EVALUATING STORMWATER TREATMENT BMP'S PERFORMANCE? A REVIEW OF THE ISSUES.

New Zealand Stormwater Conference 2006

1. INTRODUCTION

With increasing developments in new stormwater treatment technology, problems have arisen for individuals and organizations that would like to compare the performance of these tools. There are large amounts of money being spent, and there are limited resources to implement BMP's. There is an increasing desire/ need from stakeholders to evaluate the effectiveness of BMP's to determine which the most appropriate method to be used is.

New technologies are continually being developed buy manufacturers. There is a need for a greater understanding of how to evaluate these systems. Several methods of evaluating performance have been developed in the USA in response to the need for verification of a theoretical performance prediction.

In many regions such as in Auckland a simple performance standard has been specified i.e. 75% Total Suspended Solids (TSS) removal on an average annual basis is the goal. This is a very simple regulation to a complex problem. As other areas of New Zealand develop stormwater regulations, consideration must be made of some of the existing issues and how to evaluate performance data.

This paper reviews different methods of measuring performance in reference to evaluating TSS removal. The paper attempts to highlight the complexity of issues surrounding evaluating a BMP. The paper suggests that all methods require a degree of professional judgment in evaluating a BMP performance,

2. CORE ISSUES WITH TSS

TSS is the most regulated pollutant; it is considered a good yard stick to the performance of a BMP. TSS is possibly the simplest contaminant to evaluate the performance of a BMP with. TSS is also possibly the simplest contaminant to remove for stormwater; however the following section highlights some of the complex issues associated with stormwater pollution

2.1 DEFINITION OF TSS

There is no agreed definition of what TSS is and how to test for it. Some agencies consider TSS to be particles less than 62 micron in size, some others consider particles under 500 microns to be TSS, while some again consider all suspended sediment to be TSS. Many manufactures make claims about TSS removal but fail to provide a definition of what it was; any claim on TSS removal should state the particle size distribution of the influent. Stormwater sediments also have varied range of specific gravity and can have a high percentage of volatile solids which can have a large effect on the performance of settling BMP's

Solids are transported in Stormwater in many forms i.e.

- Gross Solids
- Grit
- Fine solids and organics
- Soluble

A defined and consistent method for measuring TSS is required when measuring performance. Without a clear definition an evaluation of TSS may only be an evaluation of grit.

2.2 MEASUREMENT OF TSS

The methods for evaluating TSS were developed for waste water and may not be appropriate for stormwater. Waste water sediments are typically more consistent than stormwater sediments. Wastewater sediments do not derive from as many different sources and do not vary in concentration/specific gravity and particle size as much as storm sediments.

In the USA a debate has been raging over the most appropriate method to test for TSS. Research has shown that the traditional method of measuring TSS under estimates the solids in stormwater. TSS is typically measured by taking a sample of stormwater, mixing it, waiting some period of time and then removing a pipette or subsample from the sample and filtering it through filter paper. The problem occurs because some of the solids caught by the automatic sampler have a high specific gravity and instantly fall to the bottom of the sample container and are not captured by the pipette. An alternative method has been suggested suspend solid concentration or SSC. In this method the whole sample is filtered through the filter paper measuring all solids

Unfortunately most research to date has been performed using a TSS e.g. the measurement of background concentration in urban streams or evaluation of traditional treatment options. This research has been carried out with little realization that stormwater is very different to wastewater. It is now considered appropriate to carry out both methods as the variability in specific gravity will greatly affect the performance.

2.3 FUGITIVE SOLIDS

Another issue in measuring TSS is Fugitive solids. Fugitive solids are solids that are often too large to be measure by automatic samplers. These solids can enter a BMP, and not be sampled by the influent sampler. In the BMP they may sit for long period of time, slowly decomposing. After a period of time the solids can be partially remobilized and leave the BMP and because they are smaller sampled by the effluent sampler. This can give low or even negative TSS results as the original mass of the leaf was never considered on the up stream side. Fugitive solids are a large concern. As large organic solids break down the will release dissolved nutrients

2.4 INFLUENCE OF CONCENTRATION / BACKGROUND CONCENTRATION

Most contaminants in stormwater also exist in nature and every site will have an irreducible background concentration that can not be removed from the runoff. This is commonly thought to be approximately 20 mg/l. The effect of this is that if a storm event has an influent concentration of 50 mg/l the most the effluent can be reduced to is 20 mg/l. If the standard is for a 75% removal, and the site is a clean site never having an effluent concentration greater than 80 mg/l the 75% removal standard can never be met, despite the fact the BMP may be working well.

Another problem with concentration and TSS is that higher concentrations of TSS are usually associated with a greater percentage of larger particles. This is because larger particles tend to have a greater mass and are often mobilized by larger events. Larger particles are easily removed by BMP’s, therefore there is a tendency to see higher removal efficiencies with higher concentrations

2.5 LAB DATA VS FIELD DATA

Laboratory analysis of BMP’s is an effective method for preliminary analysis of a BMP. It can be an effective method to examine the performance as some of the variables that exist in a storm event can be held constant. For example operating rates, particle size distribution and pollutant loadings are highly variable from site to site and within a storm event. The use of synthetic sediment of known particle size distribution in the laboratory under controlled operating rates has been used to evaluate removal efficiencies of the BMP at differing operational rates. Figure 1 shows a series of curves developed from laboratory testing for a BMP. The curves show the removal efficiency at different operating rates. The BMP is a settling device; all settling devices will tend to be capable of removing finer particles with longer residence time. As operating rates increases the residence time decrease, hence a lowering efficiency.

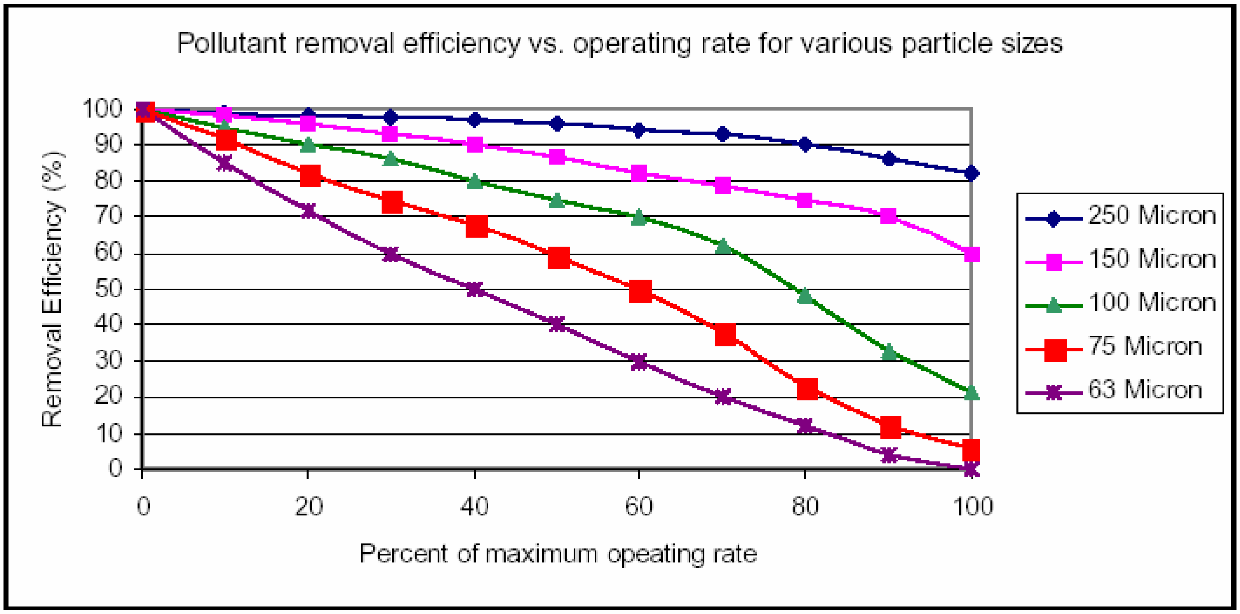

Figure 1: Removal Efficiency Vs Operating rate, from a BMP's labortatory Testing

Such curves and laboratory analysis is beneficial in estimating removal efficiency and determining the optimal operating conditions however in the field the BMP may not operate in this way. For example synthetic sediment has a consistent specific gravity. Stormwater sediments derive from many different anthropogenic and natural sources and hence they have a large amount of variability in the specific gravity. Specific gravity will greatly affect the ability of a particle to settle there for the above curves may or may not occur in the field.

Another draw back of laboratory testing is that it is good for mimicking the performance but it doesn't mimic the operation or longevity in the field. For example for filtration devices the organic material and hydrocarbons present in stormwater sediments cause occlusion as the breakdown or get stuck within the filter media. In laboratory testing organic material or hydrocarbon are not present in synthetic sediment.

The advantage of field testing is that stormwater, sediments and contaminants are real. All the influencing factors that influence the contamination of stormwater are present and an installed BMP can be evaluated to see if it is meeting the objective for installing it. I.e. for Auckland does the system achieve 75% TSS removal?

The big problem with field studies is the cost. The minimum equipment required is 2 flow monitors, 2 automatic samplers and a rain gauge. These will cost approximately $50,000 new and if you were to hire them for 9 months they would cost the same. Stormwater sampling is not easy it requires a high degree of expertise to carry it out efficiently. A stormwater sampling programme requires detailed calibration and programming of the equipment on an ongoing basis through the study to ensure that the sampling is representative of the objective of the study. It is imperative that a good project plan is developed that outlines what the objective of the study is and the process to achieve these objectives. These requirements of a good study require a large amount of labor costs which can be multiplied if the site is in a remote location.

Another drawback with field testing is that it can't be replicated well. Every site is different and every storm is different. There are wet years and there are dry years. There are seasonal variations that can produce easily treated heavy sediments loads in winter and hard to treat loadings such as pollen and grass clippings in summer. This often leads to very confusing data and again a high degree of expertise in need to decipher the data.

2.6 PERFORMANCE AT DESIGN FLOWS

Consideration must be taken of the system design. When evaluating the performance consideration must be taken into account at what percentage of design flow the BMP was working at. For settling devices a system operating at 50% of it design will have a longer resident time and therefore have greater ability to settle out particles. Like wise if a system encounters a storm event greater than its design capacity it can be assumed the system is in bypass and expected to have a lower performance.

3. DATA ANALYSIS

There are many ways to analyze the data collected to evaluate weather a BMP is working. Like most things in stormwater it is very complex and requires numerous methods and a degree of professional judgment. Often data analysis is simplified to only looking at percentage concentration reduction to determine if a BMP is working. Often this does not tell the whole story. The following section details different method of analyzing performance data.

3.1 SUMMARY STATISTICS

Summary statistics give a good starting point for analysis. Examples of summary statistic are total load, standard deviation, mean effluent quality, event mean concentration and mean removal rates. These stats are very useful but they do necessarily tell the whole picture. Judgment should not be drawn on these alone.

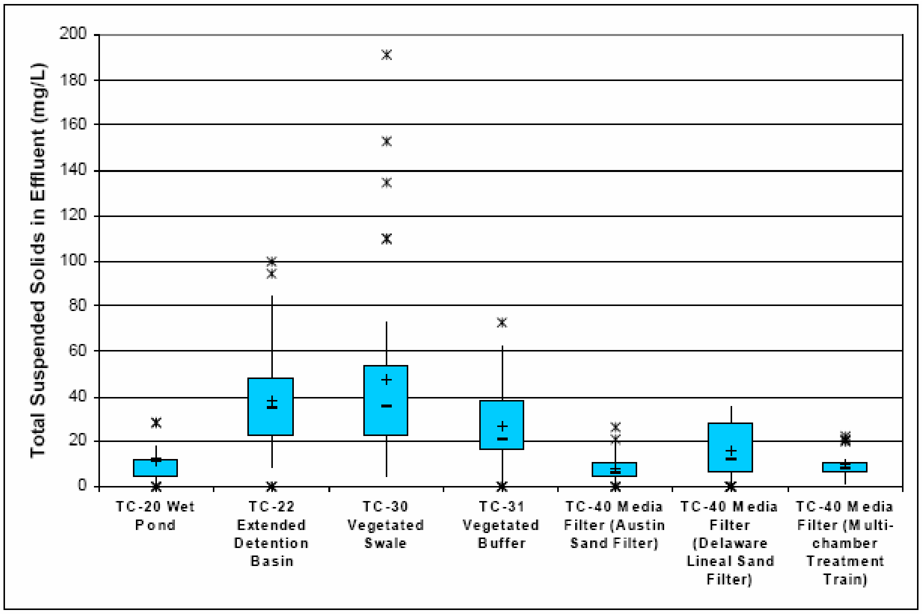

Figure 2: Box and Whisker Plot International BMP database

Figure 2 above is a good example how statistic information can be presented relative to other BMP's. This form of presentation could also be used to demonstrate the performance of a system over a series of events.

3.2 LINEAR REGRESSION

Linear regression is a good method or process for determining the relationship between influent and effluent. Influent concentrations are plotted against effluent concentrations such as shown in Figure 3. A regression line (line of best fit) is calculated from the data points and an equation is determined. The slope of this equation is the inverse of the removal efficiency, i.e. the removal efficiency for TSS under 500 microns is 1-0.37 = 63%. The y intercept in the equation is the base line concentration. All BMP's tend to have some base line concentration that the BMP can not reduce below. This will very from site to site and is important to consider when looking at the data. Figure 4 tabulates the results from the regression analysis

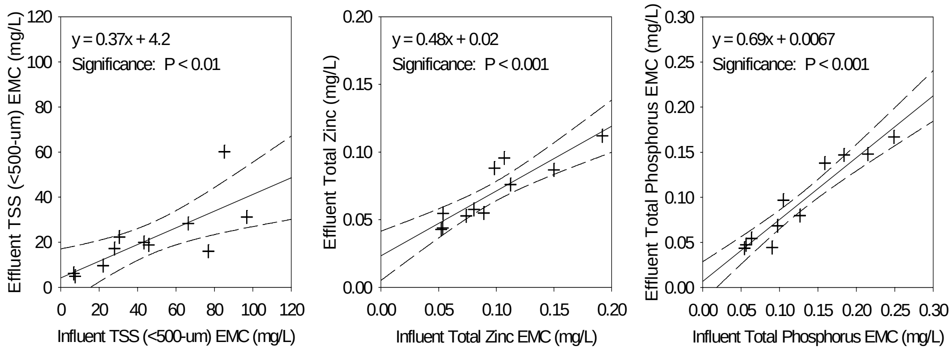

Figure 3: StormFilter Regression Analysis

Analyte	*n*	Range of Influent EMCs (mg/L)	Median Influent EMC (mg/L)	Mean Removal Efficiency Estimate (%)	95% Confidence Interval for the Mean Removal Efficiency Estimate (%)	Median Effluent EMC Estimate (mg/L)	95% Confidence Interval for the Median Effluent EMC Estimate (mg/L)
TSS<500-um	11	6.9 to 97	43.4	63	38 to 88	20	13 to 28
Total Zn	11	0.052 to 0.19	0.089	52	34 to 70	0.066	0.058 to 0.074
Total Phos.	11	0.054 to 0.17	0.11	31	15 to 48	0.079	0.069 to 0.090

Figure 4: Table of Stormfilter Regression Static's

3.3 LOAD VS CONCENTRATION REDUCTION

Often we simply evaluate performance of a treatment device by its concentration reduction. However we also need to consider the load reduction as both methods can be misleading to the performance of the BMP.

Event mean concentration is the mass of contaminant transported in a storm by the volume of runoff. It is often calculated by taking flow proportional discrete samples through a storm event and compositing into one sample to determine the EMC. This process often underestimates the performance of the BMP at higher concentrations. Figure 5 shows a line up of discrete samples before they are composited. The line on the top are the influent samples and the line on the bottom are the effluent. Bottles 2 and 3, in the influent, clearly have a higher concentration of suspended solids because of there darker color. While bottles 16 and 17 have a very low concentration because the runoff is clean. Looking at the corresponding bottle in the effluent it can be seen that the BMP is removing a significant proportion of the TSS when the concentration is higher and there is no change when the sample is clean. When the samples are composited the high concentration and high efficiency of the system is diluted by the samples that have low concentration (which can be considered clean)

Figure 5: A line up of Discrete Proportional Samples

Alternatively we may have monitored a collection of storms were there is a low intensity and low concentration and hence a low removal from the BMP. A large storm event may then occur which mobilizes a large amount of larger particles. Larger particles tend to be less toxic and easily settled out in BMP's. Calculating the load reduction for this series of storm will over estimate the performance of the BMP

	Influent Conc. mg/l	Effluent Conc. mg/l	Mass transported in Storm (kg)	EMC Reduction %	Mass Reduction (kg)
storm 1	35	30	2	14%	0.285714286
storm 2	20	20	1	0%	0
storm 3	100	33	10	67%	6.7

Average EMC Reduction	27%
Total Load reduction	46%

3.4 LINE OF COMPARATIVE PERFORMANCE

Above we have talked about the background concentration or the limit to the capabilities of BMP's. This means that it is very unlikely that the effluent concentration would ever be zero. It also means that very low concentrations will not be significantly reduced. This lower limit or background concentration is approximately 20 mg/l, however this can vary from site to site. The line of comparative performance is a method of reviewing the performance of a BMP that takes into account this phenomenon. Figure 6 is a plot of the expression:

$$\frac{\textit{Influent} - \textit{Lower Limit}}{\textit{Influent}}$$

With a lower limit of 20 mg/l.

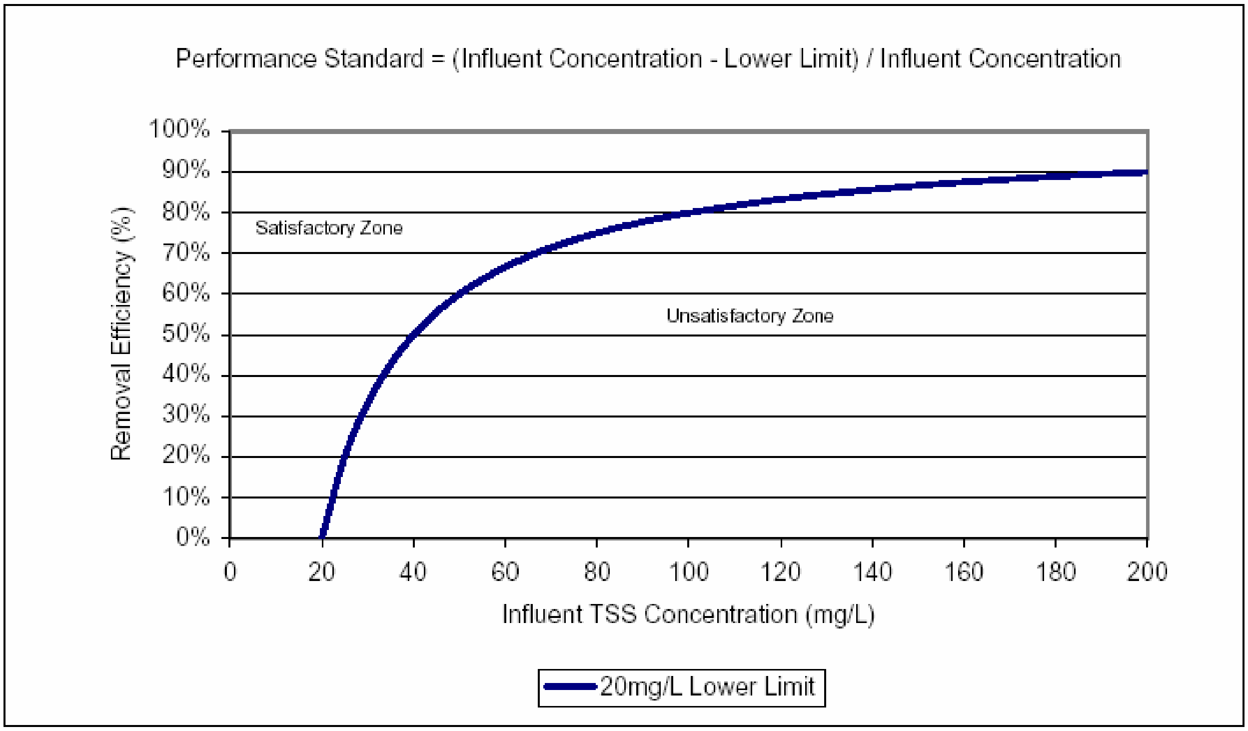

Figure 6: Line of Comparative Performance

The performance of the BMP for individual storms (or even samples) is plotted on the graph such as in Figure 7. Points that sit above the line are considered satisfactory and the points below the line are considered unsatisfactory. The advantage of the method is that EMC's can be used without unfairly representing the systems efficiency. The error that can occur with this method is that in sites where soils surrounding the BMP are gritty or sandy, storms of higher concentration tend to mobilize these larger particles showing the system is satisfactory.

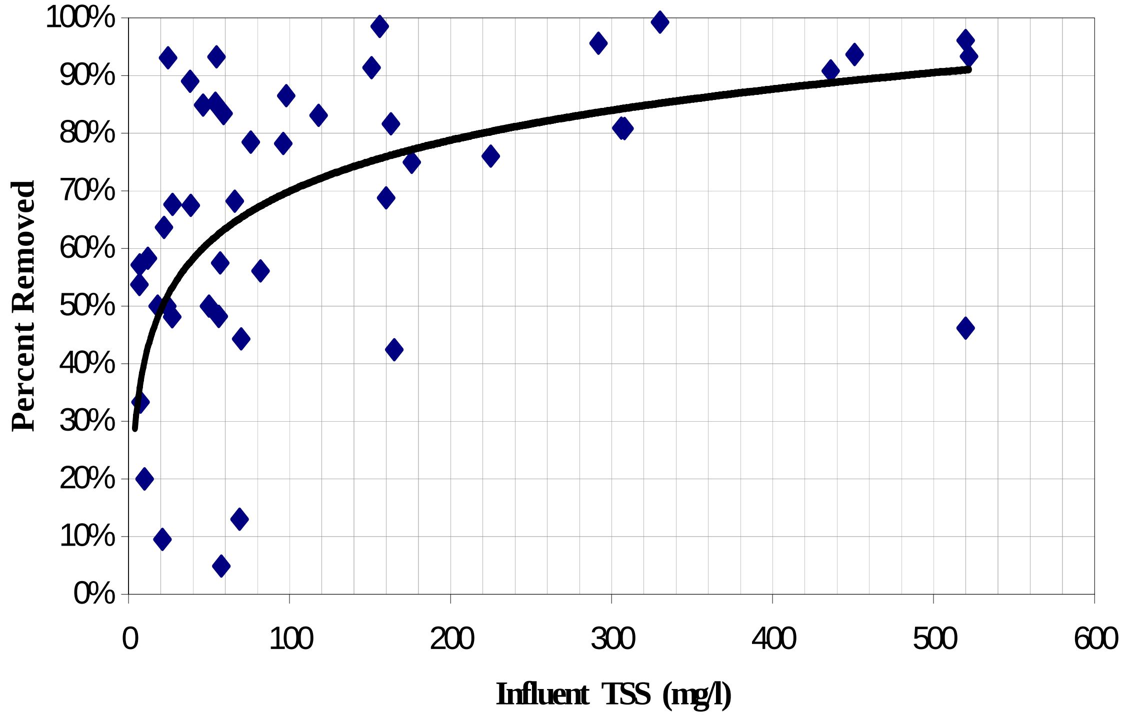

Figure 7: Plotted Line of Comparative Performance for BMP

3.5 EXPECTED VS OBSERVED PERFORMANCE

Expected vs. observed is a slight variation of the comparative line of performance. Developed by Stormwater360 in conjunction with some public agencies in the USA, the system involves agreeing a base line concentration between the BMP supplier and the public agency. It also involves agreeing some performance limits e.g. For concentrations less than 100 mg/l the expected effluent concentration is 20 mg/l and for concentrations greater than 100 mg/l the expected effluent is 80% of the influent. A similar curve can be drawn as for the line of comparison as shown in Figure 8. If the data point falls above the expected performance curve the value the system is above the curve is credited i.e. At 100 mg/l there are 2 points on the curve. The first at 81% and the second at 61% removal. The expected performance at 100 mg/l is 80% removal the data point of 81% removal would get a 1% credit while the data point at 61% would get a -19% credit. In this method all the observed results are compared with the expected to evaluate the performance of the BMP. A satisfactory result would be if the sum of the differences between expected and observed totaled to a value greater than 0

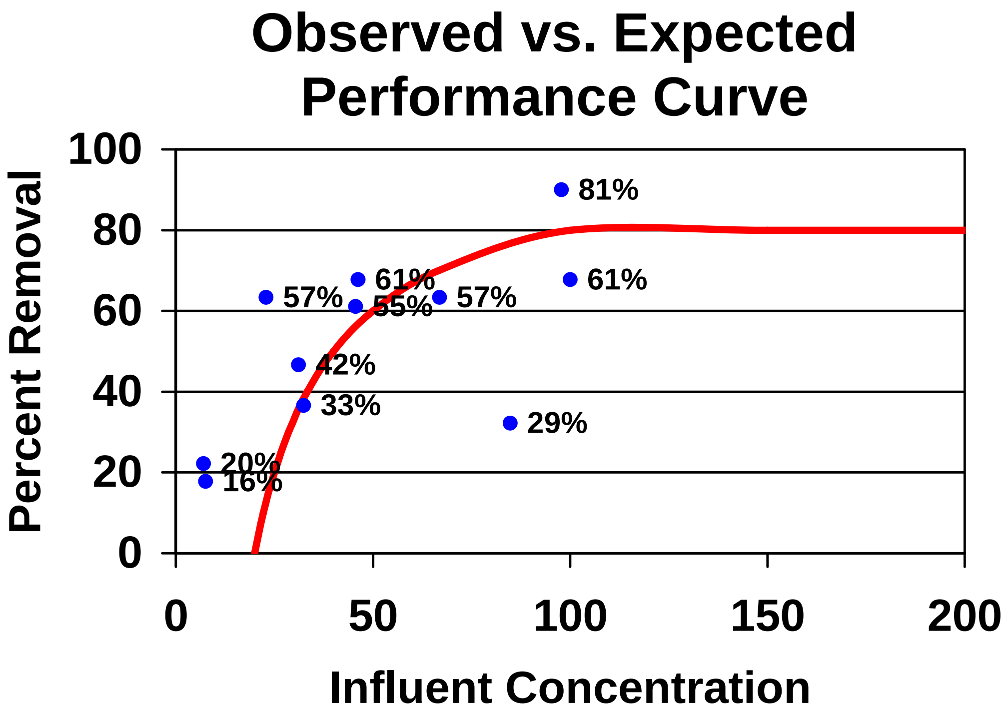

Figure 8: Observed vs. Expected Performance Curve

3.6 BEST PROFESSIONAL JUDGMENT

Best professional judgment is the use of sound engineering principles and knowledge of present to evaluate and qualify storms and results. This also includes using different analysis techniques while understanding the there strengths and weakness.

It is also important to consider non performance related factors such as robustness, maintenance and other benefits or weakness. For example considering the maintenance cycle of a system, how often will it be maintained as well as how easily will it be maintained or is the a potential of effects such as visual pollution

4. CONCLUSIONS

Clear definitions of methods need to be determined before testing and performance evaluation is started and included in the methodology of the evaluation to ensure they are addressed.

Laboratory testing is very useful for the development and fine tuning of BMP's, however field testing is imperative as more factors are present in nature that can be simulated in the Laboratory. Field testing also ensures the performance is sustainable as laboratory testing can simulate prolonged natural effects

There are many methods for evaluating the performance of a BMP data, most with pro's and con's. All methods provides useful information but should not be considered alone.

Analysis of BMP performance data needs to be carried out carefully and credibly considering many different factors. In the end the results of all methods need to be evaluated and weighted up against each other. In the end a decision needs to be made using best professional judgment based on all information available

5. REFERENCES

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