

Urban Stormwater Runoff Phosphorus Loading and BMP Treatment Capabilities

Scott Perry¹, CPSWQ, **Joel Garbon**², **Brian Lee**³

¹ Imbrium Systems Corporation – Rockville, Maryland

² Imbrium Systems Corporation – Portland, Oregon

³ Imbrium Systems Incorporated – Toronto, Canada

Corresponding author e-mail: sperry@imbriumsystems.com

ABSTRACT

Continued land development through urbanization is deteriorating surface water quality. A significant concern with our limited global fresh water resources is the onset of toxic algae blooms and reduced dissolved oxygen due to continued, uncontrolled phosphorus loading from an ever increasing source, urban development. This is leading to negative ecologic, economic, and human health impacts. As a result, regulators are beginning to acknowledge the impairment of fresh water bodies, and have begun implementation of Total Maximum Daily Loads (TMDLs). However, applying phosphorus related TMDLs specifically to urban stormwater runoff may not be effective without first understanding the available mechanisms and limitations involved in phosphorus treatment for stormwater applications.

To achieve high levels of permanent phosphorus removal, review of the fate and transport of Phosphorus, including both particulate-bound and dissolved phosphorus, in urban stormwater runoff is necessary. Significant field monitoring data of various stormwater Best Management Practices (BMPs) exists which illustrates advantages and disadvantages of removal mechanisms, and ranges of performance variance in both conventional Best Management Practices (BMPs) as well as newer Low Impact Development (LID) applications.

Advances in phosphorus treatment technologies have recently become available and better understood, providing the ability to capture high levels of both particulate-bound and dissolved phosphorus. Amending both conventional BMPs and LID applications with engineered solutions offers increased ability to achieve existing and future phosphorus based TMDLs. These concepts, performance data and design amendments are discussed as a potential means to protect our fresh water resources from remaining eutrophication.

INTRODUCTION

Phosphorus is an essential nutrient for life, and comprises roughly 10% by mass of the Earth's crust. It is not found in free elemental form in nature, but is widely distributed in minerals, primarily in magmatic, sedimentary rocks and ocean sediments. Phosphorus naturally complexes with other molecules to form organic and inorganic phosphates. It is

present in both the dissolved phase (commonly measured as orthophosphate, and referred to as bio-available or Soluble Reactive Phosphorus (SRP)), and particulate-bound phase (adsorbed to sediment particles). Like most chemical constituents present in the environment, phosphorus is cyclic. Under natural conditions phosphorus migrates slowly from rock and sediment deposits, with a portion metabolized into the tissues of living organisms, to be released upon excretion and decay back into the soil and water. Human activities have significantly short-circuited and accelerated this naturally slow phosphorus cycle through agricultural practices, industrialization, land development and urbanization. Some research suggests land development activities account for a 300% load increase in the phosphorus cycle (Howarth et.al., 2005) compromising surface water quality.

Commonly phosphorus is the limiting fresh water nutrient, and when present in excess can quickly lead to significant water quality degradation. Trends in agricultural practices, energy use, and population growth indicate that eutrophication of lakes, streams, rivers, and bays are an expanding problem globally (WRI, 2008). Eutrophication is the result of excess nutrient availability and over enrichment, often identified by toxic algal blooms or oxygen depletion (hypoxia). Algal blooms can result in fish kills, shellfish poisoning and human illness, and even death of mammals and birds. An extreme result of algal blooms is hypoxia, which occurs when algae and other organisms die and begin decomposing, consuming dissolved oxygen (DO) from the water column. As DO levels drop, oxygen required for native species is not available and aquatic ecology suffocates. By monitoring increases in orthophosphate levels (dissolved phosphorus) in the water column, algal blooms can be predicted (EPA, 1997). Though orthophosphate is not the only source of phosphorus in a water body, it does function as the “quick sugar” for algae formation as it is highly bio-available, therefore if untreated or uncontrolled water quality degradation can be anticipated.

Water quality degradation as a result of continued phosphorus loading is beginning to be acknowledged by North American policy decision makers. In the U.S., this is pursued in the Clean Water Act section 303(d), waters listed as impaired by pollutant(s). In Canada, the Ontario Ministry of the Environment is in the process of developing the Lake Simcoe Act to similar effect. To effectively address these impairments it is important to strengthen connections between two key federal programs under the Clean Water Act – the TMDL program and the NPDES stormwater permitting program (EPA, 2008). However, applying TMDLs specifically to stormwater treatment practices (e.g. Total Phosphorus effluents of < 0.1 mg/L) may not be effective without first understanding the available mechanisms and limitations involved in phosphorus treatment for stormwater applications.

Before implementing BMPs to mitigate impaired water bodies and achieve necessary pollutant reductions, a thorough understanding of the problem is required, including: 1) the transport and fate of the specific root-cause pollutant; 2) the effects of continual loadings to the watershed if gone untreated; and 3) assessing the functional mechanisms and limitations of available treatment practices.

TRANSPORT AND FATE OF PHOSPHORUS IN STORMWATER RUNOFF

The transport and fate of a pollutant describes the migration and possible altered chemistry resulting from prevailing chemical conditions. To determine which mechanisms will be effective in removing a given pollutant, its transport and fate in stormwater runoff must be understood. Considerable hydrologic variation exists when considering stormwater runoff characteristics during a rain event or between successive rain events. Transport of sediment becomes rather complex when considering the resulting variable rain intensity, runoff rate and volume, and pollutant load generation during antecedent conditions. Considering this variability, research over the decades have provided a better understanding on how best to treat sediment in stormwater runoff through a variety of practices. Sediment has been generally thought of as the surrogate of stormwater pollutants, and is identified and is often quantified as Total Suspended Solids (TSS), or Suspended Sediment Concentration (SSC). Sediment fate remains virtually unchanged as it is not impacted through water chemistry changes typical in stormwater.

However, when considering phosphorus transport, water chemistry adds an additional level of complexity that alters the fate and ability to capture and retain this critical pollutant.

Phosphorus is commonly quantified in two forms: Total Phosphorus (TP) and Dissolved Phosphorus (DP). TP accounts for both particulate-bound phosphorus and all forms of DP. DP comprises a large portion of the bio-available phosphorus, also known as soluble reactive phosphorus or the “quick sugar” for algal blooms. Measurements of orthophosphate, HPO_4^{2-} and $\text{H}_2\text{PO}_4^{-1}$ are commonly used to quantify DP. The TP and DP speciation are site, watershed, land use, water chemistry and time sensitive. This sensitivity results in an even more dynamic transport and fate of phosphorus from site to site, event to event, and water body to water body. Partitioning of TP in rainfall runoff between the particulate-bound and DP fractions can vary from 20% to more than 90% (NYS DEC, 2008). Phosphorus partitioning from urbanized settings (residential and commercial) where characterized within the New York State Department of Environmental Conservation Stormwater Management Design Manual as listed in **Table 1**. **Table 1** quantifies the partitioning of phosphorus by land use, suggesting that generally half of the phosphorus load in runoff from residential and commercial sites is particulate-bound, with slightly larger particulate-bound fractions likely in runoff from industrial and open space areas.

Table 1. Phosphorus Concentrations in Runoff by Land Use (NYS DEC, 2008)

	Residential	Commercial	Industrial	Open Space
Average TP, mg/L (Number of Observations)	0.41 (963)	0.34 (446)	0.45 (434)	0.59 (46)
Average DP, mg/L (Number of Observations)	0.20 (738)	0.18 (323)	0.16 (325)	0.16 (44)
Approximate % TP	51	47	64	73
Approximate % DP	49	53	36	27

Other research has quantified the transport of particulate-bound phosphorus by the particle size of suspended solids in runoff. The outcome of the research identified that particulate-bound phosphorus is largely concentrated on the finer fraction of suspended sediment from 1 to 25 μm (Madge, 2004 and Vaze et al., 2004). Research conducted by Vaze (2004) on an urban road surface suggested that less than 15% of TP was attached to sediment particles greater than 300 μm , while 20% to 30% was in DP form. Results from testing of a residential site (Madge, 2004) found that the majority of phosphorus was attached to particles in the range of 5 to 20 μm . The DP fraction made up only 20% of the TP load, with 96% of the dissolved phosphorus being determined to be bio-available. Both studies concluded that BMPs capable of removing and securing smaller sized particles provide effective TP treatment by capturing a high percentage of particulate-bound phosphorus. Additionally, the research indicates that treatment focused on capture of particulates does not address DP removal nor the bio-availability of phosphorus.

It is important to recognize that phosphorus fate will shift speciation as water chemistry conditions (pH, alkalinity, temperature, redox potential, concentration, etc...) naturally change in stormwater runoff and treatment systems. These shifts in speciation may occur both during the transport and/or storage of particulate-bound phosphorus within the conveyance and treatment structures, such as piping, detention/retention facilities, settling basins, and filtration/infiltration treatment practices. Speciation shifts may result in particulate-bound phosphorus re-solublizing into DP and becoming readily bio-available. Despite having been previously captured in the particulate-bound form, phosphorus that has transitioned to a dissolved form has high propensity to be carried downstream into a surface water body to feed algal growth.

CURRENT PHOSPHORUS REMOVAL TARGETS

Several State-level stormwater guidelines suggest an effective stormwater treatment practice, considered a “stand-alone practice”, captures a minimum 80% TSS and a minimum 40% TP on an average annual basis (MDE 2000, MOE 2003, NYS DEC 2003). New regulatory requirements have begun to be adopted that specify a higher degree of phosphorus removal. For example, Maine and specific regions in New York State are targeting 65% TP removal, but neither specifically addresses DP removal. Virginia is more aggressively addressing nutrient capture from stormwater by working towards implementation of a post-development TP pollutant load limit of 0.28 pounds per acre, per year. Nonetheless, these requirements may be inadequate to improve the quality of threatened or impaired water bodies if the ratio of particulate-bound and bio-available dissolved phosphorus is not considered.

A compilation of previous stormwater research on many conventional stormwater treatment practices commonly implemented to achieve 80% TSS removal (dry ponds, wet ponds, wetlands, filtrating and bioretention practices) were extracted and analyzed from the National Pollutant Removal Performance Database (CWP, 2007) in **Table 2, and presented in Figure 1 and Figure 2**. The information data set for each of these

practices demonstrated variable phosphorus removal rates, and highlighted difficulty in achieving greater than 65% TP removal. Additionally, median performance reviewed indicated *all practices excluding wet ponds and infiltration indicated variable or even negative soluble phosphorus removal*.

Table 2. BMP Removal Efficiency Statistics from the Analyses of data from the National Pollutant Removal Database, Version 3 (CWP, 2007)

Pollutant Median Removals	Dry Ponds	Wet Ponds	Wetland	Filtering Practices	Bio-retention	Infiltration Practices	Open Channel
TSS % (number of observations)	49 (10)	80 (44)	72 (37)	86 (18)	59 (4)	89 (4)	81 (17)
TP % (number of observations)	20 (10)	52 (45)	48 (37)	59 (17)	5 (10)	65 (8)	24 (16)
Soluble P % (number of observations)	- 3 (6)	64 (28)	25 (26)	3 (7)	-9 (5)	84 (4)	-38 (14)

Figure 1. BMP Total Phosphorus Removal Efficiency Analyses of data from the National Pollutant Removal Database, Version 3 (CWP, 2007)

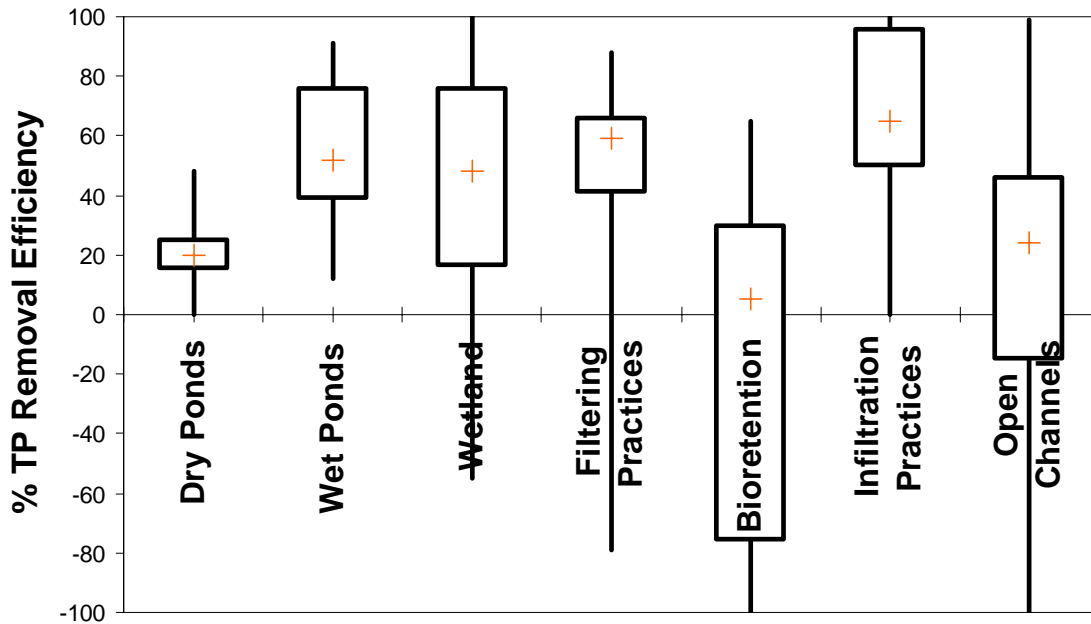
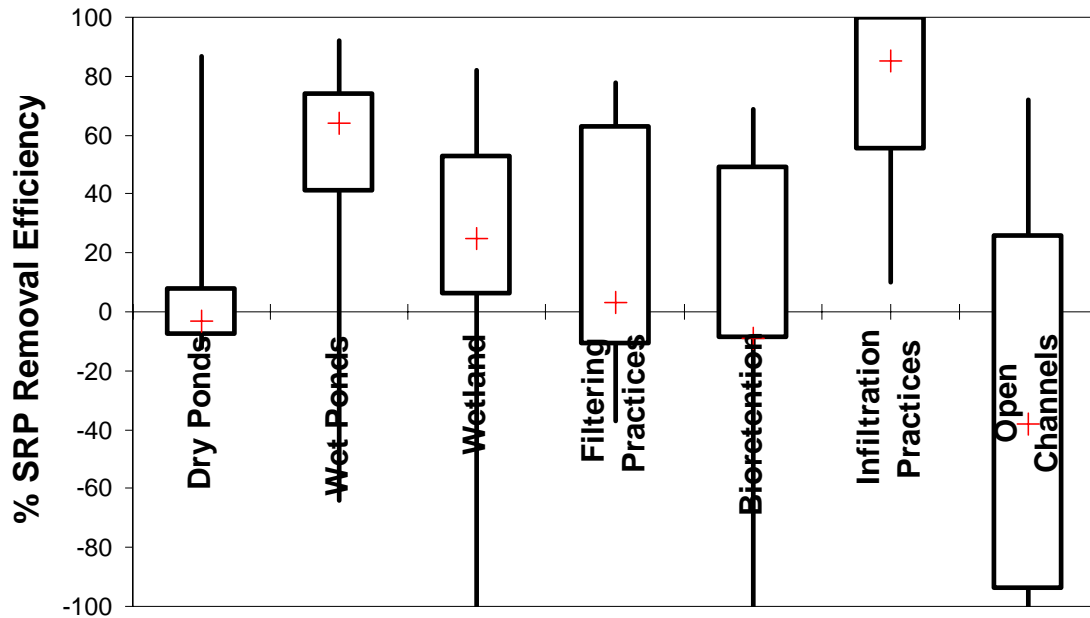


Figure 2. BMP Soluble Reactive Phosphorus Removal Efficiency Analyses of data from the National Pollutant Removal Database, Version 3 (CWP, 2007)



CONVENTIONAL PHOSPHORUS REMOVAL MECHANISMS

Through analyses of hydrology, it has been recognized that small storm hydrology naturally dominates the volume of runoff accumulated on an annual basis. For treatment practices to be effective they need to address smaller storms as these generally contribute the majority of the annual pollutant load (Pitt, 1999). Most current North American stormwater treatment regulations drive towards treating a required water quality volume (WQ_v) of 80% to 90% based on local historical rainfall records. This provides comfort that the majority of the pollutant load (sediment basis) will be treated to the maximum extent practicable (ASCE and WEF, 1998; USEPA, 2004, MOE, 2003).

Considering the dynamic transport and fate of phosphorus, relying solely on these water quality volume principles will not provide effective results. To achieve high levels of phosphorus removal required to address a TMDL for an impaired water body, not only does the water quality volume need to be considered, but so do several other parameters which impact phosphorus removal, such as: (1) the mechanisms, capacities, and limitations of unit operations and processes (UOPs) of treatment practices; (2) recognition that the transport and fate of phosphorus is dynamic and speciation changes over time; and (3) ensuring regular maintenance to remove sediment and particulate-bound phosphorus, not only to ensure systems are functioning as designed, but also to help mitigate phosphorus from re-solubilizing into DP and transporting downstream.

Well-recognized mechanisms employed to capture particulate-bound phosphorus are UOPs of sedimentation and filtration. Sedimentation has been heavily studied, and when using this mechanism alone in stormwater treatment practices significant limitations are

encountered in regards to removal of finer particulates, especially with under-sized facilities. Limitations can be mitigated through proper basin design, or within proprietary practices through proper sizing and accounting for a realistic particle size distribution (PSD) that includes the finer fraction of sediment. For sedimentation practices to be effective they need to demonstrate capture of a finer fraction of particles and be able to retain the material and prevent re-suspension. The preventative design feature of incorporating an effective sedimentation basin bypass is often overlooked with smaller conventional and proprietary practices, to the detriment of overall performance and system capability.

BMPs with UOPs of filtration, including infiltration, are generally more effective for capturing the finer fraction of particulates in addition to the coarse fraction. However, system design needs to consider clogging or plugging of the filtering surfaces. Pre-treatment using sedimentation can be effectively implemented to remove settleable solids and gross pollutants prior to the filtration and infiltration practice, improving performance while extending the maintenance interval. Overall, filtration practices generally have a higher TP removal rate as compared to sedimentation practices, but most do not effectively remove DP.

Management and maintenance of all unit operations, including physical, chemical and biological processes, are critical to ensure removal of phosphorus from stormwater (Strecker et al., 2005). Without regular removal of phosphorus-laden particles, a system may be vulnerable to a phosphorus speciation shift, and release of DP downstream.

EVALUATING DISSOLVED PHOSPHORUS REMOVAL PERFORMANCE

In order to address impaired water bodies, higher levels of phosphorus removal are necessary to begin to make a positive impact. Establishing effluent load reduction targets are more appropriate for achieving the objective, however many State requirements dilute the impact of such targets by simply requiring a higher % TP removal, while neglecting to address removal of the bio-available DP fraction.

A method that has been considered for increasing TP removal is increasing the required treated annual WQ_v , with the assumption that treatment practices are appropriately sized to manage the runoff peaks and total volume. This action will incrementally treat additional volume and incrementally increase particulate-bound phosphorus removal. In many cases, this action may not be viable and may be a costly solution due to land availability, capital costs and maintenance feasibility. Increasing the annual treated WQ_v does not change the removal mechanism, and does not impart a mechanism to directly address DP removal. Additionally, there is risk with the increased volume, if detention and storage is part of the practice, that these systems will undergo natural water chemistry changes which can transform captured particulate-bound phosphorus to the dissolved phase, which will then be carried downstream, worsening the situation.

The earlier referenced studies by Madge, 2004 and Vaze et al., 2004 suggest that in order to consistently achieve higher levels of TP removal (> 65%), treatment practices need to not only remove particles as small as 11 μm , but must also capture and retain a significant fraction of the DP. In order to address the dissolved phase of phosphorus, advanced mechanisms must be implemented as part of, or in addition to, conventional stormwater treatment practices.

One advanced mechanism for treating DP is sorption, which is beginning to be incorporated into some proprietary and non-proprietary stormwater treatment practices.

Sorption is a combination of physio-chemical interactions including; adsorption, absorption and surface complexation, often referred to as adsorption. The sorption mechanism has been utilized for decades in industrial air and water treatments. Materials, or media, utilizing sorption have pollutant removal capacities that are specific to a given pollutant under defined conditions, and such capacity must be thoroughly understood in order to predict media performance and service life. A rigorous media performance analysis is required and should be based on in-depth testing of adsorption isotherm, reaction kinetics, breakthrough, and desorption (Wu et.al., 2008).

Media characteristics such as specific surface area, porosity, organic content and gradation are also important, but do not indicate a media's ability to capture and retain dissolved pollutants. To properly and successfully implement the use of sorption-based materials all four descriptive performance parameters (adsorption isotherm, reaction kinetics, breakthrough, and desorption) must be understood, as each are interlinked.

Adsorption isotherm quantifies the available sorption capacity of media for a given pollutant for a known quantity of media and volume of solute over a fixed period of time. Testing is performed under controlled conditions over a wide variety of pollutant concentrations, allowing for an isotherm model to be generated. Often for water treatment media, the Freundlich isotherm is utilized to model media performance due to the heterogeneous nature of the material. This performance indicator assessed alone will be misleading as contact time for this test parameter is fixed and maximized, which is certainly not the case in stormwater treatment.

Reaction kinetics illustrates performance over a variety of contact times. This evaluates how fast pollutant sorption takes place with a given media mass, known volume of solute and pollutant concentration. Without sufficiently fast kinetics, a material may have high available sorption capacity but still requires a very large volume of media to achieve its removal due to poor kinetics. This may not be a practical or cost effective solution as larger volumes of media will consume significant land space to treat swiftly flowing runoff.

Breakthrough indicates the volume of polluted water that can be treated by a quantity of media while still providing the target degree of pollutant removal. In more practical terms, breakthrough illustrates long-term performance and determines the service life of the media. Water containing a known pollutant concentration is passed through a known

mass of media at a given surface loading rate. Samples are analyzed for pollutant removal efficiency as the total treated water volume increases. Breakthrough is best quantified by the volume of pollutant laden solute which has passed through a given volume of a media bed, known as Bed Volumes (BV). One liquid BV equals an equivalent volume of media. Performance can then be quantified by the number of BVs, or total volume passed through the media before pollutant removal efficiency drops below a pre-specified level. For example, 50% breakthrough would indicate the number of BVs of solute treated before a single BV of media no longer achieved 50% pollutant removal. The breakthrough evaluation should be taken to exhaustion (0% removal), as this indicates how long the media can last and the rate of performance decline.

Desorption demonstrates the tendency for a given media to desorb, or release, a given pollutant that is naturally occurring in the media, or to desorb the pollutant of interest (e.g. phosphorus) after the media reached its full capacity. This test can be conducted by extending the breakthrough evaluation beyond exhaustion and determining if the effluent concentration of the pollutant increases above the influent.

Without this full array of performance metrics clearly defined, claiming the ability to remove a given dissolved pollutant such as phosphorus may lead to false expectations of performance. Often filtration media are marketed by highlighting a media's capacity value (mg/g) to retain a dissolved pollutant. A capacity value (mg/g) is meaningless if the testing conditions are not stated, and if breakthrough (longevity) and kinetics are not evaluated and clearly understood. Additionally, relying only on surface area or porosity data is misleading as well.

For example, many stormwater practices have incorporated granulated filtration media such as perlite, blends of perlite/zeolite/carbon, organic-based media, expanded aggregates, slag-based materials or other by-products such as recycled tires, and even bioretention soil mixes to filter out sediment and sediment-associated pollutants, while claiming the ability to also capture phosphorus. However, these materials have been found to have very limited phosphorus treatment performance as they lack either sufficient DP sorptive capacity, kinetics, or phosphorus capture longevity, BVs (Wu et.al., 2008). It is possible for a media to have sufficiently high sorption capacity as indicated by an isotherm and sufficiently fast kinetics, but poor breakthrough (e.g. expanded shale, bioretention soil media), which renders the media unacceptable from a longevity standpoint. It is also possible to have a high specific surface area but virtually no capacity at all for dissolved phosphorus (e.g. granulated carbon, zeolite, or perlite).

Some filtration materials have demonstrated desorption of phosphorus from the fresh filtration media (e.g. some composts, organics and expanded aggregates). Other media such as slag-based materials and granulated tires are known to have a tendency to leach other pollutants of concern (e.g. metals, pH). Recycled media, which are often waste by-products and sometimes marketed as "green technology", may contain debris or potentially leach toxic pollutants that become apparent when tested in stormwater of typically low background pollutant concentration (Minton, 2005). One study documented activated aluminum and expanded shale leaching heavy metals or changing

the pH (Patel, 2004) of the effluent. These materials have been found not to be effective in addressing the higher phosphorus removal standards (> 65% TP), nor a phosphorus TMDL.

Current and newer stormwater practices are generally designed to maximize the hydraulic surface loading rates of BMPs to effectively manage and treat the prescribed WQ_v . To achieve this while still physically filtering or straining sediment from runoff, high flows are often hydraulically loaded through filtration media (1 mm to 10mm) such as perlite, blends of perlite/zeolite/carbon, ASTM C-33 sand (0.1 mm to 10mm) or through practices that use sandy soils. Soils and agricultural research have identified that sandy soils have low adsorptive capacity for phosphorus, and have greater tendency to desorb phosphorus that is adsorbed below the root zone into surface water through subsurface flow when saturated (Havline, J. . 2004). Similar findings have been found for some clay soils through transport in macropores (Djodjic et al., 1999; Laubel et al., 1999).

Low capacity, desorption and leaching of phosphorus from these filtration media types are a significant limitation on current practices. An alternate mechanism to capture phosphorus has been biological uptake used for design of wetlands, and recently for bioretention cells. Limitations exist with biological uptake, such as dissolved phosphorus migrating past the limited root zone, or from lack of vegetative maintenance. As vegetation grows, pollinates, and dies, this cycle takes nutrient rich vegetation and re-emits these nutrients back into the growth media. These practices commonly use a sand-soil with limited to no dissolved phosphorus sorption capacity, hence there is a limited net impact if the vegetation is not continually harvested and managed. A combination of a wide variety of bioretention mixes, soil types and chemistry, and this vegetative cycle begins to explain the large variance in phosphorus removal performance, and at times phosphorus export from bioretention cells (Dietz et al., 2005, Hunt et al., 2006, Davis et al., 2006).

AMENDING STORMWATER PRACTICES

Faced with an escalating number of eutrophied water bodies, and knowing that common stormwater treatment practices and system designs continue to provide insufficient phosphorus removal, it is sensible that proven high-performing sorption-based amendments should be applied to both new and existing BMPs to capture and retain dissolved phosphorus. Employing such amendments will drive elevated phosphorus removal performance, design requirements and improve water quality.

For many media, well-described behavior exists for phosphorus removal. Media that can cost effectively capture dissolved phosphorus commonly contain oxides of iron and aluminum, with aluminum oxides typically outperforming all other materials for dissolved phosphorus capture and retention (Wu et al., 2008). Amending treatment practices by incorporating proven sorption-based media into conventional stormwater treatment practices and LID applications will enhance phosphorus removal and elevate overall performance. As long as the performance description is well understood based on in-depth analyses of adsorption isotherms, reaction kinetics, breakthrough and desorption

tendency, a system can be easily and properly designed to incorporate these advanced media types, with the ability to predict performance and maintenance frequency. Without a full performance description, stakeholders are “flying blind” when trying to use a filter media or material to capture dissolved phosphorus.

For example, sand has limited to virtually no sorption capacity for dissolved phosphorus. Amending a sand filter by displacing a sand layer (6-inches to 18-inches in depth) with a sorptive media of the same ASTM C-33 gradation would significantly compliment this treatment practice. Amendment by incorporating an advanced removal mechanism provides a tool to achieve significant enhancement of TP and DP removal, while maintaining hydraulic conductivity of the filtration bed. This eliminates the need to treat additional runoff volume with costly enlarged systems that take up more land area. Amending a conventional stormwater treatment practice provides elevated phosphorus removal performance while also fitting within the concept of LID, better site design (BSD), and environmental site design principles (ESD).

Another example would be to use a multi-inch layer of sorptive media as part of the bioretention cell or similar filtration cell to address the known DP capacity limitations of sandy-soils. Commonly these systems employ an under drain and do not capture DP. Sorption-based media can also be employed downstream of the under drain system to allow DP treatment of the bioretention cell’s effluent after it has filtered alternate pollutants. This treatment train approach cost effectively takes advantage of the conventional treatment practice, but provides a tool for dissolved phosphorus removal. This treatment amendment may be necessary if trying to achieve a phosphorus TMDL of less than 0.1 mg/L.

This same amendment concept can be employed as part of a pervious pavement system, utilizing the sorptive media as part of the sub-base, or with permeable interlocking concrete pavers, utilizing this media as the joint fill and bedding layer. Alternatively, lightweight sorption-based media can be considered for green roof media, or incorporated into other landscaping features used to treat runoff.

These advanced sorption-based medias can be used in radial cartridge systems to capture TP, as well as DP. One study using aluminum oxide based sorption filtration media inside multiple radial cartridges demonstrated over 85% sediment capture, 70% TP removal and greater than 40% DP removal over a series of storm events, while being able to consistently achieve a TMDL of less than 0.1 mg/L TP (Liu et al, 2007). Additionally, retrofitting pre-existing stormwater infrastructure, including replacement of low-performance media in underground filtration cartridges and other filter systems is a viable option to address bio-available dissolved phosphorus.

CONCLUSION

Phosphorus induced eutrophication continues to degrade freshwater resources globally, as evidenced by increasing incidents of toxic algae blooms, hypoxic conditions, and aquatic

ecosystem stress. Phosphorus loading in runoff has not been adequately addressed by conventional treatment approaches. Common stormwater treatment practices, designs and regulations are deficient in regards to capturing bio-available dissolved phosphorus.

To make the necessary progress in protecting our recreational and drinking water resources, and to have the ability to achieve a phosphorus TMDL of 0.1 mg/L or lower, the use of high-performance sorption-based media should be considered for incorporation into conventional and proprietary stormwater treatment practices, further driving the concepts of LID, BSD, ESD. Aluminum oxide-containing media, supported by well-defined performance testing, shows particular promise for cost-effective total and dissolved phosphorus removal. Without addressing bio-available dissolved phosphorus through practice, amended design and regulatory requirements, our water resources will continue to degrade.

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