Impacts of Stormwater Control Measures on Water Quality in Austin, TX

September 2013

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Report Number: CM-13-02

Executive Summary

Flow and water quality data from several stormwater quality control measures (SCMs) have been collected since the early 1980s by the City of Austin (COA) Stormwater Quality Evaluation (SQE) program. Former analytical techniques for these water quality data may have produced misleading results. This report attempts to correct potential problems in two ways. First, the same quality assurance and quality control protocols were applied to all of the data regardless of when the data were collected, and event mean concentrations (EMCs) were computed in the same manner. Second, the performance of the different classes of SCMs were evaluated using the effluent probability method recommended by the International BMP Database project (Geosyntec and Wright Water, 2009) instead of the less-reliable percent removal method used in the past.

This study will cover four primary SCMs employed in COA in the past: sedimentation (SED), sand filtration (SF), wet ponds (WP), and biofiltration (BF). Sedimentation basins are detention basins with increased runoff residence times sufficient to remove some settleable pollutants. Sand filters are structural SCMs that capture and temporarily store stormwater runoff and filter the runoff through a bed of sand. The objective of sand filters is to remove sediment and the pollutants from the first flush of pavement and impervious area runoff. Wet ponds are constructed stormwater basins that retain permanent pools of water. Runoff from individual runoff events is detained by displacing the corresponding volume of water in permanent pools. The primary pollutant removal mechanisms in a wet pond are sedimentation and biological conversion. Biofiltration basins use the chemical, biological, and physical properties of plants, microbes, and soils for removal of pollutants from stormwater runoff.

Various analytical and statistical techniques were used in the production of this report. These techniques were used to analyze event mean concentrations (EMCs). Since this report is based on effluent probability analyses, all effluent EMCs for a class of SCM were combined for analyses. Several methods were conducted to compute descriptive statistics for each class of SCMs. Parameters are used to describe the conditions of the class but are not used to compare the class directly to another. These parameters are divided into four categories: non-parametric, arithmetic (normal), log transformed (lognormal) and bootstrap. The four categories of the descriptive statistics are described in this report.

While the descriptive statistics are common to other SQE reports, SCM analyses require comparative tests to evaluate performance. Traditionally the only comparative statistic used for SCM evaluation was the efficiency ratio or percent removal. However, this may produce misleading results and does not indicate if the difference between the influent and effluent is statistically significant. It has been recommended by the International BMP Database project that this method of comparison not be used (Geosyntec and Wright Water, 2009). This report describes the shortcoming of using the efficiency ratio, describes the effluent probability method used in this report, and outlines the various comparative statistics used and when they may be appropriate.

Two types of data plots are generated in this report to assist in comparing the effluent concentrations and to help interpret the results. The first plot is a lognormal probability plot with the concentration of the influent and effluent on the x-axis with a log scale and the probability the concentration is less than that value on the y-axis using a probability scale. These effluent probability plots help determine if the SCMs perform differently and how they behave across the full range of data, not just at the mean or median. The second plot is a box-and-whisker plot on a log scale. This may be used in a manner similar to the probability plot.

This report compares the performance of four different types of SCMs with respect to the effluent concentrations of eighteen different pollutants. These pollutants are grouped into five general categories for discussion: solids, nutrients, metals, oxygen demand, and bacteria. Lognormal probability plot and box-and-whisker plot are shown and used in the performance comparison.

Sand filters exhibited significantly lower effluent concentrations with respect to solids. Biofiltration and wet pond effluent concentrations were not significantly different from each other, while sedimentation concentrations were typically higher than the other SCMs.

For nutrient effluent concentrations there was little difference between sand filters, wet ponds and sedimentation for pollutants that are adsorbed to particulates. Sand filters performed poorly with nitrate plus nitrite due to conversion from other forms of nitrogen, which is primarily a dissolved constituent. However, sand filters did perform well with dissolved phosphorus, probably due to local condition (high pH soils) and the greater opportunity for dissolved phosphorus to bind to particles. Biofiltration effluent concentrations were higher than expected, especially for total and dissolved phosphorus. This is likely due to the filtration media used in the biofiltration basins monitored for this study.

In the Austin area where most of the metals are adsorbed, filtration is a superior treatment mechanism compared to sedimentation and wet ponds, which rely on settling. Since most of the metals are adsorbed onto clay-sized particles, settling will be less effective unless the settling time is very long. The media used in biofiltration may have a negative impact on the effluent concentration of some metals.

Sand filter effluent concentrations are significantly lower than that of other SCMs for the oxygen demand pollutants and for total organic carbon. The effluent EMCs for bacteria pollutant parameters were lowest for sand filters.

Overall, sand filters had the lowest effluent concentration for most pollutants, the notable exception being nitrate plus nitrite. Wet pond effluent concentrations of nitrate plus nitrite were the lowest of the SCMs studied. Biofiltration effluent concentrations were similar to sand filter concentrations with the notable exceptions of copper, phosphorus and, to a lesser extent, nitrogen. The poor performance of biofiltration with respect to these parameters is explored in the special comparison of Canyon Creek sand filter and biofiltration.

The comparison of performance for different filtration media at Canyon Creek shows that for most pollutants, the effluent concentrations are similar for both media. The biggest effluent concentration differences were observed in total and dissolved phosphorus. The effluent concentration differences were also observed in total nitrogen, total Kjeldahl nitrogen, and total and dissolved copper. For all these differences, the effluent concentrations from biofiltration media were higher than the effluent concentrations from sand media. Given the media used in the Canyon Creek biofiltration basin, the biofiltration basin exported nutrients and copper but otherwise performed equivalently to a sand filter. Adjusting the media mix should result in overall biofiltration performance meeting or exceeding sand filters.

The results of this study may be used to estimate runoff loads from developed sites in two ways. First, the mean effluent concentration for different SCM types (Table 6.1) may be applied to the volume of treated runoff on an average annual basis to estimate the load from a site. The second method would require a more rigorous approach using continuous simulation of the runoff and Monte Carlo simulation of the effluent concentration. For each runoff event, the effluent concentration for each parameter from the SCM would be randomly generated using a random number generator and the mean and standard deviation specified in Table 6.1, assuming a lognormal data distribution.

Table of Contents

List of Figures

List of Tables

1 Introduction

The City of Austin (COA) Stormwater Quality Evaluation (SQE) program has collected flow and water quality data from several stormwater quality control systems since the early 1980s. These systems include sedimentation basins, sand filters, wet ponds and initial monitoring of biofiltration basins. The focus of this study is the comparison of effluent quality for these classes of stormwater control measures (SCMs) for 18 stormwater quality constituents. For data related to the performance of an individual SCM, see *Stormwater Control Measures in Austin, TX: Data Report* (COA, 2013a).

These data have been presented and analyzed in different forms through the years. The analyses have not always been consistent. In addition, former analytical techniques may have produced misleading results. This report attempts to correct those potential problems in two ways. First, the same quality assurance and quality control protocols were applied to all of the data regardless of when the data were collected and event mean concentrations (EMCs) were computed in the same manner (see COA, 2009 for details). Second, the performance of the different classes of SCMs were evaluated using the effluent probability method recommended by the International BMP Database project (Geosyntec and Wright Water, 2009) instead of the less reliable percent removal method used in the past.

2 Description of SCM Types

This study will cover four primary SCMs employed in COA in the past: sedimentation (SED), sand filtration (SF), wet ponds (WP) and biofiltration (BF). While retention-irrigation is employed in some areas of Austin, the primary treatment mechanism is infiltration, which cannot be fully addressed using the effluent probability method. Data for other secondary (filter strips, swales, etc.) and proprietary SCMs may be found in the companion data report (COA, 2013) but are not presented here. A brief description of these SCM types follows.

2.1 Sedimentation Basins

Sedimentation basins, also referred to as extended detention, are detention basins with increased runoff residence times sufficient to remove some settleable pollutants. Because the primary mechanism at work in a sedimentation basin is settling, a sedimentation basin usually has only moderate treatment efficiencies for some pollutants and is often used as pretreatment in an SCM system, such as sedimentation/filtration system. The sedimentation basin reduces the amount of sediment that reaches the sand filter, extending the life of the filtration basin. Details of sedimentation basins used in this manner can be found in City of Austin Environmental Criteria Manual (COA, 2013b). However, since sedimentation basins are not allowed as stand-alone treatment devices, no design criteria area are presented for that case.

Factors that may affect performance are residence time and surface area. Longer residence times allow for more settling while larger surface areas result in shorter settling distances for a given volume. Sedimentation basins are typically off-line systems. Data presented in this report are for the effluent of the system; any bypass would need to be considered when evaluating overall performance.

2.2 Sand Filters

Sand filters are structural SCMs that capture and temporarily store stormwater runoff and filter the runoff through a bed of sand. There are many sand filter designs; the typical Austin sand filter has two basic components: the pretreatment sedimentation basin and the sand filter basin. The sedimentation basin reduces the amount of sediment that reaches the sand filter and in some cases helps to ensure that stormwater reaches the sand filter as sheet flow. The sand filter traps the finer sediment and sediment-bound pollutants and may provide media for microbial removal of bacteria. The filtered runoff is collected by an underdrain and discharged to a creek or storm sewer. The rate of discharge is often regulated, either at the sedimentation basin or the discharge of the underdrain, depending on the design, to meet a specified drawdown rate.

The objective of sand filters is to remove sediment and the pollutants from the first flush of pavement and impervious area runoff. Sand filters have been demonstrated to be effective in removing many of the common pollutants found in urban stormwater runoff, especially those found in particulate form. They have been shown to have at least a moderate level of bacterial removal, but have not been effective at removing dissolved pollutants such as total dissolved solids and nitrate-nitrogen. The details of sand filters can be found in City of Austin Environmental Criteria Manual (COA, 2013b). As with sedimentation basins, these are off-line systems and bypass flows need to be taken into account.

2.3 Wet Ponds

A wet pond is a constructed stormwater basin that retains a permanent pool of water. Runoff from individual events is detained in the basin by displacing a corresponding volume of water in the permanent pool. The primary pollutant removal mechanisms in a wet pond are sedimentation and biological conversion. Significant loads of suspended pollutants, such as metals, nutrients, sediments, and organics, may be removed by sedimentation but wet ponds have longer resident times than sedimentation basins. Dissolved contaminants are removed by a combination of processes: physical adsorption to bottom sediments and suspended fine sediments, natural chemical flocculation, bacterial decomposition, and uptake by aquatic plants and algae.

Wet ponds have a moderate to high capacity for removing most urban pollutants, depending on how large the volume of the permanent pool is in relation to the runoff from the surrounding watershed. Soil conditions are important for the proper functioning of the wet pond. The pond is a permanent pool, and thus must be constructed such that the water must not be allowed to exfiltrate from the permanent portion of the pool. Unlike other SCMs, wet ponds treat all runoff. Wet ponds may offer flood-control benefits.

A well-designed and landscaped wet pond can be an aesthetic feature on a development site when planned and located properly. However, if the wet pond is not properly maintained or the pond becomes stagnant, floating debris, scum, algal blooms, unpleasant odors, and insects may appear. Sediment removal from the main portion of the pond is usually necessary after the pond has been functional for about 20 years. The details of wet ponds can be found in City of Austin Environmental Criteria Manual (COA, 2013b).

2.4 Biofiltration Basins

Biofiltration basins are SCMs that use the chemical, biological, and physical properties of plants, microbes, and soils for removal of pollutants from stormwater runoff. The COA design of a biofiltration system is similar to that of a sand filter except the filtration media are biologically active and can support plant growth. The primary difference between sand filters and biofiltration is the presence of a biological community of plants and microorganism in a biofiltration system that can theoretically provide more treatment of runoff, especially nitrates, which are problematic in sand filters. Another benefit of having a plant community is that the permeability of the biofiltration media may be sustained for longer periods without maintenance. The effluent concentrations from a biofiltration basin may be influenced by the filtration media used. High levels of compost may result in an export of nutrients. The details of biofiltration can be found in City of Austin Environmental Criteria Manual (COA, 2013b).

3 Description of Data Analyses

This section documents the various analytical and statistical techniques that were used in the production of this report. These techniques were used to analyze event mean concentrations (EMCs). For a detailed explanation of the SQE methodology to compute EMCs and the quality control procedures, refer to the SQE small watershed report (COA, 2009). Since this report is based on effluent probability analyses, all effluent EMCs for a class of SCMs are combined for analyses.

3.1 Descriptive Statistics

Several methods were conducted to compute descriptive statistics for each class of SCMs. Parameters are used to describe the conditions of the class but are not used to compare the classes directly to another. These parameters are most easily divided into four categories based on assumption used in later analyses. These four categories are non-parametric, arithmetic (normal), log transformed (lognormal) and bootstrap.

Non-parametric

Non-parametric descriptive statistics assume no underlying data distribution and as such may be very robust because they make fewer assumptions about the data. But in cases where parametric analyses would be appropriate, they tend to have less power. This is often the case with small sample sizes. Non-parametric descriptive statistics include: number of samples, maximum, minimum, median (50th percentile), upper quartile (75th percentile), and lower quartile (25th percentile).

Arithmetic

Arithmetic descriptive statistics assume a normal distribution of the data. The computation of these parameters is familiar to most users of data. The most common of these are the mean and standard deviation. The upper and lower confidence limits of the mean are computed using the following test:

$$\bar{x} \pm t_{1-\alpha,n-1}\frac{s}{\sqrt{n}} \qquad [1]$$

where,

$\bar{x}$ = is the sample mean,

$t_{1-\alpha,n-1}$ = is the student-t value for a give confidence interval (1- α) and *n* samples,

s = is the sample standard deviation, and

n = the number of samples.

If *n* is sufficiently large, $Z_{1-\alpha}$ may be used instead of $t_{1-\alpha,n-1}$.

Another descriptive statistic tests the assumption of normality using the *W* test developed by Shapiro and Wilk (1965). While other tests are available, the *W* test is considered one of the most powerful tests for detecting departure from normal or log-normal distributions for small (n<50) datasets (Gilbert, 1987). The test is computed by:

$$W = \frac{\left(\sum_1^k a_i\left(x_{n-i+1} - x_i\right)\right)^2}{\sum_1^n \left(x_i - \bar{x}\right)^2} \qquad [2]$$

where k=*n*/2 if n is even, k=(*n*-1)/2 if n is odd, and a_i are coefficients developed by Shapiro and Wilk (1965). Normality is rejected if the value of *W* is less than a value associated with *n* and the desired α. If normality is rejected, arithmetic descriptive statistics should not be used.

It is often difficult to reject normality in favor of a lognormal distribution with small sample sizes (Motulsky, 2007). In these cases SQE uses bootstrapping techniques or assumes a lognormal distribution of EMCs based on prior studies without compelling evidence to the contrary.

Log Transformed

Log transformed descriptive statistics assume the data follow a lognormal distribution. Descriptive statistics assuming a normal distribution were generally developed between 1920 and 1950 and have been well investigated. This is not the case with lognormal-based methods which have received less scrutiny (Singh et al., 1997). Further, with the advent of more powerful computers, older methods that may have been simpler should be replaced with more robust methods.

There are two primary methods to estimate the mean, μ, and the variance, σ^2, for lognormal data. (Note: It is tempting to estimate μ of a log-normal distribution using the geometric mean; however, the geometric mean is a bias estimator of the true mean of the data [Gilbert, 1987]). A simplified method to estimate μ and σ^2 for log-normally distributed data that has long been used and was accepted by EPA as part of the NURP report and the BMP database project (EPA, 1983; Geosyntec and Wright Water, 2009) is defined as follows:

$$\hat{\mu} = e^{\left(\bar{y}+\frac{s_y^2}{2}\right)} \qquad [3]$$

and

$$\hat{\sigma}^2 = \hat{\mu}^2\left(e^{s_y^2} - 1\right) \qquad [4]$$

where,

$\hat{\mu}$ = the estimate of the mean of data from a lognormal distribution,

$\hat{\sigma}^2$ = the estimate of the variance of data from a lognormal distribution,

$\bar{y}$ = the arithmetic sample mean of the log transformed data, and

s_y^2 = the sample variance of the log transformed data.

This method has been used by SQE in the past but it does have the drawback of having a positive bias. Kendall and Stuart (1961) found that the bias approaches zero as *n* becomes large. One advantage of this method is the simple computation; however, with current computing capacities this is not an issue. While this method has been widely used in the past to compute the mean of log-normally distributed data, the bias should be considered for small, highly variable datasets (Gilbert, 1987). The bias on the mean of Eqn. 3 may be estimated by:

$$\left(1-\frac{\hat{\sigma}^2}{n}\right)^{-(n-1)/2}\exp\left(-\frac{n-1}{2n}\hat{\sigma}^2\right) \qquad [5]$$

Finney (1941) and Sichel (1952, 1966) independently developed the minimum variance unbiased (MVE) method to compute the mean for log-normally distributed data. This method has been recommended by USEPA for computing the mean of log-normally distributed data (Singh et al., 1997). This method is defined as follows:

$$\hat{\mu} = \left(e^{\bar{y}}\right)\Psi_n\left(\frac{s_y^2}{2}\right) \qquad [6]$$

and

$$\hat{\sigma}^2 = \left(e^{(2\bar{y})}\right)\left[\Psi_n\left(2s_y^2\right)-\Psi_n\left(\frac{s_y^2(n-2)}{n-1}\right)\right] \qquad [7]$$

This report used Eqn. 6 and 7 means and variances of log-normally distributed data.

As with the mean and variance, there has been much confusion related to computing the confidence limits on the mean for log-normally distributed data. Using Eqn. 1 for lognormal data will produce biased results since the right hand tail of the lognormal data is much longer unless the data set is very large (Gilbert, 1987) assuming $\bar{x}$ and s are computed using Eqn. 6 and 7; however, no guidance is provided as to how large n needs to be.

Cox and modified Cox methods (Olsson, 2005) are similar procedures; the Cox method uses $Z_{1-\alpha}$ and the modified Cox method uses $t_{1-\alpha,n-1}$. As such they will be discussed together. The general form of the Cox equation is

$$\exp\left(\bar{y}+\frac{s^2}{2}\pm z_{1-\alpha}\sqrt{\frac{s^2}{n}+\frac{s^4}{2(n-1)}}\right) \qquad [8]$$

Both methods produced reasonable results but the modified Cox method produced slightly better results for smaller samples sizes. It should be noted that the estimation of the mean in the Cox method is based on the biased estimator in Eqn. 3.

Land (1971) proposed a generalized method to compute the confidence intervals for linear functions of the normal mean and variance. This method will work for many distributions given the correct coefficients and is the preferred method if the underlying distribution is lognormal (Gilbert, 1987). The upper and lower limits are expressed as:

$$UL_{1-\alpha} = \exp\left(\bar{y} + \frac{s_y^2}{2} + \frac{s_y H_{1-\alpha}}{\sqrt{n-1}} \right) \qquad [9]$$

and

$$LL_{\alpha} = \exp\left(\bar{y} + \frac{s_y^2}{2} + \frac{s_y H_{\alpha}}{\sqrt{n-1}} \right) \qquad [10]$$

The difficulty of using this approach had been computing the coefficient *H*, which is dependent on α, *n*, and s_y. Land (1975) provided tables with values for *H* but looking up values and interpolating for different values of *n* and s_y was tedious. Lyon and Land (1999) developed a computer program to compute values of *H* for a given set of variables or to create detailed tables for various values of α, *n*, and s_y. SQE has computed upper and lower limit values for *H* for α at 0.90, 0.95 and 0.975, *n* ranging between 6 and 51, and s_y between 0.10 and 4.00 (incremented by 0.01). These tables may be used as lookup tables to compute upper and lower limits on the means. While this method theoretically has the optimum properties when the data are log-normally distributed, field investigations (Hardin and Gilbert, 1993; Singh et al., 1997) found that it may overestimate the upper confidence limit if the data come from a mixed distribution or is poorly defined with a small dataset.

To overcome the limitations of all of these methods, SQE further modified the modified Cox approach to take advantage of the more robust estimate of the mean and used the following equations:

$$LCL = \frac{\hat{\mu}}{\exp\left(t_{\alpha,n-1}\sqrt{\frac{s^2}{n}+\frac{s^4}{2(n-1)}}\right)} \qquad [11]$$

$$UCL = \hat{\mu} \bullet \exp\left(t_{1-\alpha,n-1}\sqrt{\frac{s^2}{n}+\frac{s^4}{2(n-1)}}\right) \qquad [12]$$

where $\hat{\mu}$ is computed based on Eqn. 6.

The last descriptive statistic in the lognormal class is the W test. The same W test described in Eqn. 2 is used but on the log-transformed data. This is used to determine if the data fit the lognormal distribution. If not, the parameters in the section should be ignored.

Bootstrap

Bootstrapping refers to a resampling technique used to compute descriptive statistics. The tests are useful if the underlying data distribution is unknown or if the sample size is too small to make statistical inferences. However, if the underlying assumption is known with a degree of certainty to not be normal, it may produce misleading results based on the assumption of the computations.

Bootstrapping is accomplished by creating multiple synthetic datasets from the given data. A bootstrap dataset is created by selecting n random samples, with replacement from the given dataset, where n is the number of samples in the given dataset. Basic statistics are computed from this synthetic dataset using the assumption of normality. For example, the mean would be $\bar{x}_1$. A second synthetic dataset is created in the same manner resulting in $\bar{x}_2$. This is repeated a large number of times (for this report 1,000 synthetic datasets were used). The bootstrap statistic is created as follows:

$$\bar{x} = \frac{\sum_{n=1}^{1000} \bar{x}_n}{1000} \qquad [13]$$

This technique was used to estimate the mean, standard deviation and upper and lower confidence limits of the mean. The bootstrap statistics were used in cases where the *W* test either rejected both normal and lognormal distributions or accepted both distributions.

3.2 Comparative Statistics

While the descriptive statistics are common to other SQE reports, SCM analyses require comparative tests to evaluate performance. Traditionally, the only comparative statistic used for SCM evaluation was the efficiency ratio or percent removal. However, this may produce misleading results and does not indicate if the difference between the influent and effluent is statistically significant. It has been recommended by the International BMP Database project that this method of comparison not be used (Geosyntec and Wright Water, 2009).

This section will describe the shortcoming of using the efficiency ratio, describe the effluent probability method used in this report and outline the various comparative statistics used and when they may be appropriate. (Note: Throughout this report the level of significance is $\alpha \leq 0.05$ unless noted otherwise.)

Drawback of using Efficiency Ratio

The efficiency ratio compares the fractional change in the concentration at the influent and effluent of the SCM and is computed as follows:

$$ER = 1 - \frac{MC_{out}}{MC_{in}} \qquad [14]$$

where,

MC_{out} = is the mean or median concentration at the effluent,

MC_{out} = is the mean or median concentration at the influent.

The efficiency ratio may be computed using the median, as is the case with non-parametric results, or the mean computed in any manner described above. While this method has been used historically to evaluate SCM performance and is an easy-to-understand concept, its shortcomings are significant and therefore require an alternative measure of SCM performance. The main shortcoming of using the efficiency ratio is that it is primarily a function of influent quality. Higher influent concentrations into SCMs result in reporting of higher pollutant removals than those with cleaner influent. Two properly functioning SCMs with similar effluent concentrations may have very different efficiency ratios if the influent concentrations are different. In other words, use of percent removal may be more reflective of how “dirty” the influent water is than how well the SCM is actually performing. Secondly, an SCM may have a good percent removal but still have an unacceptable effluent concentration. Further, there is no indication whether the difference is statistically significant. For these and other reasons, the International BMP Database project does not recommend using efficiency ratios to evaluate performance as a stand-alone parameter.

The influent and effluent mean concentrations (MCs) and removal efficiencies of several pollutants are compared in Table 3.1 for two wet ponds which SQE has monitored: Wood Hollow and Ross Road. For most pollutants, COD, NH_3, TKN, TOC, TP, and TSS, the influent MCs at Ross Road wet pond are higher and the removal efficiencies are higher accordingly. However, the effluent MCs are higher (except TSS) at Ross Road. Evaluation of removal efficiency alone would lead to an erroneous conclusion that the Ross Road SCM is performing better even though the effluent concentrations are similar to those at Wood Hollow.

The efficiency ratio at Wood Hollow for Pb is a reasonable 64%, but the concentration is higher than Rose Road at 18.21 μg/L. In this case, the Wood Hollow pond appears to have a better efficiency ratio but the performance is worse than Ross Road. (Note: Wood Hollow was monitored during a period when leaded gasoline was still common.)

Another common problem with the use of efficiency ratios is that they may indicate the removal of a pollutant when there is no significant difference between the influent and effluent (Geosyntec and Wright Water, 2009). There may be a difference between the means (or medians) indicating removal, but that difference may not be statistically significant. If efficiency ratios are used, they should be accompanied by rigorous statistical analyses. Effluent probability analyses will allow for a more complete, and stable, comparison of the performance of SCMs.

Table 3.1: Comparison of MCs and removal efficiencies for two wet ponds

Parameter	**Wood Hollow**			**Ross Road**		
	MC_{in}	MC_{out}	ER	MC_{in}	MC_{out}	ER
COD	30.38	21.13	30%	96.1	30.9	68%
NH_3	0.2	0.16	20%	0.31	0.17	45%
Pb	50.67	18.21	64%	4.52	3.37	25%
TKN	0.7	0.68	4%	1.38	0.86	38%
TOC	6.93	6.16	11%	14.36	7.81	46%
TP	0.22	0.13	43%	0.54	0.24	56%
TSS	152.6	79.03	48%	285.72	71.02	75%

Non-Parametric Tests

One non-parametric test was used to compare effluent concentrations from different classes of SCMs. The Kruskal-Wallis (KW) test was used to compare the effluent datasets. The KW test is an extension of the Mann-Whitney U test to allow for the comparison of three or more groups. This test examines the rank order of the data sets and infers whether they came from the same population (Gilbert, 1987). This test is appropriate regardless of any underlying data distribution. In cases where the KW test indicated at least one data set was different from the others, pairwise comparisons were performed on the different combinations to determine which data sets were different.

Parametric Tests

The same parametric comparative statistics were computed using the assumptions of normal and lognormal distributions. For the assumption of a lognormal distribution, these tests were conducted using log transformed data. This does introduce an anomaly. Rather than comparing the means from lognormal data computed using Eqn. 6, the comparison is on the geometric means. Levels of significance should still be valid.

The primary parametric test used in this study was the Tukey's HSD test. This test compares the means of each data set to the means of all other data sets. The basic test statistic is:

$$q_s = \frac{Y_A - Y_B}{SE} \qquad [15]$$

Where,

Y_A = is the larger of the means being compared,
Y_B = is the smaller mean, and
SE = is the standard error of the data in question.

To simplify data presentation for both non-parametric and parametric comparisons, a letter was assigned to the mean of each class to indicate if it was significantly different from the others at the 0.05 level.

Data Plots

SQE generated two data plots to assist in comparing the effluent concentrations and to help interpret the results. The first plot is a lognormal probability plot with the concentration of the influent and effluent on the x-axis with a log scale and the probability the concentration is less than that value on the y-axis using a probability scale. The slope of a regression line through the data is a representation of the variance and the data cross 0.5 on the y-axis at the median.

These effluent probability plots help determine if the SCMs perform differently and how they behave across the full range of data, not just at the mean or median. There are four general types of effluent probability plots: Type I, the lines are parallel and separate – the variance is the same and the effluents are different across the range of data; Type II, the lines are parallel and not separate – the variances are equal so the effluent concentrations are not different across the range of data; Type III, the lines are not parallel and converge at the high or low end of the range – the variances are not equal, there is some difference in effluent concentrations across some portion of the data range, but there may be some limiting treatment factor affecting the data on the high or low range; and Type IV, the lines are not parallel and cross near the median – different variances and probable different treatment mechanisms, no statistical difference.

The second graph is box-and-whisker plot on a log scale. This may be used in a manner similar to the probability plot, indicating the range and distribution of the data.

4 Comparisons of Effluent EMCs for Different SCM Types

This report compares the performance of four different types of SCMs with respect to the effluent concentrations of eighteen different pollutants. These pollutants will be grouped into five general categories for discussion: solids, nutrients, metals, oxygen demand, and bacteria.

4.1 Solids

Two parameters are included in this group: total suspended solids (TSS) and volatile suspended solids (VSS). Solids are of primary concern because they may result in increased sediment load in creeks and may transport other pollutants adsorbed onto the solids. In the absence of other data, SCM performance with solids may be a good indicator of how it will perform with other pollutants.

Total Suspended Solids

The box-and-whisker plot and effluent probability plot for TSS effluent are shown in Figure 4.1. (The complete statistical summary may be found in table A.1 in the appendix.) Statistical analyses and the probability plot indicate that the effluent concentrations from a sand filter are significantly lower than those from a sedimentation basin. The probability plot for those two parameters is a Type I, indicating better performance from a sand filter across the range of data.

Wet ponds and biofiltration SCM data are more difficult to interpret. The probability plots are Type III with respect to the other SCMs and Type IV with respect to each other. Statistical analyses indicate that the effluent concentrations from these SCMs are not significantly different from each other but are significantly lower than sedimentation and higher than sand filtration. The box-and-whisker plot indicates a wide inter-quartile range (IQR) which may be a result of ‘ripening’ of the filtration media; because there are more fines in biofiltration media, the concentrations of TSS may be higher initially until those fines are flushed from the system, resulting in greater variability and a wider IQR. Performance of wet ponds may be impacted by settling as the treatment mechanism for solids, especially at lower concentrations. At lower concentrations, TSS is often composed of primarily smaller silt and clay-sized particles that have settling times measured in days and weeks rather than minutes for sand and aggregates, thus reducing the performance of wet ponds.

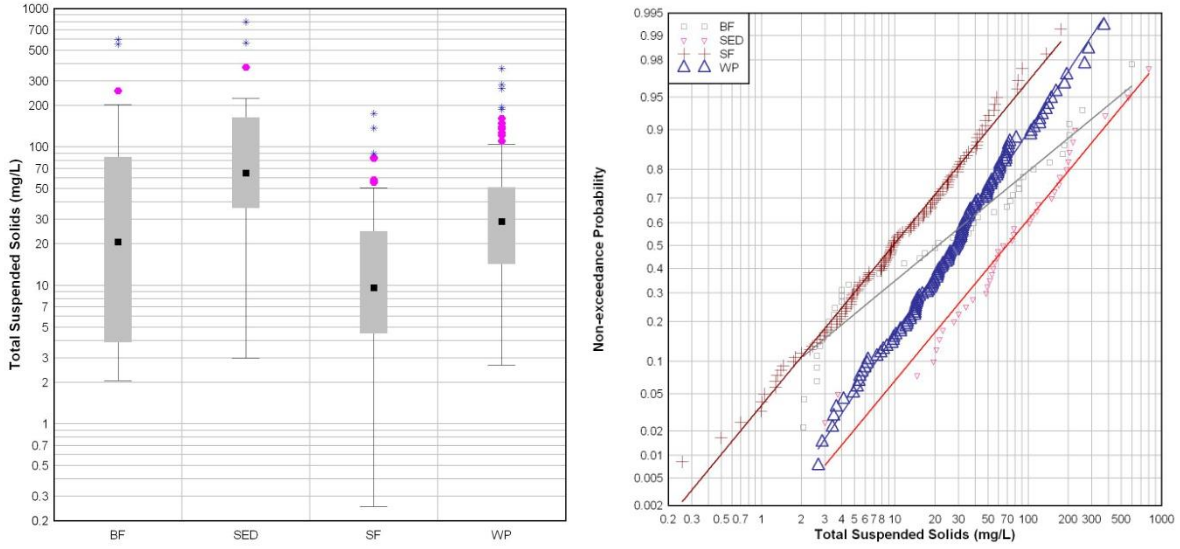

Figure 4.1: Box-and-whisker plot and lognormal non-exceedance probability plot of effluent TSS EMCs different SCM classes.

Volatile Suspended Solids

Figure 4.2 is the box-and-whisker plot and probability plot of effluent EMCs for VSS by SCM type. Sand filter, biofiltration and sedimentation effluent concentrations generally exhibit Type I effluent probability plots with sand filtration having the lowest concentrations followed by biofiltration. Wet pond concentrations generally displayed Type IV trends with respect to biofiltration and sedimentation. Statistical analyses were mixed (Table A.2) depending on parametric and non-parametric analyses. Non-parametric analyses suggest the effluent concentrations from all four SCM classes are significantly different. Parametric analyses found sand filter concentrations to be significantly lower than all SCMs and biofiltration concentrations to be significantly lower than sedimentation effluent concentrations. No significant differences existed between effluent concentrations from wet ponds compared to biofiltration and sedimentation when using log transformed parametric analyses.

In general, sand filters exhibited significantly lower effluent concentrations with respect to solids. Biofiltration and wet pond effluent concentrations were not significantly different from each other, while sedimentation concentrations were typically higher than the other SCMs.

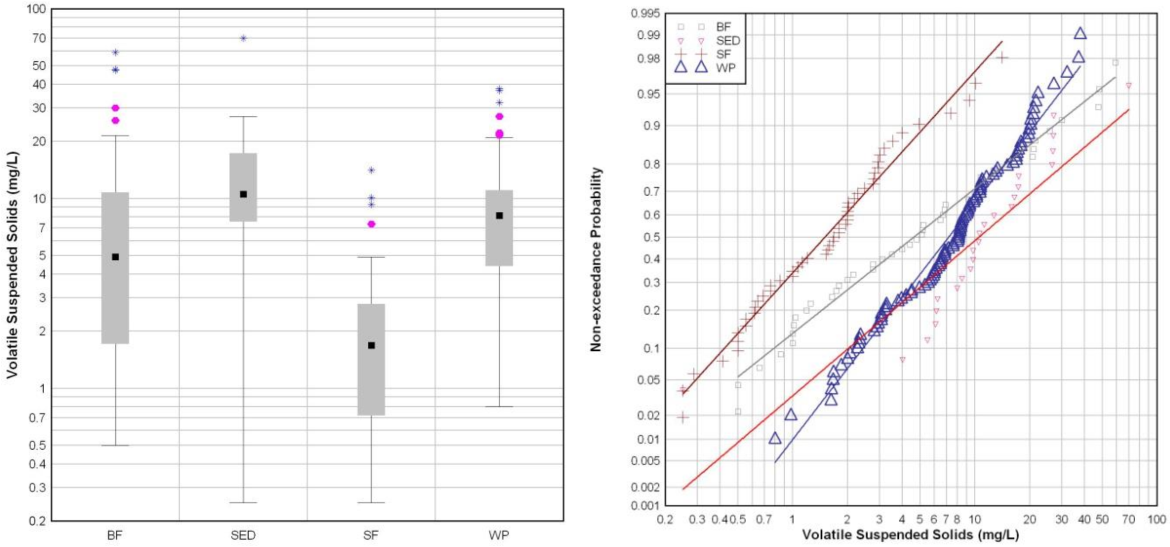

Figure 4.2: Box-and-whisker plot and lognormal non-exceedance probability plot of effluent VSS EMCs different SCM classes.

4.2 Nutrients

Six parameters are included in this group: total nitrogen (TN), nitrate plus nitrite (NO_2+NO_3), total Kjeldahl nitrogen (TKN), ammonia (NH_3), total phosphorus (TP), and dissolved phosphorus (DP). Nutrients are primarily of concern because excess nitrogen or phosphorus may cause algae blooms, affecting aesthetics and lowering dissolved oxygen that would be harmful to aquatic fauna.

Total Nitrogen

The box-and-whisker plot probability plot for total nitrogen effluent concentrations are presented in Figure 4.3 with statistical analyses in the appendix. The probability plots are Type IV and there are few notable differences seen in the box-and-whisker plot. Statistical differences are also weak. Parametric and non-parametric analyses indicated that sand filters have significantly lower effluent concentrations compared to biofiltration but no other trends are evident.

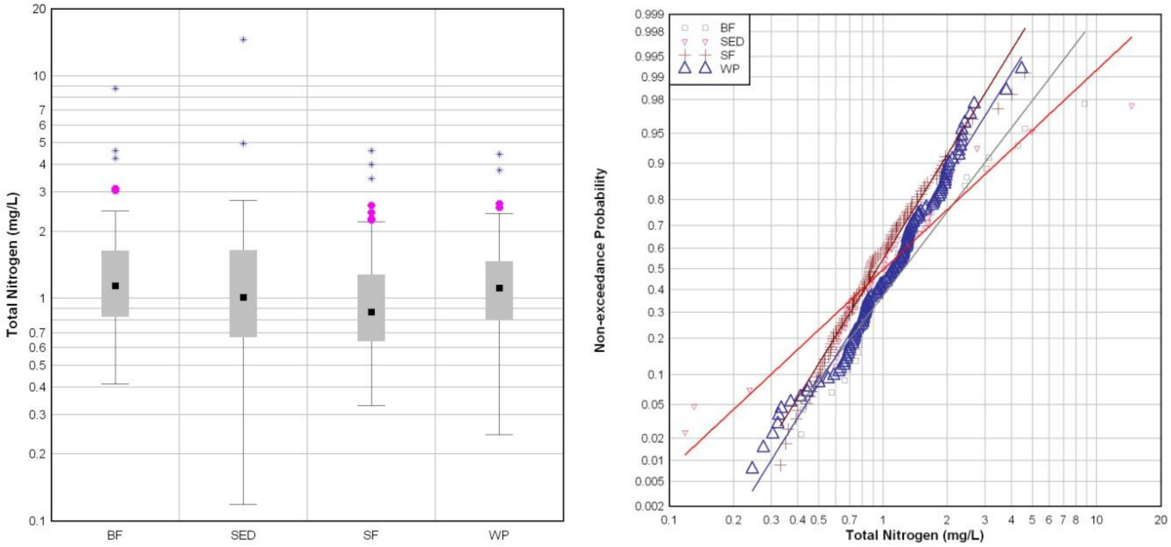

Figure 4.3: Box-and-whisker plot and lognormal non-exceedance probability plot of effluent TN EMCs different SCM classes.

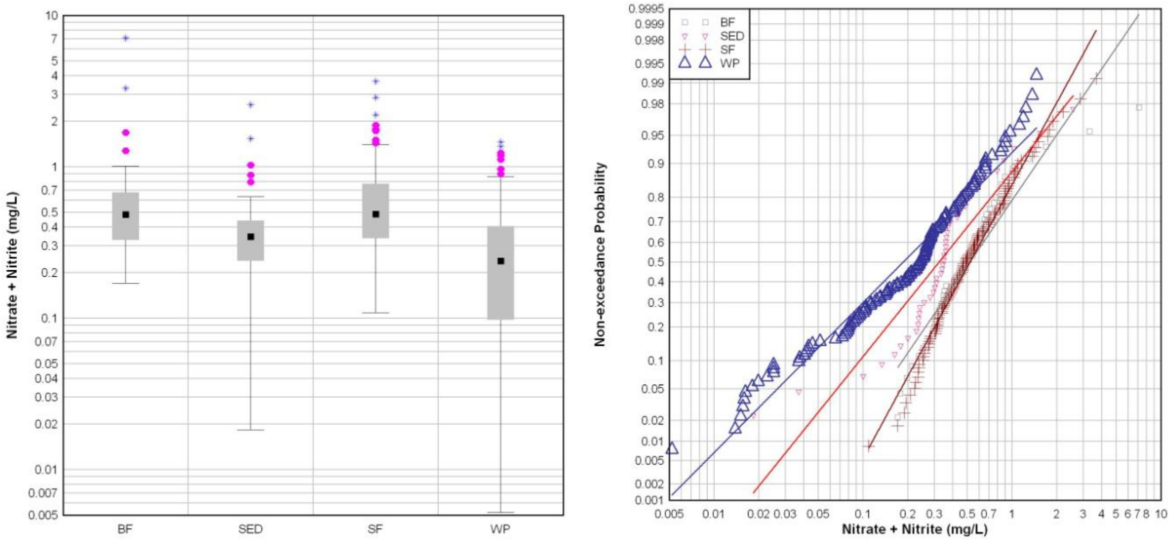

Figure 4.4: Box-and-whisker plot and lognormal non-exceedance probability plot of effluent NO_2+NO_3 EMCs different SCM classes.

Nitrate plus Nitrite

The box-and-whisker and probability plots for nitrate plus nitrite are in Figure 4.4. NO_2+NO_3 is one of the more problematic parameters in the nitrogen series because it is primarily in the dissolved phase. By comparing the plots in Figure 4.4 and the statistical results in Table

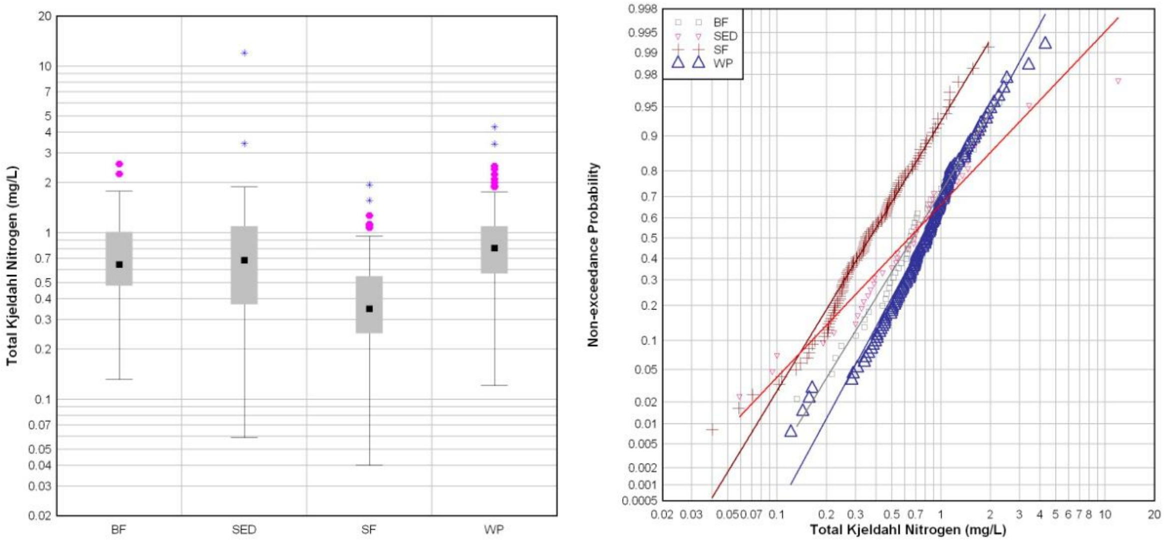

Figure 4.5: Box-and-whisker plot and lognormal non-exceedance probability plot of effluent TKN EMCs different SCM classes.

A.4, one notes that filtration type treatments (SF and BF) have higher effluent concentrations than both sedimentation and wet ponds. The probability plots are Type II for the filtration SCMs. In addition, effluent concentrations for NO_2+NO_3 are often higher than influent concentrations in sand filters, assumed to be due to conversion from others forms of nitrogen. Data for biofiltration are limited at this time and the media used in the biofiltration systems may be confounding the results. (A more detailed explanation of this will follow in Section 5.) Sedimentation effluent concentrations do not have a strong lognormal distribution but the concentrations appear to be less than the filtration SCMs and follow a Type III probability distribution. While the effluent concentrations are lower than filtration SCMs, there is little treatment of the runoff. Wet ponds effluent concentrations are significantly lower than those of the other SCMs. It appears that biological treatment, plant uptake or conversion to others forms of nitrogen may be the only viable treatment mechanisms for NO_2+NO_3.

Total Kjedahl Nitrogen

Unlike NO_2+NO_3, sand filters have significantly lower effluent concentrations of TKN compared to the other SCMs. (See Figure 4.5 and Appendix Table A.5.) There is no significant

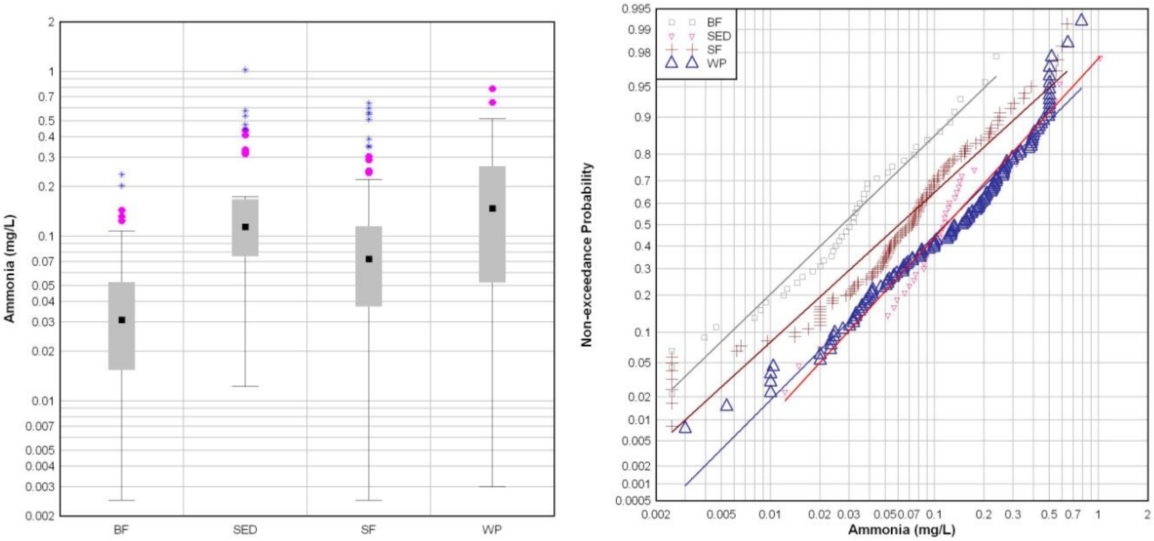

Figure 4.6: Box-and-whisker plot and lognormal non-exceedance probability plot of effluent NH_3 EMCs for different SCM classes.

difference among the other SCMs. Since TKN is primarily associated with particulate matter, this is not surprising. Once again, the results for biofiltration may be influenced by the media used in the biofiltration basins used in this study.

Ammonia

Ammonia presents an interesting case (Figure 4.6). While the effluent concentrations for other components of the nitrogen series were possibly elevated for biofiltration due to the media, ammonia effluent concentrations are significantly lower for biofiltration than for all other SCMs. Biofiltration has a Type I probability plot compared to the other SCMs. Sand filters have the second-lowest effluent concentrations and are significantly lower than wet ponds and sedimentation. Wet ponds and sedimentation basins exhibit Type II probability plots and have significantly higher effluent concentrations compared to the other SCMs.

Total Phosphorus

The results for TP are presented in Figure 4.7. Wet ponds and sedimentation basins display a Type II probability relationship with each other and a roughly Type III relationship with sand filters and biofiltration. Sand filter effluent concentrations are significantly lower than

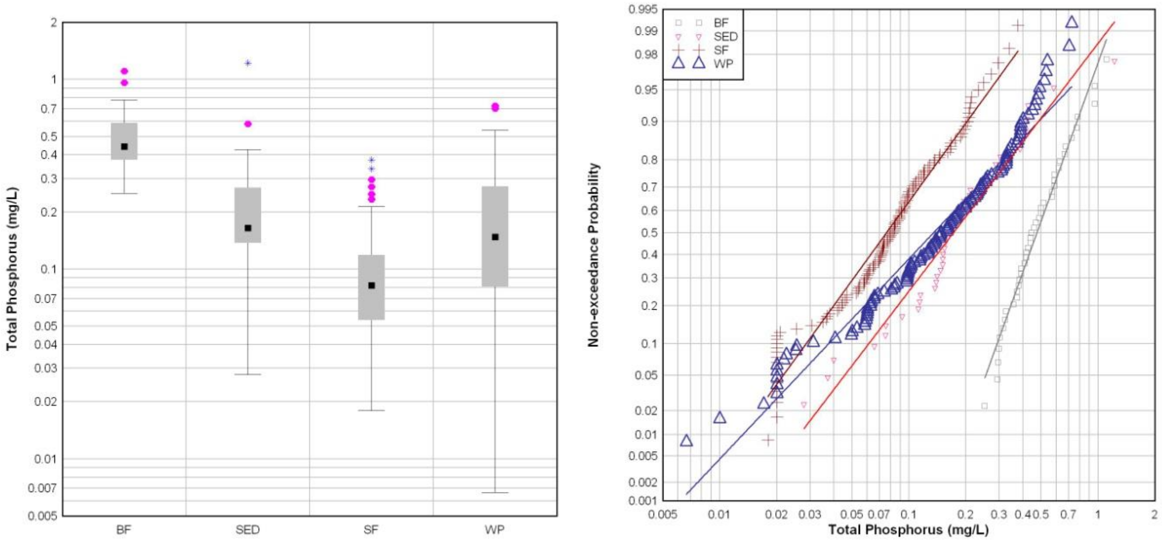

Figure 4.7: Box-and-whisker plot and lognormal non-exceedance probability plot of effluent TP EMCs different SCM classes.

the other SCMs, while effluent concentrations for biofiltration are significantly higher. Since most TP in the Austin area is associated with the particulate phase due to the pH of the soil, filtration is typically a good treatment mechanism for TP and other adsorbed pollutants like metals. This may not be the case in areas with more acidic soils.

Dissolved Phosphorus

Dissolved phosphorus (DP) results are similar to those for TP (Figure 4.8) in that the effluent concentrations from biofiltration are significantly higher than those from the other SCMs. The probability plots of the effluents from sand filters, wet ponds and sedimentation are generally Type III or Type IV and the effluent concentrations are not significantly different. The effluent probability plots for sand filters and biofiltration are Type I. Since the treatment mechanism for both is filtration, some other mechanism is increasing the concentrations for biofiltration, likely the filtration media.

In general, for nutrient effluent concentrations there is little difference between sand filters, wet ponds and sedimentation for pollutants that are adsorbed to particulates. Sand filters perform poorly with NO_2+NO_3 due to conversion from other forms of nitrogen, which is primarily a dissolved constituent. However, sand filters do perform well with DP, probably due

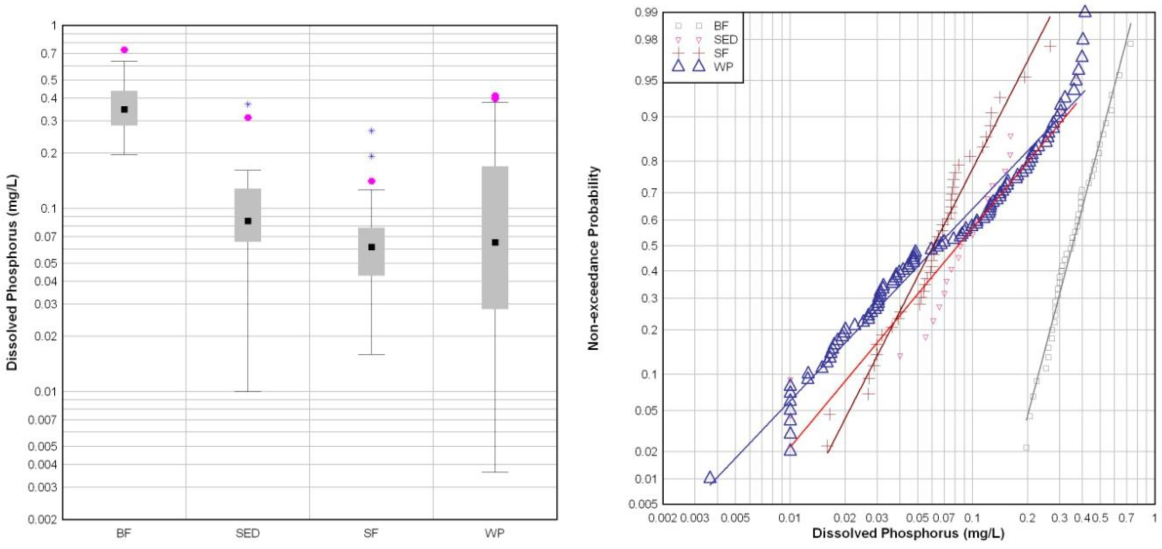

Figure 4.8: Box-and-whisker plot and lognormal non-exceedance probability plot of effluent DP EMCs different SCM classes.

to local condition (high pH soils) and the greater opportunity for DP to bind to particles. Biofiltration effluent concentrations were higher than expected, especially for TP and DP. This is likely due to the filtration media used in the biofiltration basins monitored for this study.

4.3 Metals

Four metals are included in this group: total lead (Pb), total zinc (Zn), total copper (Cu), and total cadmium (Cd). SQE has collected limited data on dissolved metals, total iron, and total silver. Those data will not be presented as a part of this report but will be referenced in cases where they may provide additional information of SCM performance.

Metals are normally associated with urbanization, primarily with automobiles. Two difficulties were present in analyzing the effluent concentrations for metals in this study. The first issue is related to Pb; some of the data from the early part of the study were collected when leaded gasoline was still available, which may have resulted in higher Pb concentrations in the effluent. The second issue is related to changing detection limits. As previously mentioned, in cases where the value of the effluent was reported as less than the detection limit, half the detection limit was used. This impacted the results for all metals except Zn but had the most impact on Cd.

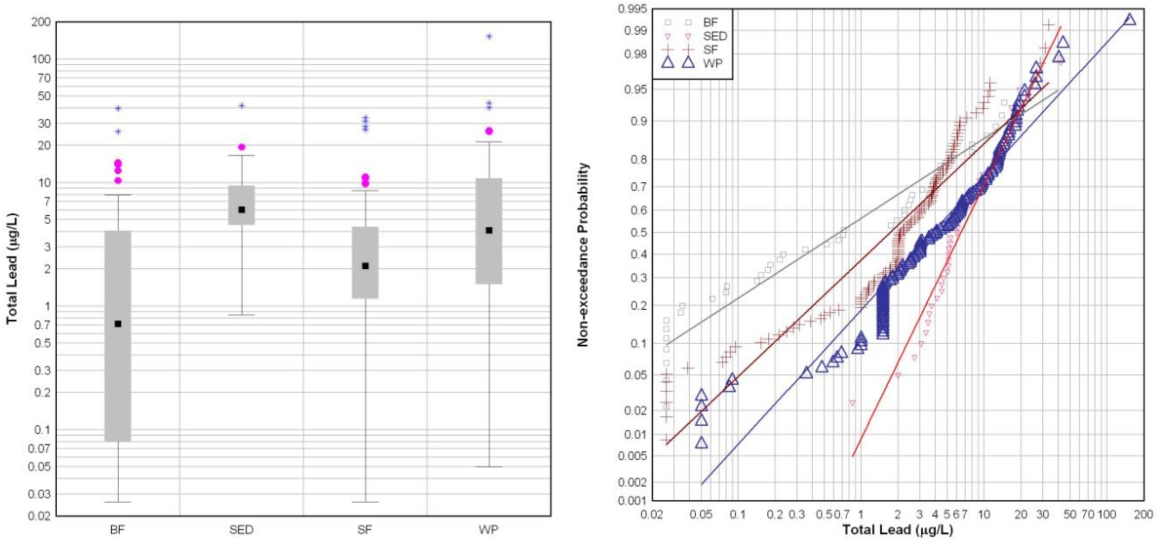

Figure 4.9: Box-and-whisker plot and lognormal non-exceedance probability plot of effluent Pb EMCs different SCM classes.

<u>Total Lead</u>

Figure 4.9 contains the box-and-whisker and effluent probability plots for total lead (Pb). The probability plots are Type III with the effluent concentrations converging on the upper range of the data. Non-parametric analyses indicate the effluent concentrations from all SCM types are significantly different, with biofiltration and sand filters having the lowest concentrations and wet ponds and sedimentation the highest. Parametric analyses are similar, with sand filters being significantly lower that all other SCMs followed by biofiltration. Wet ponds and sedimentation effluent concentrations were not significantly different from each other but were significantly higher than sand filter and biofiltration. This is likely due to the Pb being adsorbed and the filtration treatment mechanism being more effective at removing smaller particles with adsorbed Pb.

<u>Total Zinc</u>

Probability plots for effluent concentrations for total zinc (Zn) from biofiltration and sand filters are Type II (Figure 4.10). The data from sedimentation is Type I compared to the other two SCMs while wet pond data exhibit Type III behavior compared to other SCMs, converging

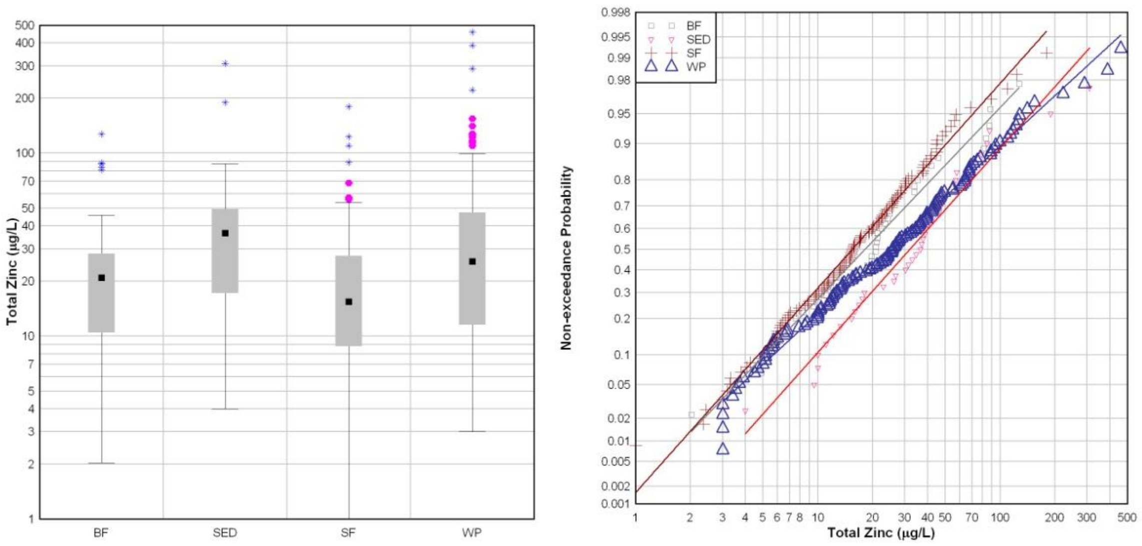

Figure 4.10: Box-and-whisker plot and lognormal non-exceedance probability plot of effluent Zn EMCs different SCM classes.

with sand filter and biofiltration on the low end and sedimentation on the upper end. Statistical tests (see Appendix Table A.10) are similar. Sand filter effluent concentrations are statistically lower than those from sedimentation and wet ponds. Biofiltration concentrations were statistically lower than those from sedimentation but not statistically different from sand filters or wet ponds.

Total Copper

Effluent concentrations of Cu (Figure 4.11) are similar to those of Zn but are confounded by detection limit issues. Concentrations from wet ponds and sand filters (Type II) are significantly lower than the effluent concentrations from sedimentation (Type I). Biofiltration effluent concentrations are not significantly different from other SCMs. The results from biofiltration may be influenced by the filtration media; while not presented in this report, SQE data indicate elevated effluent concentrations of dissolved Cu in biofiltration data.

Total Cadmium

The issue of detection limits is most notable in the probability plots for total Cd (Figure 4.12). All of the biofiltration data were analyzed using lower detection limits, resulting in a more uniform probability that is significantly lower than the others. Due to the confounding issues of detection limits, non-parametric analyses are more reliable and indicate the effluent concentrations from all SCM types are significantly different.

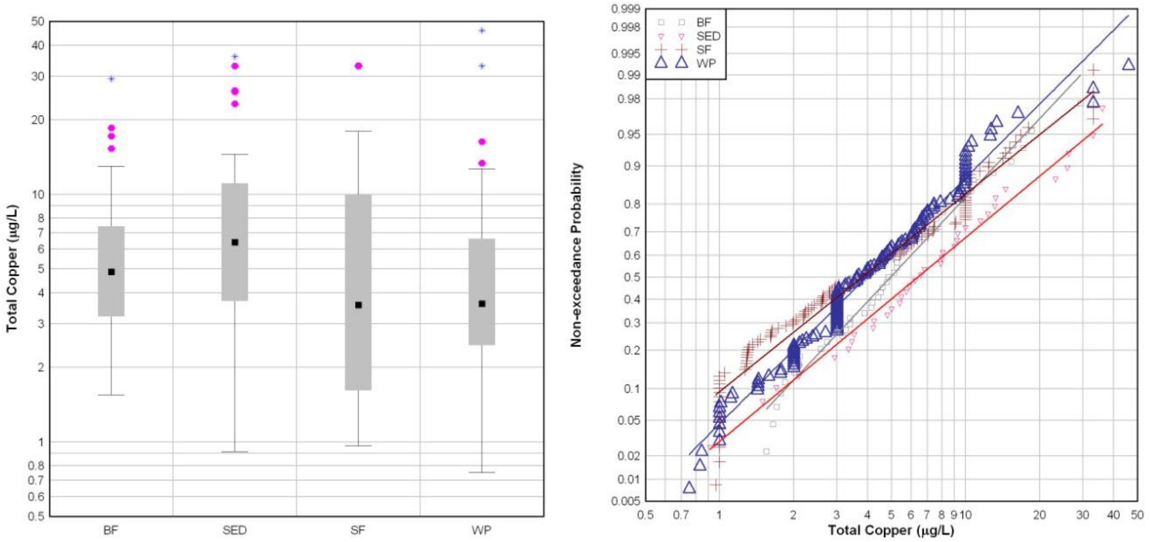

Figure 4.11: Box-and-whisker plot and lognormal non-exceedance probability plot of effluent Cu EMCs different SCM classes.

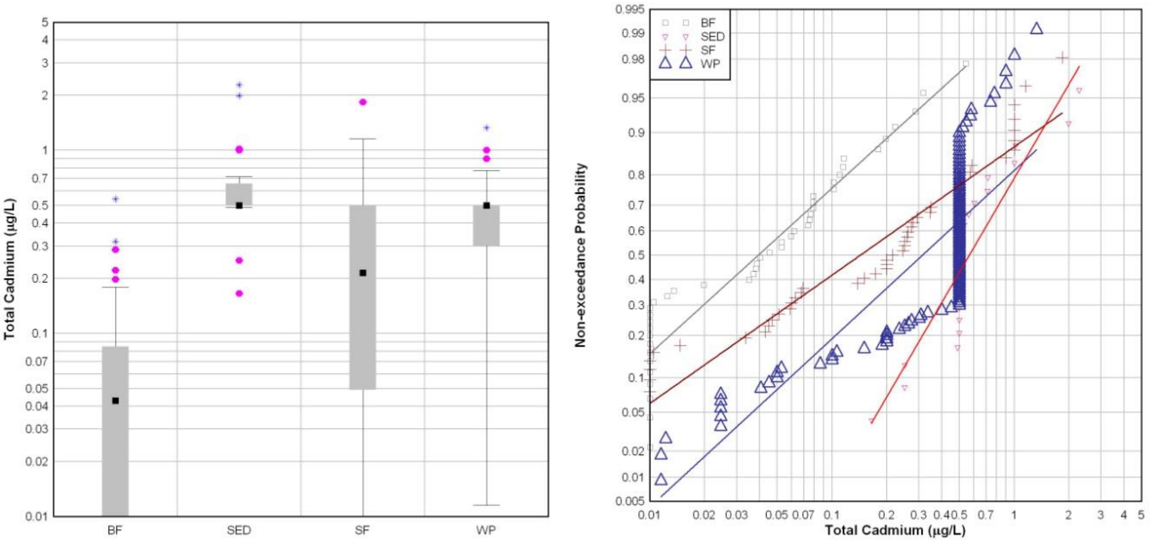

Figure 4.12: Box-and-whisker plot and lognormal non-exceedance probability plot of effluent Cd EMCs different SCM classes.

In general, in the Austin area where most of the metals are adsorbed, filtration is a superior treatment mechanism compared to sedimentation and wet ponds, which rely on settling.

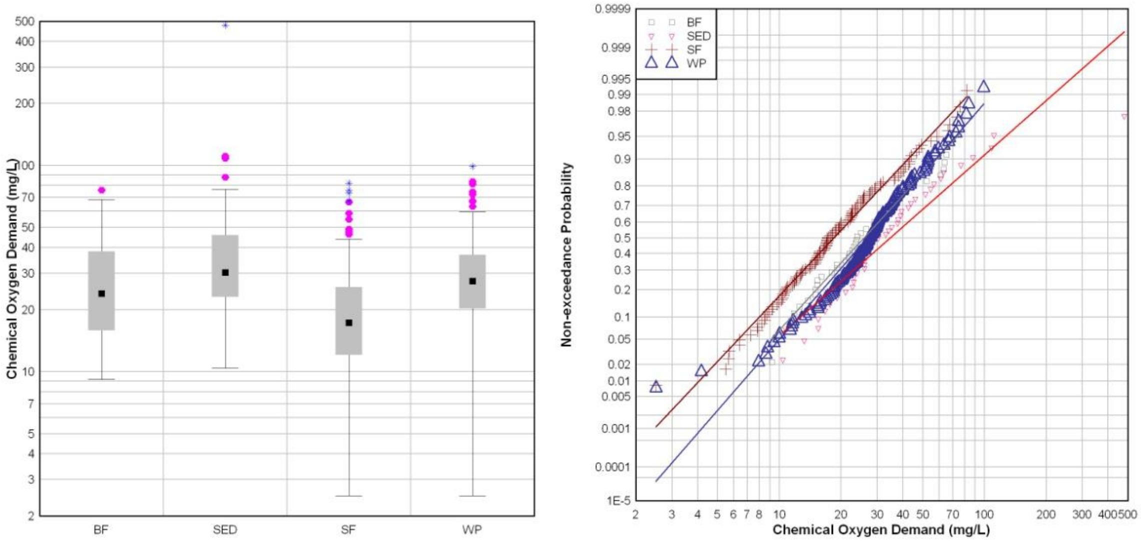

Figure 4.13: Box-and-whisker plot and lognormal non-exceedance probability plot of effluent COD EMCs different SCM classes.

Since most of the metals are adsorbed onto clay-sized particles, settling will be less effective unless the settling time is very long. The media used in biofiltration may have a negative impact on the effluent concentration of some metals which may have larger dissolved fractions.

4.4 Oxygen Demand and Organic Carbon

This category contains three parameters: chemical oxygen demand (COD), 5-day bio-chemical oxygen demand (BOD), and total organic carbon (TOC). The oxygen demand parameters measure how much dissolved oxygen the runoff will use. Dissolved oxygen is critical for aquatic fauna; if the oxygen demand is too high, the dissolved oxygen will drop to a level that will be harmful to aquatic species. Total organic carbon is included in that class because the organic carbon often has an oxygen demand associated with it.

<u>Chemical Oxygen Demand</u>

Figure 4.13 contains the box-and-whisker and effluent probability plots for COD. The probability plot of effluent concentrations from sand filters exhibit a Type I plot compared to the other SCMs. Statistical analyses (Appendix Table A.13) indicate the effluent concentrations from sand filters are significantly lower than other SCM. Effluent concentrations from sedimentation basins (43.8 mg/L) were higher than those from biofiltration and wet ponds (30.6 and 31.6 mg/L, respectively), but the difference was not statistically significant.

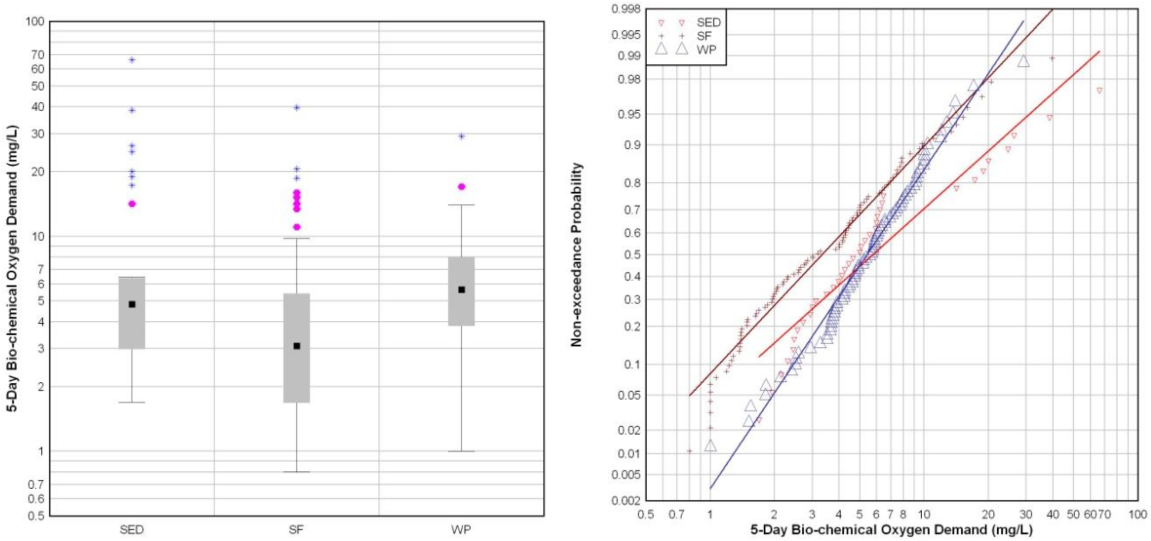

Figure 4.14: Box-and-whisker plot and lognormal non-exceedance probability plot of effluent BOD EMCs different SCM classes.

5-day Bio-chemical Oxygen Demand

BOD is a historical parameter that is no longer collected by SQE due to problems with holding time requirements. Therefore, there are no data for biofiltration. Effluent concentrations from sand filter and sedimentation have Type I probability plots (Figure 4.14) while wet pond concentrations tend to be Type III compared to the other two. Statistically, the effluent concentrations from sand filter SCMs are significantly lower than the other two SCM types.

Total Organic Carbon

Probability plots for TOC are generally Type IV (Figure 4.15). Statistically, the effluent concentrations from sand filters are lower that the effluent from sedimentation but there are no other statistical differences.

In general, sand filter effluent concentrations are significantly lower than that from other SCMs for the oxygen demand pollutants and for total organic carbon.

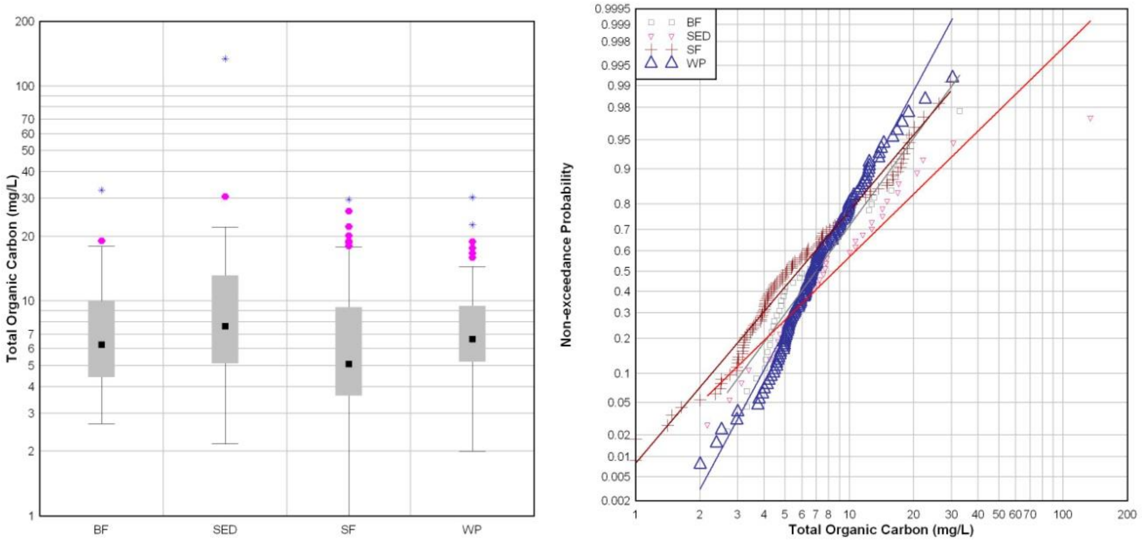

Figure 4.15: Box-and-whisker plot and lognormal non-exceedance probability plot of effluent TOC EMCs different SCM classes.

4.5 Bacteria

Three parameters are included in this group: *Escherichia coli* (EC), *Fecal coliform* (FCOL) and *Fecal Streptococci* (FSTR). These bacteria are generally considered indicators of other more harmful pathogens and are often limiting factors with respect to contact recreation in area water bodies. There are also ongoing TMDL plans in several Austin area watersheds related to bacteria.

SQE has not collected regular bacteria samples for some time due to issues with holding times. However, there is a large historical data set for FCOL and FSTR and more recent EC data have been collected for biofiltration. Since EC was not collected historically, EC concentrations for historical data were estimated by a relationship with FCOL developed based on COA monitoring data (Richter, 2013).

Escherichia Coli

Box-and-whisker and effluent probability plots for EC are in Figure 4.16. The effluent concentration probability plots for sand filters and biofiltration are general Type II and have lower concentrations than the other SCMs. Sedimentation probability plots are generally Type I compared to sand filter and biofiltration and have higher concentrations. Wet pond effluent concentrations produced a Type III plot compared to the other SCMs with a mean concentration similar to sedimentation. Filtration SMCs had significantly lower EC effluent concentrations.

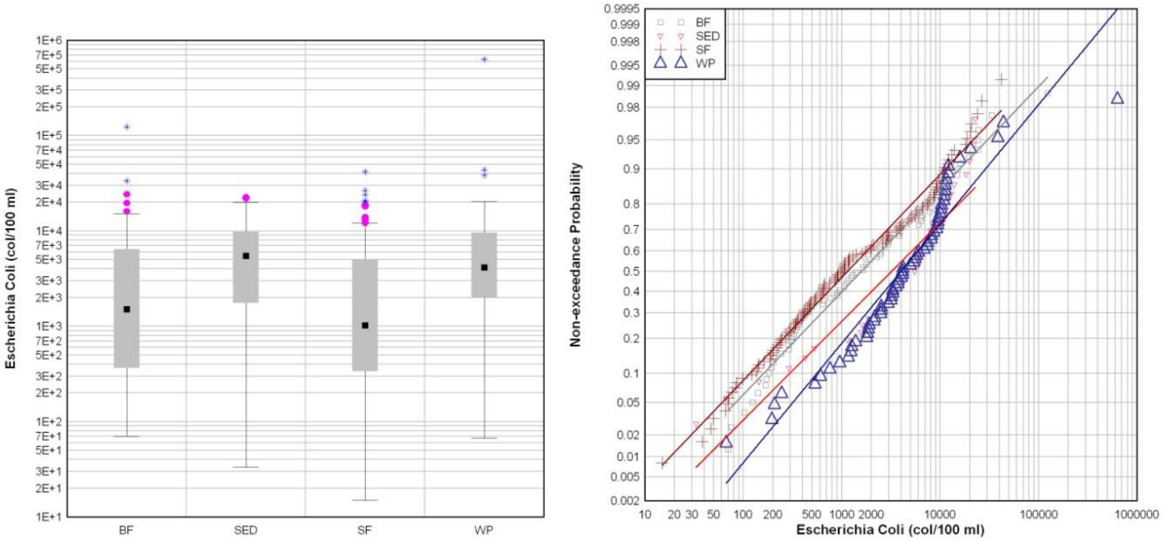

Figure 4.16: Box-and-whisker plot and lognormal non-exceedance probability plot of effluent EC EMCs different SCM classes.

Fecal Coliform

The FCOL plots (Figure 4.17) are similar to those for EC, which is not surprising since many of the EC data points were estimated from FCOL. Sand filter effluent concentrations for FCOL were significantly lower than those from wet ponds and sedimentation. Wet pond effluent concentrations were also significantly higher than those from biofiltration.

Fecal Streptococci

FSTR is a historical bacteria parameter that is no longer collected by SQE but the data are presented here (Figure 4.18) for reference. The sedimentation and wet pond probability plots are Type II compared to each other and Type I compared to sand filters. The effluent concentrations from sand filters were significantly lower than that from wet ponds and sedimentation.

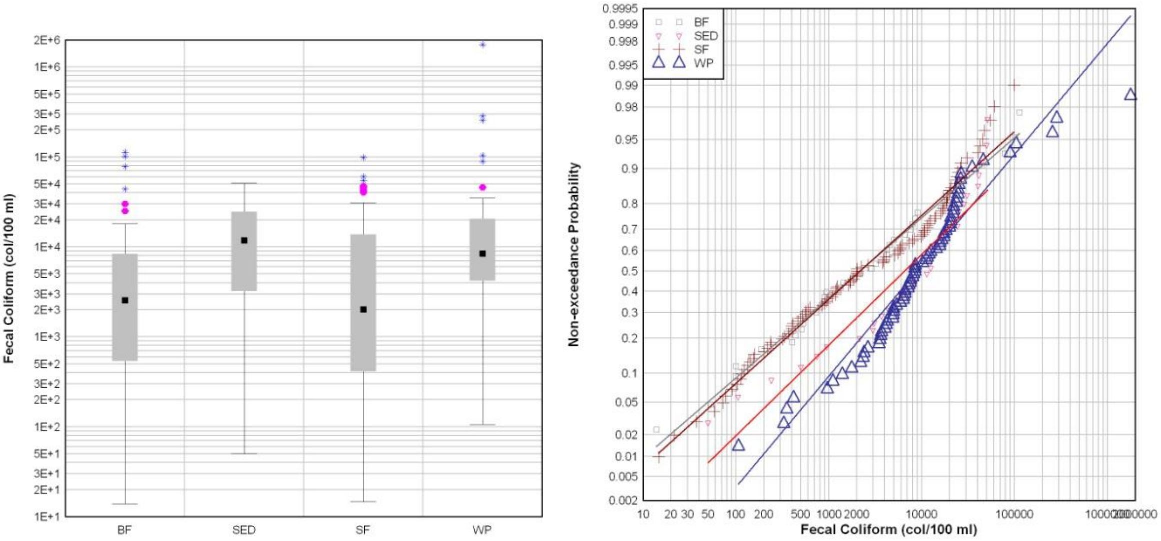

Figure 4.17: Box-and-whisker plot and lognormal non-exceedance probability plot of effluent FC EMCs different SCM classes.

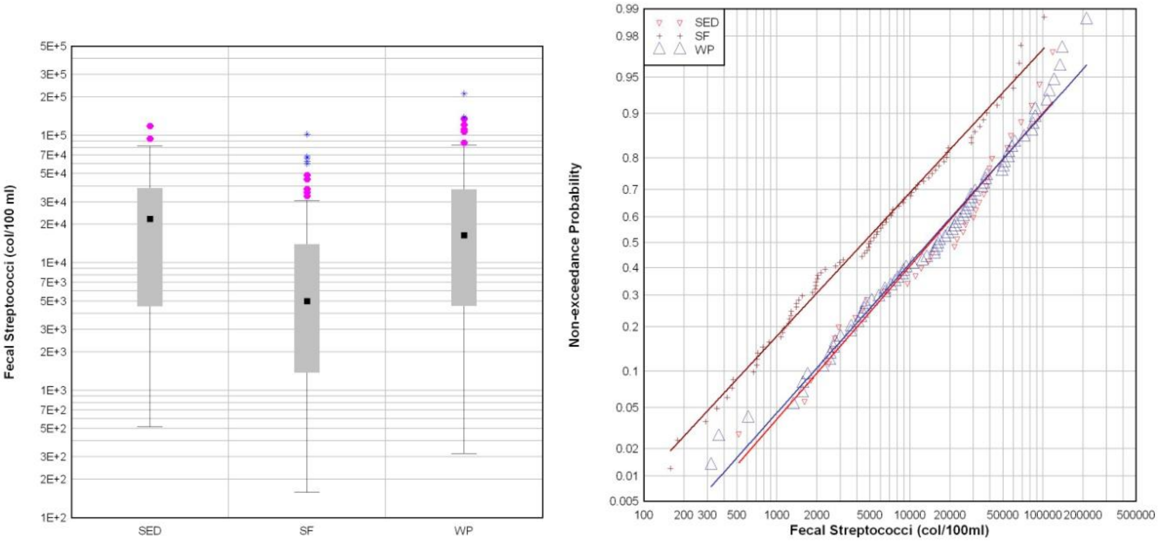

Figure 4.18: Box-and-whisker plot and lognormal non-exceedance probability plot of effluent FS EMCs different SCM classes.

In summary, the effluent EMCs for bacteria pollutant parameters were lower for filtration-type SCMs. This may be due to the bacteria adhering to filtration media. It has been hypothesized that there may be predation of bacteria in some filtration designs but the contact time for this to occur is limited in most designs included in this study.

4.6 Summary of Results

Overall, sand filters had the lower effluent concentration for most pollutants, the notable exception being NO_2+NO_3. It has been assumed that the poor performance of sand filters related to NO_2+NO_3 is a result of the conversion of nitrogen from other forms. This appears to be a reasonable assumption given the performance for other forms of nitrogen. Wet pond effluent concentrations of NO_2+NO_3 were the lowest of the SCMs studied but performance for other SCMs was limited. Biofiltration effluent concentrations were similar to sand filter concentrations with the notable exceptions of Cu, phosphorus and to a lesser extent nitrogen. The poor performance of biofiltration with respect to these parameters is likely a result of filtration media and will be more fully explored in the next section. Sedimentation effluent concentrations tended to be the highest among the SCM classes studied with the exception of NO_2+NO_3 and the pollutants that have been noted as problematic for biofiltration.

5 Special Comparison of Canyon Creek Sand Filter and Biofiltration

Originally built in 1996 to test the possibilities of bio-activation using different microbes in sand filters, the Canyon Creek SCM is unique because it has one sedimentation basin delivering runoff to two filtration basins. The system was retrofitted in 2008 with a sand media on one side (CCS) and a biofiltration media on the other side (CCN). Bermudagrass turf was planted in the biofiltration media while the sand was left bare. The Canyon Creek filtration basin presents a unique opportunity to directly compare the performance of different filtration media.

With respect to nutrients, concentrations of total phosphorus and dissolved phosphorus in the effluent are significantly greater from the biofiltration media (Figure 5.1). In addition, the sand filter removed total P and was neutral for dissolved P while the biofiltration media exported in both cases. It has been hypothesized that biofiltration media may export nutrients initially but the concentration will decrease over time. These data cover two years and this trend was not observed (Figure 5.2). There was a temporal trend that was dependent on the growing season; high concentrations were observed in the biofiltration effluent during warmer periods when vegetation was active. This trend was not observed with the sand filter effluent. The concentrations of the various nitrogen species were similar from both media. The biofiltration media had slightly higher concentrations for total N and TKN (Figure 5.3). Both media exported nitrate but exhibited marginal removal of other nitrogen species.

With respect to metals, both media have similar effluent concentrations of total and dissolved Cd, Pb and Zn. However, the effluent concentrations for total and dissolved Cu were higher from the biofiltration media (Figure 5.4). While the sand filter had moderate removal of total Cu, the biofiltration effluents were similar to the influent concentrations. For dissolved Cu the sand filter was minimally effective while the biofiltration media exported dissolved Cu.

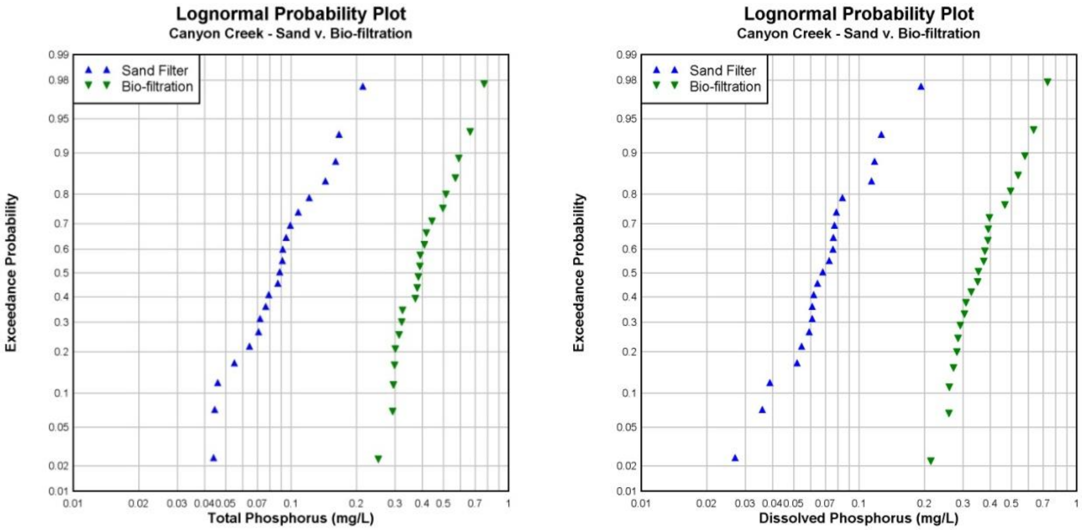

Figure 5.1: Comparison of effluent concentrations for TP and DP at Canyon Creek

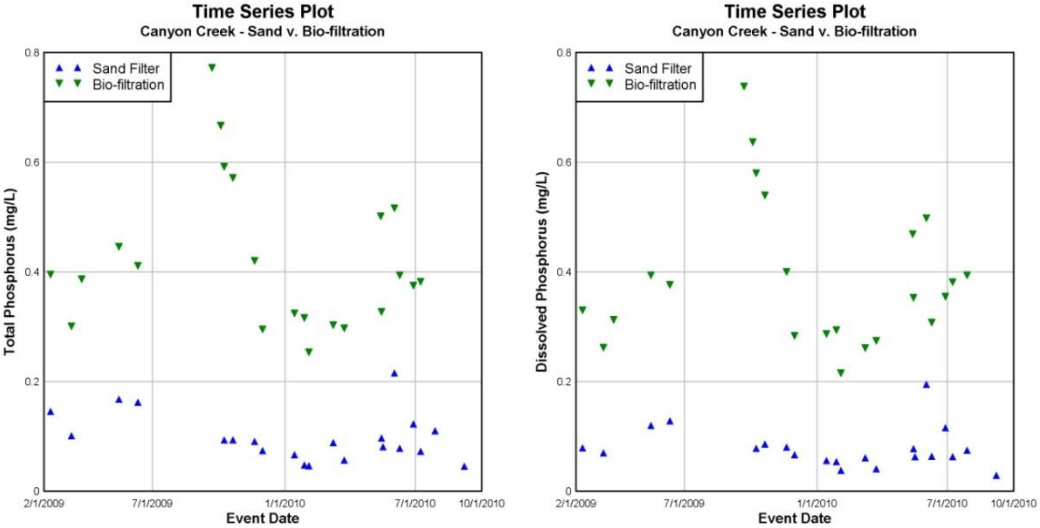

Figure 5.2: Change of effluent concentrations over time for TP and DP at Canyon Creek

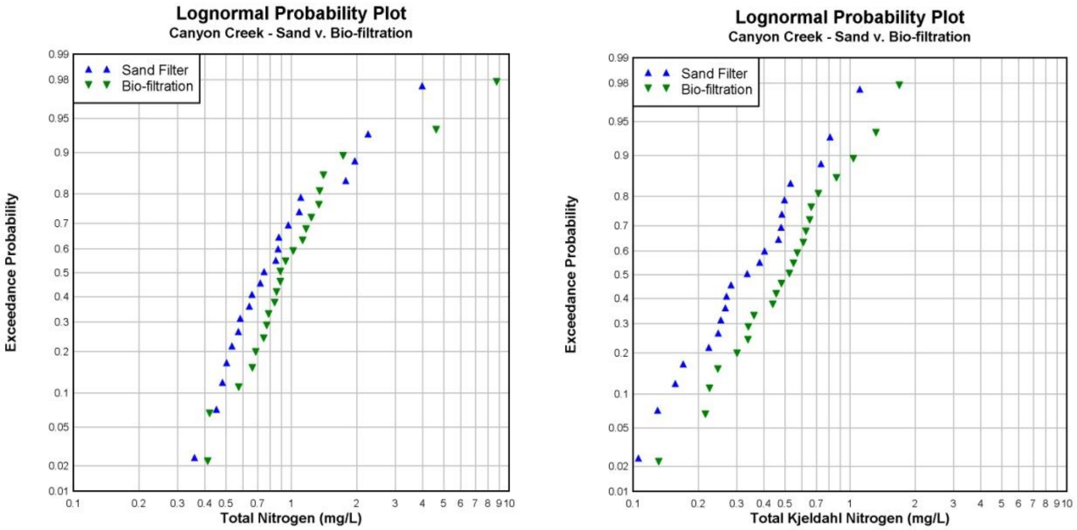

Figure 5.3: Comparison of effluent concentrations for TN and TKN at Canyon Creek

This would indicate that the biofiltration media are leaching Cu. There were slight temporal trends related to temperature.

For the other constituents measured including bacteria, solids, organic carbon, oxygen demand, and hardness, the only difference between the media was in hardness. In both cases the hardness was higher in the effluent than in the influent with the effluent from the biofiltration media having higher levels.

The comparison of performance for different filtration media at Canyon Creek shows that for most pollutants, the effluent concentrations are similar for both media. The biggest effluent concentration differences were observed in total and dissolved phosphorus. The effluent concentration differences were also observed in total nitrogen, total Kjeldahl nitrogen, and total and dissolved Cu. For all these differences, the effluent concentrations from biofiltration media were higher than the effluent concentrations from sand media.

These increases in nutrients, especially phosphorus and Cu, are likely due to the media used in the biofiltration basin. At the time of the retrofit of the system, COA biofiltration media specifications allowed for the incorporation of compost in to the media. Canyon Creek biofiltration media included 20% Dillo-Dirt™ in the media. Dillo-Dirt™ is compost made from

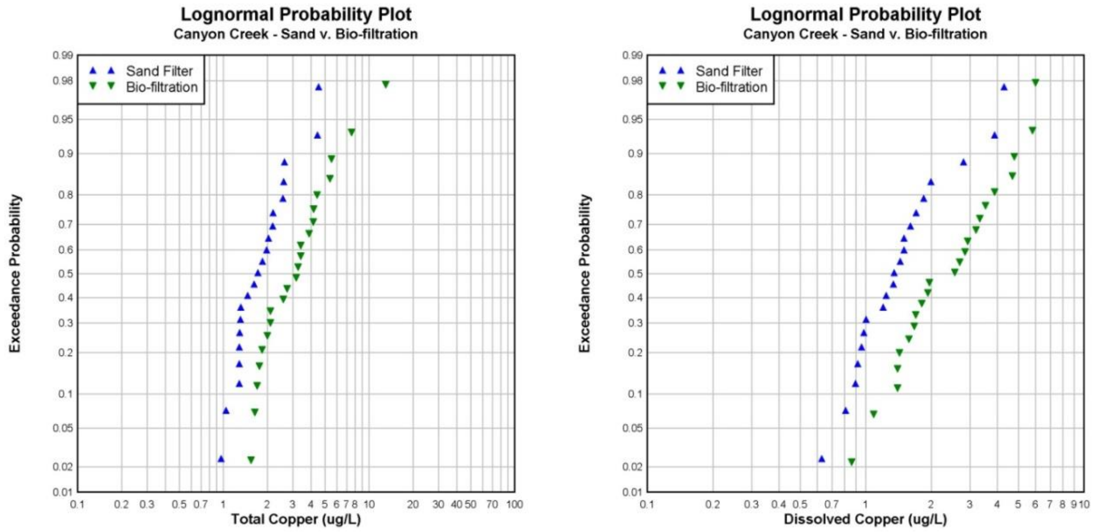

Figure 5.4: Comparison of effluent concentrations for total and dissolved Cu at Canyon Creek

sewage sludge and known to be high in phosphorus. Current COA biofiltration media guidelines specifically disallow compost of any kind due to the problem of exporting nutrients. Preliminary monitoring by SQE is indicating that removal of compost from the media is having the desired effect of reducing the export of nutrients and metals compared biofiltration media with compost. This information may also be useful in the design of other SCMs that use growing media, like green roofs.

In summary, the comparison of performance for different filtration media at Canyon Creek shows that for most pollutants, the effluent concentrations are similar for both media. The biggest effluent concentration differences were observed in total and dissolved phosphorus. The effluent concentration differences were also observed in total nitrogen, total Kjeldahl nitrogen, and total and dissolved Cu. For all these differences, the effluent concentrations from biofiltration media were higher than the effluent concentrations from sand media. Given the media used in the Canyon Creek biofiltration basin, the biofiltration basin exported nutrients and Cu but otherwise performed equivalently to a sand filter. Adjusting the media mix should result in overall biofiltration performance meeting or exceeding sand filters.

6 Recommendations for Expected Effluent Concentrations

The results of this study may be used to estimate runoff loads from developed sites in two ways. First, the mean effluent concentration for different SCM types (Table 6.1) may be applied to the volume of treated runoff on an average annual basis to estimate the load from a site. This would be similar to the procedure outlined in the City of Austin Environmental Criteria Manual (COA, 2013).

The second method would require a more rigorous approach using continuous simulation of the runoff and Monte Carlo simulation of the effluent concentration. For each runoff event, the effluent concentration for each parameter from the SCM would be randomly generated using a random number generator and the mean and standard deviation specified in Table 6.1, assuming a lognormal data distribution. This approach would also allow for an examination of exceedance frequencies in cases where that may be a concern.

Table 6.1: Summary of effluent EMC statistics for different SCM types, assuming a lognormal data distribution. Units are in mg/L for all parameters except metal (Pb, Zn, Cu, and Cd) which are in µg/L and bacteria (EC, FCOL and FSTR) which are cfu/100 mL.

Parameter	SED		SF		BF*		WP	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
TSS	133.8	208	20.62	37.61	85.7	274.9	44.6	57.2
VSS	17.35	21.29	2.287	2.555	10.25	18.66	9.919	9.377
TN	1.42	1.38	1.07	0.60	1.50	0.99	1.24	0.70
NO_2+NO_3	0.452	0.433	0.63	0.429	0.667	0.534	0.347	0.537
TKN	0.996	1.161	0.452	0.327	0.815	0.569	0.927	0.584
NH_3	0.188	0.226	0.125	0.218	0.050	0.074	0.215	0.329
TP	0.224	0.184	0.099	0.082	0.504	0.182	0.211	0.250
DP	0.12	0.12	0.072	0.046	0.368	0.117	0.122	0.193
Pb	8.31	6.59	5.74	16.95	7.50	50.12	9.94	23.01
Zn	45.30	44.42	22.96	24.94	27.32	29.92	43.88	64.82
Cu	9.49	10.14	5.98	7.20	6.31	4.96	5.34	4.85
Cd	0.664	0.405	0.461	1.231	0.078	0.124	0.526	0.696
COD	43.79	33.35	22.4	15.45	30.6	19.37	31.58	19.52
BOD	8.50	8.97	4.65	4.47	---	---	6.40	4.05
TOC	11.45	10.02	7.33	5.74	8.20	5.03	7.77	3.60
EC	11065	29719	4895	18459	6452	22214	12138	28978
FCOL	28249	90018	17990	118436	18139	97841	27569	73212
FSTR	34524	67436	14288	39272	---	---	39433	96850

* As noted previously, values for biofiltration do not reflect effluent concentrations from systems using currently approved biofiltration media mixes. Use of these values may result in a misleading conclusion.

7 Conclusion

Use of rigorous statistical analyses and effluent probability allow for a more complete and stable comparison of the performance of SCMs.

With respect to solids (total suspended solids, TSS, and volatile suspended solids, VSS), sand filters exhibited significantly lower effluent concentrations. Effluent concentrations from biofiltration and wet ponds were not significantly different from each other, while effluent concentrations from sedimentation were typically higher than those from other SCMs.

With respect to ammonia (NH_3), the effluent concentrations were lowest for biofiltration basins and second lowest for sand filters. There was no significant difference between effluent concentrations for NH_3 from sedimentation basins and effluent concentrations from wet ponds. The effluent concentrations for nitrate and nitrite (NO_2+NO_3) were lowest for wet ponds. There was no significant difference between effluent concentrations for NO_2+NO_3 from each other for other SCMs.

With respect to total nitrogen (TN), the only significant difference between effluent concentrations was between those from biofiltration basins and sand filters, and the effluent concentrations for TN from sand filters were lower than the effluent concentrations from biofiltration basins. The effluent concentrations for total Kjeldahl nitrogen (TKN) were lowest from sand filters. There was no significant difference between effluent concentrations for TKN from each other for other SCMs.

With respect to dissolved phosphorus (DP), the effluent concentrations were highest from biofiltration basins. There was no significant difference between effluent concentrations for DP from each other from other SCMs. The effluent concentrations for total phosphorus (TP) were lowest from sand filters and highest from biofiltration basins. There was no significant difference between effluent concentrations for TP from sedimentation basins and effluent concentrations from wet ponds.

With respect to metals, the effluent concentrations for total cadmium (Cd) were lowest from biofiltration basins and highest from sedimentation basins. There was no significant difference between effluent concentrations for Cd from sand filters and effluent concentrations from wet ponds. The effluent concentrations for total copper (Cu) from sedimentation basins were higher than the effluent concentrations from sand filters and wet ponds. There was no significant difference between effluent concentrations for Cu for other SCMs. The effluent concentrations for total lead (Pb) were lowest from biofiltration basins and highest from sedimentation basins. There was no significant difference between effluent concentrations for Pb from sedimentation basins and from wet ponds. The effluent concentrations for total zinc (Zn) were lower in biofiltration basins than from sand filters, and there was no significant difference between them. There was no significant difference between effluent concentrations for Zn from sedimentation basins and from wet ponds.

With respect to oxygen demand (5-day biochemical oxygen demand, BOD, and chemical oxygen demand, COD), the effluent concentrations were lowest from sand filters. There was no significant difference between effluent concentrations from each other from other SCMs.

With respect to total organic carbon (TOC), the only significant difference for effluent concentrations was between sand filters and sedimentation basins. The effluent concentrations from sand filters were lower than the effluent concentrations from sedimentation basins.

Comparing the performance for Canyon Creek sand and biofiltration, the effluent concentration differences from different media were only observed in total nitrogen (TN), total Kjeldahl nitrogen (TKN), and total and dissolved Cu. In all these cases, the effluent concentrations from biofiltration media were higher than the effluent concentrations from sand media due to the use of compost in the biofiltration media.

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Appendix A Statistical Summaries for Different SCMs

Table A.1: Statistical summary for TSS effluent concentrations (mg/L) from selected SCMs in the Austin, TX area.

Type	Statistic	SED	SF	BF	WP
Non-Parametric	Count	39	119	44	135
	Maximum	800	175.3	595.8	369.1
	Upper Quartile	169.4	24.9	85	52.5
	Median	64.7	9.6	20.6	29
	KW	acd	abd	bc	bc
	Lower Quartile	34	4.4	3.8	14.3
	Minimum	3	0.3	2	2.7
Arithmetic	UCL	174.7	23.6	114.2	53.9
	Mean	124.1	19	75	44.6
	Tukey	acd	ab	bc	b
	LCL	73.5	14.4	35.9	35.3
	Std. Dev.	156.2	25.5	128.8	54.6
	Wilk	0.6619	0.6493	0.5984	0.6471
	Wilk (p-value)	0.0001	0.0001	0.0001	0.0001
Log Transformed	UCL	220.2	27.8	196.8	55
	Mean	133.8	20.6	85.7	44.6
	Tukey	acd	abd	bc	bc
	LCL	81.2	15.3	37.3	36.2
	Std. Dev.	208	37.6	274.9	57.2
	Wilk	0.9688	0.9926	0.9222	0.9919
	Wilk (p-value)	0.3448	0.7812	0.0057	0.6343
Bootstrap	UCL	177.2	23.9	116.1	54.4
	Mean	127.5	19.3	77.5	45.1
	LCL	77.8	14.7	38.9	35.8
	Std. Dev.	153.2	25.4	127	54.7

In the KW and Tukey fields indicate that SCM is significantly different ($\alpha<0.05$) from the other specified SCM. ‘a’ indicates different than BF, ‘b’ indicates different than SED, ‘c’ indicates different than SF, and ‘d’ indicates different than WP.

Table A.2: Statistical summary for VSS effluent concentrations (mg/L) from selected SCMs in the Austin, TX area.

Type	**Statistic**	**SED**	**SF**	**BF**	**WP**
Non-Parametric	Count	24	51	44	100
	Maximum	70	14.1	58.8	37.8
	Upper Quartile	17.4	2.8	10.8	11.2
	Median	10.6	1.7	4.9	8.1
	KW	acd	abd	bcd	abc
	Lower Quartile	7.1	0.7	1.7	4.3
	Minimum	0.3	0.3	0.5	0.8
Arithmetic	UCL	21	3.1	14.1	11.1
	Mean	15.1	2.3	10	9.6
	Tukey	cd	abd	c	bc
	LCL	9.2	1.6	5.8	8.1
	Std. Dev.	14	2.6	13.5	7.4
	Wilk	0.7063	0.666	0.6865	0.8516
	Wilk (p-value)	0.0001	0.0001	0.0001	0.0001
Log Transformed	UCL	29.8	3.1	17.4	11.9
	Mean	17.3	2.3	10.2	9.9
	Tukey	ac	abd	bc	c
	LCL	10.1	1.7	6	8.2
	Std. Dev.	21.3	2.6	18.7	9.4
	Wilk	0.8249	0.9774	0.9735	0.9785
	Wilk (p-value)	0.0008	0.4357	0.3995	0.1011
Bootstrap	UCL	21.1	3.1	14.3	11.2
	Mean	15.4	2.4	10.2	9.7
	LCL	9.8	1.6	6.1	8.2
	Std. Dev.	13.4	2.6	13.4	7.5

In the KW and Tukey fields indicate that SCM is significantly different ($\alpha<0.05$) from the other specified SCM. ‘a’ indicates different than BF, ‘b’ indicates different than SED, ‘c’ indicates different than SF, and ‘d’ indicates different than WP.

Table A.3: Statistical summary for TN effluent concentrations (mg/L) from selected SCMs in the Austin, TX area.

Type	**Statistic**	**SED**	**SF**	**BF**	**WP**
Non-Parametric	Count	41	115	44	131
	Maximum	14.57	4.62	8.78	4.45
	Upper Quartile	1.65	1.29	1.66	1.47
	Median	1.01	0.87	1.14	1.11
	KW	-	ad	C	c
	Lower Quartile	0.67	0.64	0.82	0.79
	Minimum	0.12	0.33	0.41	0.24
Arithmetic	UCL	2.23	1.22	2.00	1.34
	Mean	1.52	1.09	1.56	1.23
	Tukey	-	-	-	-
	LCL	0.80	0.96	1.12	1.12
	Std. Dev.	2.26	0.70	1.44	0.66
	Wilk	0.4238	0.7759	0.6146	0.8900
	Wilk (p-value)	0.0001	0.0001	0.0001	0.0001
Log Transformed	UCL	1.94	1.19	1.83	1.37
	Mean	1.42	1.07	1.50	1.24
	Tukey	-	a	C	-
	LCL	1.04	0.97	1.22	1.12
	Std. Dev.	1.38	0.60	0.99	0.70
	Wilk	0.9239	0.9792	0.9375	0.9818
	Wilk (p-value)	0.0091	0.0710	0.0192	0.0769
Bootstrap	UCL	2.22	1.22	2.01	1.35
	Mean	1.56	1.09	1.59	1.24
	LCL	0.90	0.97	1.16	1.12
	Std. Dev.	2.09	0.70	1.40	0.66

In the KW and Tukey fields indicate that SCM is significantly different ($\alpha<0.05$) from the other specified SCM. ‘a’ indicates different than BF, ‘b’ indicates different than SED, ‘c’ indicates different than SF, and ‘d’ indicates different than WP.

Table A.4: Statistical summary for NO_2+NO_3 effluent concentrations (mg/L) from selected SCMs in the Austin, TX area.

Type	**Statistic**	**SED**	**SF**	**BF**	**WP**
Non-Parametric	Count	42	117	44	131
	Maximum	2.570	3.658	7.090	1.461
	Upper Quartile	0.446	0.771	0.688	0.408
	Median	0.345	0.487	0.483	0.239
	KW	acd	bd	bd	abc
	Lower Quartile	0.238	0.337	0.325	0.095
	Minimum	0.018	0.109	0.171	0.005
Arithmetic	UCL	0.574	0.739	1.083	0.353
	Mean	0.439	0.644	0.748	0.303
	Tukey		d	d	ac
	LCL	0.305	0.549	0.412	0.253
	Std. Dev.	0.432	0.520	1.104	0.289
	Wilk	0.6201	0.7130	0.4210	0.8193
	Wilk (p-value)	0.0001	0.0001	0.0001	0.0001
Log Transformed	UCL	0.611	0.713	0.853	0.445
	Mean	0.452	0.630	0.667	0.347
	Tukey	cd	bd	d	abc
	LCL	0.334	0.556	0.522	0.271
	Std. Dev.	0.433	0.429	0.534	0.537
	Wilk	0.8924	0.9813	0.9057	0.9584
	Wilk (p-value)	0.0009	0.1031	0.0016	0.0005
Bootstrap	UCL	0.580	0.744	1.086	0.356
	Mean	0.448	0.649	0.768	0.306
	LCL	0.317	0.554	0.451	0.256
	Std. Dev.	0.421	0.519	1.044	0.290

In the KW and Tukey fields indicate that SCM is significantly different ($\alpha<0.05$) from the other specified SCM. ‘a’ indicates different than BF, ‘b’ indicates different than SED, ‘c’ indicates different than SF, and ‘d’ indicates different than WP.

Table A.5: Statistical summary for TKN effluent concentrations (mg/L) from selected SCMs in the Austin, TX area.

Type	**Statistic**	**SED**	**SF**	**BF**	**WP**
Non-Parametric	Count	41	119	44	133
	Maximum	12	1.938	2.593	4.31
	Upper Quartile	1.09	0.55	1.02	1.09
	Median	0.69	0.35	0.65	0.81
	KW	c	abd	c	c
	Lower Quartile	0.37	0.25	0.47	0.57
	Minimum	0.06	0.04	0.13	0.12
Arithmetic	UCL	1.66	0.50	0.98	1.02
	Mean	1.07	0.45	0.81	0.92
	Tukey	c	abd	c	c
	LCL	0.49	0.39	0.65	0.82
	Std. Dev.	1.86	0.31	0.54	0.59
	Wilk	0.4016	0.8378	0.8579	0.8017
	Wilk (p-value)	0.0001	0.0001	0.0001	0.0001
Log Transformed	UCL	1.44	0.52	1.01	1.03
	Mean	1.00	0.45	0.82	0.93
	Tukey	c	abd	c	c
	LCL	0.69	0.40	0.66	0.83
	Std. Dev.	1.16	0.33	0.57	0.58
	Wilk	0.9635	0.9841	0.9873	0.9777
	Wilk (p-value)	0.2081	0.1757	0.9024	0.0277
Bootstrap	UCL	1.65	0.51	0.99	1.03
	Mean	1.11	0.45	0.82	0.93
	LCL	0.57	0.40	0.66	0.83
	Std. Dev.	1.71	0.31	0.54	0.59

In the KW and Tukey fields indicate that SCM is significantly different ($\alpha<0.05$) from the other specified SCM. ‘a’ indicates different than BF, ‘b’ indicates different than SED, ‘c’ indicates different than SF, and ‘d’ indicates different than WP.

Table A.6: Statistical summary for NH_3 effluent concentrations (mg/L) from selected SCMs in the Austin, TX area.

Type	**Statistic**	**SED**	**SF**	**BF**	**WP**
Non-Parametric	Count	42	120	44	131
	Maximum	1.020	0.641	0.237	0.786
	Upper Quartile	0.174	0.115	0.053	0.266
	Median	0.114	0.073	0.031	0.147
	KW	ac	abd	bcd	ac
	Lower Quartile	0.075	0.036	0.015	0.052
	Minimum	0.012	0.003	0.003	0.003
Arithmetic	UCL	0.248	0.131	0.063	0.217
	Mean	0.185	0.108	0.047	0.188
	Tukey	ac	bd	bd	ac
	LCL	0.123	0.085	0.031	0.160
	Std. Dev.	0.200	0.125	0.052	0.164
	Wilk	0.7181	0.6993	0.7445	0.8789
	Wilk (p-value)	0.0001	0.0001	0.0001	0.0001
Log Transformed	UCL	0.274	0.167	0.078	0.276
	Mean	0.188	0.125	0.050	0.215
	Tukey	ac	abd	bcd	ac
	LCL	0.129	0.094	0.032	0.168
	Std. Dev.	0.226	0.218	0.074	0.329
	Wilk	0.9595	0.9357	0.9657	0.9569
	Wilk (p-value)	0.1421	0.0001	0.2117	0.0004
Bootstrap	UCL	0.251	0.132	0.063	0.218
	Mean	0.189	0.109	0.048	0.189
	LCL	0.127	0.086	0.032	0.161
	Std. Dev.	0.198	0.125	0.051	0.164

In the KW and Tukey fields indicate that SCM is significantly different ($\alpha<0.05$) from the other specified SCM. ‘a’ indicates different than BF, ‘b’ indicates different than SED, ‘c’ indicates different than SF, and ‘d’ indicates different than WP.

Table A.7: Statistical summary for TP effluent concentrations (mg/L) from selected SCMs in the Austin, TX area.

Type	**Statistic**	**SED**	**SF**	**BF**	**WP**
Non-Parametric	Count	41	118	43	125
	Maximum	1.220	0.377	1.105	0.725
	Upper Quartile	0.268	0.119	0.589	0.273
	Median	0.164	0.082	0.444	0.148
	KW	ac	abd	bcd	ac
	Lower Quartile	0.137	0.054	0.373	0.081
	Minimum	0.028	0.018	0.252	0.007
Arithmetic	UCL	0.288	0.110	0.566	0.220
	Mean	0.224	0.097	0.506	0.193
	Tukey	ac	abd	bcd	ac
	LCL	0.161	0.084	0.446	0.167
	Std. Dev.	0.201	0.069	0.194	0.150
	Wilk	0.6777	0.8626	0.891	0.9002
	Wilk (p-value)	0.0001	0.0001	0.0007	0.0001
Log Transformed	UCL	0.291	0.115	0.564	0.258
	Mean	0.224	0.099	0.504	0.211
	Tukey	ac	abd	bcd	ac
	LCL	0.172	0.085	0.451	0.172
	Std. Dev.	0.184	0.082	0.182	0.250
	Wilk	0.9678	0.9598	0.9722	0.9574
	Wilk (p-value)	0.2926	0.0014	0.3759	0.0006
Bootstrap	UCL	0.290	0.110	0.569	0.221
	Mean	0.228	0.098	0.510	0.194
	LCL	0.167	0.085	0.450	0.168
	Std. Dev.	0.195	0.069	0.193	0.150

In the KW and Tukey fields indicate that SCM is significantly different ($\alpha<0.05$) from the other specified SCM. ‘a’ indicates different than BF, ‘b’ indicates different than SED, ‘c’ indicates different than SF, and ‘d’ indicates different than WP.

Table A.8: Statistical summary for DP effluent concentrations (mg/L) from selected SCMs in the Austin, TX area.

Type	**Statistic**	**SED**	**SF**	**BF**	**WP**
Non-Parametric	Count	21	42	44	98
	Maximum	0.370	0.265	0.736	0.412
	Upper Quartile	0.128	0.079	0.442	0.174
	Median	0.085	0.061	0.348	0.065
	KW	ac	ab	bcd	a
	Lower Quartile	0.065	0.04	0.284	0.028
	Minimum	0.01	0.016	0.197	0.004
Arithmetic	UCL	0.152	0.087	0.406	0.134
	Mean	0.112	0.072	0.369	0.112
	Tukey	a	a	bcd	a
	LCL	0.072	0.057	0.332	0.090
	Std. Dev.	0.088	0.047	0.121	0.110
	Wilk	0.8085	0.8086	0.9259	0.8371
	Wilk (p-value)	0.0009	0.0001	0.0075	0.0001
Log Transformed	UCL	0.193	0.088	0.406	0.164
	Mean	0.120	0.072	0.368	0.122
	Tukey	a	a	bcd	a
	LCL	0.074	0.059	0.335	0.091
	Std. Dev.	0.120	0.046	0.117	0.193
	Wilk	0.8925	0.9741	0.9805	0.9602
	Wilk (p-value)	0.0251	0.4474	0.6520	0.0047
Bootstrap	UCL	0.153	0.088	0.408	0.135
	Mean	0.114	0.073	0.371	0.113
	LCL	0.076	0.059	0.335	0.091
	Std. Dev.	0.085	0.047	0.120	0.110

In the KW and Tukey fields indicate that SCM is significantly different ($\alpha<0.05$) from the other specified SCM. ‘a’ indicates different than BF, ‘b’ indicates different than SED, ‘c’ indicates different than SF, and ‘d’ indicates different than WP.

Table A.9: Statistical summary for Pb effluent concentrations (µg/L) from selected SCMs in the Austin, TX area.

Type	**Statistic**	**SED**	**SF**	**BF**	**WP**
Non-Parametric	Count	39	117	44	134
	Maximum	42.0	33.5	39.9	152.4
	Upper Quartile	9.7	4.4	4.1	10.8
	Median	6.0	2.1	0.7	4.1
	KW	acd	abd	bcd	abc
	Lower Quartile	4.5	1.1	0.1	1.5
	Minimum	0.8	0.0	0.0	0.0
Arithmetic	UCL	10.7	4.9	6.4	10.7
	Mean	8.4	3.8	4.0	8.2
	Tukey		d		c
	LCL	6.0	2.8	1.7	5.7
	Std. Dev.	7.2	5.6	7.6	14.7
	Wilk	0.7081	0.5597	0.5758	0.4198
	Wilk (p-value)	0.0001	0.0001	0.0001	0.0001
Log Transformed	UCL	10.8	8.8	28.4	13.9
	Mean	8.3	5.7	7.5	9.9
	Tukey	ac	abd	bcd	ac
	LCL	6.4	3.7	2.0	7.1
	Std. Dev.	6.6	16.9	50.1	23.0
	Wilk	0.9676	0.8824	0.9260	0.9302
	Wilk (p-value)	0.3169	0.0001	0.0076	0.0001
Bootstrap	UCL	10.8	4.9	6.5	10.7
	Mean	8.5	3.9	4.2	8.3
	LCL	6.2	2.9	1.9	5.9
	Std. Dev.	7.1	5.5	7.5	14.1

In the KW and Tukey fields indicate that SCM is significantly different ($\alpha<0.05$) from the other specified SCM. ‘a’ indicates different than BF, ‘b’ indicates different than SED, ‘c’ indicates different than SF, and ‘d’ indicates different than WP.

Table A.10: Statistical summary for Zn effluent concentrations (μg/L) from selected SCMs in the Austin, TX area.

Type	**Statistic**	**SED**	**SF**	**BF**	**WP**
Non-Parametric	Count	39	117	44	134
	Maximum	309.0	179.3	127.0	459.2
	Upper Quartile	50.8	27.5	30.0	47.5
	Median	36.6	15.4	20.8	25.6
	KW	ac	bd	b	c
	Lower Quartile	16.8	8.8	10.1	11.5
	Minimum	4.0	1.0	2.0	3.0
Arithmetic	UCL	64.1	27.4	35.2	55.0
	Mean	46.6	22.8	27.0	44.2
	Tukey	c	bd		c
	LCL	29.0	18.3	18.8	33.4
	Std. Dev.	54.0	24.6	26.9	63.3
	Wilk	0.5931	0.6673	0.7413	0.5720
	Wilk (p-value)	0.0001	0.0001	0.0001	0.0001
Log Transformed	UCL	62.5	27.9	38.2	55.6
	Mean	45.3	23.0	27.3	43.9
	Tukey	ac	bd	b	c
	LCL	32.8	18.9	19.6	34.6
	Std. Dev.	44.4	24.9	29.9	64.8
	Wilk	0.9761	0.9948	0.9780	0.9870
	Wilk (p-value)	0.5645	0.9468	0.5571	0.2394
Bootstrap	UCL	64.6	27.6	35.6	55.5
	Mean	47.7	23.1	27.5	44.8
	LCL	30.8	18.6	19.4	34.0
	Std. Dev.	52.2	24.6	26.6	63.0

In the KW and Tukey fields indicate that SCM is significantly different ($\alpha<0.05$) from the other specified SCM. 'a' indicates different than BF, 'b' indicates different than SED, 'c' indicates different than SF, and 'd' indicates different than WP.

Table A.11: Statistical summary for Cu effluent concentrations (μg/L) from selected SCMs in the Austin, TX area.

Type	**Statistic**	**SED**	**SF**	**BF**	**WP**
Non-Parametric	Count	38	117	43	133
	Maximum	36.0	33.1	29.2	45.9
	Upper Quartile	11.5	10.0	7.6	6.6
	Median	6.4	3.6	4.9	3.6
	KW	cd	b	d	ab
	Lower Quartile	3.5	1.6	3.2	2.4
	Minimum	0.9	1.0	1.5	0.8
Arithmetic	UCL	12.2	7.2	8.1	6.5
	Mean	9.3	6.0	6.4	5.5
	Tukey	cd	b		b
	LCL	6.5	4.8	4.7	4.5
	Std. Dev.	8.7	6.6	5.4	5.9
	Wilk	0.7852	0.7060	0.7562	0.5985
	Wilk (p-value)	0.0001	0.0001	0.0001	0.0001
Log Transformed	UCL	13.5	7.4	8.1	6.2
	Mean	9.5	6.0	6.3	5.3
	Tukey	cd	b		b
	LCL	6.7	4.8	4.9	4.6
	Std. Dev.	10.1	7.2	5.0	4.9
	Wilk	0.9813	0.9457	0.9722	0.9766
	Wilk (p-value)	0.7620	0.0001	0.3760	0.0213
Bootstrap	UCL	12.3	7.3	8.2	6.5
	Mean	9.5	6.1	6.5	5.5
	LCL	6.7	4.9	4.9	4.5
	Std. Dev.	8.6	6.6	5.4	5.8

In the KW and Tukey fields indicate that SCM is significantly different ($\alpha<0.05$) from the other specified SCM. 'a' indicates different than BF, 'b' indicates different than SED, 'c' indicates different than SF, and 'd' indicates different than WP.

Table A.12: Statistical summary for Cd effluent concentrations (μg/L) from selected SCMs in the Austin, TX area.

Type	**Statistic**	**SED**	**SF**	**BF**	**WP**
Non-Parametric	Count	23	51	44	109
	Maximum	2.30	1.80	0.50	1.30
	Upper Quartile	0.70	0.50	0.10	0.50
	Median	0.50	0.20	0.04	0.50
	KW	acd	abd	bcd	abc
	Lower Quartile	0.50	0.00	0.00	0.30
	Minimum	0.20	0.00	0.00	0.00
Arithmetic	UCL	0.90	0.40	0.10	0.50
	Mean	0.70	0.30	0.10	0.40
	Tukey	acd	ab	bcd	ab
	LCL	0.50	0.20	0.00	0.40
	Std. Dev.	0.50	0.40	0.10	0.20
	Wilk	0.6552	0.7876	0.6681	0.7762
	Wilk (p-value)	0.0001	0.0001	0.0001	0.0001
Log Transformed	UCL	0.90	0.90	0.10	0.70
	Mean	0.70	0.50	0.10	0.50
	Tukey	ac	abd	bcd	ac
	LCL	0.50	0.20	0.00	0.40
	Std. Dev.	0.40	1.20	0.10	0.70
	Wilk	0.8589	0.9161	0.8937	0.6612
	Wilk (p-value)	0.0040	0.0015	0.0007	0.0001
Bootstrap	UCL	0.90	0.50	0.10	0.50
	Mean	0.70	0.30	0.10	0.40
	LCL	0.50	0.20	0.00	0.40
	Std. Dev.	0.50	0.40	0.10	0.20

In the KW and Tukey fields indicate that SCM is significantly different ($\alpha<0.05$) from the other specified SCM. ‘a’ indicates different than BF, ‘b’ indicates different than SED, ‘c’ indicates different than SF, and ‘d’ indicates different than WP.

Table A.13: Statistical summary for COD effluent concentrations (mg/L) from selected SCMs in the Austin, TX area.

Type	Statistic	SED	SF	BF	WP
Non-Parametric	Count	41	120	44	134
	Maximum	480.0	82.1	76.0	99.0
	Upper Quartile	45.9	25.8	38.7	37.0
	Median	30.2	17.3	23.9	27.5
	KW	c	abd	c	c
	Lower Quartile	23.1	12.0	15.7	20.2
	Minimum	10.4	2.5	9.2	2.5
Arithmetic	UCL	71.9	25.3	36.3	34.0
	Mean	48.9	22.5	30.6	31.1
	Tukey	acd	b	b	b
	LCL	25.9	19.7	25.0	28.2
	Std. Dev.	73.0	15.6	18.6	17.0
	Wilk	0.3902	0.8247	0.8725	0.9021
	Wilk (p-value)	0.0001	0.0001	0.0002	0.0001
Log Transformed	UCL	55.9	25.4	37.2	35.1
	Mean	43.8	22.4	30.6	31.6
	Tukey	C	abd	c	c
	LCL	34.3	19.8	25.2	28.4
	Std. Dev.	33.4	15.5	19.4	19.5
	Wilk	0.9103	0.9899	0.9656	0.9651
	Wilk (p-value)	0.0034	0.5218	0.2100	0.0016
Bootstrap	UCL	71.3	25.4	36.5	34.2
	Mean	50.2	22.6	30.9	31.2
	LCL	29.2	19.8	25.4	28.3
	Std. Dev.	66.8	15.6	18.4	17.0

In the KW and Tukey fields indicate that SCM is significantly different ($\alpha<0.05$) from the other specified SCM. ‘a’ indicates different than BF, ‘b’ indicates different than SED, ‘c’ indicates different than SF, and ‘d’ indicates different than WP.

Table A.14: Statistical summary for BOD effluent concentrations (mg/L) from selected SCMs in the Austin, TX area.

Type	Statistic	SED	SF	BF	WP
Non-Parametric	Count	36	92	80	
	Maximum	65.98	39.65	29.14	
	Upper Quartile	6.41	5.44	8.04	
	Median	4.84	3.09	5.64	
	KW	c	bd	c	
	Lower Quartile	2.97	1.67	3.81	
	Minimum	1.69	0.80	1.00	
Arithmetic	UCL	13.78	5.95	7.29	
	Mean	9.45	4.83	6.38	
	Tukey	c	b	0.00	
	LCL	5.12	3.71	5.47	
	Std. Dev.	12.79	5.40	4.09	
	Wilk	0.5899	0.6356	0.8047	
	Wilk (p-value)	0.0001	0.0001	0.0001	
Log Transformed	UCL	12.21	5.66	7.37	
	Mean	8.50	4.64	6.40	
	Tukey	c	bd	c	
	LCL	5.91	3.81	5.55	
	Std. Dev.	8.97	4.47	4.05	
	Wilk	0.8947	0.9686	0.9880	
	Wilk (p-value)	0.0024	0.0256	0.6635	
Bootstrap	UCL	13.89	6.00	7.32	
	Mean	9.69	4.89	6.42	
	LCL	5.48	3.78	5.52	
	Std. Dev.	12.43	5.35	4.05	

In the KW and Tukey fields indicate that SCM is significantly different ($\alpha<0.05$) from the other specified SCM. ‘a’ indicates different than BF, ‘b’ indicates different than SED, ‘c’ indicates different than SF, and ‘d’ indicates different than WP.

Table A.15: Statistical summary for TOC effluent concentrations (mg/L) from selected SCMs in the Austin, TX area.

Type	Statistic	SED	SF	BF	WP
Non-Parametric	Count	36	112	44	128
	Maximum	134.00	29.68	32.75	30.29
	Upper Quartile	13.50	9.43	10.05	9.50
	Median	7.64	5.09	6.26	6.66
	KW	c	bd	c	
	Lower Quartile	5.04	3.61	4.41	5.21
	Minimum	2.17	1.00	2.68	2.00
Arithmetic	UCL	20.35	8.42	10.11	8.50
	Mean	13.02	7.37	8.35	7.80
	Tukey	cd	b	b	
	LCL	5.70	6.31	6.58	7.11
	Std. Dev.	21.65	5.63	5.82	3.98
	Wilk	0.3833	0.8168	0.7753	0.8209
	Wilk (p-value)	0.0001	0.0001	0.0001	0.0001
Log Transformed	UCL	15.47	8.48	9.90	8.42
	Mean	11.45	7.33	8.20	7.76
	Tukey	c	b		
	LCL	8.47	6.34	6.79	7.16
	Std. Dev.	10.02	5.74	5.03	3.60
	Wilk	0.9315	0.9779	0.9436	0.9851
	Wilk (p-value)	0.0277	0.0604	0.0319	0.1760
Bootstrap	UCL	20.05	8.47	10.20	8.54
	Mean	13.42	7.42	8.45	7.84
	LCL	6.79	6.36	6.70	7.14
	Std. Dev.	19.59	5.63	5.75	3.99

In the KW and Tukey fields indicate that SCM is significantly different ($\alpha<0.05$) from the other specified SCM. ‘a’ indicates different than BF, ‘b’ indicates different than SED, ‘c’ indicates different than SF, and ‘d’ indicates different than WP.

Table A.16: Statistical summary for EC effluent concentrations (cfu/100 mL) from selected SCMs in the Austin, TX area.

Type	**Statistic**	**SED**	**SF**	**BF**	**WP**
Non-Parametric	Count	35	124	78	69
	Maximum	22636	41622	124000	632774
	Upper Quartile	11215	5061	6445	9579
	Median	5452	1000	1515	4135
	KW	ac	bd	bd	ac
	Lower Quartile	1602	329	364	2157
	Minimum	33	1	70	67
Arithmetic	UCL	8957	5025	9606	37037
	Mean	6749	3893	6187	18458
	Tukey				
	LCL	4540	2760	2767	0
	Std. Dev.	6428	6372	15167	77341
	Wilk	0.8668	0.6340	0.3800	0.1973
	Wilk (p-value)	0.0006	0.0001	0.0001	0.0001
Log Transformed	UCL	28138	8175	12282	20669
	Mean	11065	4895	6452	12138
	Tukey	c	bd	d	ac
	LCL	5098	3103	3694	7571
	Std. Dev.	29720	18459	22214	28978
	Wilk	0.8850	0.9814	0.9752	0.9507
	Wilk (p-value)	0.0016	0.0871	0.1326	0.0084
Bootstrap	UCL	8894	4991	9339	34900
	Mean	6739	3880	6204	18850
	LCL	4584	2769	3069	2799
	Std. Dev.	6273	6251	13905	66813

In the KW and Tukey fields indicate that SCM is significantly different ($\alpha<0.05$) from the other specified SCM. ‘a’ indicates different than BF, ‘b’ indicates different than SED, ‘c’ indicates different than SF, and ‘d’ indicates different than WP.

Table A.17: Statistical summary for FCOL effluent concentrations (cfu/100 mL) from selected SCMs in the Austin, TX area.

Type	**Statistic**	**SED**	**SF**	**BF**	**WP**
Non-Parametric	Count	34	101	42	71
	Maximum	51,420	98,224	113,000	1,770,741
	Upper Quartile	24,711	13,708	8,494	20,618
	Median	11,899	2,030	2,550	8,445
	KW	ac	bd	bd	ac
	Lower Quartile	3,084	411	527	4,157
	Minimum	50	15	14	106
Arithmetic	UCL	20,840	12,828	20,610	96,155
	Mean	15,464	9,742	12,540	45,808
	Tukey				
	LCL	10,087	6,656	4,470	-4,538
	Std. Dev.	15,409	15,633	25,897	212,706
	Wilk	0.8566	0.6525	0.5231	0.1795
	Wilk (p-value)	0.0004	0.0001	0.0001	0.0001
Log Transformed	UCL	76,534	37,557	61,155	47,002
	Mean	28,249	17,990	18,139	27,569
	Tukey	c	bd	d	ac
	LCL	10,427	8,617	5,380	16,171
	Std. Dev.	90,018	118,436	97,841	73,212
	Wilk	0.8883	0.9665	0.9861	0.9493
	Wilk (p-value)	0.0023	0.0115	0.8820	0.0062
Bootstrap	UCL	21,067	13,018	20,965	92,029
	Mean	15,762	9,930	13,028	47,860
	LCL	10,458	6,842	5,091	3,691
	Std. Dev.	15,203	15,641	25,471	186,607

In the KW and Tukey fields indicate that SCM is significantly different ($\alpha<0.05$) from the other specified SCM. ‘a’ indicates different than BF, ‘b’ indicates different than SED, ‘c’ indicates different than SF, and ‘d’ indicates different than WP.

Table A.18: Statistical summary for FSTR effluent concentrations (cfu/100 mL) from selected SCMs in the Austin, TX area.

Type	**Statistic**	**SED**	**SF**	**BF**	**WP**
Non-Parametric	Count	34	80		74
	Maximum	118,351	101,766		212,047
	Upper Quartile	38,581	14,163		37,653
	Median	22,034	5,008		16,414
	KW	c	bd		c
	Lower Quartile	4,447	1,339		4,539
	Minimum	517	158		320
Arithmetic	UCL	38,096	16,803		41,087
	Mean	28,033	12,543		31,786
	Tukey	c	bd		c
	LCL	17,970	8,284		22,486
	Std. Dev.	28,840	19,140		40,144
	Wilk	0.8398	0.6560		0.7427
	Wilk (p-value)	0.0002	0.0001		0.0001
Log Transformed	UCL	67,310	23,766		64,484
	Mean	34,524	14,288		39,433
	Tukey	c	bd		c
	LCL	17,708	8,590		24,114
	Std. Dev.	67,436	39,272		96,850
	Wilk	0.9483	0.9838		0.9768
	Wilk (p-value)	0.1090	0.4066		0.1906
Bootstrap	UCL	38,548	16,991		41,536
	Mean	28,636	12,756		32,277
	LCL	18,723	8,520		23,018
	Std. Dev.	28,409	19,034		39,964

In the KW and Tukey fields indicate that SCM is significantly different (α<0.05) from the other specified SCM. ‘a’ indicates different than BF, ‘b’ indicates different than SED, ‘c’ indicates different than SF, and ‘d’ indicates different than WP.

Appendix B Statistical Comparisons from Canyon Creek

Table B.1: Statistical summary for TSS effluent concentrations (mg/L) from Canyon Creek sand filter (CCS) and biofiltration (CCN).

	PARAMETER	TSS (mg/L)	
Type	**Statistic**	**INF: CCS**	**EFF: CCN**
	Site Count	21	23
	Pairs Count	16	16
Non-Parametric	Maximum	55.5	41.7
	Upper Quartile	5.4	7.9
	Median	4.7	4.0
	Lower Quartile	2.6	2.7
	Minimum	1.3	2.0
	Efficiency	NA	
	Mann-Whitney	0.9256	
	Wilcoxon (paired)	0.4637	
Arithmetic	UCL	14.8	13.1
	Mean	9.0	8.4
	LCL	3.1	3.7
	Std. Dev.	12.8	10.8
	Wilk (p-value)	0.0001 **	0.0001 **
	Efficiency	NA	
	t-Test (equal var.)	0.8696	
	t-Test (unequal var.)	0.8707	
	t-test (paired)	0.6803	
	Levene Test	0.7031	
Log Transformed	UCL	14.3	11.8
	Mean	8.0	7.5
	LCL	4.5	4.8
	Std. Dev.	9.6	7.5
	Wilk (p-value)	0.0732 *	0.0025 **
	Efficiency	NA	
	t-Test (equal var.)	0.8604	
	t-Test (unequal var.)	0.8613	
	t-Test (paired)	0.7158	
	Levene Test	0.5316	
Bootstrap	UCL	14.3	12.7
	Mean	8.9	8.4
	LCL	3.5	4.0
	Std. Dev.	11.8	10.1
	Efficiency	NA	

Table B.2: Statistical summary for VSS effluent concentrations (mg/L) from Canyon Creek sand filter (CCS) and biofiltration (CCN).

	PARAMETER	**VSS (mg/L)**	
Type	**Statistic**	**INF: CCS**	**EFF: CCN**
	Site Count	21	23
	Pairs Count	16	16
Non-Parametric	Maximum	14.1	6.9
	Upper Quartile	2.8	3.1
	Median	1.2	1.7
	Lower Quartile	.6	1.0
	Minimum	.5	.5
	Efficiency	NA	
	Mann-Whitney	0.2962	
	Wilcoxon (paired)	0.2524	
Arithmetic	UCL	3.5	3.0
	Mean	2.1	2.3
	LCL	.8	1.5
	Std. Dev.	2.9	1.7
	Wilk (p-value)	0.0001 **	0.0040 **
	Efficiency	NA	
	t-Test (equal var.)	0.8627	
	t-Test (unequal var.)	0.8660	
	t-test (paired)	0.2091	
	Levene Test	0.4147	
Log Transformed	UCL	3.1	3.3
	Mean	2.0	2.3
	LCL	1.2	1.6
	Std. Dev.	1.9	1.9
	Wilk (p-value)	0.0487 **	0.6556
	Efficiency	NA	
	t-Test (equal var.)	0.3278	
	t-Test (unequal var.)	0.3317	
	t-Test (paired)	0.1018	
	Levene Test	0.4616	
Bootstrap	UCL	3.3	3.0
	Mean	2.1	2.3
	LCL	1.0	1.5
	Std. Dev.	2.6	1.7
	Efficiency	NA	

Table B.3: Statistical summary for TN effluent concentrations (mg/L) from Canyon Creek sand filter (CCS) and biofiltration (CCN).

	PARAMETER	**TN (mg/L)**	
Type	**Statistic**	**INF: CCS**	**EFF: CCN**
	Site Count	21	23
	Pairs Count	16	16
Non-Parametric	Maximum	3.990	8.780
	Upper Quartile	1.088	1.339
	Median	0.750	0.889
	Lower Quartile	0.570	0.746
	Minimum	0.359	0.413
	Efficiency	NA	
	Mann-Whitney	0.1875	
	Wilcoxon (paired)	0.1754	
Arithmetic	UCL	1.431	2.225
	Mean	1.047	1.445
	LCL	0.663	0.666
	Std. Dev.	0.843	1.802
	Wilk (p-value)	0.0001 **	0.0001 **
	Efficiency	NA	
	t-Test (equal var.)	0.3607	
	t-Test (unequal var.)	0.3483	
	t-test (paired)	0.6743	
	Levene Test	0.3344	
Log Transformed	UCL	1.364	1.814
	Mean	1.013	1.309
	LCL	0.753	0.944
	Std. Dev.	0.642	0.958
	Wilk (p-value)	0.1039	0.0017 **
	Efficiency	NA	
	t-Test (equal var.)	0.2913	
	t-Test (unequal var.)	0.2885	
	t-Test (paired)	0.2045	
	Levene Test	0.6908	
Bootstrap	UCL	1.409	2.164
	Mean	1.052	1.459
	LCL	0.696	0.755
	Std. Dev.	0.783	1.628
	Efficiency	NA	

Table B.4: Statistical summary for NO_2+NO_3 effluent concentrations (mg/L) from Canyon Creek sand filter (CCS) and biofiltration (CCN).

	PARAMETER	**NO2 + NO3 (mg/L)**	
Type	**Statistic**	**INF: CCS**	**EFF: CCN**
	Site Count	21	23
	Pairs Count	16	16
Non-Parametric	Maximum	2.880	7.090
	Upper Quartile	0.590	0.671
	Median	0.466	0.406
	Lower Quartile	0.284	0.313
	Minimum	0.235	0.178
	Efficiency	NA	
	Mann-Whitney	1.0000	
	Wilcoxon (paired)	0.9799	
Arithmetic	UCL	0.939	1.512
	Mean	0.650	0.864
	LCL	0.360	0.217
	Std. Dev.	0.636	1.497
	Wilk (p-value)	0.0001 **	0.0001 **
	Efficiency	NA	
	t-Test (equal var.)	0.5461	
	t-Test (unequal var.)	0.5344	
	t-test (paired)	0.4568	
	Levene Test	0.3286	
Log Transformed	UCL	0.873	1.100
	Mean	0.615	0.710
	LCL	0.434	0.459
	Std. Dev.	0.455	0.689
	Wilk (p-value)	0.0177 **	0.0020 **
	Efficiency	NA	
	t-Test (equal var.)	0.9416	
	t-Test (unequal var.)	0.9410	
	t-Test (paired)	0.4521	
	Levene Test	0.4939	
Bootstrap	UCL	0.920	1.456
	Mean	0.653	0.877
	LCL	0.386	0.299
	Std. Dev.	0.587	1.338
	Efficiency	NA	

Table B.5: Statistical summary for TKN effluent concentrations (mg/L) from Canyon Creek sand filter (CCS) and biofiltration (CCN).

	PARAMETER	**TKN (mg/L)**	
Type	**Statistic**	**INF: CCS**	**EFF: CCN**
	Site Count	21	23
	Pairs Count	16	16
Non-Parametric	Maximum	1.110	1.690
	Upper Quartile	0.485	0.661
	Median	0.335	0.526
	Lower Quartile	0.247	0.339
	Minimum	0.106	0.131
	Efficiency	NA	
	Mann-Whitney	0.0577 *	
	Wilcoxon (paired)	0.0002 **	
Arithmetic	UCL	0.510	0.740
	Mean	0.397	0.581
	LCL	0.284	0.422
	Std. Dev.	0.248	0.367
	Wilk (p-value)	0.0146 **	0.0042 **
	Efficiency	NA	
	t-Test (equal var.)	0.0611 *	
	t-Test (unequal var.)	0.0575 *	
	t-test (paired)	0.0001 **	
	Levene Test	0.2711	
Log Transformed	UCL	0.538	0.773
	Mean	0.398	0.582
	LCL	0.294	0.438
	Std. Dev.	0.256	0.372
	Wilk (p-value)	0.9740	0.9934
	Efficiency	NA	
	t-Test (equal var.)	0.0427 **	
	t-Test (unequal var.)	0.0428 **	
	t-Test (paired)	0.0001 **	
	Levene Test	0.9769	
Bootstrap	UCL	0.507	0.735
	Mean	0.399	0.582
	LCL	0.291	0.429
	Std. Dev.	0.237	0.353
	Efficiency	NA	

Table B.6: Statistical summary for NH_3 effluent concentrations (mg/L) from Canyon Creek sand filter (CCS) and biofiltration (CCN).

	PARAMETER	NH3 (mg/L)	
Type	**Statistic**	**INF: CCS**	**EFF: CCN**
	Site Count	21	23
	Pairs Count	16	16
Non-Parametric	Maximum	0.243	0.131
	Upper Quartile	0.034	0.039
	Median	0.014	0.024
	Lower Quartile	0.003	0.009
	Minimum	0.003	0.003
	Efficiency	NA	
	Mann-Whitney	0.5116	
	Wilcoxon (paired)	0.1763	
Arithmetic	UCL	0.073	0.048
	Mean	0.042	0.033
	LCL	0.012	0.018
	Std. Dev.	0.067	0.034
	Wilk (p-value)	0.0001 **	0.0002 **
	Efficiency	NA	
	t-Test (equal var.)	0.5411	
	t-Test (unequal var.)	0.5534	
	t-test (paired)	0.0871 *	
	Levene Test	0.1643	
Log Transformed	UCL	0.128	0.069
	Mean	0.044	0.036
	LCL	0.015	0.018
	Std. Dev.	0.098	0.052
	Wilk (p-value)	0.0249 **	0.2642
	Efficiency	NA	
	t-Test (equal var.)	0.5400	
	t-Test (unequal var.)	0.5457	
	t-Test (paired)	0.6687	
	Levene Test	0.0809 *	
Bootstrap	UCL	0.071	0.046
	Mean	0.043	0.032
	LCL	0.014	0.018
	Std. Dev.	0.063	0.032
	Efficiency	NA	

Table B.7: Statistical summary for TP effluent concentrations (mg/L) from Canyon Creek sand filter (CCS) and biofiltration (CCN).

	PARAMETER	**TP (mg/L)**	
Type	**Statistic**	**INF: CCS**	**EFF: CCN**
	Site Count	21	22
	Pairs Count	15	15
Non-Parametric	Maximum	0.214	0.770
	Upper Quartile	0.108	0.499
	Median	0.089	0.388
	Lower Quartile	0.071	0.314
	Minimum	0.044	0.252
	Efficiency	NA	
	Mann-Whitney	0.0000 **	
	Wilcoxon (paired)	0.0001 **	
Arithmetic	UCL	0.116	0.477
	Mean	0.096	0.418
	LCL	0.076	0.359
	Std. Dev.	0.044	0.133
	Wilk (p-value)	0.0310 **	0.0203 **
	Efficiency	NA	
	t-Test (equal var.)	0.0000 **	
	t-Test (unequal var.)	0.0000 **	
	t-test (paired)	0.0000 **	
	Levene Test	0.0166 **	
Log Transfomed	UCL	0.118	0.477
	Mean	0.096	0.417
	LCL	0.078	0.365
	Std. Dev.	0.043	0.124
	Wilk (p-value)	0.6827	0.3370
	Efficiency	NA	
	t-Test (equal var.)	0.0000 **	
	t-Test (unequal var.)	0.0000 **	
	t-Test (paired)	0.0000 **	
	Levene Test	0.0746 *	
Bootstrap	UCL	0.115	0.472
	Mean	0.096	0.416
	LCL	0.076	0.360
	Std. Dev.	0.042	0.126
	Efficiency	NA	

Table B.8: Statistical summary for DP effluent concentrations (mg/L) from Canyon Creek sand filter (CCS) and biofiltration (CCN).

Type	Statistic	INF: CCS	EFF: CCN
	PARAMETER	**DP (mg/L)**	
	Site Count	21	23
	Pairs Count	16	16
Non-Parametric	Maximum	0.193	0.736
	Upper Quartile	0.079	0.467
	Median	0.068	0.353
	Lower Quartile	0.059	0.285
	Minimum	0.027	0.213
	Efficiency	NA	
	Mann-Whitney	0.0000 **	
	Wilcoxon (paired)	0.0000 **	
Arithmetic	UCL	0.093	0.444
	Mean	0.076	0.387
	LCL	0.059	0.329
	Std. Dev.	0.037	0.132
	Wilk (p-value)	0.0036 **	0.0202 **
	Efficiency	NA	
	t-Test (equal var.)	0.0000 **	
	t-Test (unequal var.)	0.0000 **	
	t-test (paired)	0.0000 **	
	Levene Test	0.0130 **	
Log Transformed	UCL	0.094	0.444
	Mean	0.076	0.386
	LCL	0.062	0.335
	Std. Dev.	0.035	0.124
	Wilk (p-value)	0.6404	0.5218
	Efficiency	NA	
	t-Test (equal var.)	0.0000 **	
	t-Test (unequal var.)	0.0000 **	
	t-Test (paired)	0.0000 **	
	Levene Test	0.1872	
Bootstrap	UCL	0.092	0.439
	Mean	0.076	0.385
	LCL	0.060	0.331
	Std. Dev.	0.035	0.126
	Efficiency	NA	

Table B.9: Statistical summary for Pb effluent concentrations (µg/L) from Canyon Creek sand filter (CCS) and biofiltration (CCN).

	PARAMETER	**Lead (µg/L)**	
Type	**Statistic**	**INF: CCS**	**EFF: CCN**
	Site Count	21	23
	Pairs Count	16	16
Non-Parametric	Maximum	1.1	0.7
	Upper Quartile	0.3	0.2
	Median	0.1	0.1
	Lower Quartile	0.0	0.0
	Minimum	0.0	0.0
	Efficiency	NA	
	Mann-Whitney	0.8698	
	Wilcoxon (paired)	0.0785 *	
Arithmetic	UCL	0.3	0.3
	Mean	0.2	0.2
	LCL	0.1	0.1
	Std. Dev.	0.3	0.2
	Wilk (p-value)	0.0001 **	0.0001 **
	Efficiency	NA	
	t-Test (equal var.)	0.7887	
	t-Test (unequal var.)	0.7903	
	t-test (paired)	0.2442	
	Levene Test	0.6537	
Log Transformed	UCL	0.5	0.4
	Mean	0.2	0.2
	LCL	0.1	0.1
	Std. Dev.	0.3	0.3
	Wilk (p-value)	0.0656 *	0.0073 **
	Efficiency	NA	
	t-Test (equal var.)	0.7506	
	t-Test (unequal var.)	0.7505	
	t-Test (paired)	0.0844 *	
	Levene Test	0.9405	
Bootstrap	UCL	0.3	0.3
	Mean	0.2	0.2
	LCL	0.1	0.1
	Std. Dev.	0.3	0.2
	Efficiency	NA	

Table B.10: Statistical summary for Zn effluent concentrations (µg/L) from Canyon Creek sand filter (CCS) and biofiltration (CCN).

	PARAMETER	**Zinc (µg/L)**	
Type	**Statistic**	**INF: CCS**	**EFF: CCN**
	Site Count	21	23
	Pairs Count	16	16
Non-Parametric	Maximum	50.3	88.3
	Upper Quartile	14.0	20.9
	Median	6.0	10.8
	Lower Quartile	3.8	6.0
	Minimum	2.4	2.0
	Efficiency	NA	
	Mann-Whitney	0.1800	
	Wilcoxon (paired)	0.3225	
Arithmetic	UCL	16.3	24.3
	Mean	11.1	16.3
	LCL	5.9	8.4
	Std. Dev.	11.4	18.4
	Wilk (p-value)	0.0001 **	0.0001 **
	Efficiency	NA	
	t-Test (equal var.)	0.2740	
	t-Test (unequal var.)	0.2651	
	t-test (paired)	0.3160	
	Levene Test	0.4139	
Log Transformed	UCL	17.1	24.5
	Mean	10.8	15.7
	LCL	6.8	10.1
	Std. Dev.	10.4	15.5
	Wilk (p-value)	0.2437	0.8717
	Efficiency	NA	
	t-Test (equal var.)	0.1650	
	t-Test (unequal var.)	0.1649	
	t-Test (paired)	0.1177	
	Levene Test	0.9589	
Bootstrap	UCL	16.0	23.7
	Mean	11.1	16.4
	LCL	6.2	9.1
	Std. Dev.	10.7	16.9
	Efficiency	NA	

Table B.11: Statistical summary for Cu effluent concentrations (µg/L) from Canyon Creek sand filter (CCS) and biofiltration (CCN).

	PARAMETER	**Copper (µg/L)**	
Type	**Statistic**	**INF: CCS**	**EFF: CCN**
	Site Count	21	22
	Pairs Count	15	15
Non-Parametric	Maximum	4.5	13.0
	Upper Quartile	2.2	4.2
	Median	1.7	3.2
	Lower Quartile	1.3	2.0
	Minimum	1.0	1.5
	Efficiency	NA	
	Mann-Whitney	0.0025 **	
	Wilcoxon (paired)	0.0001 **	
Arithmetic	UCL	2.4	4.8
	Mean	2.0	3.7
	LCL	1.5	2.6
	Std. Dev.	1.0	2.6
	Wilk (p-value)	0.0007 **	0.0001 **
	Efficiency	NA	
	t-Test (equal var.)	0.0066 **	
	t-Test (unequal var.)	0.0071 **	
	t-test (paired)	0.0050 **	
	Levene Test	0.1801	
Log Transformed	UCL	2.4	4.7
	Mean	2.0	3.6
	LCL	1.6	2.8
	Std. Dev.	0.9	2.1
	Wilk (p-value)	0.1268	0.1736
	Efficiency	NA	
	t-Test (equal var.)	0.0006 **	
	t-Test (unequal var.)	0.0006 **	
	t-Test (paired)	0.0000 **	
	Levene Test	0.2949	
Bootstrap	UCL	2.4	4.8
	Mean	2.0	3.7
	LCL	1.6	2.7
	Std. Dev.	0.9	2.4
	Efficiency	NA	

Table B.12: Statistical summary for Cd effluent concentrations (µg/L) from Canyon Creek sand filter (CCS) and biofiltration (CCN).

	PARAMETER	**Cadmium (µg/L)**	
Type	**Statistic**	**INF: CCS**	**EFF: CCN**
	Site Count	21	23
	Pairs Count	16	16
Non-Parametric	Maximum	0.3	0.1
	Upper Quartile	0.1	0.1
	Median	0.0	0.0
	Lower Quartile	0.0	0.0
	Minimum	0.0	0.0
	Efficiency	NA	
	Mann-Whitney	0.7880	
	Wilcoxon (paired)	0.8910	
Arithmetic	UCL	0.1	0.1
	Mean	0.1	0.0
	LCL	0.0	0.0
	Std. Dev.	0.1	0.0
	Wilk (p-value)	0.0001 **	0.0003 **
	Efficiency	NA	
	t-Test (equal var.)	0.4356	
	t-Test (unequal var.)	0.4502	
	t-test (paired)	0.3890	
	Levene Test	0.2458	
Log Transformed	UCL	0.1	0.1
	Mean	0.1	0.0
	LCL	0.0	0.0
	Std. Dev.	0.1	0.1
	Wilk (p-value)	0.0084 **	0.0003 **
	Efficiency	NA	
	t-Test (equal var.)	0.6474	
	t-Test (unequal var.)	0.6486	
	t-Test (paired)	0.5091	
	Levene Test	0.5973	
Bootstrap	UCL	0.1	0.1
	Mean	0.1	0.0
	LCL	0.0	0.0
	Std. Dev.	0.1	0.0
	Efficiency	NA	

Table B.13: Statistical summary for COD effluent concentrations (mg/L) from Canyon Creek sand filter (CCS) and biofiltration (CCN).

	PARAMETER	**COD (mg/L)**	
Type	**Statistic**	**INF: CCS**	**EFF: CCN**
	Site Count	21	23
	Pairs Count	16	16
Non-Parametric	Maximum	44.00	63.35
	Upper Quartile	25.00	28.91
	Median	16.43	18.00
	Lower Quartile	10.34	12.51
	Minimum	7.21	9.19
	Efficiency	NA	
	Mann-Whitney	0.4355	
	Wilcoxon (paired)	0.6788	
Arithmetic	UCL	24.28	29.66
	Mean	19.44	23.35
	LCL	14.60	17.04
	Std. Dev.	10.63	14.60
	Wilk (p-value)	0.0162 **	0.0020 **
	Efficiency	NA	
	t-Test (equal var.)	0.3197	
	t-Test (unequal var.)	0.3132	
	t-test (paired)	0.5095	
	Levene Test	0.2628	
Log Transformed	UCL	25.09	29.98
	Mean	19.40	23.11
	LCL	15.00	17.81
	Std. Dev.	10.70	13.60
	Wilk (p-value)	0.5008	0.3105
	Efficiency	NA	
	t-Test (equal var.)	0.3403	
	t-Test (unequal var.)	0.3390	
	t-Test (paired)	0.9030	
	Levene Test	0.7268	
Bootstrap	UCL	24.20	29.38
	Mean	19.52	23.33
	LCL	14.84	17.28
	Std. Dev.	10.29	13.99
	Efficiency	NA	

Table B.14: Statistical summary for TOC effluent concentrations (mg/L) from Canyon Creek sand filter (CCS) and biofiltration (CCN).

	PARAMETER	**TOC (mg/L)**	
Type	**Statistic**	**INF: CCS**	**EFF: CCN**
	Site Count	21	23
	Pairs Count	16	16
Non-Parametric	Maximum	16.00	16.10
	Upper Quartile	7.53	8.44
	Median	4.89	5.85
	Lower Quartile	3.85	4.14
	Minimum	2.53	2.68
	Efficiency	NA	
	Mann-Whitney	0.3180	
	Wilcoxon (paired)	0.7057	
Arithmetic	UCL	7.84	8.64
	Mean	6.16	6.94
	LCL	4.48	5.23
	Std. Dev.	3.68	3.94
	Wilk (p-value)	0.0007 **	0.0017 **
	Efficiency	NA	
	t-Test (equal var.)	0.5051	
	t-Test (unequal var.)	0.5038	
	t-test (paired)	0.6294	
	Levene Test	0.7982	
Log Transformed	UCL	7.80	8.72
	Mean	6.09	6.88
	LCL	4.75	5.43
	Std. Dev.	3.24	3.70
	Wilk (p-value)	0.1771	0.2173
	Efficiency	NA	
	t-Test (equal var.)	0.4385	
	t-Test (unequal var.)	0.4384	
	t-Test (paired)	0.5985	
	Levene Test	0.9651	
Bootstrap	UCL	7.80	8.62
	Mean	6.20	6.96
	LCL	4.60	5.30
	Std. Dev.	3.52	3.84
	Efficiency	NA	

Table B.15: Statistical summary for EC effluent concentrations (cfu/100 mL) from Canyon Creek sand filter (CCS) and biofiltration (CCN).

	PARAMETER	**E. Coli (cfu/100ml)**	
Type	**Statistic**	**INF: CCS**	**EFF: CCN**
	Site Count	21	23
	Pairs Count	16	16
Non-Parametric	Maximum	922,000	397,000
	Upper Quartile	116,000	140,000
	Median	48,000	64,856
	Lower Quartile	20,100	17,300
	Minimum	7,019	7,033
	Efficiency	NA	
	Mann-Whitney	0.8701	
	Wilcoxon (paired)	0.1439	
Arithmetic	UCL	220,865	148,982
	Mean	124,358	100,039
	LCL	27,852	51,096
	Std. Dev.	212,008	113,174
	Wilk (p-value)	0.0001 **	0.0002 **
	Efficiency	NA	
	t-Test (equal var.)	0.6333	
	t-Test (unequal var.)	0.6430	
	t-test (paired)	0.9785	
	Levene Test	0.2991	
Log Transformed	UCL	243,016	217,626
	Mean	111,409	106,372
	LCL	51,075	51,993
	Std. Dev.	179,263	167,708
	Wilk (p-value)	0.6376	0.4006
	Efficiency	NA	
	t-Test (equal var.)	0.9607	
	t-Test (unequal var.)	0.9607	
	t-Test (paired)	0.6615	
	Levene Test	0.9062	
Bootstrap	UCL	218,384	145,653
	Mean	127,533	99,092
	LCL	36,682	52,532
	Std. Dev.	199,586	107,671
	Efficiency	NA	

Table B.16: Statistical summary for FCOL effluent concentrations (cfu/100 mL) from Canyon Creek sand filter (CCS) and biofiltration (CCN).

	PARAMETER	F. Coliform (cfu/100ml)	
Type	**Statistic**	**INF: CCS**	**EFF: CCN**
	Site Count	21	23
	Pairs Count	16	16
Non-Parametric	Maximum	18,000	25,200
	Upper Quartile	1,969	1,436
	Median	567	727
	Lower Quartile	154	144
	Minimum	15	14
	Efficiency	NA	
	Mann-Whitney	0.9814	
	Wilcoxon (paired)	0.2522	
Arithmetic	UCL	5,924	4,491
	Mean	3,286	2,209
	LCL	647	-73
	Std. Dev.	5,796	5,276
	Wilk (p-value)	0.0001 **	0.0001 **
	Efficiency	NA	
	t-Test (equal var.)	0.5224	
	t-Test (unequal var.)	0.5243	
	t-test (paired)	0.7945	
	Levene Test	0.8433	
Log Transformed	UCL	17,437	6,747
	Mean	3,655	2,127
	LCL	766	671
	Std. Dev.	12,340	5,572
	Wilk (p-value)	0.5599	0.9459
	Efficiency	NA	
	t-Test (equal var.)	0.8266	
	t-Test (unequal var.)	0.8279	
	t-Test (paired)	0.9849	
	Levene Test	0.4567	
Bootstrap	UCL	5,960	4,368
	Mean	3,399	2,298
	LCL	839	228
	Std. Dev.	5,626	4,787
	Efficiency	NA	