Removal of Phosphorus From Urban Runoff Using PhosphoSorb Media

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Abstract

Urban stormwater quality regulations in many parts of USA have been rapidly expanding and some standards now include numeric treatment criteria for total phosphorus. There is an increasing consensus that the receiving waters impaired by excess phosphorus loading are not likely to be sufficiently protected by stormwater best management practices (BMPs) that retain solids and associated phosphorus without targeting the dissolved fraction of phosphorus. Advanced technologies and products with multiple field evaluations approved by regulation agencies are paramount to meet water quality goals of phosphorus in many watersheds. To that end, an adsorptive filter media (PhosphoSorb®) was recently developed. Deployed in the Stormwater Management StormFilter® (StormFilter), PhosphoSorb media was evaluated for phosphorus removal at two sites in the northwest of USA. Six StormFilter cartridges were operated at Site 1 in Washington State and one StormFilter cartridge was employed at Site 2 in Oregon State. Twenty nine storm events have been successfully monitored at these two locations since early 2009. Data showed a robust sample population with 14 storm events having event mean concentrations (EMCs) for total phosphorus (TP) less than 0.1 mg/L and 15 events having EMCs for TP from 0.1 mg/L to 0.5 mg/L. The results indicate that PhosphoSorb media can capture and retain a substantial portion of TP load in stormwater runoff by targeting both particulate and dissolved phosphorus. TP removal rate of 65% or higher can be expected for influent EMCs greater than 0.1 mg/L. For events of low influent EMCs for TP, PhosphoSorb media in StormFilter is capable of significantly reducing effluent EMCs for TP to near the method detection limit.

Keywords: Filter media, phosphorus removal, stormwater treatment, urban runoff

Introduction

In many parts of North America stormwater quality regulations are rapidly evolving and many standards now include numeric treatment criteria for phosphorus. Historically, total suspended solids (TSS) were assumed to be a surrogate for other stormwater pollutants, but we have since learned that meeting water quality goals requires more robust pollutant specific standards be
implemented. Many of the receiving waters impaired by excess phosphorus loading are not likely to be sufficiently protected by stormwater best management practices (BMPs) that retain solids and associated phosphorus but do not target the soluble fraction of the phosphorus load.

**Phosphorus Removal Mechanisms**

Phosphorus transported by stormwater runoff can be generally described as either particulate or dissolved. The effectiveness of a given unit process (sedimentation, filtration, and sorption) at capturing phosphorus is largely influenced by partitioning between particulate and dissolved phases. For example, relying on filtration to capture fine solids often proves to be a highly effective strategy for particulate phosphorus removal but is not likely to address the soluble fraction. Partitioning between soluble and particulate phases is highly variable depending on site specific conditions and ratio of particulate fraction to dissolved fraction. For many residential and commercial locations, past research indicates that the phosphorus load transported by stormwater is likely to be about 50% particulate and 50% soluble (NYSDEC, 2010).

Given that significant fractions of both particulate and soluble phosphorus are typically present in stormwater runoff, a mitigation strategy that effectively targets both particulate and soluble forms of phosphorus is paramount to achieving high levels of TP reduction. When media filtration is being considered as the primary control strategy, the filtration system must be capable of removing fine particulates and have an affinity for soluble phosphorus. Many of the commercially available filter media that have been relied upon for stormwater management in recent years are highly effective for fine particulate removal but lack the sorption capacity needed to target soluble phosphorus. In fact, some media used in media filtration and biofiltration, contain soluble fractions of Phosphorus which leaches out during operation.

**PhosphoSorb Media**

To meet the challenging new P standards and stringent removal criteria Contech Engineered Solutions has developed an adsorptive filter media of PhosphoSorb which specifically target both the particulate and soluble phosphorus fractions. The media is comprised of heat expanded volcanic granules impregnated by activated alumina. The light weight expanded volumetric granules provide exceptional removal of fine particulates. Numerous studies showed that activated alumina can effectively adsorb soluble phosphorus with a rapid kinetic rate (Hano et al. 1997; Genz et al. 2004). Several years of research and development effort were devoted to optimizing PhosphoSorb to ensure the highest possible level of performance is achieved. PhosphoSorb media is stable and will not leach harmful substances over time. Additionally, care was taken to maximize media longevity in order to limit life cycle costs. Finally, it is worth noting that PhosphoSorb is manufactured in an environmentally friendly manner resulting in no toxic or otherwise harmful byproducts.

**Results**

**Lab-Scale Testing**

Since physical filtration performance is primarily determined by the media gradation, the PhosphoSorb granule size was selected to be consistent with proven stormwater filtration media, therefore the ability of PhosphoSorb media to remove solids (particulate phosphorus) from stormwater runoff would be well understood. With that understanding, much of the initial
laboratory research focused on optimizing retention of soluble phosphorus (Ma et al. 2010). Figure 1 compares dissolved phosphorus adsorption capacity of PhosphoSorb and three other typical filtration media widely used in stormwater treatment: perlite, zeolite, and granular activated carbon. Lighter media is conducive for economic handling, shipping and disposal. Figure 2 shows their bulk densities. Apparently, PhosphoSorb merits light weight and highest adsorption capacity.

![Figure 1. Adsorption capacity of filter media (mg/g).](image1)

![Figure 2. Bulk densities of filter media.](image2)

After the retention of soluble phosphorus under controlled conditions was confirmed, research efforts next focused on evaluating performance under conditions consistent with the intended media deployment. PhosphoSorb was then tested under conditions to assess soluble phosphorus removal over time. Figure 3 illustrates the testing apparatus and Figure 4 shows one set of testing.
results. Performance results indicate that PhosphoSorb provided a high level of soluble phosphorus removal throughout these trials with a slight decrease in performance after the first 175 empty bed volumes. The overall reduction of soluble phosphorus for the 299 empty bed volume trials was 66% based on the summation of load method.

![Testing apparatus for dissolved phosphorus removal.](image)

**Figure 3.** Testing apparatus for dissolved phosphorus removal.

![Dissolved phosphorus removal under flow through situation.](image)

**Figure 4.** Dissolved phosphorus removal under flow through situation.

Influent concentration of 0.5 mg/l Potassium Dihydrogen Phosphate (KH2PO4)

To put these laboratory results in perspective, recall the assumption that soluble phosphorus often represents approximately 50% of TP load. If 66% of the soluble phosphorus load was successfully retained by PhosphoSorb, it would expect a 33% reduction of the TP load (66% removal of 50% of the total load) as a result of soluble phosphorus removal. When the soluble phosphorus reduction is added to the load reduction resulting from particulate phosphorous removal, the overall TP reduction would be >70% (assumes 40% TP reduction from particulate phosphorus removal).
**Field-Scale Testing**

The StormFilter with PhosphoSorb media was evaluated for phosphorus removal at two sites in the northwest of United States. Both sites were monitored according to the Washington State Department of Ecology (Ecology) TAPE protocol (Ecology, 2008) including the development of a quality assurance project plan subject to third party audit. These sites were:

- Site 1 - Cable Street (roadway), Whatcom County, WA. Six StormFilter cartridges.
- Site 2 - Glenn Widing Dr (parking lot), Portland, OR. A single StormFilter cartridge.

Site 1 monitoring began in April 2009 and Site 2 was initiated in September 2009. Site 1 field evaluation was conducted in conjunction with Whatcom County Public Works. The results of this site are currently under review by Ecology for approval as enhanced phosphorus removal designation. Site 2 consists of a pump and treat configuration located at Contech’s research facility in Portland, Oregon. Runoff from the parking lot is pumped from an onsite catch basin to a full scale StormFilter with a single StormFilter cartridge containing PhosphoSorb media.

To date, 29 storm events have been successfully monitored at these two locations. The data include a robust sample population of low and medium influent EMCs for TP with 14 storms less than 0.1 mg/L and 15 storms greater than 0.1 mg/L. None of the events contained high influent concentrations which are defined as greater than 0.5 mg/L in this study. To demonstrate the effectiveness of PhosphoSorb for addressing both low and medium influent TP concentrations, the data has been pooled accordingly.

For low influent concentrations less than 0.1 mg/L, it seems more appropriate to examine the effluent quality rather than the removal efficiency since the method detection limit (0.02 mg/L) inhibits the ability to accurately report the removal efficiency. Table 1 summarizes the statistical analysis of TP data with influent EMC values less than 0.1 mg/L. The median influent EMC value for these low influent events (n=14) was 0.047 mg/L while the median effluent EMC value was 0.025 mg/L (confidence intervals +/- 0.0046 mg/L). The results suggest that even at very low influent concentrations PhosphoSorb media is highly effective at removing phosphorus.

<table>
<thead>
<tr>
<th>Analyte</th>
<th># of event</th>
<th>Influent EMCs</th>
<th>Effluent EMCs</th>
<th>95% CI for the median Effluent EMC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Range (mg/L)</td>
<td>Median (mg/L)</td>
<td>(mg/L)</td>
</tr>
<tr>
<td>TP</td>
<td>14</td>
<td>0.020-0.099</td>
<td>0.047</td>
<td>0.025 0.021-0.030</td>
</tr>
</tbody>
</table>

Table 1. Statistical analysis of TP data with influent EMCs less than 0.1 mg/L
The remaining 15 storm events contained influent EMCs for TP between 0.1 mg/L to 0.5 mg/L. Evaluating data in this concentration range increase precision and/or the accuracy of a performance assessment as the concentrations are substantially higher than the non-detection limit. Table 2 presents the results of the 15 storm events exhibiting influent EMC values for TP greater than 0.1 mg/L. The range of measured EMC values for these events was 0.1 mg/L to 0.49 mg/L so none of the events had abnormally high influent loading. The mean removal efficiency estimate for these 15 events was 67%, with 95% confidence intervals of 48% and 85%.

Table 2. Statistical analysis of TP data with influent EMCs ranging 0.1 to 0.5 mg/L

<table>
<thead>
<tr>
<th>Analyte</th>
<th># of event</th>
<th>Range (mg/L)</th>
<th>Median (mg/L)</th>
<th>Median (mg/L)</th>
<th>Mean %</th>
<th>95% CI for the mean removal %</th>
</tr>
</thead>
<tbody>
<tr>
<td>TP</td>
<td>15</td>
<td>0.100-0.490</td>
<td>0.166</td>
<td>0.083</td>
<td>0.065-0.101</td>
<td>67</td>
</tr>
</tbody>
</table>

**Discussion**

Based on the results of initial lab and field testing, the StormFilter with PhosphoSorb media is expected to capture and retain a substantial portion of TP load in stormwater runoff by targeting both particulate and soluble phosphorus. Field results by far suggest removal of greater than 65% of TP load can be expected when influent concentrations exceed 0.1 mg/L. In instances when low influent concentrations are experienced (Influent EMC < 0.1 mg/L) field results indicate that StormFilter with PhosphoSorb media is capable of reducing effluent concentrations substantially with median effluent EMCs for TP near the method detection limit.

In addition to the performance data already discussed, the ongoing field monitoring efforts have yielded valuable insights into the longevity characteristics of PhosphoSorb media. Minimizing the need for media replacement is important in order to control the maintenance frequency and associated costs. The StormFilter with PhosphoSorb at Site 1 remained in operation for 17 consecutive months (April 2009 – September 2010) before requiring maintenance due to media occlusion. The StormFilter with PhosphoSorb at Site 2 was in operation for 10 consecutive months (September 2009 – July 2010). Site 1 cartridge media was fully exhausted prior to maintenance. Site 2 monitoring was concluded with the media only partially exhausted for experimental purposes as the summer months produce very low rainfall in the Pacific Northwest.
When considering the field monitoring results presented herein it is important to remember that both studies represent a flow through configuration of the StormFilter. Future field studies will include systems designed for different operating rates. It is expected that reducing the operating rate of the system will lead to even higher levels of TP removal as a result of longer residence times leading to additional particulate capture and longer media contact times resulting in additional removal of soluble phosphorus. Past experience has also shown that reducing the operating rate of the system typically extends the useful life of the media.

References


