Product Evaluation

Evaluation of the Stormwater Management StormFilter® system for the removal of total nitrogen:

Kearny Mesa Maintenance Station case study

Overview

This study summarizes the ability of a Stormwater Management StormFilter® (StormFilter) system installation to remove nitrogen compounds from stormwater runoff. Only limited data exist documenting the total nitrogen removal performance of the StormFilter system. Presently, the only study that has documented the total nitrogen removal of a StormFilter system over the course of multiple storm events is the California Department of Transportation 3-year study of the Kearny Mesa Maintenance Station (KMMS) site. The KMMS StormFilter system contains 79 coarse perlite/coarse zeolite cartridges operating at 15 gpm/cartridge and treats 1.5 acres of a road equipment maintenance facility. Based upon data collected between March 1999 and April 2001, total nitrogen removal is evident.

Background on Nitrogen

Nitrogen is a very dynamic and biologically important element. It is an integral part of protein, and thus is omnipotent in water bodies associated with biologically rich environments. Except for most saltwater ecosystems and some desert aquatic environments (environments that are nitrogen limited), nitrogen is usually present in quantities that exceed what is needed for biological productivity, allowing phosphorus availability to dictate productivity instead (phosphorus limited). Although it is possible for stormwater BMPs to demonstrate the removal of nitrogen compounds during an individual storm event, retention of nitrogen by these systems over time is a much more important issue (Scheuler, undated).

In chemical terms, nitrogen in stormwater is usually present in 2 forms: organic nitrogen and inorganic nitrogen. Total nitrogen encompasses the sum of these nitrogen compounds. Each of these forms of nitrogen is susceptible to different removal mechanisms, though removal can often be complicated by the transformation of one nitrogen compound into another following capture. Thus, in determining the nitrogen removal potential of a specific stormwater BMP, it is necessary to first understand the various nitrogen compounds and the mechanisms by which they can be removed from an aquatic system.

Organic nitrogen (organic-N) describes biogenic nitrogen compounds such as protein, urea, and nucleic acids. It can be measured by quantifying the total kjeldahl nitrogen (TK-N) content of a sample minus the ammonia-N concentration. TK-N assesses the ammonification potential of the nitrogen compounds in a sample and thus detects biogenic nitrogen as well as existing ammonia-N, hence the need to account for the pre-existing ammonia-N. Since bulk biological solids contain a substantial quantity of organic cellular material, the removal of such solids can result in the removal of some fraction of the nitrogen load encountered by a system. The removal of fine biological solids such as bacteria and cells, as well as the removal of dissolved organic nitrogen compounds such as urea and protein, is much more difficult and not easily accomplished through settling or screening. While per-storm removal is possible and documented, the challenge of removing solid-phase organic-N as solids from stormwater lies in preventing the digestion and eventual processing of this material into other, more difficult to remove, nitrogen compounds.

Inorganic Nitrogen (inorganic-N) is usually broken down into oxidized nitrogen compounds and reduced nitrogen compounds. These two types of inorganic nitrogen have very different characteristics.

Oxidized nitrogen compounds of importance in aquatic environments are nitrate-N (NO_3^--N) and nitrite-N (NO_2^--N). These are oxidized, anionic, inorganic forms of nitrogen that are highly soluble in water, with NO_3^--N being the predominant compound and NO_2^--N being an intermediate. These oxidized forms of nitrogen are the usual fate of other nitrogen compounds in aerobic aquatic environments such as stormwater runoff. The solubility and stability of these nitrogen compounds makes their removal a challenge, and the only high volume commercial process that is currently available for oxidized nitrogen removal is anaerobic digestion wherein denitrification (NO_3^--N → NO_2^--N → N_2 gas) is performed by specific anaerobic microbes—an intensive, controlled process. While these microbes are naturally occurring and probably present to some degree in most stormwater BMPs, their effectiveness is dependent upon basic environmental parameters such as temperature and oxygen content, making their effectiveness both random and seasonal.

Where nitrate-N and nitrite-N represent important oxidized, inorganic forms of nitrogen, ammonia-N is the most important reduced form of inorganic nitrogen. As with the oxidized forms of nitrogen, NH_3-N is highly water soluble. While most often referred to as ammonia-N, in solution it is most often present as ammonium-N (NH_4^+-N), though reference to ammonia-N will be continued in this document. Unlike the oxidized forms of nitrogen, NH_3-N is highly toxic and volatile, which makes it the nitrogen compound of most concern in aquatic ecosystems. In oxic, aquatic environments, NH_3-N is rapidly transformed into oxidized nitrogen via biochemical nitrification processes (NH_3-N → NO_2^--N → NO_3^--N). This is the primary mechanism utilized in aquaculture to address nitrogen toxicity issues, whereas nitrogen load issues are addressed through frequent water changes wherein water high in nitrogen is discharged and replaced with water with lower nitrogen concentrations. However, when water bearing NH_3-N is passed through a medium with cation exchange properties, both toxicity and load issues associated with NH_3-N can be addressed.

While the Stormwater Management StormFilter® (StormFilter) is susceptible to the same total nitrogen removal challenges (i.e. uncontrollable nitrogen transformations, sensitivity of biological natural attenuation functions to environmental conditions) encountered by engineered surface water ecosystems, it has some distinct advantages. The availability of cation exchange media, the dewatering characteristics of the system, and the physical removal of used cartridges and the associated captured materials from the site all provide the potential for the substantial reduction of the total nitrogen load of a system on an annual basis (assuming annual maintenance). Maintenance assures the true removal of the contaminants from a system since stormwater BMPs capture and store non-biodegradable contaminants such as metals, inorganic solids, and nutrients.

Unfortunately, evaluation of the total nitrogen removal capabilities of a stormwater BMP requires monitoring of all three nitrogen compounds discussed above for an extended period of time. All three compounds must be monitored because organic-N captured during one event may degrade into NH_3-N between events and gradually leave the system as NO_3^--N over the course of subsequent storm events. The need to track total nitrogen loads over time also makes extended monitoring imperative as the loss of previously captured nitrogen is a gradual process which is difficult to monitor if substantial data gaps exist. Conducting monitoring for an extended period of time will account for seasonable variables such as temperature, water chemistry, microbial activity, and nutrient loading, which all affect the biochemical transformation of nitrogen compounds and thus system performance.

Procedure

Monitoring data for this system is publicly available from the National Stormwater BMP Database (www.bmpdatabase.org) and was used to evaluate the total nitrogen removal potential of a StormFilter system.

Results

Using paired influent and effluent EMC data for TK-N and NO_3^--N obtained from the National Stormwater BMP Database, the performance of the system was summarized using the Regression of EMC method ($y_0 \neq 0$) (SMI, 2002). Unlike the Regression of Load method, the Regression of EMC method limits the incorporation of errors associated with flow measurement by assuming that influent volume equals effluent volume—a logical assumption for flow-through stormwater BMPs such as the StormFilter. Figures 1 and 2 illustrate the summarized removal efficiencies for TK-N and NO_3^--N, respectively. Based upon this data summarization method, mean TK-N removal efficiency demonstrated by the KMMS StormFilter system was 31% (P=0.05: L1=39%, L2=23%), and mean NO_3^--N removal efficiency was observed to be 21% (P=0.05: L1=39%, L2=4%).

Assuming that the NO_2^--N is either insignificant or accounted for (see Discussion), the TK-N and NO_3^--N EMCs can be combined to produce the total nitrogen EMC. Under this assumption, total nitrogen influent and effluent EMCs were calculated using the data presented in Figures 1 and 2. The extrapolated total nitrogen data is shown in Figure 3 and evaluated using the Regression of EMC method. It yields a mean total nitrogen removal efficiency of 27% (P=0.05: L1=35%, L2=18%).

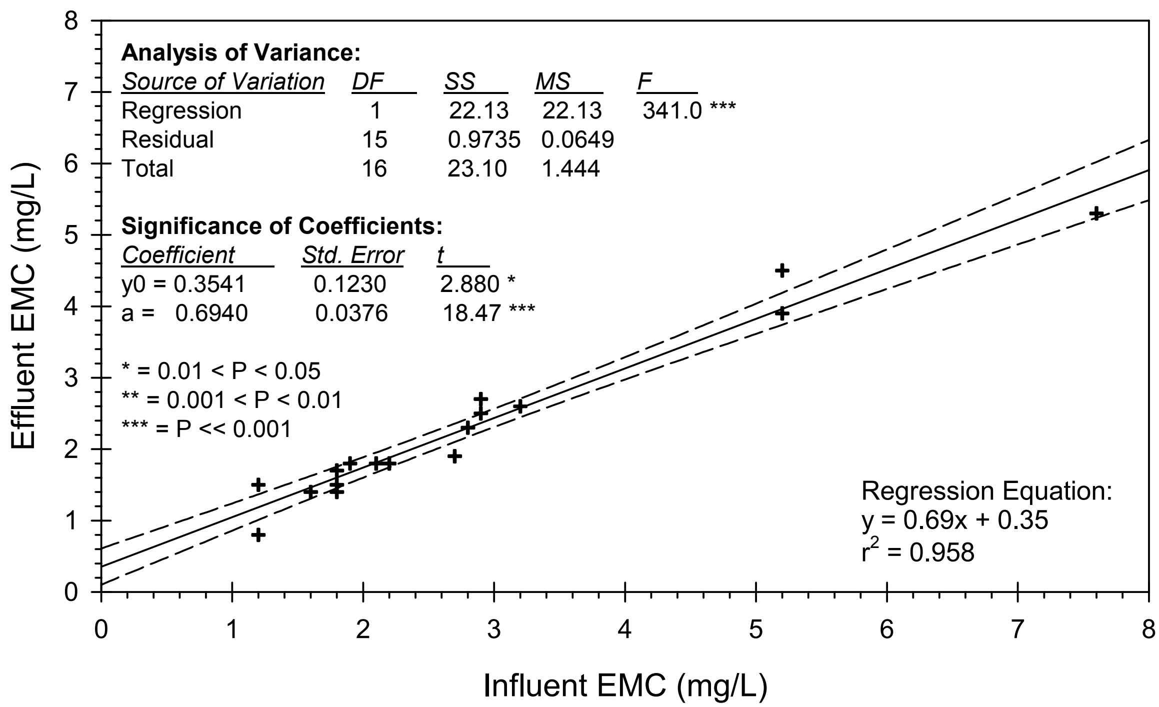

Figure 1. Total Kjeldahl Nitrogen (TK-N) EMC data for the KMMS StormFilter system with coarse perlite/coarse zeolite cartridges with a design flow rate of 15 gpm/cartridge. Using the regression of EMC performance evaluation method, TK-N removal is determined by subtracting the regression slope from 1 and thus estimated to be 31% (P=0.05: L1=39%, L2=23%).

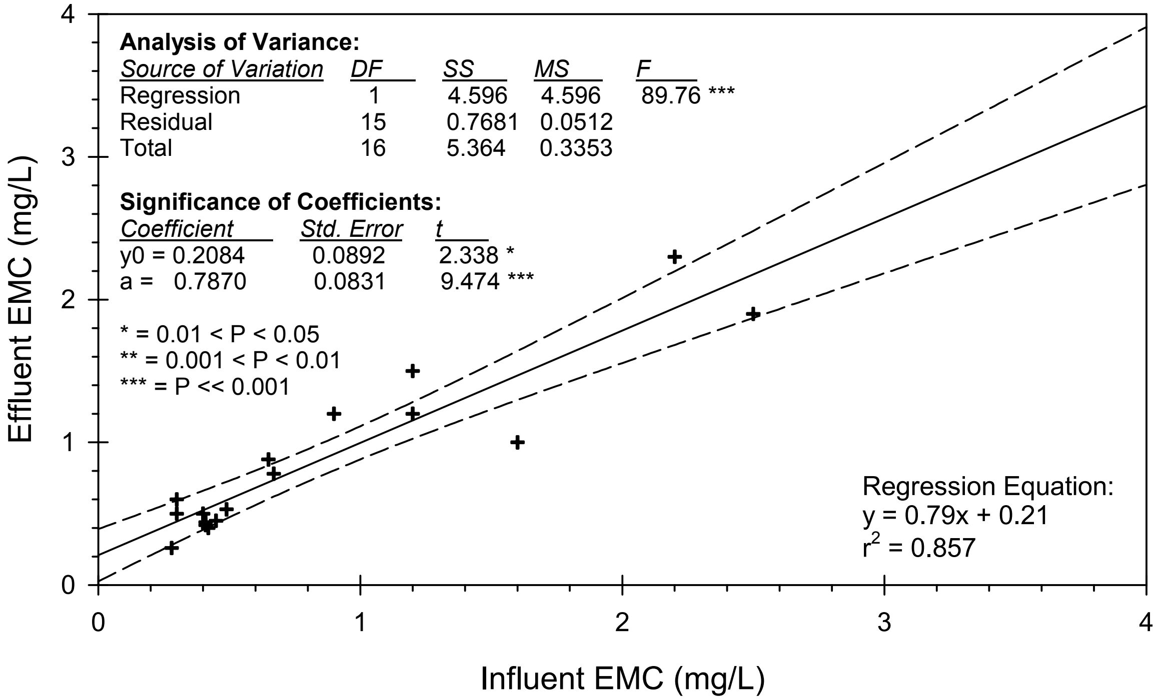

Figure 2. Nitrate Nitrogen (NO_3^--N) EMC data for the KMMS StormFilter system with coarse perlite/coarse zeolite cartridges with a design flow rate of 15 gpm/cartridge. Using the regression of EMC performance evaluation method, NO_3^--N removal is estimated to be 21% (P=0.05: L1=39%, L2=4%).

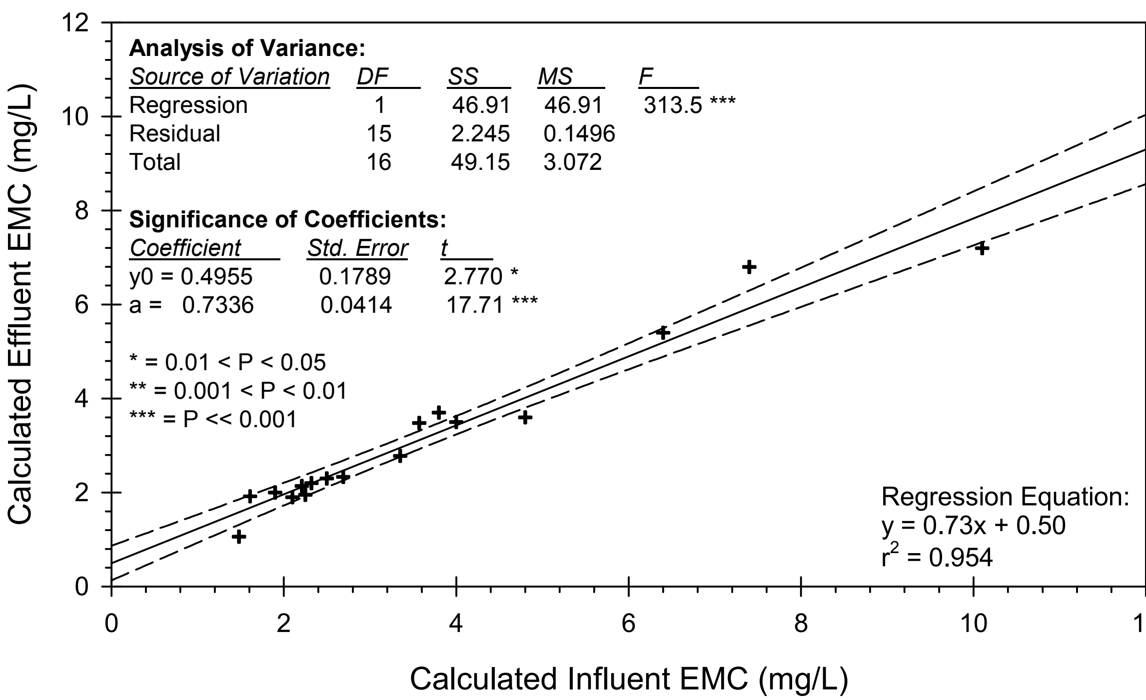

Figure 3. Total nitrogen EMC data extrapolated from available TK-N and NO_3^--N data for the KMMS StormFilter system with coarse perlite/coarse zeolite cartridges with a design flow rate of 15 gpm/cartridge. Using the regression of EMC performance evaluation method, total nitrogen removal is estimated to be 27% (P=0.05: L1=35%, L2=18%).

Discussion

The relationship observed between the influent and effluent EMC data shown in Tables 1, 2, and 3 is surprisingly linear considering the range of potential variables that affect system performance in the field. The validity of the linear relationships and the regression equations is verified by the very low probability ($P \ll 0.001$) of a type I error (the probability that the linear relationships are falsely identified and that no observable relationship exists). This suggests that as with the total suspended solids removal efficiency of the StormFilter, the TK-N, NO_3^--N, and possibly total nitrogen removal performance of the StormFilter is constant regardless of influent contaminant concentrations.

Though NO_2^--N concentration had to be assumed to be insignificant in order to extrapolate total nitrogen EMCs, the assumption has weight given the fact that NO_2^--N concentration is usually much less than NO_3^--N concentration. Thus an assumption was made in order to utilize the invaluable data provided by the KMMS StormFilter monitoring project. Other than NO_2^--N, all other important forms of nitrogen were accounted for.

Again, under the assumption that TK-N and NO_3^--N represent the bulk of total nitrogen load encountered by the KMMS StormFilter system, the positive TK-N and NO_3^--N removal performance demonstrated by the system indicates a net removal of part of the total nitrogen load to the system. Considering that biological denitrification is usually responsible for the removal of oxidized nitrogen in natural systems, this suggests that an underappreciated biological component was active within this engineered system. Much like the denitrification processes at work in the bed of a fluvial system, moist conditions, anaerobic microsites, and the ready availability of oxidized nitrogen may have sustained a population of denitrifying microorganisms within the system throughout its use. Considering the net removal of oxidized nitrogen from the system (between 4% and 39% with 95% confidence), and the absence of an intentional physicochemical oxidized nitrogen removal component from the StormFilter system, it can be said that the KMMS StormFilter system demonstrated some degree of biological denitrification throughout the 3-year monitoring period.

While the KMMS system did contain cation exchange media in the form of zeolite, the effectiveness of the media on NH_3-N removal could not be evaluated. The TK-N data includes, and thus accounts for, any NH_3-N present in the system; however, the fraction of TK-N present in the form of NH_3-N was not determined for influent/effluent sample pairs. Based upon the wide-spread, specific use of zeolite in the aquaculture industry for NH_3-N removal, it can be said that some of the TK-N removal demonstrated by the system was most likely due to the cation exchange media.

Conclusions

The analysis of 3 years of winter/spring monitoring data shows that the KMMS StormFilter system demonstrated a net removal of total nitrogen from stormwater originating from a road equipment maintenance facility. The total nitrogen removal efficiency of the system was estimated to be between 35% and 18% with 95% confidence.

The total nitrogen removal performance estimated by this study is thought to be conservative. This is based upon the observation that the bulk of the solids found within the KMMS system were observed to be organic, with recognizable leaf debris (Caltrans, 1999). It is impossible to account for the nitrogen load entering the system in the form of bulk leaf material using automated sampling equipment; however, this material eventually breaks down into smaller solids and even dissolved components that can easily be detected with automated sampling equipment upon leaving the system. Thus not accounting for this material on the influent end but accounting for it on the effluent end results in artificially depressed influent concentrations that negatively affect removal performance observations.

Considering the difficulty of accounting for nitrogen influx into a system in the form of bulk solids, as well as the potential environmental gains afforded by keeping bulk solids from degrading within a system, a very simple option may be exercised in the future. The screening of bulk solids can be performed at the intake for the system (usually catch basins) or within the system itself. In the interest of both accurate monitoring of the system as well as maximum total nitrogen removal, these devices could be cleaned between monitoring events and the nitrogen content represented by the bulk debris could be quantified. The only drawback to this activity is that it increases both the frequency and level of maintenance required for the system.

Stormwater360, Stormwater Management Inc, and Vortechnics Inc. are now CONTECH Stormwater Solutions Inc.

References

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Revision Summary

PE-C013
Document rebranded.

PE-C012
Document number changed; document rebranded; no substantial changes.

PE-02-001.1
Document reformatted; references updated.

PE-02-001.0
Original.