Guidance for Evaluating Emerging Stormwater Treatment Technologies

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Technology Assessment Protocol – Ecology (TAPE)

DRAFT

Modification: Evaluating Stormwater Treatment Technologies with Long Detention Times

November 2008

PREFACE

In completion of EA Study Code 06-063, a method for evaluating stormwater treatment technologies (Best Management Practices – BMPs) with long detention times is presented in this draft modification to TAPE. The method applies to Western Washington, with its prolonged periods of winter wet weather. Detailed documentation of the development of the method, its rationale and assumptions, and the sources of literature upon which it draws are also included. A detailed step-by-step example of data analysis appears as Appendix H.

This draft modification includes content specific to project planning and data analysis for BMPs with long detention times. A final version may be adapted for inclusion in the current TAPE. Some sections of the January 2008 TAPE guidance apply to this modification and some do not apply. Those sections that do not apply are included below. This list does not encompass every sentence of the TAPE that does not apply but covers the major sections that are not applicable.

- The **Number of Stormwater Samples** section (p. 16) does not apply. A discussion of required number of sampling events is included in this draft modification.

- The **Storm Event Guidelines** section (p. 16) does not apply.

- In the **Stormwater Field Sampling** Procedures (pgs. 16-17), the only applicable sampling method is #1 – *Automatic flow-weighted composite sampling*. The other two methods involve sampling within individual storm events – a time resolution too fine for BMPs with long detention times.

- The size of BMPs with long detention times generally precludes the possibility of full-scale laboratory studies (pgs. 23-24) but the applicability of laboratory testing has otherwise not been determined.

- Only methods #1 (when extended to all sampling events) and #2 of **Appendix A: Treatment Efficiency Calculation Methods**, apply (p. 29). The other two methods are for individual storm sampling or partial-storm data – both have a time resolution too fine for BMPs with long detention times. Methods #1 and #2 are altered somewhat in this draft modification to apply to long detention time BMPs.

- **Appendix D: Statistical Considerations** is essentially replaced in this draft modification. Methods for study design and data analysis for BMPs with long detention times comprise much of the scope of this draft modification.

To avoid confusion, the appendices to this memorandum have been lettered so as not to overlap those of the current TAPE. Because the methods for evaluating long-detention-time BMPs in this memorandum are, for the most part, new and not familiar, the method is presented with a detailed example to aid those undertaking such evaluations.

INTRODUCTION

In the 1990's as required by the Clean Water Act the U.S. Environmental Protection Agency (USEPA) mandated that most municipalities in the United States with populations larger than 10,000 obtain a stormwater runoff discharge permit. One of the requirements of this permit program is the use of non-structural and structural best management practices (BMPs) appropriate to reduce pollutants to the Maximum Extent Practicable (MEP). In response to this program, communities need to know which types of BMPs are appropriate for them (e.g., which BMPs function best in cold climates or in areas of heavy rainfall) and how to monitor the performance of the BMPs they select to ensure they function properly.

The Washington Department of Ecology published a revised Stormwater Management Manual (SWMM) for Western Washington in 2005. The SWMM includes stormwater treatment design criteria, performance goals, and a process for evaluating the effectiveness of stormwater treatment facilities. Methods for evaluating the performance of emerging stormwater treatment technologies are specified in the Ecology publication: *Guidance for Evaluating Emerging Stormwater Treatment Technologies: Technology Assessment Protocol – Ecology (TAPE).*

TAPE includes technical guidelines for assessing stormwater BMPs. The methods presented in TAPE are commonly used in stormwater BMP monitoring and apply to BMPs with short detention times. TAPE recognizes the need for addressing monitoring of BMPs with long detention times. This document provides a method for monitoring BMPs with long detention times in western Washington.

THE PROBLEM

Detention time, also referred to as retention time, is the time that a parcel of water remains within a BMP before outflow. Detention time is defined mathematically as:

$\tau = V/Q \times (1 \text{ hour} / 3600 \text{ seconds})$

where:
τ = detention time in hours
Q = flow rate through BMP in ft^3 / sec
V = volume of BMP in ft^3

For BMPs with short detention times such as hydrodynamic devices, τ is typically on the order of minutes. This is a short time period relative to typical storm durations of hours. BMPs with long detention times of hours or days include detention ponds, sand filters, and other large BMPs.

Stormwater BMPs with short detention times are evaluated by comparing the quantity and quality of water flowing into the BMP compared with that flowing out. Field data are typically collected simultaneously (concurrently) as pairs of influent and effluent samples. For BMPs with short detention times, influent pollutant concentrations can be compared directly with effluent concentrations. The water flowing out is essentially the same water that is flowing in. At any given time, the reduction in pollutant concentration between influent and effluent is a direct indication of the effect of treatment within the BMP.

For cases where BMP detention time is on the order of hours or days, paired data may not apply. For paired data to apply, it must be determined that a sampled parcel of water exiting the BMP is mostly the same parcel of water that was sampled entering the facility.

The method presented here deliberately decouples inflow and outflow samples to be collected randomly and not paired. It takes advantage of a climate with a wet season of frequent precipitation including overlapping storms.

In concept, an approach to a quantitative evaluation of stormwater BMPs with long detention times requires the collection of relatively long-term data. Effluent data can be compared with influent data only when monitoring is for a time considerably longer than the BMP's detention time.

The following two figures illustrate why many BMPs cannot be evaluated in the usual way as with other BMPs.

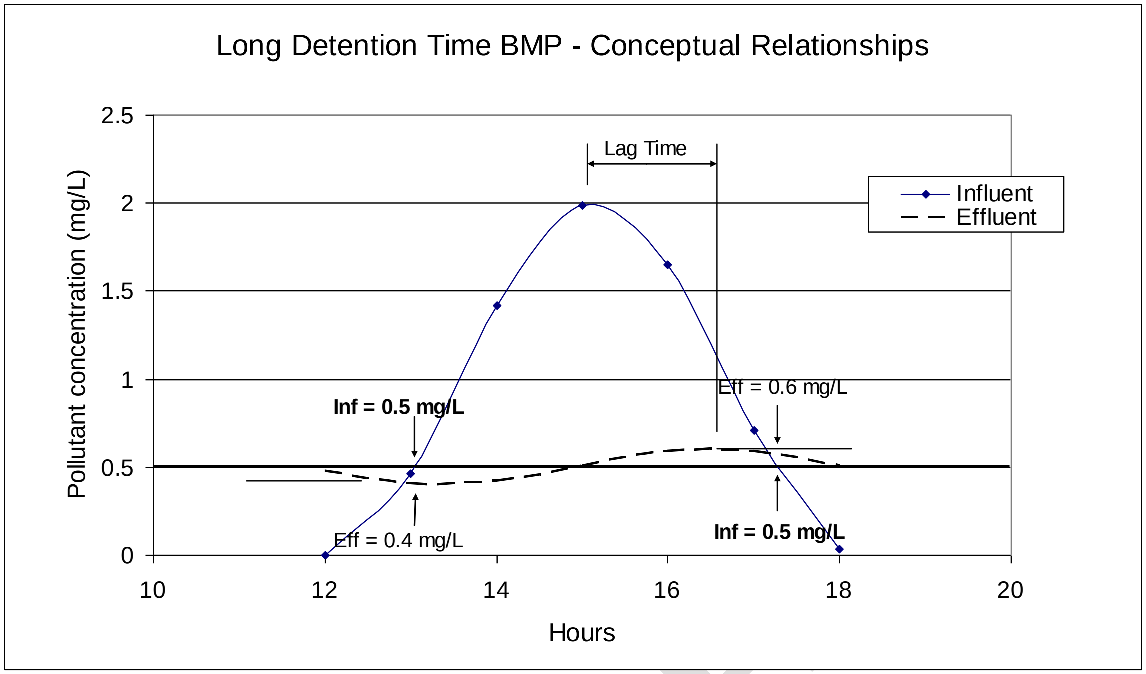

Figure 1 - Conceptual Relationships of Influent and Effluent for BMPs with Long Detention Times

Figure 1 illustrates why BMPs with long detention times cannot sample influent and effluent simultaneously as pairs.

1. Hydraulic lag time between influent and effluent. Effluent flow peaks later than influent flow ("What is going in is not what is coming out.")
2. A given influent concentration can be associated with more than one effluent concentration, depending on whether pollutant concentrations are on the rise or decline.

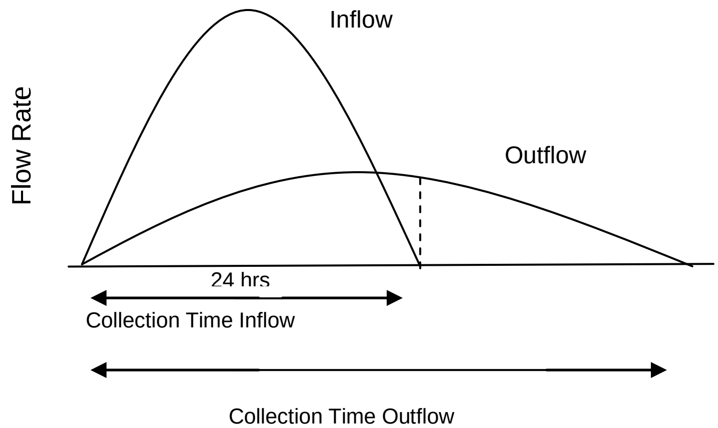

Figure 2 - Depiction of Portions of Influent and Effluent Hydrographs for a BMP with a Long Detention Time
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A traditional, alternative way to represent inflow and outflow from a BMP with long detention times is to compare results from the entire hydrograph inflow to that of the outflow (Figure 2). If the volume of water entering a BMP is comparable with that exiting, the BMP efficiency can be readily determined. The difficulty with the method is that in wet climates where inflow and outflow are not isolated events, preceded and followed by dry periods, it may be not possible to isolate inflow and outflow events.

The problem of monitoring BMPs with long detention times has gone largely unrecognized within the field of BMP monitoring and evaluation. There is little in the literature concerning the issue. Strecker noted the need for enough data during storms to comprise a continuous sample over an extended period (Strecker, et al, 2001). Robert Pitt, in response to an inquiry, stated that seasonal mass sums are best, requiring almost complete sampling, or at least complete flow monitoring and adequate water quality sampling to calculate the influent and effluent concentrations within acceptable levels of error (Pitt, 2006).

For all methods of determining BMP treatment efficiency, in order to determine treatment efficiency on a mass-loading basis, inflow and outflow data must be collected. For this method, flow data need be collected for an entire season (or year) to estimate seasonal (or yearly) mass-loading.

CATEGORIZING BMPS IN TERMS OF DETENTION TIME

Before developing a sampling design, categorize the stormwater BMP in terms of its detention (retention) time. This should be done on a case-by case basis. Methods for data collection and analysis both depend upon the determination of which applies:

- a short residence time

- a long residence time

Previous versions of TAPE described a short residence time as minutes and a long residence time as hours. While this may serve as a rough guideline, the distinction between a BMP with a short and long residence time, as defined in this guidance, is based on the comparability of its effluent with its influent. If influent and effluent samples represent the same hydraulic mass, the BMP may be analyzed as a short-detention-time BMP. If a parcel of water exiting a BMP does not represent a parcel concurrently entering – if “what comes in is not what is going out” – the BMP cannot be evaluated as a short-term BMP with paired data.

Points to consider in determining that a BMP should be evaluated as having a long detention time:

1. A relatively long residence time within the BMP on the order of hours rather than minutes.

2. A detention time not comparable to a typical storm duration. If the detention time is larger than or even somewhat less than a storm duration, there will be insufficient time for the inflow to a BMP to comprise a significant part of the outflow.

These and other conditions that may prevent the meaningful pairing of effluent samples with simultaneously collected influent samples should be considered. The Quality Assurance Project Plan must include a description of the how the BMP was characterized as a short or long detention time BMP.

CURRENT TAPE APPROACH TO BMPS WITH LAG TIMES

A common misunderstanding among those monitoring BMPs is that when a lag time is known, two hours for example, effluent can be collected two hours after the influent in order to represent treatment through the BMP. The implicit assumption is that water flowing through a BMP does so as a discrete unit, that is, as plug flow. The hydraulics of actual BMPs are complex, with aspects of both plug flow and complete mix taking place between inflow and outflow.

The current TAPE recognizes this and provides guidance intended to maximize the chances of sampling the same volume of water at the influent and effluent locations. TAPE calls for sampling influent and effluent over a period for which the volume passing the samplers is equal to 8 times the treatment unit’s detention volume. In cases where the duration of stormwater inflows and outflows is less than 8 times, it may be that the method cannot be used.

MONITORING LONG DETENTION TIME BMPS – A NEW METHOD

As already discussed, there are many instances when the analysis of pairs of data or of entire storm hydrographs is not possible.

The concept for an approach to monitoring BMPs with long detention times is to collect influent and effluent samples, not as pairs, but in a true random fashion, so that, given sufficient data, values for influent and effluent parameters will be representative, while derived independently. Given a sufficiently large sample size, aggregate influent and effluent data can be compared and BMP effectiveness quantified.

This strategy for data collection was developed by Shapiro and Associates for the Bellevue Utilities Department for Evaluating BMPs with long detention times in Lakemont, Washington. The system employed two sand filters and the residence time was approximately 42 hours.

In conventional sampling, flow-weighted samples are collected for entire storm events. The flow-weighted concentration is the Event Mean Concentration – EMC. In this long detention time method, the collection period is set at a maximum of 24-hours. The flow-weighted concentration we will term the “Sample Mean Concentration” – SMC. In cases where inflow or outflow stop before 24-hours of sampling, sampling times can be as short as 6 hours.
Note: Storms with sampling periods lasting less than 6 hours can be used if the sampling period catches at least 75% of the runoff volume.

Storms occurring after several days or more of no precipitation may be specifically targeted for sampling. As is always the case when sampling individual storm events, it must be determined that sampling is of sufficient duration to represent inflow and outflow hydrographs. This exception to the protocol of random sampling allows for the inclusion of important first-flush events, such as occur during the dry season.

INFILTRATION

For facilities such as wet ponds, the amount of groundwater which may infiltrate into the facility, and the amount of stormwater that may exfiltrate to the ground can influence performance. The degree of infiltration/exfiltration will not be used as a criterion for site selection because relationships between inflow and outflow are complex and would require at least an entire year of continuous inflow and outflow data in advance of the sampling program. However, an estimate of the amount of infiltration/exfiltration through continuous inflow and outflow data <u>is necessary</u> concurrent with the sampling program to document how the facility functions.

Calculations of mass (load) based treatment efficiency (Method #2 of the section, *Calculate and Evaluate Treatment Efficiency*, can take infiltration or exfiltration into account by scaling-up <u>sampled</u> inflow and outflow volumes to <u>total</u> inflow and outflow volumes respectively.

Although not required in the study report, effective detention times and percent infiltration can be calculated based on total inflow and outflow volumes as well as the total volume of the BMP. These are not required to be reported because a number of methods can be used by those calculating percentage inflow and effective detention time.

DEVELOPING A STUDY DESIGN

A sampling program for evaluating a BMP with this method is based on a statistical approach that involves three steps: 1) a preliminary estimate of the number of samples needed to meet the statistical goals; 2) estimating the number of random sampling dates necessary to successfully collect the estimated number of samples; and 3) advance scheduling of the sampling days through a random process before the sampling season begins.

DETERMINING NECESSARY SAMPLE SIZE

An important part of a study design is to determine a sample size large enough that the sampling data, when obtained, will be adequate to meet the objectives for evaluating a BMP.

- Appendix D of TAPE provides a statistical method for designing a study to evaluate stormwater BMPs and evaluating data. The methods presented in this section: *Developing a Study Design*, and in the following section: *Data Evaluation Methodology*, modify and largely substitute for Appendix D.

A freely available online calculator can be used to estimate number of samples required for two populations (influent and effluent) given their mean, standard deviation, level of significance and power level. A 95% level of significance and a power level of 80% may be used as guidelines. (95% significance is input to the calculator as “5%” and 80% power is input as “20%). See Appendix J for more information and a link to the online calculator.

Table 1 of TAPE shows typical COV (coefficients of variation) for different treatment levels. These COVs can be converted to means and standard deviations to input to the online calculator with the equation: COV = (STD DEV) / (SAMPLE MEAN), where STD DEV is as defined by the Excel STDEV function.

As in all experimental designs, the number of samples (*n*) specified, should be extended in practice. Stated in TAPE Appendix D: If the COV values of the concentrations are relatively low (about 0.4, or less), the corresponding distributions are close to normal As the COV values increase, greater errors will occur in these estimates. Therefore, these are only guidelines and it is suggested that the actual sampling effort be increased to cover the expected errors. It is important that the confidence and power levels be calculated for the actual tests, in addition to the measured %.

In addition to comparing data collected with the online calculator, it may be useful to run the Efficiency Calculator during the season to determine whether the calculated removal rates have sufficient statistical confidence.

In general, the evaluation of the effectiveness of a BMP within a reasonable statistical confidence interval requires a considerable amount of data. It is rare that a sampling schedule will include more days than are required. The use of the Efficiency Calculator mid-season will determine if there has been sufficient sampling or give an idea of the amount of additional sampling necessary.

ESTIMATING THE NUMBER OF SAMPLING DAYS

Planning the sampling schedule with a statistical basis for the number of days to attempt to sample is an important part of Study Design. Ideally, this would determine the number of days to schedule random sampling prior to the sampling season. The number of days would depend upon the percentage of time to expect there to be inflow and outflow to sample. This in turn would depend on the expected precipitation pattern as well as the BMP's functioning in terms of inflow and outflow. Outflow time periods can be significantly longer than rainfall periods.

Unfortunately, given the variability of winter precipitation patterns from one year to the next, it is not possible to predict with any statistical certainty the number of days with runoff producing precipitation to expect for a study of one or two years. It is necessary to make assumptions in order to try to collect sufficient samples within a time period designated for the study. In the case of the phase I municipal stormwater permits, the goal is to collect sufficient samples to meet the specified statistical goals, complete laboratory analyses, and make final reports within the time frame of the permit. This restricts the sample collection time frame to 2-years for collaboratively developed programs, and 2 ½ years for independent programs.

After estimating the necessary sample size using the methods explained above, estimate the number of random sampling days within a certain time period that may produce the target number of samples. For instance, if the estimate from the statistics is that we need 40 influent and 40 effluent samples, determine how many random attempts need to be programmed of each in order to collect approximately that many samples. If there are 80 days of runoff within a 150 day sample period, you have an 80/150 (0.53) chance that a random sampling day will actually collect a sample. If you need 40 influent samples, then 40/0.53, random days must be identified within the 150 day period. It would be best to split the allowable sample collection time period into sub-periods that have different rainfall frequencies. A higher success ratio is possible in the wet season. However, collection of some samples during the drier season is probably necessary in order to get a desirable range of influent concentrations. It would also help provide a more accurate assessment of annual average performance.

In addition to the above, it is necessary to increase the number of random sampling days by a safety factor in order to account for days of equipment malfunction, operator error, etc.

Inflow and outflow flow recording for the entire sampling season are necessary for this method. They provide for the calculating of mass load on a seasonal basis. Alternatively, flow measurements can be made for one year (for mass load on an annual basis).

SCHEDULING THE SAMPLING DAYS

Consecutively numbering the days from first to last dates of the chosen sampling season ensures a random distribution of sampling events. A random number generator, such as that in Microsoft Excel®, can be set to generate numbers between the first (1) and last (n) day of the sampling schedule (i.e. from 1 to n). Influent and effluent are to be sampled independently, each with its own set of dates. Each sampling event will be conducted on the predetermined date, unless there is no discharge on that date.

One advantage of the strategy of random sampling is that it enables a larger number of samples to be collected than might have been the case where sampling of individual storm events is required.

SAMPLING METHODS

Sampling is to be done for a period of up to 24 hours by automatic flow-weighted composite sampling (Method #1 of current TAPE section *Stormwater Field Sampling Procedures).* This may be done by setting up an automatic sampler with a flow meter so the volume of each subsample is proportionate to flow. Continuous flow monitoring to encompass the entire sampling season or calendar year is necessary to determine total mass-loading. Inflow and outflow must be monitored separately.

The subsections under Stormwater Field Sampling Procedures (p.18 of TAPE) that follow: *Sampling locations, Sampler installation, operation, and maintenance, flow monitoring* and *rainfall monitoring*, all apply.

In conventional stormwater sampling and in this modified guidance, automatic samplers are used to collect flow-weighted subsamples. In this way, periods of high intensity in a storm will be sampled proportionate to the flow. The concentration of the overall sample is termed an “Event Mean Concentration” (EMC). A mass-load can be determined for the sampling event by multiplying the EMC by the total flow during that event.

Mass (load) = EMC x total flow   (storm event basis)

For monitoring flows for BMPs with long detention times, the sampling duration is defined, not as the length of a storm event, but as 24-hours. Since samples are flow-weighted, the result is analogous to an EMC. We can define a sampling-event mean concentration as an SMC.

Mass (load) = SMC x total flow (24-hour basis)

A 24-hour sample collection window is recommended because:

1. It will capture many shorter storms and a significant portion of extended storms that are typical of the local maritime climate.

2. It is a timeframe over which sampling equipment can be easily programmed and operated to obtain representative samples.

DATA EVALUATION METHODOLOGY

Following is a procedure for evaluating data from monitoring studies of BMPs with long detention times. Given the extensive human and monetary resources required for generating monitoring data, it is worthwhile to organize and present the data in a number of ways. Several methods are included here to provide variety of statistical and visual descriptions of results.

CONSIDERATION OF BASE FLOW

Base flows are flows that occur independent of a rainfall event. They can be caused by high groundwater, routing of naturally occurring springs or creeks into the storm drain system. A sampling location that does not have a base flow is preferable. Where sampling a site with base flow is necessary, adjustments in the sampling program are necessary.

Base flow can be readily determined by observing inflow rates on several dates for which none of the inflow can be expected to be stormwater runoff. Depending on weather patterns, this may be on the order of days or weeks of preceding dry weather. Base flow rates can vary significantly among the seasons. Observed base flow rates should be reported in the study report.

It is logical to consider the percent of base flow relative to wet weather flow to determine that a particular BMP qualifies for a study, but this is complicated by what may be considerable variation in wet weather inflows between years. Unless base flow is found to be considerable, it is usually sufficiently low relative to wet weather flow to be not an important factor. BMPs observed to have considerable base flow relative to observed or expected magnitudes of flow (10% or more) may be disqualified for a monitoring study. There are two concerns: the base flow reduces influent concentrations significantly so that performance during higher influent concentrations is never tested; and 2) the presence of a continuous flow compromises the treatment facilities performance. In the latter case, examples of consequences include premature exhaustion of media, and lack of time for treatment surfaces and volumes (e.g. sand filters) to breath.

Besides reporting observed dry weather base flows, it is necessary to try to set automatic sampling equipment so that it does not sample base flows. Samples collected during times obviously not associated wit a rain event should be discarded. Samples collected during times where the baseflow was a significant percentage should be evaluated on a case-by-case basis. If the base flow is a usually very low turbidity, the collected samples exhibit low turbidity, and they were collected at flow rates not significantly greater than base flow, then the samples should be discarded.

At the time of data evaluation and reporting, the influence of base flow on the hydraulic loading rates (e.g. gpd/ft2) and detention times during sampled events needs to be reported and considered in the discussion about performance results.

AN OUTLINE OF THE STEPS FOR DATA EVALUATION

A flow chart, Figure 3, shows all steps of data evaluation. The steps are presented in this section (p.12-18). Appendix I is a detailed example. It should be followed while reviewing the steps below.

Analyses to be included are:

- Treatment efficiency – concentration basis
- Treatment efficiency – mass (load) basis.
- Calculation of confidence interval associated with concentration-based treatment efficiency. (EFFICIENCY CALCULATOR Excel macro)
- Scatter plot (with original concentrations)
- Cumulative probability plot (log basis)
- Test for normal distribution
- Test to determine effluent concentration is significantly different from influent concentration (that is, that there is treatment).

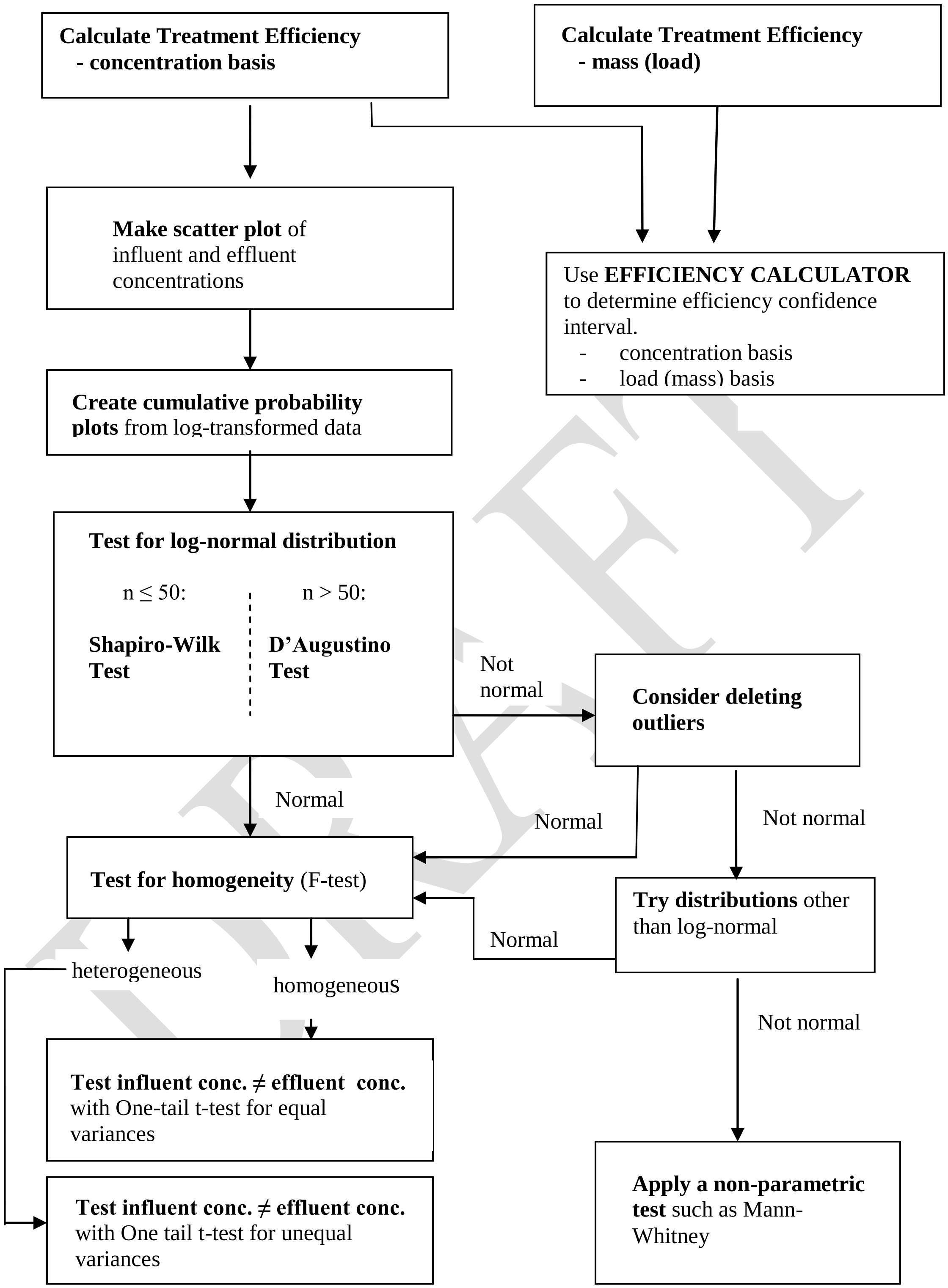


Figure 3 – Steps for Data Analysis – BMPs with Long Detention

1. CALCULATE AND EVALUATE TREATMENT EFFICIENCY

Treatment efficiency is a measure of the percentage reduction of a pollutant between a BMP's influent and effluent. By itself a calculated value for treatment efficiency may not tell the whole story. In the case, for example, where influent pollutant concentrations are low, the calculated efficiency may be low although the effluent concentration is at the irreducible low limit for effluent treatment. This should be noted in a discussion of experimental results.

Two forms of treatment efficiency are to be calculated: concentration based and load based. Concentration-based treatment efficiency (a modification of Method #1 of TAPE Appendix A) is useful where receiving water standards, usually in terms of concentration, are of concern. Mass-loading based treatment efficiency is useful when the total mass of a pollutant discharged to a receiving water is of interest. Both forms of treatment efficiency should be calculated.

Method #1: Treatment Efficiency – Concentration Based

Concentration-based treatment efficiency is an indication of the reduction in pollutant concentration from the arithmetic means of all influent and all effluent samples collected during a sampling season(s). Treatment efficiency is simple to calculate because it does not depend on volumes of inflow our outflow.

The USEPA and ASCE (2002) monitoring guidance extends Method#1 from a single event to all events of a sampling season. Their term "ER" – efficiency ratio is equivalent to our term "treatment efficiency."

Treatment efficiency (concentration basis)
= 1 – (avg. outlet EMC/avg. inlet EMC)
= (avg. inlet EMC – avg. outlet EMC) / avg. inlet EMC

or in terms of SMC (24-hour sampling event mean concentration):

Treatment efficiency (concentration basis)
= 1- (avg. outlet SMC/avg. inlet SMC)
= (avg. inlet SMC – avg. outlet SMC) / avg. inlet SMC

Method #2: Treatment Efficiency – mass (load) based

This treatment efficiency is based on the total mass of pollutants in the BMP inflow and outflow.

a. For treatment facilities without significant internal water gains or losses, the basis for mass-based efficiency calculations is the assumption that for a sampling season the sum of the outflow volume sampled should be set to equal to the sum of inflow volume sampled as follows:

Proportion in/out = (Sum of flow volumes for influent samples) / (Sum of flow volumes for effluent samples)

Multiply each of the 24-hour sample effluent flows by this proportion.

The reasonable assumption is that to evaluate BMPs in a standard way, outflows should be set equal to inflows. This is a correction factor to provide for an estimate of mass removal.
For the following mass loading calculations, normalize (proportion) flows so that the total seasonal (or annual) sampling-period inflow volume is set equal to the outflow volume. Then proportion volumes from individual samples accordingly. The assumption here is that outflow load should be the basis for BMP evaluation.

Calculate the aggregate pollutant loading removal for all storms sampled as follows:

100(A-B)/A

- Where the sampling volumes shown below have been normalized to outflow seasonal flow before entering into the equations below:

Where: A= the total mass of pollutant entering the BMP during the sampling season(s)

= (Sampling event #1 influent concentration)*(Sampling event #1 total volume) * + (Sampling event #2 influent concentration)*(Sampling event #2 total volume) + … (Sampling event #N influent concentration)*(Sampling event #N total volume)

B = the total mass of pollutant exiting the BMP during the sampling season(s)

= (Sampling event1 effluent concentration) * (Sampling event 1volume) + (Sampling event 2 effluent concentration)* (Sampling event 2 volume) +… (Sampling event N effluent concentration) * (volume of sampling event n)

b. For treatment facilities with potentially significant internal water gains or losses (e.g. ponds without artificial liners, the above normalization procedure is not used. Instead, the total mass of pollutants determined by "A" above is multiplied by the ratio of the total sample season influent volume divided by the total sampled volume for that season. Similarly, the total mass of pollutants determined by "B" above is multiplied by the ratio of the total sample season effluent volume divided by the total sampled volume for that season. The modified "A" and "B" values are used in the aggregate equation: 100(A-B)/A. This method requires continuous influent and effluent monitoring over the sample season in order to estimate total influent and effluent volumes..

2. CALCULATE CONFIDENCE INTERVAL OF TREATMENT EFFICIENCY

EFFICIENCY CALCULATOR is an Excel VBA program developed for this project. It calculates treatment efficiency as in the above equations and a confidence interval as well. The need for the Efficiency Calculator is because confidence intervals for the unlike numbers of influent and effluent points (resulting from the long detention time method) are not readily determined. Inputs are simple arithmetic means and standard deviations. Outputs are estimated treatment efficiency and confidence limits (e.g., 56.2% +/- 7.3%). Appendix I shows how to use the Efficiency Calculator.

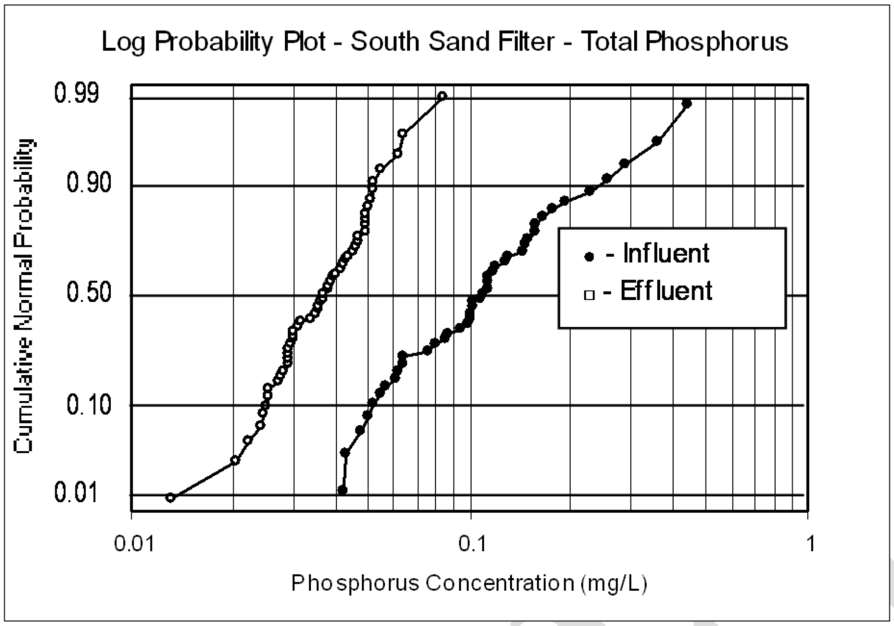
3. CREATE SCATTER PLOTS

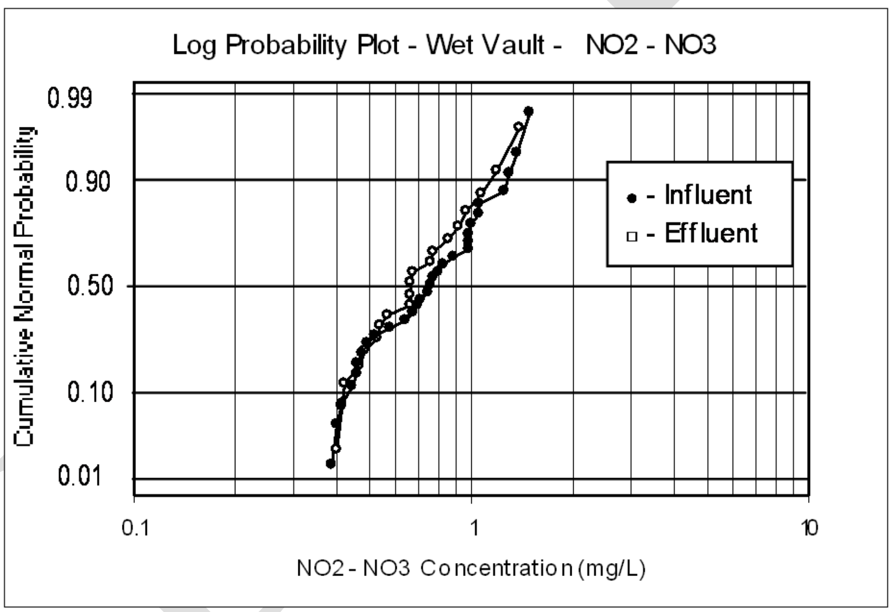
Plot actual concentration values (not log-normalized) of influent and effluent values at different locations on the x-axis and concentration on the y-axis. A scatter plot shows most directly the relationship between influent and effluent concentrations. Also, if effluent concentrations tend to group about a minimum concentration, this may indicate an irreducible concentration (a concentration below which, for practical reasons, a treatment process cannot achieve). With data sets for which an irreducible concentration is apparent on a scatter plot, the irreducible concentration should be reported.

4. CREATE PROBABILITY PLOTS

Rank-order influent and effluent data separately from lowest to highest concentration. Plot both data sets with log concentration on the x axis, and cumulative probability on the y-axis. In Excel, the y-axis can be set to statistic z value, then converted to a probability scale the data on log-normal probability paper. See Appendix K for detailed instructions for creating probability plots.

Two example plots:





The first plot shows a large separation between influent and effluent plots, consistent with effective removal. The second plot shows little separation and a t-test for the data show no significant difference between influent and effluent (no significant treatment).

Appendix L provides extensive information about the creation and interpretation of probability plots, a method proposed in the document Urban Stormwater BMP Performance Monitoring (USEPA and ASCE, 2002).

3. TEST THAT TREATMENT IS OCCURING: EFFLUENT CONCENTRATION ≠ INFLUENT CONCENTRATION

The following test for normality is a prerequisite for applying a t-test to determine whether the average effluent concentration is significantly different from the average influent concentration, that is, whether treatment is taking place.

1) Test for Normality

The first step is to test the data to determine whether they follow a normal distribution. If so, powerful parametric (normal) tests such as the t-test can be applied.

It has been found, in general, that stormwater influent and effluent data follow a log-normal distribution. Begin by taking the logs (base 10) of each concentration value and then test for the normality of this log-transposed data. It is this transposed data that will be input to the t-test in step 2.

Determine whether the log-transformed data for each of the two plots deviate significantly from normality. The *Shapiro-Wilk test* is generally recognized as the most powerful test for determining non-normality but alternate tests may be used. The test produces a W coefficient. Commonly, W corresponds to a normal distribution when > 0.95.

If the test shows that data are not log-normally distributed, consider excluding data points that appear to be outliers at the lowest 10^{th} percentile level, then test for normality again. The two-sample t-test (below) is parametric (requires a normal distribution). If log-transformed data for influent or effluent are still not normally distributed, consider applying other than a log transformation. For data not normally distributed, apply a non-parametric test such as the Mann-Whitney signed rank test in place of the t-test.

2) Apply t-test to test for significant difference

For data shown to be log-normally distributed, use a two-sample t-test (one tailed) for log-normal unpaired data (i.e. an independent t-test) to determine whether treatment is taking place. Treatment is indicated when there is a significant difference between influent and effluent mean sample concentrations. Other statistical tests for unpaired parametric data may be use in place of the t-test. Apply p = 0.05 confidence for basic treatment and p = 0.10 for advanced treatment BMPs (Appendix D – Ecology TAPE).

Apply a one-tail F-test to determine which form of independent t-test to use. If the test finds $p<0.05$, the variance between the influent and effluent data sets is significant and the t-test for heterogeneous variances should be applied. Otherwise the t-test for homogeneous (equal) variances should be used.

The determination of a significant difference between influent and effluent mean sample concentrations for the t-test indicates that significant treatment is taking place.

The Shapiro-Wilk test for normality in step 1 is used in the place of the Kolmogorov-Smirnov test suggested in the USEPA/ASCE guidance because that test is for paired data. The independent two-sample one-tail t-test, a parametric test, is used to determine significant difference between influent and effluent means, with the less powerful non-Mann-Whitney signed rank suggested in Appendix D of TAPE used only when data are not normally distributed.

Confidence limits for the Shapiro-Wilk test for normality should be set at 95%, the generally accepted limit for the test. Confidence limits for other tests can be set at 90%.

REFERENCES

Edwards, Thomas C. Jr. 2003. FRWS 6500 Biometry.

California Stormwater BMP Handbook, 2003. Appendix B. www.cabmphandbooks.com. January 2003.

DSS Research. Free online calculator to determine sample size for experimental design. http://www.dssresearch.com/toolkit/sscalc/size_a2.asp

GraphPad software: Comparing the Fits of Two Models http://www.graphpad.com/curvefit/2_models__1_dataset.htm 2006.

Jon Peltier, 2006. Online instructions for creating probability plots with Excel. http://peltiertech.com/Excel/Charts/ProbabilityChart.html

Pitt, Robert. 2006. E-mail communication, October 19, 2006.

Strecker, Eric W.; Marcus Quigley; Ben R. Urbonas; Jonathan E. Jones. *Determining Urban Storm Water BMP Effectiveness*. J. Water Resources, Planning, and Management, Vol. 127, Issue 3, pp 144-149 (May/June 2001)

Shapiro and Associates; City of Bellevue Utilities Department, 1999. *Lakemont Storm Water Treatment Facility Monitoring Program: Final Report*. Partially funded by the Washington State Department of Ecology, Storm Water Soil Infiltration Monitoring Study; Grant number TAX 91131.

USEPA and ASCE, 2002. *Urban Stormwater BMP Performance Monitoring: A Guidance Manual for Meeting the National Stormwater BMP Database Requirements*. EPA-821-B-02-001. April 2002.

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Appendix H – Data Analysis Procedure – Example

The following example follows the data analysis procedure outlined on pages 14 - 20 and shown in the flow chart (Figure 3).

The example chosen is from Lakemont data for phosphorus treatment by the south sand filter. The data used for this example appears in Appendix M. The following table is a data summary, including sums from the data columns in Appendix M.

Lakemont south sand filter – phosphorus removal

Influent Data (n=**43**)

Mean concentration (mg/L)	**0.12657**
Standard Deviation	**0.08328**
Mean of log concentrations	-0.9683
Standard deviation of log concentrations	0.24227
Total mass (load,) Kg	13.22
Total volume, L	9.422 E7

Effluent Data (n=**53**)*

Mean concentration (mg/L)	**0.03809**
Standard Deviation	**0.01314**
Mean of log concentrations	-1.44522
Standard deviation of log concentrations	0.15580
Total mass (load,) Kg	3.2519
Total volume, L	7.9584 E7

*excluding one outlier

Treatment efficiency – concentration basis:

Calculate pollutant concentration treatment efficiency from all samples of a monitoring season(s) as follows:

Pollutant concentration treatment efficiency = 100(A-B)/A

Where: A = arithmetic mean of *influent* concentration data during the sampling season(s)

= 0.12657

Where: B = arithmetic mean of *effluent* concentration data during the sampling season(s)

= 0.03809

100(A-B)/A = 100 (0.12657 – 0.03809) / 0.12657

= **69.9% percent reduction in phosphorus concentration**

Using EFFICIENCY CALCULATOR Excel macro to calculate confidence interval for treatment efficiency (see Appendix I).

Input: influent
mean = 0.12657
Std dev = 0.08328
n = 43

effluent
mean = 0.03809
Std dev = 0.01314
n = 53

Output:

The results of 2 runs, 5,000 iterations each:

69.6% +/- 7.0% (95% confidence interval)
+/- 5.9% (90% confidence interval)
+/- 4.6% (80% confidence interval)

69.5% +/- 6.8% (95% confidence interval)
+/- 5.7% (90% confidence interval)
+/- 4.4% (80% confidence interval)

Decision: 69.6% or 69.5% are close enough to 69.9% (above)

Treatment efficiency – mass loading basis

Treatment efficiency is based on the total mass of pollutants in the BMP inflow and outflow during sampling events. Calculate treatment efficiency on a mass (loading) basis:

Calculate the aggregate pollutant loading removal for all storms sampled as follows:
100(A-B)/A

Where: A = the total mass of pollutant entering the BMP during the sampling season(s)

= (Sampling event1 influent concentration)*(Event1 volume flow) * + (Sampling event2 influent concentration)*(Event2 volume flow) + … (Sampling event N influent concentration)*(Event N volume flow)

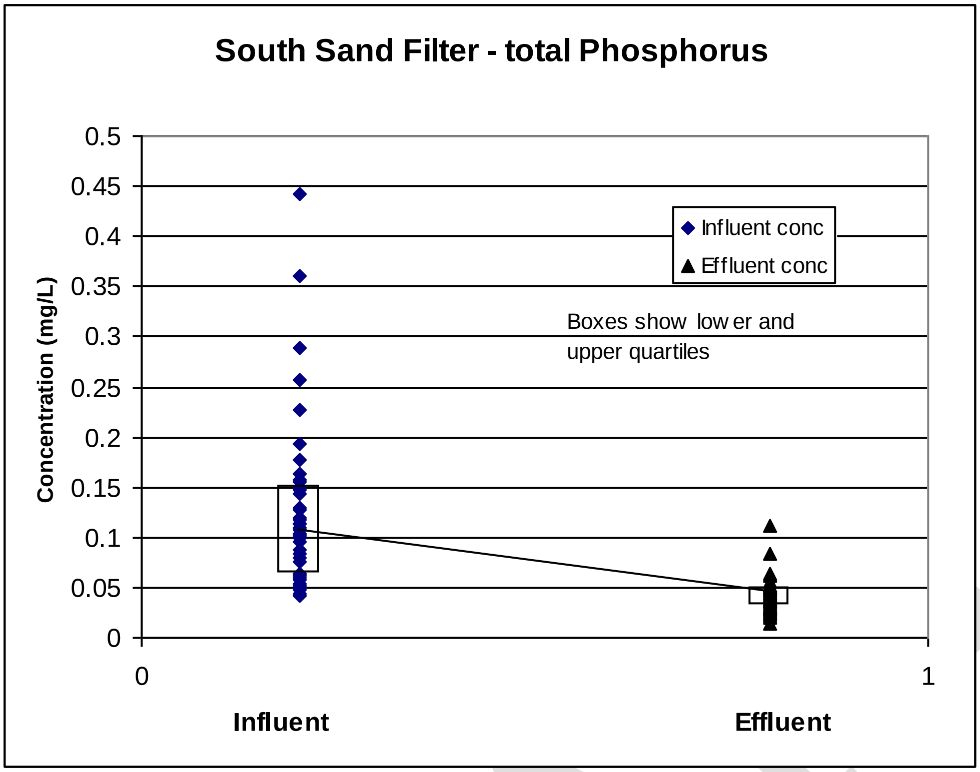
B = the total mass of pollutant exiting the BMP during the sampling season(s)

= (Sampling event1 Effluent concentration) * (Sampling event 1volume) + (Sampling event 2 Effluent concentration)* (Sampling event 2 volume) +Storm event 1 Effluent concentration storm 2 effluent concentration) +… (Sampling event N effluent concentration) * (volume of Sampling event N)

From data summary tables above:
A = total mass of influent = 13.22 Kg
B = total mass of effluent *normalized to influent volume* = 3.2519 (1.184) = 3.850 Kg (where ratio of vol in/vol out = 1.184)

From sum of loads shown in summary table, above.

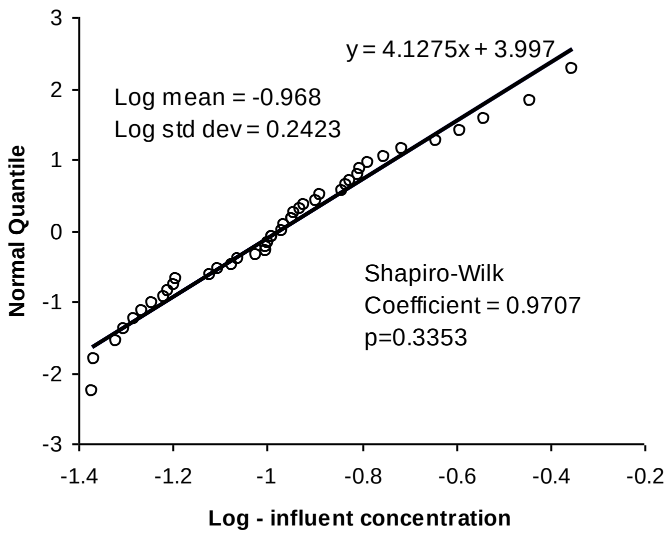
100(A-B)/A = 100(13.22 – 3.850)/13.22 = **70.1% percentage reduction in phosphorus mass loading**



Scatter plot: Lakemont South sand filter, phosphorus removal.

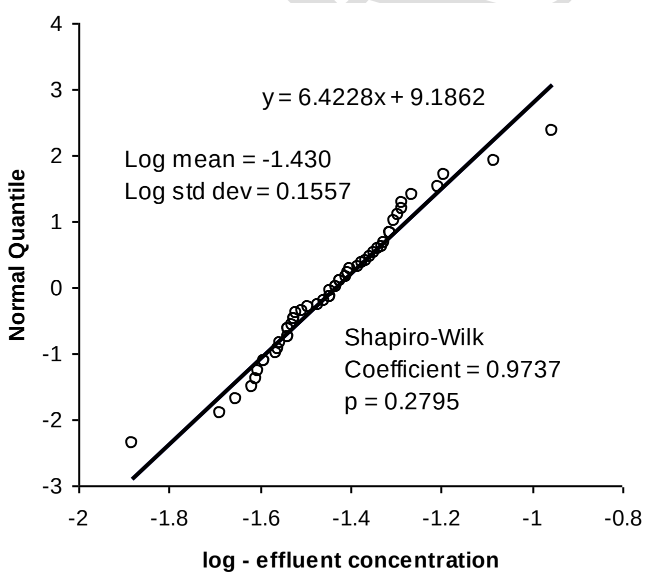
This scatter plot shows that for a wide range in influent concentrations (up to about 0.44 mg/L) effluent concentrations are consistently low (below about 0.12 mg/L). From this figure it can be seen that although removal efficiencies calculated for the lowest concentrations of influent may be low, the BMP may, in practical terms, be effective in that it produces a consistently low phosphorus concentration.

Lakemont – South Sand Filter Influent, Total Phosphorus log concentrations



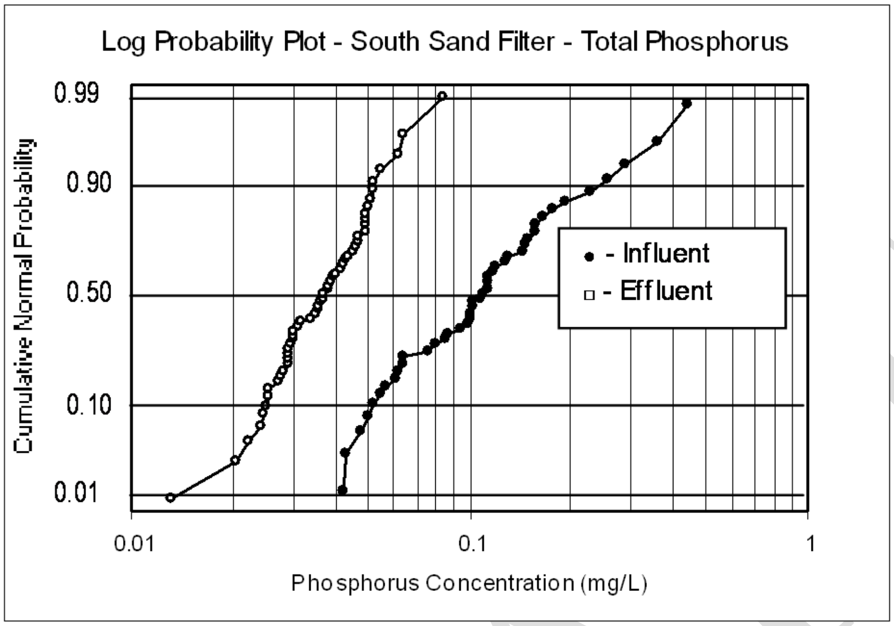
The data appear to fit a straight line well, a visual indication of normality.
The Shapiro-Wilk W coefficient = 0.9737 > 0.95. **The distribution of the log concentrations can be considered normal.**

Lakemont – South Sand Filter Effluent, Total Phosphorus log concentrations



The Shapiro-Wilk W coefficient = 0.9707 > 0.95. **The distribution of the log concentrations can be considered normal.**

Lakemont South Sand Filter – total phosphorus – cumulative probability plot



The cumulative probability plot shows a wide separation between influent and effluent lines. The plot provides a clear visual sense that variability within each (influent and effluent) is low in comparison with variability between them.

One-tail F-Test for homogeneity (equal variances): If the P-value is less than the conventional 0.05, the null hypothesis is rejected and the conclusion is that **the two variances differ significantly.**

Example: 41 and 52 degrees of freedom: F-test p=0.0014
Since 0.0014 < 0.05, the variances are heterogeneous (significantly different at 5% confidence level).

One-tail t-test for heterogeneous (unequal) variances:

P < 0.0001, so 99.9% confident that the **effluent and influent means are significantly different.**

Appendix I – TO USE EFFICIENCY CALCULATOR

EFFICIENCY CALCULATOR is an Excel VBA macro developed for this modified guidance. It was developed specifically to compare influent and effluent data to produce the confidence limits of the treatment efficiency when two data sets have unequal values for *n*, sample size.

With the "Efficiency Calculator" software for Excel, simply input the number of inflow and outflow points and the means and standard deviations of SMC values in order to arrive at the Treatment Efficiency (TE) for concentration. If the confidence interval is sufficiently narrow, you are finished evaluating the BMP. The confidence interval should be no broader than +/- 50% of TE (for example 60% TE +/- 30 %). If you desire to show, for example, that the BMP provides at least 50% removal, your desired confidence interval would be +/- 10% or smaller, requiring more data to show.

The Efficiency Calculator should also be used to calculate the TE on a loading basis. (See Methods #1 and #2 in the "DATA EVALUATION METHODOLOGY" section of the long-detention time BMP guidance. The calculator will show TE (treatment efficiency) and a confidence interval. If not as narrow as desired, collect more data points.

The efficiency calculator can be applied to results at mid-season to provide an indication of whether sufficient data have been collected, or to what extent more data need be collected.

The calculator employs a Monte Carlo approach to generate simulated concentration values for the number of influent and effluent data points. A distribution for actual influent as well as effluent concentrations is delineated by mean and standard deviation. This distribution is then used to generate simulated from which removal efficiencies are calculated. For example if concentrations for 12 influent and 15 effluent samples have been determined, the Efficiency Calculator will generate large numbers of simulated samples (with 12 influent and 15 effluent data points each.) Then the mean and standard deviation of the resulting simulated removal efficiencies is calculated (for example 2,000 removal efficiency values for 2,000 iterations). From this, the confidence limits of the removal efficiencies are calculated.

Its use is simple and intuitive. Input the mean, standard deviation, and *n* (sample size) for influent data as well as effluent data. Output is the treatment efficiency and its confidence interval. (eg. 56% +/- 6.8% for 95% confidence).

Inputs should be simple means (averages) and standard deviations (*not* log means or log standard deviations). This enables EFICIENCY CALCULATOR to calculate confidence intervals for treatment efficiency.

EFFICIENCY CALCULATOR is based on the assumption that the *mean* of all SMCs (Sample Mean Concentrations) resulting from a season(s) of sampling are normally distributed. This tends to be the case for data that themselves are not normally distributed. That is, the *values* of SMCs may tend to be log-normally distributed, but the means of all those values can be expected to be normally distributed. EFFICIENCY CALCULATOR processes at the level of individual mean values – one for influent and one for effluent no matter how large the study.

Settings for EFFICIENCY CALCULATOR

Set:

Tools> Add-ins:	check boxes for:	- Analysis ToolPak - Analysis ToolPak VBA - Solver Add-in

Appendix J – Calculating sample size for experimental design

The experimental design prior to sampling requires an estimate of mean and standard deviation of influent as well as effluent data. The user provides an estimate of expected influent and effluent mean concentrations as well as standard deviation. If standard deviations cannot be estimated, predicted, the typical COV values shown in Table 1 of TAPE Appendix D gives COVs (Coefficients of Variation) for BMPs with different treatment levels. COV can be used to estimate standard deviations (since COV = standard deviation / mean). The online calculator referenced below can be used to determine desired sample size for studies of long-detention time BMPs (in the place of Tables 1-3 and Figure 2).

The calculator gives a single value for sample size, to be used both for influent and effluent samples. It is only upon actual monitoring that a difference in influent and effluent sample sizes will be known.

The use of the calculator is unrestricted. It is stated at the internet site: "Feel free to use these and pass the links along to anyone that might be interested."

Link to calculator:
http://www.dssresearch.com/toolkit/sscalc/size_a2.asp
DSS Research homepage:
http://www.dssresearch.com/home.asp

Two Samples Using Average Values

Average Value for Sample 1:	4.0	(Value measured from Sample 1 or expected from it)
Average Value for Sample 2:	3.1	(Value measured from Sample 2 or expected from it)
Standard Deviation for Sample 1:	1.0	
Standard Deviation for Sample 2:	0.8	
Alpha Error Level or Confidence Level:	5%	(Probability of incorrectly rejecting the null hypothesis that there is no difference in the average values). An Alpha of 5% corresponds to a 95% Confidence Interval.
Beta Error Level or Statistical Power [1 - Beta]:	20%	(Probability of incorrectly failing to reject the null hypothesis that there is NO difference in the average values -- assuming no difference when a real difference exists). A Beta of 50% is used in most simple calculations of sampling error.

Calculate Sample Size   Sample Size = 13 for both samples!

Notes for use of the calculator:

- The values for alpha and beta recommended by Pitt (Appendix D of TAPE) are 95% and 80% respectively. These are entered on the online calculator as alpha (5%) and beta (20%). Other values can be used.
- Both standard deviations can be input as the same value.
- The COVs for stormwater BMPs listed in Table 1 of Appendix D can be used to derive inputs to the online calculator. COV = (standard deviation) / (mean). For an expected standard deviation, COV values can be used to calculate mean values to enter into the online calculator. Similarly for expected means, COV values can be used to calculate standard deviations to enter.

Appendix K - Creating Probability Plots with Excel

Plot concentration vs. z value. Create a table to develop data to plot. The Excel table below is an example. First plot concentration vs. z value. “f” is the number of data points for each concentration. “cf” is a ranking of results with shared values (eg, “8”) for values of equal concentrations.

To calculate values for the table:

- % cf = 100*(cf/n) where n = sample size.
- z statistic = NORMSINV(% cf / 100)

mg/L	f	cf	%cf	Z
0.0131	1	1	1.851852	-2.08536
0.0205	1	2	3.703704	-1.78616
0.0222	1	3	5.555556	-1.59322
0.0242	1	4	7.407407	-1.4461
0.0246	1	5	9.259259	-1.32496
0.0249	1	6	11.11111	-1.22064
0.0256	2	8	14.81481	-1.04441
0.0256		8	14.81481	-1.04441
0.0273	1	9	16.66667	-0.96742
0.0275	1	10	18.51852	-0.89578
0.028	1	11	20.37037	-0.82846
0.029	2	13	24.07407	-0.70392
0.029		13	24.07407	-0.70392

The site below presents a method for producing probability plots with EXCEL. It converts the y-axis form z values to a probability scale.

http://peltiertech.com/Excel/Charts/ProbabilityChart.html

Jon Peltier has granted permission to cite the link above.

Appendix L – The Effluent Probability Method (Probability Plots)

A project to develop a detailed stormwater BMP monitoring guidance was undertaken by a team of experts from the Urban Water Resources Research Council of the American Society of Civil Engineers (ASCE) under a grant from the USEPA. The team identified a wide variety of measures that have been used historically to assess BMP performance, resulting in wide variations in reported BMP effectiveness. Additionally, the team developed an approach to BMP performance assessment that went beyond the traditional approach of calculating percent removal: the Effluent Probability Method (USEPA – ASCE, 2002).

The most important feature of the Effluent Probability Method is the creation of standard parallel probability plots. The authors of the guidance state that the curves are the most instructive piece of information that can result from a BMP evaluation study. The authors strongly recommend that the stormwater industry accept this approach as a standard “rating curve” for BMP evaluation studies.

Figure 1 is an example of a typical parallel probability plot from the USEPA/ASCE guidance:

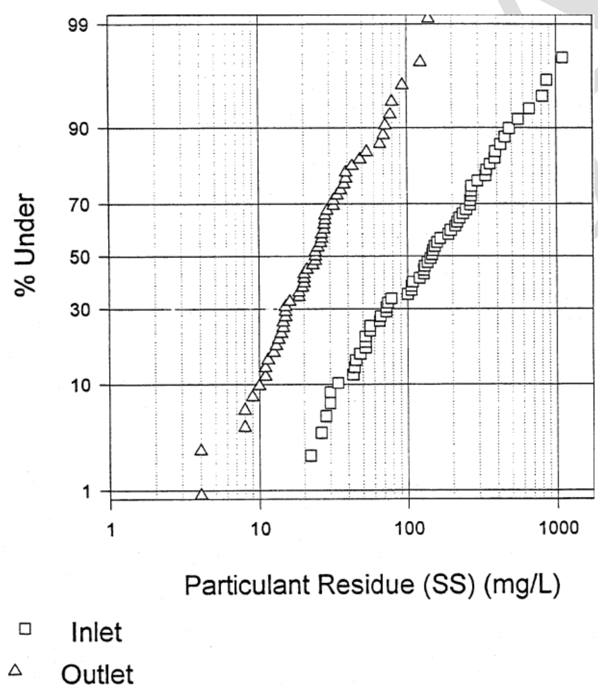


Figure – Probability Plot for Suspended Solids (Figure 2.8 of USEPA/ASCE guidance)

In the figure concentrations are plotted on a log scale vs. probability. The right line shows all influent data. The near-parallel line to the left shows effluent data.

The first step in creating a plot is to separately rank-order influent and effluent data by concentration. A probability plot is created by plotting influent and effluent concentrations on log-normal probability paper. Alternatively, the rank-ordered data can be plotted with the x axis as a log scale and the y axis as z values (the number of standard deviations of each concentration value from the mean).

The basis for a logarithmic transform of pollutant concentration data is the observation that stormwater BMP data do not generally form a straight line on a normal probability plot, but do on a log-normal probability plot.

The plot provides more information than that of a simple treatment efficiency determination. The effectiveness of pollutant removal throughout the range of influent and effluent concentrations is shown in the plot.

The California Critique of the Effluent Probability Method

A critique of the EPM appears in the California Stormwater BMP Handbook (2003). It expresses concerns about the general applicability of the technique and whether or not it should be considered the standard approach for quantifying BMP efficiency. The following is a summary of the points raised.

An example log-normal probability plot from EPM (Figure 1) is shown to illustrate some issues with the method:

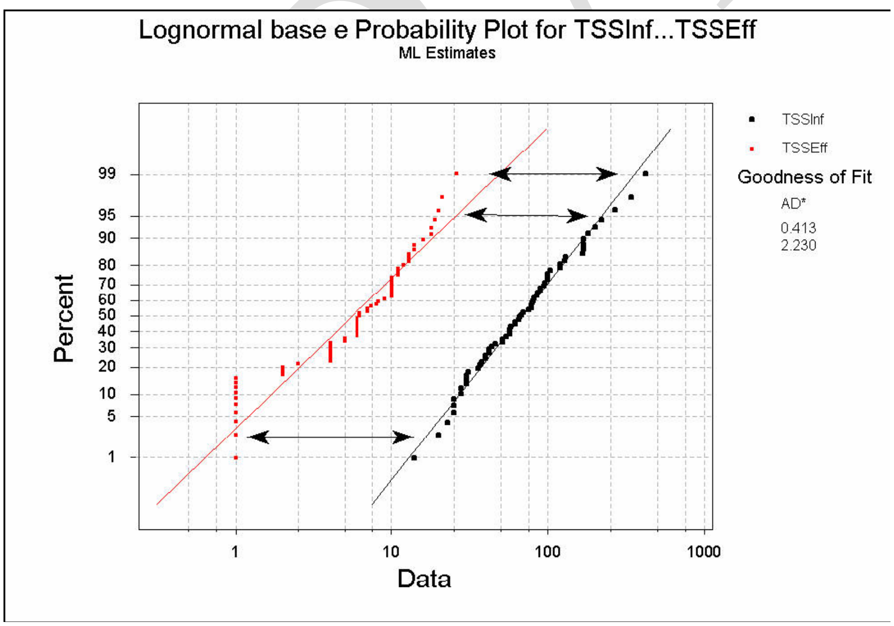


Figure 1 – Influent and Effluent data shown on a log-normal probability plot.

The plot of Figure 1 is typical of many, showing parallel lines for effluent and influent, each curve distinct with data well separated into the two groups. Because they are developed from rank-ordered data, probability plots have an orderly appearance of two distinct and often close-to-parallel plots. The plots give the appearance that for a given influent concentration, the effluent concentration is given by the corresponding point located horizontally.

California contends that the plot above, with trends appearing so clear, is misleading. The same data are shown in Figure 2 with arrows indicating paired data with great variability between influent and effluent concentrations.

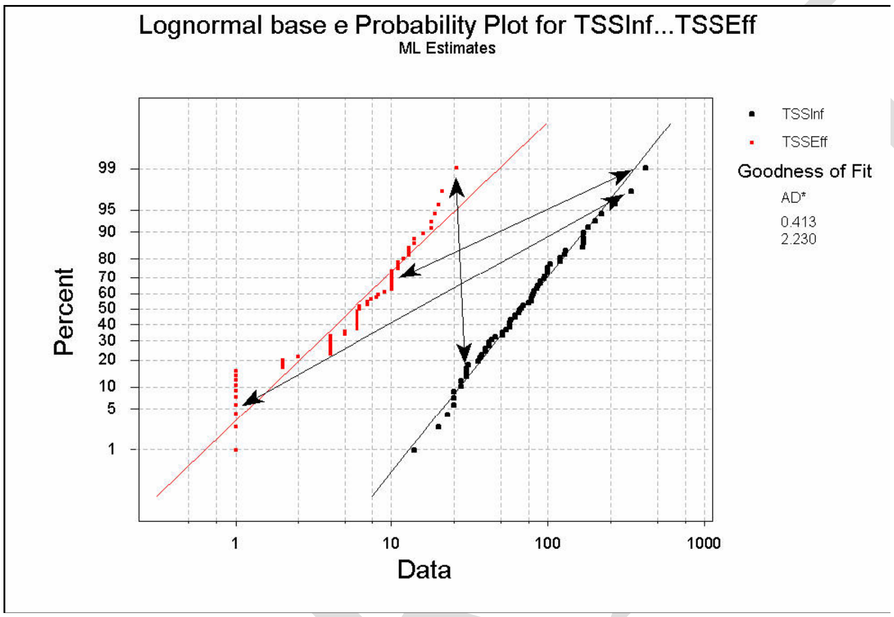


Figure 2 – Plot showing examples of paired data.

Figure 2 suggests there may be little relationship between influent concentrations and the corresponding effluent concentrations for paired samples collected concurrently. That there is a lack of relationship between influent and effluent data is shown more clearly in a scatter plot of the same data (Figure 3).

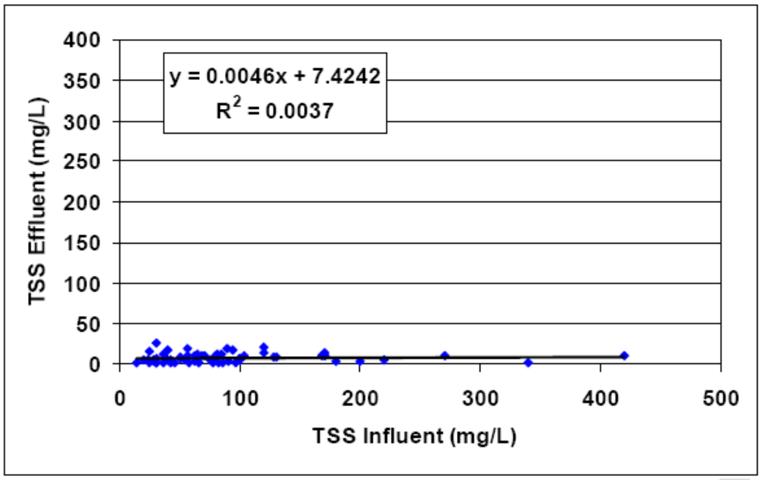


Figure 3 – A scatter plot of the same data as in Figures 1 and 2.

The California handbook then gives the example of a traditional scatter plot for a different set of influent and effluent data for which there is a true relationship (Figure 4):

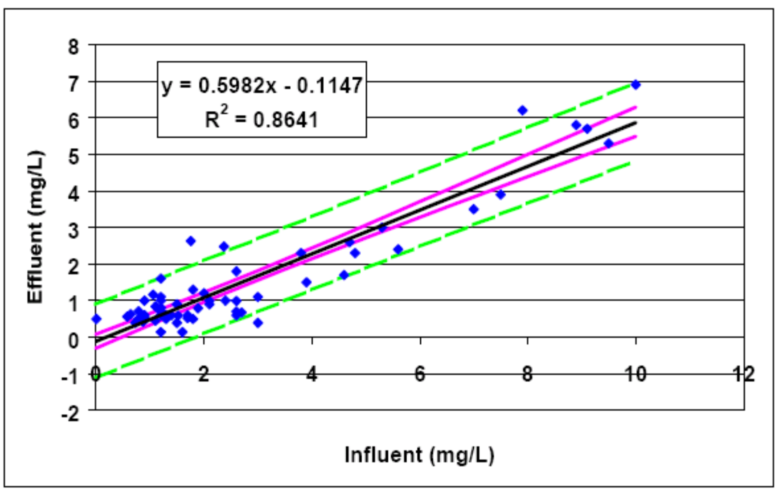


Figure 4 – Relationship between Influent and Effluent TKN Concentrations.

Figure 4 shows a scatter plot with a fairly high correlation coefficient and with a 90% confidence limit indicated

Finally, the California critique states that the probability method alone does not necessarily provide sufficient information for BMP selection. Some regulations, for example require a specific percent removal of 80% for TSS. Removal efficiency can be determined from the means of the two log-transformed curves of the EPM method, but a confidence interval for the removal efficiency value cannot be readily determined with EPM data. To do so requires an analysis of paired influent and effluent points.

Critique of the California Critique of EPM and Conclusions for Data Analysis

It is not true that the parallel lines of a probability plot provide no information concerning the relationships between influent and effluent. For every point on the influent line the horizontal projection finds a corresponding effluent point that could be said to be a likely effluent concentration for that influent concentration.

For conventional analysis of data from paired influent/effluent samples (that is, for BMPs with short detention times), the process for the EPM of rank-ordering data does lose information associated with such pairings. For this reason the EPM used alone suffers from a loss of statistical power from the original data. For BMPs with long detention times, the subject of this modified guidance, there is no loss of power in this respect since there are no pairings to begin with.

Scatter plots clearly show relationships (or lack of relationships) between influent and effluent data. This is not to say that the scatter plot of Figure 3 shows no treatment. Figure 3 shows that for all influent concentrations up to and beyond 400 mg/L there is uniform treatment with effluent concentrations all below about 30 mg/L. It is the uniformity in effluent quality that is responsible for their being no relationship between influent and effluent data.

This demonstrates a property of log-normal probability plots of which those reading the plots should be aware: The use of a log transform "stretches out" the scale of the x-axis so that the effluent curve may show less of a real trend than it might at first appear. In Figure 1, for example, influent concentrations range from about 10 to 250 mg/L. The parallel effluent plot, while appearing similar to the influent plot, shows a range of only about 1 to 25 mg/L. Effluent concentrations are low and relatively uniform, likely because they are approaching the limit of treatment, regardless of influent concentration.

Given advantages in presenting influent/effluent data in scatter plots and performing statistical analyses with paired data, the utility of probability plots also should be recognized. Probability plots are useful in providing a visual representation of variability within as well as between influent and effluent data. Probability plots provide a clear view of the overall degree of treatment (or lack of treatment as in Figure 1).

Appendix M – Raw data for Data Analysis Example (App. H).

Lakemont data: South Filter Phosphorus Data (influent)

	Conc (mg/L)	Log Conc	Volume (L)	Loading (Kg)
1996	0.36	-0.443697499	446739	0.16
	0.079	-1.102372909	1456111	0.12
	0.257	-0.590066877	633503	0.16
	0.13	-0.886056648	1807126	0.23
	0.043	-1.366531544	679604	0.03
	0.108	-0.966576245	628514	0.07
	0.443	-0.353596274	583093	0.26
	0.095	-1.022276395	1233345	0.12
	0.057	-1.244125144	792537	0.05
	0.05	-1.301029996	1541429	0.08
	0.12	-0.920818754	42271	0.01
	0.109	-0.962573502	42271	0.00
1997	0.164	-0.785156152	4661254	0.76
	0.127	-0.896196279	2263416	0.29
	0.288	-0.540607512	6175965	1.78
	0.15	-0.823908741	3786109	0.57
	0.118	-0.928117993	3291181	0.39
	0.0604	-1.218963061	1316459	0.08
	0.0616	-1.210419288	2219424	0.14
	0.144	-0.841637508	484331	0.07
	0.0478	-1.320572103	544584	0.03
	0.156	-0.806875402	1745895	0.27
	0.0846	-1.072629637	461680	0.04
	0.114	-0.943095149	1335734	0.15
	0.0869	-1.060980224	781420	0.07
	0.178	-0.749579998	257082	0.05
	0.0992	-1.003488328	944410	0.09
	0.113	-0.946921557	3202797	0.36
	0.113	-0.946921557	1186990	0.13
1998	0.193	-0.714442691	7971641	1.54
	0.0642	-1.192464972	976007	0.06
	0.147	-0.832682665	8433518	1.24
	0.103	-0.987162775	7561762	0.78
	0.228	-0.642065153	6526778	1.49
	0.0761	-1.118615343	659527	0.05
	0.0427	-1.369572125	1578152	0.07
	0.103	-0.987162775	1330269	0.14
	0.0522	-1.282329497	4595308	0.24
	0.0545	-1.263603498	2143431	0.12
	0.0634	-1.197910742	1209611	0.08
	0.101	-0.995678626	1488796	0.15
	0.1	-1	1593765	0.16
n=43	0.158	-0.801342913	3607470	0.57

Lakemont data: South Filter Phosphorus Data (effluent)

	Conc (mg/L)	Log Conc	Volume (L)	Loading (Kg)
1996	0.062	-1.207608311	552179	0.03
	0.047	-1.327902142	1189308	0.06
	0.037	-1.431798276	1189308	0.04
	0.046	-1.337242168	2123763	0.10
	0.045	-1.346787486	2123763	0.10
	0.043	-1.366531544	891981	0.04
	0.035	-1.455931956	2123763	0.07
	0.034	-1.468521083	2123763	0.07
	0.05	-1.301029996	2123763	0.11
	0.083	-1.080921908	2123763	0.18
	0.028	-1.552841969	2123763	0.06
	0.03	-1.522878745	2123763	0.06
	0.03	-1.522878745	2123763	0.06
	0.038	-1.420216403	1911387	0.07
	0.039	-1.408935393	1019406	0.04
	0.049	-1.30980392	2123763	0.10
	0.029	-1.537602002	1104357	0.03
	0.049	-1.30980392	2123763	0.10
	0.038	-1.420216403	467228	0.02
	0.052	-1.283996656	2123763	0.11
	0.049	-1.30980392	2123763	0.10
	0.032	-1.494850022	2123763	0.07
	0.064	-1.193820026	2123763	0.14
	0.049	-1.30980392	2123763	0.10
1997	0.0591	-1.228412519	2123763	0.13
	0.0441	-1.355561411	2123763	0.09
	0.036	-1.443697499	1826437	0.07
	0.0548	-1.261219442	1231783	0.07
	0.0275	-1.560667306	1316733	0.04
	0.111* (outlier)			
	0.0416	-1.380906669	976931	0.04
	0.0394	-1.404503778	976931	0.04
	0.0304	-1.517126416	1274258	0.04
	0.029	-1.537602002	1104357	0.03
	0.0222	-1.653647026	382277	0.01
	0.037	-1.431798276	807030	0.03
	0.036	-1.443697499	1189308	0.04
	0.0249	-1.603800653	339802	0.01
	0.0291	-1.536107011	1104357	0.03
	0.0132	-1.879426069	679604	0.01
1998	0.0361	-1.442492798	1489737	0.05
	0.0291	-1.536107011	525964	0.02
	0.0508	-1.294136288	3166816	0.16
	0.04	-1.397940009	2226108	0.09
	0.0298	-1.525783736	1810053	0.05
	0.0425	-1.37161107	734928	0.03
	0.0256	-1.591760035	1679817	0.04
	0.0256	-1.591760035	928134	0.02
	0.0205	-1.688246139	757384	0.02
	0.0273	-1.563837353	347830	0.01
	0.0246	-1.609064893	2192323	0.05
n=53	0.0242	-1.616184634	585009	0.01
(excluding	0.0473	-1.325138859	2924076	0.14
outlier)	0.0131	-1.882728704	453119	0.01