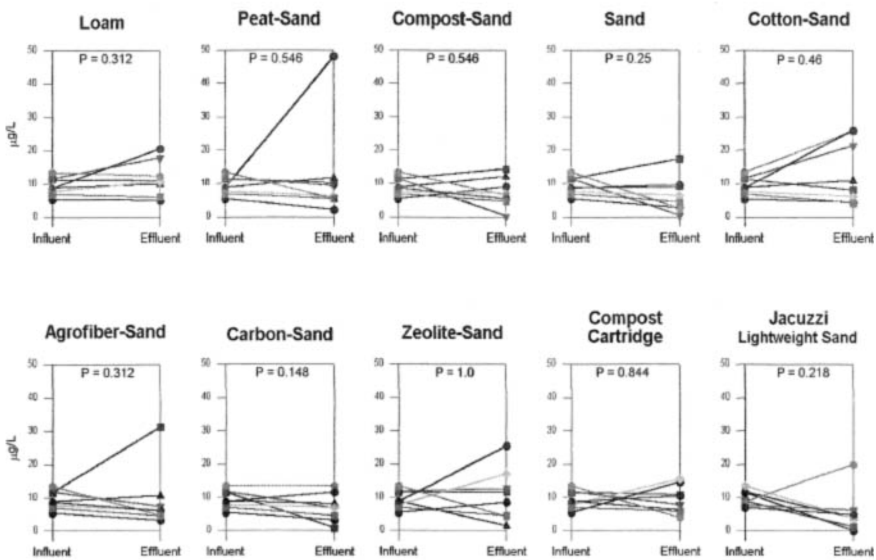

Figure 6. Copper removal during pilot-scale filtration experiments.

No filter had the ability to remove magnesium consistently. Hardness removal was only statistically significant with the peat-sand and loam filters, with only the peat-sand filter able to remove large percentages of hardness. This is not unexpected given the ability of the peat filter to remove calcium. Mimicking its behavior with calcium, the compost-sand filter contributed hardness to the runoff water.

pH. The peat-sand filter is the only filter that had a measurable effect on pH. Hydrogen as the hydronium ion, H_3O^+, is one of peat's easily exchangeable ions, and in general, as peat adsorbs other cations, it releases the hydronium ion. pH has been proposed as a method of monitoring remaining life in a peat-filter. The other filter media, when treating an influent at a neutral or near-neutral pH, tend not to affect the pH measurably. This is in contrast to the previous research in Clark (1996) where when the influent water to a compost-sand column was not near a neutral pH, compost-sand attempted to neutralize it.

In real-world applications for stormwater treatment, filters that contain adsorption media typically clog before the media can experience chemical break-though. It is not yet clear if depth filtering media will be a cost-effective stormwater control, considering the pre-treatment needed to prevent this clogging. The necessary pretreatment alone may provide adequate control, without the additional filtration cost. Large-scale filtration installations (especially sand) have been shown to perform well for extended periods of time with minimal problems. The use of supplemental materials (such as organic compounds) should increase their performance for soluble compounds. The use of upflow filtration is also expected to increase the life of filters before clogging, for some media types (not for peat/sand combinations).

The confirmation of the modeling equations for a few pollutants for some media indicate that this modeling approach has the potential to provide an estimate of the life of the filter, i.e., the time until media replacement is needed, for applications where the influent concentration is not quite as low as it was in the two detention ponds used in this pilot-scale study. The best application for these filters may then be to further treat the effluent from a detention pond in critical source areas, such as scrap metal recyclers, rather than as a polisher for effluent from a detention pond in a residential area. During these field pilot-scale tests and related full-scale tests, the minimum attainable concentration for these metals using media filtration appears to be approximately 5 to 10 μg/L for copper and lead, and approximately 10 to 20 μg/L for zinc, irrespective of media. These tests do confirm the utility of different filtration arrangements, especially concerning the problems associated with clogging and reduced filtration performance.

Role of Biomass in Metals Removal

The effect of microbial growth within filter systems on stormwater metal retention was studied in laboratory column experiments. The filter media used in the study was sand. Because the ability of unmodified sand to remove dissolved metals was more limited than many of the other media examined in this study, it was a good media to use to examine the impact of microbial growth on dissolved metal uptake. Microbial growth in filters did appear to increase metal uptake and retention. The mass of dissolved metal sorbed per gram of media was higher in the microbially colonized columns than in the growth-inhibited columns for all the metals examined except chromium. Also, statistically significant differences were found between dissolved metal removal efficiency (at equivalent levels of media saturation) in the microbially colonized and growth-inhibited columns for all of the metals examined except chromium. Microbially colonized columns also retained more particulate metals than the growth-inhibited columns, possibly due to decreased void space caused by microbial growth. Leaching experiments performed with the columns found that at equivalent effluent pHs the microbially colonized columns leached a smaller percentage of their initial metal content than the growth-inhibited columns. Comparison of the metal content and the protein content (representing microbial biomass) in media from different column sections showed that there was a fairly linear relationship between increasing metal content and increasing protein content. Based on the metal contents determined from the media digestions the microbially colonized columns retained 11-19% more Cu, Cr, Pb, and Zn and 39% more Cd than the growth inhibited columns. For the lab-scale sand media filters examined in this study, the difference between the two types of columns when comparing percent removal at the same meq/g or mg/g media saturation was statistically significant - with the microbial columns having the higher removal efficiencies - but small. However, the situation examined was one where microbial growth was limited. The sand media provided no nutritional source to encourage microbial growth. In media that would provide a better environment for microbial growth, such as compost, the impact could be more significant.

Related tests were conducted to measure the disassociation potential of heavy metals and nutrients under aerobic and anaerobic conditions having extreme Eh values. Studies on the effect of anaerobiosis on metal retention by filter systems indicated that heavy metals were not mobilized from filter systems under anaerobic conditions. It was found that metal retention within the filters, with the exception of iron on compost, was not different from what was observed in oxygenated environments (Figures 7, 8, and 9 for copper, iron and zinc, respectively). However, it is plausible that under certain specific environmental conditions, co-precipitation of metals by iron- and sulfate- reducing bacteria may take place in stormwater treatment systems.

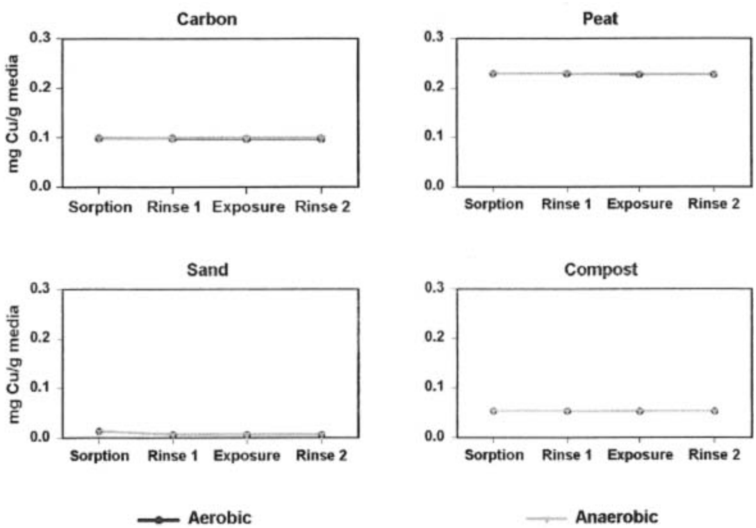

Figure 7. Behavior of copper under aerobic and anaerobic conditions.

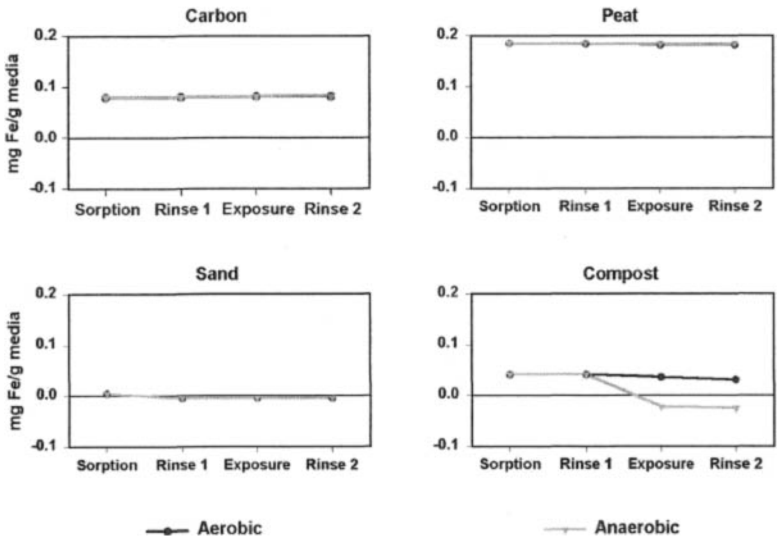

Figure 8. Behavior of iron under aerobic and anaerobic conditions.

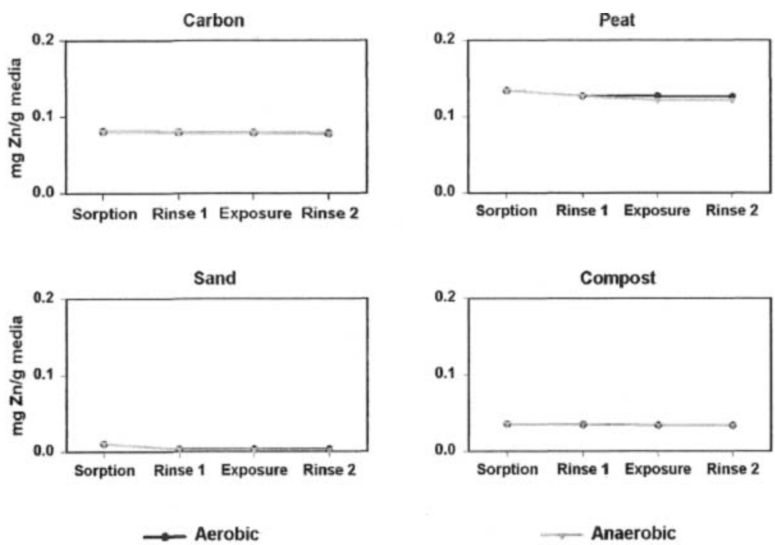

Figure 9. Behavior of zinc under aerobic and anaerobic conditions.

Treatability Testing

Treatability tests were performed to assess the effectiveness of different treatment trains and processes quantifying improvements in stormwater toxicity and metals capture. The treatability tests included intensive analyses of samples from twelve sampling locations in the Birmingham, AL, area that all had elevated toxicant concentrations, compared to the other urban source areas initially examined. The treatability tests conducted were: settling column, floatation, screening and filtering, photo-degradation, aeration, combined photo-degradation and aeration and an undisturbed control sample. More than 900 toxicity tests were performed using the Microtox™ procedure. Turbidity was also analyzed on all samples. Results indicated a reduction in toxicity as the level of treatment increased and in particular, as the solids were increasingly removed from the original stormwater (Figure 10). All samples, with one exception, showed dramatic reductions in toxicity with increasing settling times.

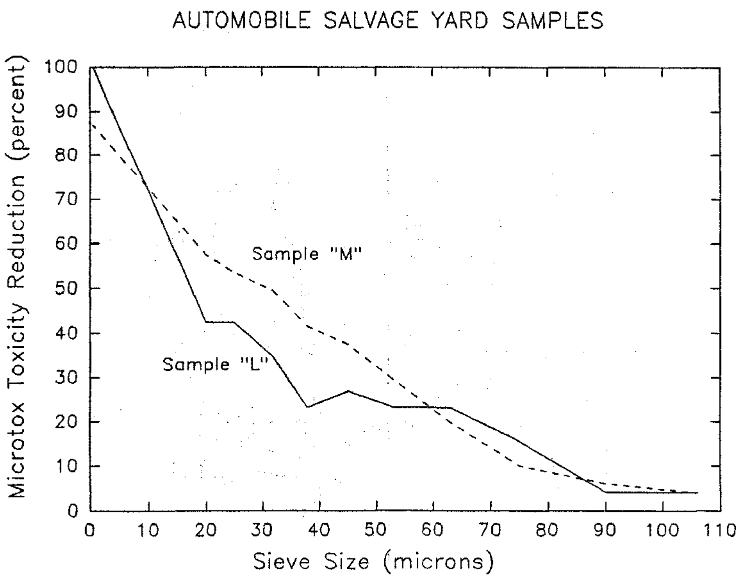

Figure 10. Toxicity reduction from sieve treatment - automobile salvage yards (Pitt, et al. 1999).

Metals Associations

Metal-particulate association tests on the parking lot runoff revealed that more than 90% of the filterable forms of Ca, Mg, K, Fe, and Zn were in ionic forms, with very little colloidal, or other bound forms. Also, more than 80% of the filterable Cr and Pb were also ionic, while only about 50% of the filterable Cu and 30% of the filterable Cd were ionic. This data can be used to estimate the level of control that may be associated with different designs of particle trapping devices. Some pollutants can be significantly reduced by a reduction in particulates, such as suspended solids, total phosphorus and most heavy metals. Other pollutants, such as nitrates, are reduced much less, even after filtration down to 0.45 μm.

Experiments were also conducted to examine the likelihood of the metals disassociating from the particulates under pH conditions ranging from about 4 to 11 with both weak and strong acids. These tests indicated that the heavy metals of concern remain strongly bound to the particulates during long exposures at the extreme pH conditions likely to occur in receiving water sediments and in control device sumps and stormwater pond sediments. Additional testing is ongoing at The University of Alabama.

Related tests were conducted as part of the filter media evaluation task of this research to measure the disassociation potential of heavy metals and nutrients under aerobic and anaerobic conditions having extreme Eh values. Studies on the effect of anaerobiosis on metal retention by filter systems indicated that heavy metals were not mobilized from filter systems under anaerobic conditions. It was found that metal retention within the filters was not different from what was observed in oxygenated environments. However, it is plausible that under certain specific environmental conditions, co-precipitation of metals by iron- and sulfate- reducing bacteria may take place in stormwater treatment systems.

Conclusions

The results of this investigation emphasize the importance of characterizing the stormwater before selecting a treatment media since the type and quantity of metals, pH, and other runoff characteristics can vary a great deal between sites. For example, determining the range of metal concentrations to be treated is crucial to selecting the best media, since the removal efficiencies of the media relative to each other changed with varying metal concentration. Media that were effective at high metals concentrations were outperformed by some media at the low metals concentrations typically found in stormwater. Upflow columns proved more effective than downflow columns in the control of detention time and a reduction in clogging of the media by solids and associated head loss in the column. Studies on the effect of anaerobiosis on metal retention by filter systems indicated that heavy metals were not mobilized from filter systems under anaerobic conditions. It was found that metal retention within the filters was not different from what was observed in oxygenated environments. However, it is plausible that under certain specific environmental conditions, co-precipitation of metals by iron- and sulfate- reducing bacteria may take place in stormwater treatment systems. Tests also indicate that the heavy metals of concern remain strongly bound to the particulates during long exposures at the extreme pH conditions likely to occur in receiving water sediments. They will also likely remain strongly bound to the particulates in stormwater control device sumps or detention pond sediments where particulate-bound metals are captured. The pilot-scale testing showed that there is a lower limit, however, to the effluent quality. Removals to concentrations below 10 – 20 μg/L for most metals are not feasible.

Acknowledgements

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The Caltran Study

Roger James, P.E. Senior consultant, Water Resources Management, 63 Ivy Drive, Orinda, CA 94563

Introduction

The California Department of Transportation (Caltrans) as part of the Best Management Practice (BMP) Retrofit Pilot Program monitored the performance of two structural end-of pipe BMPs. Each had a 31.2 l/s (1.1 cfs) capacity and was installed to treat runoff at the Interstate freeway-210 Orcas Avenue 0.44 ha (1.09 acres) and Filmore Street 1.0 ha (2.52 acres) sites located in the City of Lakeview, Los Angeles County. The expected flows from these sites are 7.1 l/s (0.25 cfs) (1-year event) and 89.8 l/s (3.17 cfs) (25-year event) and 17 l/s (0.60 cfs) (1-year event) and 210.1 l/s (7.42 cfs) (25-year event) respectively.

Flow and rainfall data for the 2000-01 and 2001-02 seasons were collected at each site. Gross pollutant and trace element data was collected during 4 storm events during 2000-01 and 6 events during 2001-02 at the Orcas Avenue site and 7 events during 2000-01 and 10 events during 2001-02 at the Filmore Street. Material trapped in the sumps of the BMP was characterized only during the 2001-02 season.
The storm water monitoring program was implemented pursuant to the BMP Operation, Maintenance, and Monitoring Plan (OMMP, Caltrans 1999) to evaluate the performance of the pilot BMPs to capture and retain floatables, trash and debris greater than 6.35 mm (0.25 inch) and fine sand and larger particles of sediment. Pollutant removal efficiency analysis using a Scoping Study Methodology (Scoping Method) derived from a Federal Highway Administration 1989 study (Woodward Clyde 1989) and the Mass Balance Approach (MBA) developed by CDS™ Technologies Inc.(2000 and 2001) produced significantly different results.

BMP Efficiency Evaluation

Researchers have used a number of different methods to evaluate the performance of storm water BMPs that primarily rely on reductions in pollutant concentrations or loads. ASCE and USEPA (April 2002) describe ten different methods for BMP water quality monitoring data analysis. Caltrans used the Scoping Method and a modification of the MBA to determine the efficiency of the BMPs. The significantly different results produced by these two methods is attributed to the sensitivity of the Scoping Method when small data sets are available for analysis, differences in the Scoping Method and MBA, incorrect application of the MBA analysis and the limitations of automatic samplers to collect representative samples of storm water runoff.

Although a number of parameters were monitored during the Caltrans studies Total Suspended Solids (TSS) is used in the following analysis of the differences in the results between the two methods.

Caltrans Scoping Study Methodology

BMP efficiencies were evaluated from a comparison of effluent and influent loadings (over a period of time) from the following relationship:

Efficiency (%) = [(Loading in – Loading out)/Loading in] x 100

The Scoping Method estimates loadings by:

- Determining influent and effluent Event Mean Concentrations (EMCs) from at least five representative storms
- Validating that the EMCs are log-normally distributed
- Computing the expected seasonal mean EMCs using log-normal distribution
- Measuring the wet season runoff volume or calculating that volume using runoff coefficients, watershed area and rainfall depth
- Calculating the expected wet season influent and effluent loads by multiplying the expected mean EMC by the measured seasonal runoff volumes

The Scoping Method was obtained from the Federal Highway Administration (FHWA) report that characterized storm water runoff pollutant loads from highways and predicted water quality impacts (Woodward-Clyde Consultants, May 1989). The FHWA report based on 993 separate storm events collected at 31 highway runoff sites distributed among 11 states notes that there is a lack of confidence in data when the number of samples is small and that a single sample can distort results. Caltrans acknowledged these limitations of the procedure when applied to small data sets and indicated that other techniques would be employed as needed to make effective use of data.

Mass Balance Analysis Methodology

The MBA was developed to overcome the inherent difficulties using automatic samplers to obtain representative samples of the wide range of solids suspended in storm water runoff including sediments larger than very fine sand and gross pollutants. The MBA was also developed to address the erroneous data that results from the TSS method of analysis of suspended sediments that has been identified by the United States Geological Survey (USGS 2000 and Gray 2000).

The MBA requires that material captured in the sump or storage area be removed, sampled and characterized for pollutants of concern. This information combined with the mass of pollutants discharged and bypassed from the unit and mass of pollutants contained in the sump and the separation chamber provides the most accurate method of determining influent loading (Figure 1). The efficiency is determined by:

$$\text{Efficiency} = \frac{\text{Sump Load} + \text{Separation Chamber Load}}{\text{Outlet Load} + \text{Sump Load} + \text{Separation Chamber Load} + \text{Bypass Load}}$$

Critical to the MBA are the accurate measurement of the runoff volumes over the period of evaluation, quantification of each of the loads and analysis of samples of each load with laboratory methods that use comparable temperatures.

Monitoring Results

2000-2001 Efficiencies

Caltrans (2001) reported TSS removal efficiencies of 29% for the Orcas Avenue unit and 3% for the Filmore Street unit as determined by the Scoping Method.

A MBA analysis was not possible during 2000-2001 because material captured in the CDS sump was not fully quantified or characterized as specified in the OMMP and MBA protocols.

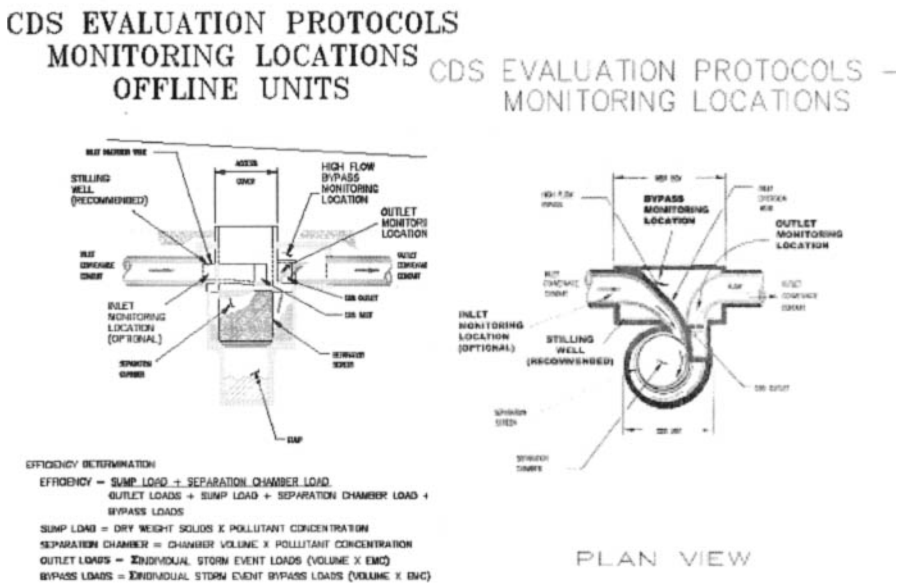

Figure 1. CDS Mass Balance Analysis Evaluation Protocols and Monitoring Locations

The following observations were made from an analysis of the gross pollutant data:

- The gross pollutants at both sites are dominated by vegetative material with vegetative material 76 to 91% of the gross pollutant volume.

- The units removed over 78% of the gross pollutants by volume and 76% by weight at the Orcas Avenue site; however, these results were skewed by 48 and 56% removals when the unit was bypassed in January 2001 during a major storm event (11 cms (4.33 inches) of rainfall) with intensity of 4.9 cm/hr (1.92 in/hr). During this event the unit lacked capacity due to inadequate maintenance and hydraulic capacity.