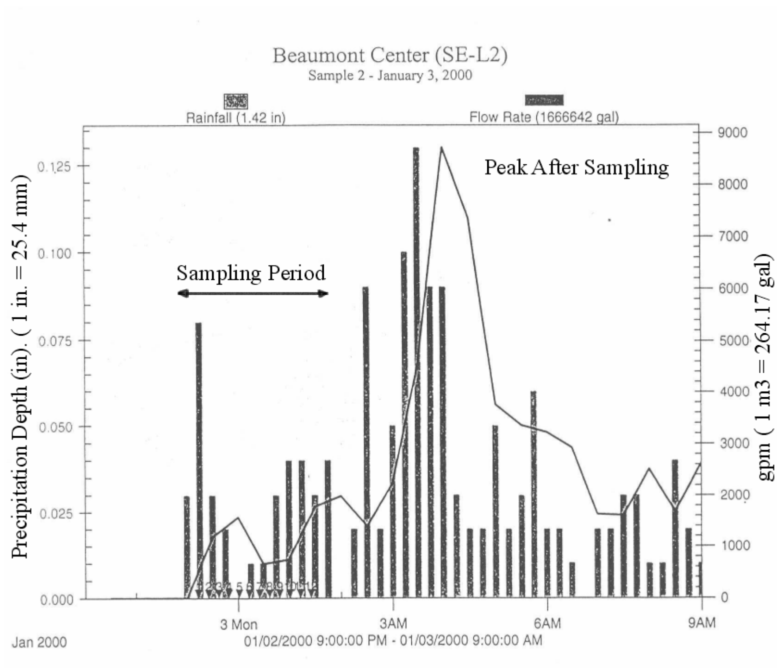


Figure 7. Example of an event with peaks after the sampling period.
(Source: NPDES permit Lexington-KY, 2000)

The 12 aliquots sampled during the first three hours are shown on the left side of Figure 7. On the right side of the figure, showing the complete event, the peak discharge occurred four hours after the event started, and was not represented in the sampling program. Not including the complete event in a monitoring program may lead to inappropriate conclusions. It is suggested that for stormwater monitoring, samples should be collected during the complete event and composited before laboratory analyses.

Another sampling example was presented by Roa-Espinosa and Bannerman (1995) who collected samples from five industrial sites using five different monitoring methods. Table 4 shows the ranking of the best methods of sampling based in six criteria. In this table a value between one and five points is assigned to each criterion. Five points indicates that the method is excellent in the specific criterion. Rao-Espinosa and Bannerman concluded that many time-composite subsamples combined for a single composite analysis can provide improved accuracy compared to fewer samples associated with flow-weighted sampling. They also found that time composite subsamples provide better results than samples collected during the first 30 minutes of the event.

Table 4. Ranking by methods of sampling (Roa-Espinosa, Bannerman, 1995)

Criteria	Flow Composite	Time Discrete	Time Composite	Old Source Sample	New Source Sample	First 30 Minutes
Site Selection	1	1	1	5	5	3
Cost	1	1	3	5	5	5
Technical difficulty	1	1	3	5	5	5
Accuracy	5	5	4	1	5	1
Reproducibility	5	5	5	1	5	1
Representativeness	1	1	3	5	5	1
TOTAL POINTS	14	14	19	22	30	16

6. CONCLUSION

A major goal of the present study is to provide guidance to stormwater managers and regulators. Especially important will be the use of this data as an updated benchmark for comparison with locally collected data. In addition, this data may be useful for preliminary calculations when using the "simple method" for predicting mass discharges for unmonitored areas. These data can also be used as guidance when designing local stormwater monitoring programs (Burton and Pitt, 2002), especially when determining the needed sampling effort based on expected variations. Continuing studies will expand on these preliminary examples and will also investigate other stormwater data and sampling issues.

The example investigation of first flush conditions indicated that a first flush effect (increased concentrations at the beginning of an event) was not present in all the land uses, and certainly not for all constituents. Commercial and residential areas were more likely to show this phenomenon, especially if the peak rainfall occurred near the beginning of the event. It is expected that this effect will be more likely to occur in a watershed with a high level of imperviousness, but the data indicated first flushes less than 50% of the time for the most impervious areas.

Groups of constituents showed different behavior for different land uses. All the heavy metals evaluated showed higher concentrations at the beginning of the event in the commercial land use category. Similarly all the nutrients show a higher concentration in the residential land use except for total nitrogen and ortho-P. This phenomenon was not found in the bacteria analyses. None of the land uses showed a higher number of colonies during the beginning of the event. Conventional constituents showed elevated concentrations in commercial, residential and institutional land uses.

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9. APPENDIX

Following tables show the results of the preliminary statistical analysis for each of the 22 constituents analyzed. A complete table is located at:
http://www.bama.ua.edu/~maest001/Research/NSQD/NSQDmain.shtml

Turbidity (NTU)	Total Events	Selected Cases	Median	Median (Log)	Var (Log)	Skew (Log)	SE Skew (Log)	Test Norm. (Log) p-value	Median Ratio
Commercial Composite	11	11	19.68	1.294	0.062	-0.984	0.661	0.186	1.32
Commercial First Flush	11	11	26.00	1.415	0.078	0.523	0.661	0.564	
Residential Composite	12	12	23.44	1.370	0.163	0.213	0.637	0.721	1.24
Residential First Flush	12	12	28.97	1.462	0.148	1.407	0.637	0.168	
All Landuses Composite	26	26	21.73	1.337	0.109	0.204	0.456	0.406	1.26
All Landuses First Flush	26	26	27.48	1.439	0.105	1.197	0.456	0.108	

Turbidity	Mann Wittn. p-value	Fligner Policello	Normality for t-test p-value	Paired t – test	Result
Commercial	0.224	U = 1.26 ; P > 0.1	0.652	0.219	Same (no first flush)
Residential	0.418	U = 0.853 ; P > 0.1	0.240	0.021	Same
All Landuses	0.124	U = 0.673 ; P = 0.25	0.134	0	Same

pH	Total Events	Selected Cases	Median	Var	Skew	SE Skew	Test Norm. p-value	Median Ratio
Commercial Composite	17	17	7.4	0.368	-0.299	0.550	0.527	1.03
Commercial First Flush	17	17	7.6	0.509	0.788	0.550	0.351	
Industrial Composite	16	16	6.755	0.194	0.482	0.564	0.179	1.00
Industrial First Flush	16	16	6.750	0.388	-0.854	0.564	0.307	
Residential Composite	26	26	7.213	0.195	-0.520	0.456	0.447	1.01
Residential First Flush	26	26	7.250	0.212	-0.283	0.456	0.408	
All Composite	63	63	7.2	0.302	0.102	0.302	0.562	1.01
All First Flush	63	63	7.3	0.437	0.036	0.302	0.110	

pH	Mann Wittn. p-value	Fligner Policello	Normality for t-test p-value	Paired t – test	Result
Commercial	0.208	U = 1.28 ; P = 0.10	0.007	N/A	Same
Industrial	N/A	U = 0.428 ; P = 0.33	0.341	0.828	Same
Residential	0.308	U = 1.32 ; P = 0.09	0	N/A	Same
All Landuses	0.219	U = 1.68 ; P = 0.05	0	N/A	Same

BOD_5 (mg/L)	Total Events	Selected Cases	Median	Median (Log)	Var (Log)	Skew (Log)	SE Skew (Log)	Test Norm. (Log) p-value	Median Ratio
Commercial Composite	83	83	15.21	1.182	0.125	0.263	0.264	0.513	1.77
Commercial First Flush	83	83	26.98	1.431	0.153	-0.241	0.264	0.390	
Industrial Composite	80	80	15.14	1.18	0.188	0.190	0.269	0.013	1.58
Industrial First Flush	80	80	23.99	1.38	0.180	-0.502	0.269	0.044	
Institutional Composite	18	18	7.48	0.874	0.151	-0.737	0.536	0.247	1.67
Institutional First Flush	18	18	12.47	1.096	0.173	-0.732	0.536	0.281	
Open Space Composite)	28	28	3.79	0.579	0.148	0.523	0.441	0.242	1.07
Open Space First Flush	28	28	4.05	0.607	0.197	0.449	0.441	0.077	
Residential Composite	133	133	12.59	1.100	0.154	0.314	0.210	0.137	1.67
Residential First Flush)	133	133	20.99	1.322	0.220	-0.150	0.210	0.010	
All Landuses Composite	344	344	12.53	1.098	0.184	0.073	0.131	0.003	1.67
All Landuses First Flush)	344	344	20.89	1.320	0.233	-0.385	0.131	0	

BOD_5	Mann Wittn. p-value	Fligner Policello	Normality for t-test p-value	Paired t – test	Result
Commercial	0	U = 4.85 ; P = 0	0.013	N/A	Different (first flush)
Industrial	0.007	U = 2.76 ; P = 0	0.434	0.012	Different
Institutional	0.027	U = 2.46 ; P = 0.01	0.056	0.001	Different
Open Space	0.706	U = 0.39 ; P = 0.35	0.183	0.614	Same (no first flush)
Residential	N/A	U = 4.89; P = 0	0	N/A	Different
All Landuses	N/A	U = 6.65 ; P = 0	0	N/A	Different

COD (mg/L)	Total Events	Selected Cases	Median	Median (Log)	Var (Log)	Skew (Log)	SE Skew (Log)	Test Norm. (Log) p-value	Median Ratio
Commercial Composite)	91	91	71.94	1.857	0.075	0.261	0.253	0.022	2.29
Commercial First Flush	91	91	164.82	2.217	0.119	-0.201	0.253	0.877	
Industrial Composite	84	84	75.34	1.877	0.100	0.167	0.263	0.014	1.43
Industrial First Flush	84	84	107.40	2.031	0.151	-0.141	0.263	0.804	
Institutional Composite	18	18	43.85	1.642	0.220	-0.456	0.536	0.567	2.73
Institutional First Flush	18	18	119.67	2.078	0.151	-0.969	0.536	0.105	
Open Space Composite	28	28	20.00	1.301	0.130	0.441	0.441	0.084	0.67
Open Space First Flush	28	28	13.43	1.128	0.211	0.731	0.441	0.013	
Residential Composite	140	140	67.92	1.832	0.095	0.271	0.205	0.008	1.63
Residential First Flush	140	140	110.41	2.043	0.138	-0.831	0.205	0.005	
All Landuses Composite	363	363	65.92	1.819	0.123	-0.293	0.128	0	1.71
All Landuses First Flush	363	363	112.98	2.053	0.194	-0.710	0.128	0	

COD	Mann Wittn. p-value	Fligner Policello	Normality for t-test p-value	Paired t – test	Result
Commercial	N/A	U = 4.83 ; P = 0	0.269	0	Different (first flush)
Industrial	N/A	U = 1.67 ; P = 0.05	0.691	0.01	Different
Institutional	0.01	U = 2.94 ; P = 0	0.677	0	Different
Open Space	N/A	U = 0.269 ; P = 0.39	0.004	N/A	Same (no first flush)
Residential	N/A	U = 6.715 ; P = 0	0	N/A	Different
All Landuses	N/A	U =9.19 ; P = 0	0	N/A	Different

TSS (mg/L)	Total Events	Selected Cases	Median	Median (Log)	Var (Log)	Skew (Log)	SE Skew (Log)	Test Norm. (Log) p-value	Median Ratio
Commercial Composite	90	90	54.95	1.740	0.106	0.168	0.254	0.730	1.85
Commercial First Flush	90	90	101.86	2.008	0.200	-0.508	0.254	0.016	
Industrial Composite	83	83	66.07	1.820	0.186	-0.021	0.264	0.336	0.97
Industrial First Flush	83	83	63.97	1.806	0.374	-0.157	0.264	0.055	
Institutional Composite	18	18	16.48	1.217	0.110	-0.176	0.536	0.122	2.12
Institutional First Flush	18	18	34.99	1.544	0.145	-0.164	0.536	0.846	
Open Space Composite	32	32	21.98	1.342	0.424	-0.526	0.414	0.511	0.95
Open Space First Flush	32	32	20.89	1.320	0.563	-0.126	0.414	0.847	
Residential Composite	144	144	37.50	1.574	0.217	-0.033	0.202	0.282	1.84
Residential First Flush	144	144	69.02	1.839	0.302	-0.267	0.202	0.533	
All Landuses Composite	372	372	44.36	1.647	0.226	-0.381	0.126	0.008	1.60
All Landuses First Flush	372	372	70.96	1.851	0.335	0.457	0.126	0	

TSS	Mann Wittn. p-value	Fligner Policello	Normality for t-test p-value	Paired t – test	Result
Commercial	N/A	U = 5.345 ; P = 0	0.014	N/A	Different (first flush)
Industrial	0.627	U = 0.483 ; P = 0.31	0.222	0.432	Same (no first flush)
Institutional	0.007	U = 3.095 ; P = 0	0.309	0.001	Different
Open Space	0.706	U = 0.39 ; P = 0.35	0.183	0.614	Same
Residential	N/A	U = 4.89 ; P = 0	0	N/A	Different
All Landuses	N/A	U = 6.65 ; P = 0	0	N/A	Different

TDS (mg/L)	Total Events	Selected Cases	Median	Median (Log)	Var (Log)	Skew (Log)	SE Skew (Log)	Test Norm. (Log) p-value	Median Ratio
Commercial Composite	82	82	73.28	1.865	0.064	-0.338	0.266	0.263	1.83
Commercial First Flush	82	82	133.97	2.127	0.065	-0.219	0.266	0.115	
Industrial Composite	82	81	97.72	1.990	0.093	-0.482	0.267	0.341	1.32
Industrial First Flush	82	81	128.82	2.110	0.126	-0.513	0.267	0.109	
Institutional Composite	18	18	52.48	1.720	0.068	-0.034	0.536	0.360	2.66
Institutional First Flush	18	18	139.64	2.145	0.090	-0.303	0.536	0.158	
Open Space Composite	31	30	69.98	1.845	0.051	0.617	0.427	0.376	1.07
Open Space First Flush	31	30	74.99	1.875	0.104	-1.483	0.427	0.005	
Residential Composite	137	133	70.31	1.870	0.119	-0.245	0.210	0.041	1.52
Residential First Flush	137	133	107.15	2.030	0.125	0.500	0.210	0.167	
All Landuses Composite	354	342	77.62	1.890	0.083	0.188	0.132	0.334	1.55
All Landuses First Flush	354	342	120.23	2.080	0.104	0.225	0.132	0.126	

TDS	Mann Wittn. p-value	Fligner Policello	Normality for t-test p-value	Paired t – test	Result
Commercial	0	U = 7.33 ; P = 0	0.160	0	Different (first flush)
Industrial	0.0245	U = 2.28 ; P = 0.01	0.070	0.003	Different
Institutional	0.0118	U = 2.945 ; P = 0	0.544	0	Different
Open Space	N/A	U = 0.161 ; P = 0.44	0	N/A	Same (no first flush)
Residential	N/A	U = 4.89 ; P = 0	0	N/A	Different
All Landuses	0	U = 7.58 ; P = 0	0	N/A	Different

O&G (mg/L)	Total Events	Selected Cases	Median	Median (Log)	Var (Log)	Skew (Log)	SE Skew (Log)	Test Norm. (Log) p-value	Median Ratio
Commercial Composite	10	10	5.19	0.715	0.068	-0.976	0.687	0.016	1.54
Commercial First Flush	10	10	8.00	0.027	0.903	1.641	0,687	0.019	
Residential Composite	8	4	5.00	0.699	0.066	1.985	1.014	0.013	2.05
Residential First Flush	8	4	10.23	1.010	0.134	0.003	1.014	0.056	
All Landuses Composite	18	14	5.00	0.699	0.073	-0.370	0.597	0.015	1.60
All Landuses First Flush	18	14	8.00	0.903	0.051	0.890	0.597	0.011	

O&G	Mann Wittn. p-value	Fligner Policello	Normality for t-test p-value	Paired t – test	Result
Commercial	N/A	U = 6.198 ; P < 0.01	0.222	0.004	Different
Residential	N/A	U = 1.069 ; P > 0.1	0.049	0.306	Same
All Landuses	N/A	U = 4.072 ; P = 0	0.036	N/A	Different

Fecal Coliforms (mpn/100 mL)	Total Events	Selected Cases	Median	Median (Log)	Var (Log)	Skew (Log)	SE Skew (Log)	Test Norm. (Log) p-value	Median Ratio
Commercial Composite	12	12	67764	4.831	1.099	-0.691	0.637	0.627	0.87
Commercial First Flush	12	12	58884	4.770	1.732	-0.388	0.637	0.228	
Residential Composite	10	9	41976	4.623	0.292	0.485	0.717	0.276	0.98
Residential First Flush	10	9	41020	4.643	0.685	0.247	0.717	0.799	
All Landuses Composite	22	21	46238	4.665	0.745	-0.886	-0.515	0.511	1.21
All Landuses First Flush	22	21	55976	4.748	1.269	0.501	0.501	0.391	

Fecal Coliforms	Mann Wittn. p-value	Fligner Policello	Normality for t-test p-value	Paired t – test	Result
Commercial	N/A	U = 0 ; P > 0.10	0.833	0.583	Same
Residential	N/A	U = 0.289 ; P > 0.1	0.016	0.973	Same
All Landuses	N/A	U = 0.181 ; P = 0.43	0.086	0.665	Same

Fecal Strep. (mpn/100 mL)	Total Events	Selected Cases	Median	Median (Log)	Var (Log)	Skew (Log)	SE Skew (Log)	Test Norm. (Log) p-value	Median Ratio
Commercial Composite	12	11	37153	4.570	0.780	-0.255	0.661	0.948	1.05
Commercial First Flush	12	11	38904	4.590	1.094	0.009	0.661	0.722	
Residential Composite	11	8	77625	4.890	0.231	-0.223	0.752	0.426	1.30
Residential First Flush	11	8	101158	5.005	0.327	-0.659	0.752	0.319	
All Landuses Composite	26	22	43651	4.640	0.536	-0.513	0.491	0.713	1.11
All Landuses First Flush	26	22	48417	4.685	0.705	-0.188	0.491	0.802	

Fecal Strep.	Mann Wittn. p-value	Fligner Policello	Normality for t-test p-value	Paired t – test	Result
Commercial	N/A	U = 0.281 ; P > 0.10	0.027	N/A	Same (no first flush)
Residential	N/A	U = 0.344 ; P > 0.10	0.109	0.905	Same
All Landuses	N/A	U = 0.309 ; P = 0.38	0.033	N/A	Same

Ammonia (mg/L)	Total Events	Selected Cases	Median	Median (Log)	Var (Log)	Skew (Log)	SE Skew (Log)	Test Norm. (Log) p-value	Median Ratio
Commercial Composite	70	52	0.76	-0.122	0.147	-0.245	0.330	0.237	2.11
Commercial First Flush	70	52	1.60	0.204	0.117	-0.718	0.330	0.027	
Industrial Composite	40	33	0.62	-0.208	0.166	-0.399	0.409	0.284	1.08
Industrial First Flush	40	33	0.67	-0.174	0.201	-0.535	0.409	0.046	
Institutional Composite	18	16	0.31	-0.509	0.058	-0.038	0.564	0.273	1.66
Institutional First Flush	18	16	0.51	-0.290	0.077	0.284	0.564	0.384	
Residential Composite	119	86	0.50	-0.301	0.370	0.779	0.260	0.001	1.36
Residential First Flush	119	86	0.68	-0.168	0.172	0.195	0.260	0.519	
All Landuses Composite	269	190	0.52	-0.284	0.251	0.501	0.176	0.002	1.54
All Landuses First Flush	269	190	0.80	-0.097	0.176	-0.197	0.176	0.713	

* Ammonia in Open Space was found in 22 events. Only 3 events had values above the detection limit

Ammonia	Mann Wittn. p-value	Fligner Policello	Normality for t-test p-value	Paired t – test	Result
Commercial	N/A	U = 4.467 ; P = 0	0.028	N/A	Different
Industrial	N/A	U = 0.113 ; P = 0.46	0.262	0.985	Same
Institutional	0.0287	U = 2.484 ; P = 0.01	0.254	0	Different
Residential	N/A	U = 2.283 ; P = 0.01	0	N/A	Different
All Landuses	N/A	U = 4.092 ; P = 0	0	N/A	Different

NO_2 + NO_3 (mg/L)	Total Events	Selected Cases	Median	Median (Log)	Var (Log)	Skew (Log)	SE Skew (Log)	Test Norm. (Log) p-value	Median Ratio
Commercial Composite	84	82	0.75	-0.125	0.095	-0.092	0.266	0.188	1.73
Commercial First Flush	84	82	1.30	0.114	0.166	-0.790	0.266	0.007	
Industrial Composite	72	71	0.90	-0.046	0.073	-0.240	0.285	0.807	1.31
Industrial First Flush	72	71	1.18	0.072	0.116	-0.839	0.285	0.030	
Institutional	18	18	0.60	-0.222	0.122	-0.714	0.536	0.117	1.70
Institutional First Flush	18	18	1.02	0.009	0.151	0.268	0.536	0.381	
Open Space Composite	30	21	0.24	-0.620	0.290	0.468	0.501	0.141	0.96
Open Space First Flush	30	21	0.23	-0.638	0.356	0.823	0.501	0.030	
Residential Composite	121	118	0.60	-0.222	0.104	-0.196	0.223	0.504	1.66
Residential First Flush	121	118	1.00	-0.002	0.125	-0.292	0.223	0.102	
All Landuses Composite	324	310	0.70	-0.155	0.124	-0.497	0.138	0	1.50
All Landuses First Flush	324	310	1.05	0.021	0.162	-0.584	0.138	0	

NO_2 + NO_3	Mann Wittn. p-value	Fligner Policello	Normality for t-test p-value	Paired t – test	Result
Commercial	N/A	U = 3.286 ; P = 0	0	N/A	Different (first flush)
Industrial	N/A	U = 1.836 ; P = 0.03	0.941	0.034	Different
Institutional	0.043	U = 2.242 ; P = 0.01	0.026	N/A	Different
Open Space	N/A	U = 0.209 ; P = 0.42	0.023	N/A	Same (no first flush)
Residential	0	U = 4.769 ; P = 0	0.023	N/A	Different
All Landuses	N/A	U = 5.834 ; P = 0	0	N/A	Different

Total N (mg/L)	Total Events	Selected Cases	Median	Median (Log)	Var (Log)	Skew (Log)	SE Skew (Log)	Test Norm. (Log) p-value	Median Ratio
Commercial Composite	19	19	1.42	0.152	0.180	-0.133	0.524	0.215	1.35
Commercial First Flush	19	19	1.91	0.281	0.203	-0.617	0.524	0.337	
Industrial Composite	19	16	2.01	0.303	0.286	-0.306	0.564	0.431	1.79
Industrial First Flush	19	16	3.61	0.557	0.349	-0.452	0.564	0.029	
Open Space Composite	6	6	1.39	0.142	0.112	-0.150	0.845	0.330	1.53
Open Space First Flush	6	6	2.12	0.326	0.248	-0.100	0.845	0.221	
Residential Composite	31	30	1.67	0.222	0.325	1.22	0.427	0.009	0.88
Residential First Flush	31	30	1.47	0.166	0.447	-0.587	0.427	0.367	
All Landuses Composite	77	73	1.60	0.204	0.253	0.769	0.281	0.136	1.22
All Landuses First Flush	77	73	1.95	0.290	0.331	0.599	0.281	0.071	

Constituent	Mann Wittn. p-value	Fligner Policello	Normality for t-test p-value	Paired t – test	Result
Commercial	0.220	U = 1.234 ; P = 0.11	0.329	0.013	Same
Industrial	N/A	U = 0.460 ; P = 0.32	0.759	0.161	Same
Open Space	N/A	U = 0 ; P > 0.104	0.339	0.703	Same
Residential	N/A	U = 0.106 ; P = 0.46	0.002	N/A	Same
All Landuses	N/A	U = 0.919 ; P = 0.18	0	N/A	Same

TKN (mg/L)	Total Events	Selected Cases	Median	Median (Log)	Var (Log)	Skew (Log)	SE Skew (Log)	Test Norm. (Log) p-value	Median Ratio
Commercial Composite	93	86	1.63	0.213	0.085	-0.275	0.260	0.003	1.71
Commercial First Flush	93	86	2.80	0.447	0.120	-0.117	0.260	0.714	
Industrial Composite	77	76	1.69	0.227	0.116	1.157	0.276	0	1.35
Industrial First Flush	77	76	2.27	0.356	0.130	0.536	0.276	0.232	
Open Space Composite	32	14	0.61	-0.215	0.142	0.585	0.597	0.109	1.28
Open Space First Flush	32	14	0.78	-0.107	0.269	0.948	0.597	0.139	
Residential Composite	131	123	1.40	0.146	0.110	1.752	0.218	0	1.65
Residential First Flush	131	123	2.31	0.364	0.115	0.309	0.218	0.076	
All Landuses Composite	335	301	1.50	0.176	0.114	0.856	0.140	0	1.60
All Landuses First Flush	335	301	2.40	0.380	0.139	0.088	0.140	0	

TKN	Mann Wittn. p-value	Fligner Policello	Normality for t-test p-value	Paired t – test	Result
Commercial	N/A	U = 6.499 ; P = 0	0.126	0	Different (first flush)
Industrial	N/A	U = 1.698 ; P = 0.04	0.054	0.063	Different
Open Space	N/A	U = 0.374 ; P = 0.35	0.116	0.364	Same (no first flush)
Residential	N/A	U = 6.079 ; P = 0	0	N/A	Different
All Landuses	N/A	U = 7.68 ; P = 0	0	N/A	Different

Total P (mg/L)	Total Events	Selected Cases	Median	Median (Log)	Var (Log)	Skew (Log)	SE Skew (Log)	Test Norm. (Log) p-value	Median Ratio
Commercial Composite	89	77	0.34	-0.469	0.160	-0.454	0.274	0.129	1.44
Commercial First Flush	89	77	0.49	-0.310	0.205	0.033	0.274	0.035	
Industrial Composite	84	71	0.29	-0.538	0.130	0.495	0.285	0.003	1.42
Industrial First Flush	84	71	0.41	-0.387	0.257	-0.441	0.285	0.397	
Institutional Composite	17	17	0.17	-0.770	0.203	-0.736	0.550	0.374	1.24
Institutional First Flush	17	17	0.21	-0.678	0.066	-0.177	0.550	0.704	
Open Space Composite	32	20	0.09	-1.023	0.147	0.613	0.512	0.218	1.05
Open Space First Flush	32	20	0.10	-1.000	0.381	0.833	0.512	0.288	
Residential Composite	140	128	0.28	-0.553	0.252	1.232	0.214	0	1.46
Residential First Flush	140	128	0.41	-0.389	0.188	-0.335	0.214	0.042	
All Landuses Composite	363	313	0.28	-0.553	0.209	0.605	0.138	0	1.45

All Landuses First Flush	363	313	0.41	-0.391	0.238	-0.258	0.138	0.003	

Total P	Mann Wittn. p-value	Fligner Policello	Normality for t-test p-value	Paired t – test	Result
Commercial	N/A	U = 3.089 ; P = 0	0.594	0	Different (first flush)
Industrial	N/A	U = 0.864 ; P = 0.19	0.194	0.667	Same (no first flush)
Institutional	N/A	U = 0.774 ; P = 0.22	0.044	N/A	Same
Open Space	N/A	U = 0.142 ; P = 0.44	0.091	0.527	Same
Residential	N/A	U = 2.671 ; P = 0	0	N/A	Different
All Landuses	N/A	U = 3.641 ; P = 0	0	N/A	Different

Dissolved P (mg/L)	Total Events	Selected Cases	Median	Median (Log)	Var (Log)	Skew (Log)	SE Skew (Log)	Test Norm. (Log) p-value	Median Ratio
Commercial Composite	91	69	0.16	-0.788	0.152	0.467	0.289	0	1.23
Commercial First Flush	91	69	0.20	-0.699	0.212	0.904	0.289	0.005	
Industrial Composite	77	50	0.14	-0.854	0.142	1.248	0.337	0.093	1.04
Industrial First Flush	77	50	0.14	-0.839	0.160	0.406	0.337	0.043	
Institutional Composite	18	14	0.13	-0.891	0.066	-0.114	0.597	0.563	1.05
Institutional First Flush	18	14	0.13	-0.870	0.095	-0.770	0.597	0.122	
Open Space Composite	32	14	0.05	-1.301	0.111	-0.073	0.597	0.601	0.69
Open Space First Flush	32	14	0.03	-1.460	0.087	1.061	0.597	0.017	
Residential Composite	130	105	0.17	-0.770	0.117	0.152	0.236	0.458	1.24
Residential First Flush	130	105	0.21	-0.678	0.170	0.121	0.236	0.044	
All Landuses Composite	350	254	0.15	-0.824	0.143	0.353	0.153	0.051	1.07
All Landuses First Flush	350	254	0.16	-0.796	0.200	0.401	0.153	0.001	

Dissolved P	Mann Wittn. p-value	Fligner Policello	Normality for t-test p-value	Paired t – test	Result
Commercial	N/A	U = 1.582 ; P = 0.06	0.046	N/A	Same
Industrial	N/A	U = 0.051 ; P = 0.48	0.063	0.881	Same
Institutional	0.549	U = 0.605 ; P = 0.27	0.015	N/A	Same
Open Space	N/A	U = 0.760 ; P = 0.22	0.018	N/A	Same
Residential	N/A	U = 1.702 ; P = 0.04	0.039	N/A	Different
All Landuses	N/A	U = 1.657 ; P = 0.05	0	N/A	Same

Orthophosphate (mg/L)	Total Events	Selected Cases	Median	Median (Log)	Var (Log)	Skew (Log)	SE Skew (Log)	Test Norm. (Log) p-value	Median Ratio
Industrial Composite	6	6	0.16	-0.797	0.287	-0.047	0.845	0.838	1.55
Industrial First Flush	6	6	0.25	-0.607	0.356	-0.106	0.845	0.720	
Residential Composite	14	14	0.19	-0.714	0.554	2.557	0.597	0.001	0.95
Residential First Flush	14	14	0.18	-0.737	0.214	0.708	0.597	0.362	
All Landuses Composite	22	22	0.19	-0.714	0.423	2.270	0.491	0.004	1.30
All Landuses First Flush	22	22	0.25	-0.600	0.222	0.260	0.491	0.503	

Orthophosphate	Mann Wittn. p-value	Fligner Policello	Normality for t-test p-value	Paired t – test	Result
Industrial	0.471	U = 0.772 ; P > 0.104	0.071	0.611	Same
Residential	N/A	U = 0.022 ; P = 0.49	0	N/A	Same
All Landuses	N/A	U = 0.460 ; P = 0.32	0	N/A	Same

Total Cadmium (µg/L)	Total Events	Selected Cases	Median	Median (Log)	Var (Log)	Skew (Log)	SE Skew (Log)	Test Norm. (Log) p-value	Median Ratio
Commercial Composite	74	48	0.56	-0.253	0.246	-0.325	0.343	0	2.15
Commercial First Flush	74	48	1.20	0.079	0.261	0.080	0.343	0.089	
Industrial Composite	80	41	1	0	0.124	-0.015	0.369	0.008	1.00
Industrial First Flush	80	41	1	0	0.130	0.261	0.369	0.065	
Open Space Composite	30	15	0.23	-0.638	0.282	1.074	0.580	0.183	1.30
Open Space First Flush	30	15	0.30	-0.523	0.325	0.465	0.580	0.402	
Residential Composite	123	33	0.28	-0.553	0.359	0.693	0.409	0.002	2.00
Residential First Flush	123	33	0.56	-0.252	0.264	0.512	0.409	0.061	
All Landuses Composite	325	139	0.60	-0.222	0.269	-0.065	0.206	0.071	1.62
All Landuses First Flush	325	139	0.97	-0.013	0.249	0.041	0.206	0.241	

Total Cadmium	Mann Wittn. p-value	Fligner Policello	Normality for t-test p-value	Paired t – test	Result
Commercial	0.006	U = 2.797 ; P = 0	0.009	N/A	Different (first flush)
Industrial	0.922	U = 0.100 ; P = 0.46	0.118	0.529	Same (no first flush)
Open Space	0.442	U = 0.765 ; P = 0.22	0.292	0.191	Same
Residential	0.038	U = 2.131 ; P = 0.02	0.015	N/A	Different
All Landuses	0.005	U = 2.839 ; P = 0	0	N/A	Different

Total Chromium (µg/L)	Total Events	Selected Cases	Median	Median (Log)	Var (Log)	Skew (Log)	SE Skew (Log)	Test Norm. (Log) p-value	Median Ratio
Commercial Composite	47	22	6.81	0.833	0.086	-0.051	0.491	0.911	1.67
Commercial First Flush	47	22	11.40	1.057	0.134	-0.796	0.491	0.121	
Industrial Composite	54	25	8.79	0.944	0.111	0.338	0.464	0.456	1.36
Industrial First Flush	54	25	11.99	1.079	0.155	-0.307	0.464	0.784	
Open Space Composite	16	4	2.64	0.422	0.169	-0.556	1.014	0.492	1.70
Open Space First Flush	16	4	4.50	0.653	0.015	1.291	1.014	0.355	
Residential Composite	86	31	8.00	0.903	0.169	-0.077	0.421	0.612	1.24
Residential First Flush	86	31	9.91	0.996	0.137	0.326	0.421	0.904	
All Landuses Composite	218	82	7.50	0.875	0.140	-0.104	0.266	0.591	1.47
All Landuses First Flush	218	82	10.99	1.041	0.141	-0.056	0.266	0.803	

Total Chromium	Mann Wittn. p-value	Fligner Policello	Normality for t-test p-value	Paired t – test	Result
Commercial	0.0513	U = 2.024 ; P = 0.02	0.283	0.036	Different
Industrial	0.3032	U = 1.023 ; P = 0.15	0.216	0.320	Same
Open Space	0.3032	U = 1.586 ; P = 0.10	0.160	0.199	Same
Residential	0.6023	U = 0.519 ; P = 0.30	0.007	N/A	Same
All Landuses	0.0547	U = 1.939 ; P = 0.03	0.001	N/A	Different

Total Copper (µg/L)	Total Events	Selected Cases	Median	Median (Log)	Var (Log)	Skew (Log)	SE Skew (Log)	Test Norm. (Log) p-value	Median Ratio
Commercial Composite	92	82	16.98	1.230	0.083	-0.038	0.266	0.117	1.62
Commercial First Flush	92	82	27.48	1.439	0.120	0.343	0.266	0.035	
Industrial Composite	84	76	25.00	1.398	0.079	0.184	0.276	0.344	1.24
Industrial First Flush	84	76	30.97	1.491	0.166	-0.014	0.276	0.007	
Institutional Composite	18	7	16.98	1.230	0.083	-0.228	0.794	0.167	0.94
Institutional First Flush	18	7	16.00	1.204	0.047	0.954	0.794	0.555	
Open Space Composite	30	22	5.14	0.711	0.103	0.085	0.491	0.252	0.78
Open Space First Flush	30	22	4.00	0.602	0.120	1.005	0.491	0.015	
Residential Composite	144	108	11.99	1.079	0.082	-0.677	0.233	0	1.33
Residential First Flush	144	108	16.00	1.204	0.087	0.023	0.233	0.256	
All Landuses Composite	368	295	15.00	1.176	0.116	-0.268	0.142	0	1.33
All Landuses First Flush	368	295	20.00	1.301	0.167	0.009	0.142	0	

Total Copper	Mann Wittn. p-value	Fligner Policello	Normality for t-test p-value	Paired t – test	Result
Commercial	N/A	U = 5.160 ; P = 0	0.001	N/A	Different (first flush)
Industrial	N/A	U = 1.864 ; P = 0.03	0.329	0.012	Different
Institutional	0.5224	U = 0.665 ; P > 0.099	0.318	0.029	Same (no first flush)
Open Space	N/A	U = 0.846 ; P = 0.19	0.074	0.337	Same
Residential	N/A	U = 4.029 ; P = 0	0.292	0	Different
All Landuses	N/A	U = 5.146 ; P = 0	0	N/A	Different

Total Lead (µg/L)	Total Events	Selected Cases	Median	Media n (Log)	Var (Log)	Skew (Log)	SE Skew (Log)	Test Norm. (Log) p-value	Median Ratio
Commercial Composite	89	83	16.98	1.230	0.062	0.075	0.264	0.824	1.65
Commercial First Flush	89	83	27.99	1.447	0.123	0.070	0.264	0.476	
Industrial Composite	84	71	16.98	1.230	0.160	0.527	0.285	0.081	1.41
Industrial First Flush	84	71	23.99	1.380	0.240	0.319	0.285	0.608	
Institutional Composite	18	13	7.00	0.845	0.082	0.675	0.616	0.158	2.28
Institutional First Flush	18	13	15.96	1.203	0.051	0.128	0.616	0.228	
Open Space Composite	31	16	5.00	0.699	0.381	-0.303	0.564	0.199	0.90
Open Space First Flush	31	16	4.48	0.651	0.346	-0.466	0.564	0.563	
Residential Composite	140	93	8.79	0.944	0.231	0.084	0.250	0.884	1.48
Residential First Flush	140	93	13.00	1.114	0.204	0.130	0.250	0.105	
All Landuses Composite	364	278	13.00	1.114	0.198	-0.365	0.146	0.006	1.50
All Landuses First Flush	364	278	19.50	1.290	0.239	-0.307	0.146	0.401	

Total Lead	Mann Wittn. p-value	Fligner Policello	Normality for t-test p-value	Paired t – test	Result
Commercial	0	U = 5.256 ; P = 0	0.794	0	Different
Industrial	0.083	U = 1.742 ; P = 0.04	0.167	0.016	Different
Institutional	0.004	U = 3.973 ; P = 0	0.680	0.000	Different
Open Space	0.771	U = 0.292 ; P = 0.39	0.008	0.578	Same
Residential	0.012	U = 2.59 ; P = 0	0.014	N/A	Different
All Landuses	N/A	U = 4.77 ; P = 0	0	N/A	Different

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Total Nickel (μg/L)	Total Events	Selected Cases	Median	Median (Log)	Var (Log)	Skew (Log)	SE Skew (Log)	Test Norm. (Log) p-value	Median Ratio
Commercial Composite	47	23	5.00	0.699	0.094	0.660	0.481	0.254	2.40
Commercial First Flush	47	23	11.99	1.079	0.134	-0.606	0.481	0.523	
Industrial Composite	51	22	7.00	0.845	0.106	-0.293	0.491	0.229	1.00
Industrial First Flush	51	22	7.00	0.845	0.197	0.605	0.491	0.228	
Residential Composite	83	18	7.48	0.874	0.094	0.152	0.536	0.814	1.20
Residential First Flush	83	18	8.99	0.954	0.115	1.551	0.536	0.048	
All Landuses Composite	213	64	6.00	0.778	0.104	0.146	0.299	0.161	1.50
All Landuses First Flush	213	64	8.99	0.954	0.147	0.322	0.299	0.443	

Total Nickel	Mann Wittn. p-value	Fligner Policello	Normality for t-test p-value	Paired t – test	Result
Commercial	0.006	U = 3.005 ; P = 0	0.128	0.002	Different (first flush)
Industrial	0.715	U = 0.365 ; P = 0.36	0.203	0.484	Same (no first flush)
Residential	N/A	U = 1.143 ; P = 0.13	0.512	0.098	Same
All Landuses	0.014	U = 2.539 ; P = 0.01	0.367	0.001	Different

Total Zinc (μg/L)	Total Events	Selected Cases	Median	Median (Log)	Var (Log)	Skew (Log)	SE Skew (Log)	Test Norm. (Log) p-value	Median Ratio
Commercial Composite	90	90	149.97	2.176	0.089	-1.359	0.254	0	1.93
Commercial First Flush	90	90	289.07	2.461	0.139	-0.374	0.254	0.647	
Industrial Composite	83	83	225.94	2.354	0.184	0.828	0.264	0	1.54
Industrial First Flush	83	83	348.34	2.542	0.135	-0.181	0.264	0.930	
Institutional Composite	18	18	304.79	2.484	0.114	-0.227	0.536	0.878	2.48
Institutional First Flush	18	18	755.09	2.878	0.133	-0.696	0.536	0.055	
Open Space Composite	21	21	20.00	1.301	0.165	0.081	0.501	0.073	1.25
Open Space First Flush	21	21	25.00	1.398	0.075	-0.242	0.501	0.295	
Residential Composite	136	136	69.34	1.841	0.114	0.824	0.208	0.003	1.58
Residential First Flush	136	136	109.90	2.041	0.200	-0.232	0.208	0.014	
All Landuses Composite	350	350	125.89	2.100	0.216	0.121	0.130	0.001	1.59
All Landuses First Flush	350	350	199.99	2.301	0.268	0.437	0.130	0.020	

Total Zinc	Mann Wittn. p-value	Fligner Policello	Normality for t-test p-value	Paired t – test	Result
Commercial	N/A	U = 6.156 ; P = 0	0	N/A	Different
Industrial	N/A	U = 2.087 ; P = 0.02	0.006	N/A	Different
Institutional	0.007	U = 3.1 ; P = 0	0.498	0	Different
Open Space	N/A	U = 0.023 ; P = 0.49	0.667	0.977	Same
Residential	N/A	U = 4.329 ; P = 0	0	N/A	Different
All Landuses	N/A	U = 5.374 ; P = 0	0	N/A	Different