A review of the application of StormFilter® in Australia

Date: August 2021

Document Control Sheet

Report title	A review of the application of StormFilter® in Australia
Suggested report reference	Dalrymple B, Wicks M. (2021). *A review of the application of StormFilter® in Australia*. Prepared on behalf of Ocean Protect.
Authors	Brad Dalrymple, Michael Wicks.
Date	August 2021
Synopsis	This report provides an analysis of the application of StormFilter® technology as a stormwater treatment asset within Australia.

Executive Summary

Over recent decades, the implementation of stormwater control measures (SCMs) to achieve a more 'water sensitive' urban environment and reduce the hydrologic and water quality impacts of urban development has increased across Australia (and overseas). The StormFilter® is a proprietary SCM comprised of one or more structures that house rechargeable, media-filled cartridges that trap particulates and adsorb pollutants from stormwater runoff such as total suspended solids, hydrocarbons, nutrients, metals, and other common pollutants.

This report provides a review of the performance of StormFilter®, and its suitability for application within Australia. This review has shown that StormFilter® is an appropriate stormwater treatment asset type for application in Australian urban environments. This finding considers a range of factors, including the following:

- **Government approvals:** StormFilter® has been accepted by many of the most stringent stormwater quality regulators within Australia and overseas.
- **Case studies and performance monitoring:** Over 27,000 StormFilter® systems have been installed within Australia – and approximately 220,000 globally. Stormwater treatment performance monitoring has been undertaken for four (4) of these systems (including one in Australia) operating in 'real world' conditions, all showing significant reductions in pollutant concentrations.
- **Peer reviews:** Two (2) separate peer reviews have been undertaken on StormFilter®. These peer reviews were undertaken by Professor Ataur Rahman from the University of Western Sydney and Damian McCann from AWC. Professor Ataur Rahman from the University of Western Sydney has undertaken a peer review in relation to the applicability of StormFilter®, and (as outlined in his peer review report,) "*it has been found that StormFilter® is likely to achieve pollution (Suspended Solids, Total Phosphorus and Total Nitrogen) removal targets (currently required by various Australian authorities) from typical urban runoff under Australian conditions including Sydney and Melbourne.*" The focus of Mr McCann's review was assessing whether performance monitoring undertaken at one of the StormFilter® performance monitoring sites (at Zigzag, Oregon, USA) compiles with the *Stormwater Quality Improvement Device Evaluation Protocol* (Stormwater Australia, 2018 Version 1.3) and Mr McCann's peer review report has confirmed that this monitoring complies with the aforementioned protocol.
- **Longevity analyses:** Flow testing of 'real world' StormFilter® applications in Gold Coast City by Renew Solutions demonstrated that "if flow rate is used as the indicator of when to replace the StormFilter® cartridges (as recommended by Blacktown City Council (2020), it is anticipated that StormFilters® would not typically require replacement before 3 years of operation (depending on the catchment characteristics)". This supports the guidance given by Ocean Protect (2019) that the expected StormFilter® media life is 1 to 3 years, noting that Ocean Protect (2019) also recommend inspections every 6 months and minor service every 12 months. Furthermore, the StormFilter® performance monitoring studies undertaken to date included studies of up to 27 months (with no replacement of filter media or other components) with no significant deterioration in stormwater treatment performance over time.
- **Applicability to local conditions:** Although climatic conditions are variable across Australia, the StormFilter® is expected to achieve similar pollutant load removal rates than observed at the aforementioned monitoring sites. This is for a combination of reasons, including:

- StormFilter® uses physical (e.g. sedimentation, filtration) and chemical (e.g. adsorption) treatment processes – and these are highly unlikely to be significantly impacted by differences in climate conditions (e.g. temperatures, rainfall frequencies/ amounts) between specific locations and the monitoring sites.
- StormFilter® operates with minimum contact time across a fixed bed depth (radial design, no short circuiting). Thus, variations in performance will predominantly be subject to sediment particle size, influent concentrations and speciation (nutrient solubility) rather than locality. For example, as described by Neumann et al (CSIRO 2010), it is easier to achieve higher pollutant load removal rates when runoff has higher pollutant concentrations – and, as noted by Professor Rahman (see Appendix A) "*concentrations of pollutants in the influent of (the* Moorseville *monitoring site were) found to be much smaller than Australian observed data reported in the literature. Hence, the efficiency ratio for StormFilter® system could be higher for typical Australian conditions*".

it is recommended that the treatment performance of PSorb StormFilter® be modelled using a detention basin node and generic treatment node, with stormwater treatment performance consistent with the values outlined in Table 3-1.

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1 Introduction

1.1 Background

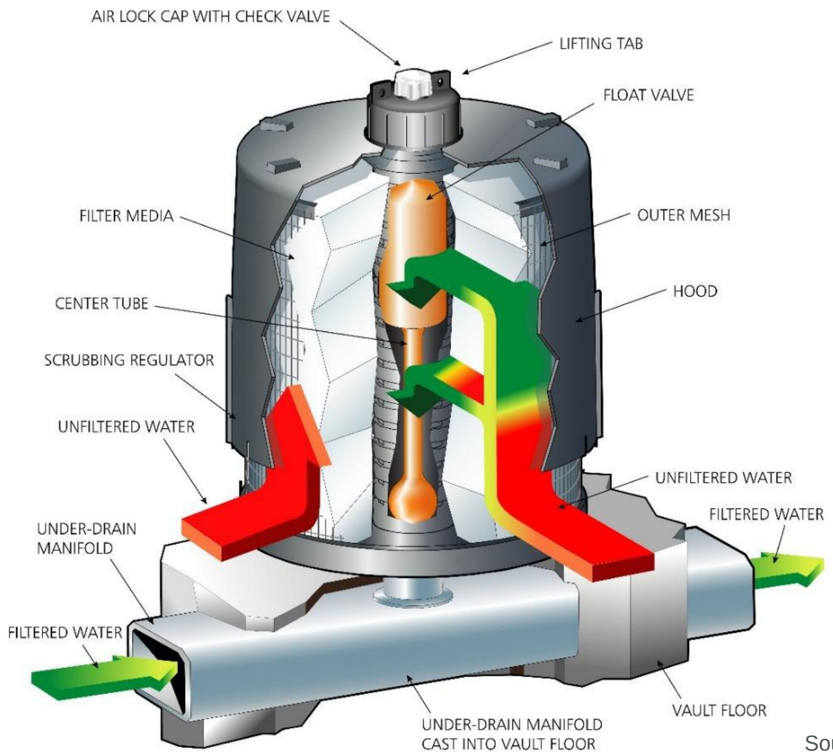
It is commonly understood that unmitigated urban stormwater is a key contributor to reduced water quality and waterway health in Australia and internationally. Traditional urban development and associated stormwater drainage practices of conveying stormwater runoff to waterways as efficiently as possible (providing minimal opportunities for treatment and reuse) have been recognised as being unsustainable and inappropriate due to changed catchment hydrology (e.g. increased frequency and volume of stormwater flows) and increased stormwater pollutant loads to waterways and associated ecological impacts.

Water Sensitive Urban Design (WSUD) is an internationally recognised concept that offers an alternative to traditional development practices, providing a holistic approach to the design of urban development that aims to minimise the negative impacts on the natural water cycle and protect the health of waterways (South East Queensland Healthy Waterways Partnership 2006). Over recent decades, the implementation of stormwater control measures (SCMs) to achieve a more 'water sensitive' urban environment and reduce the hydrologic and water quality impacts of urban development has increased across Australia (and overseas).

1.2 StormFilter® Overview

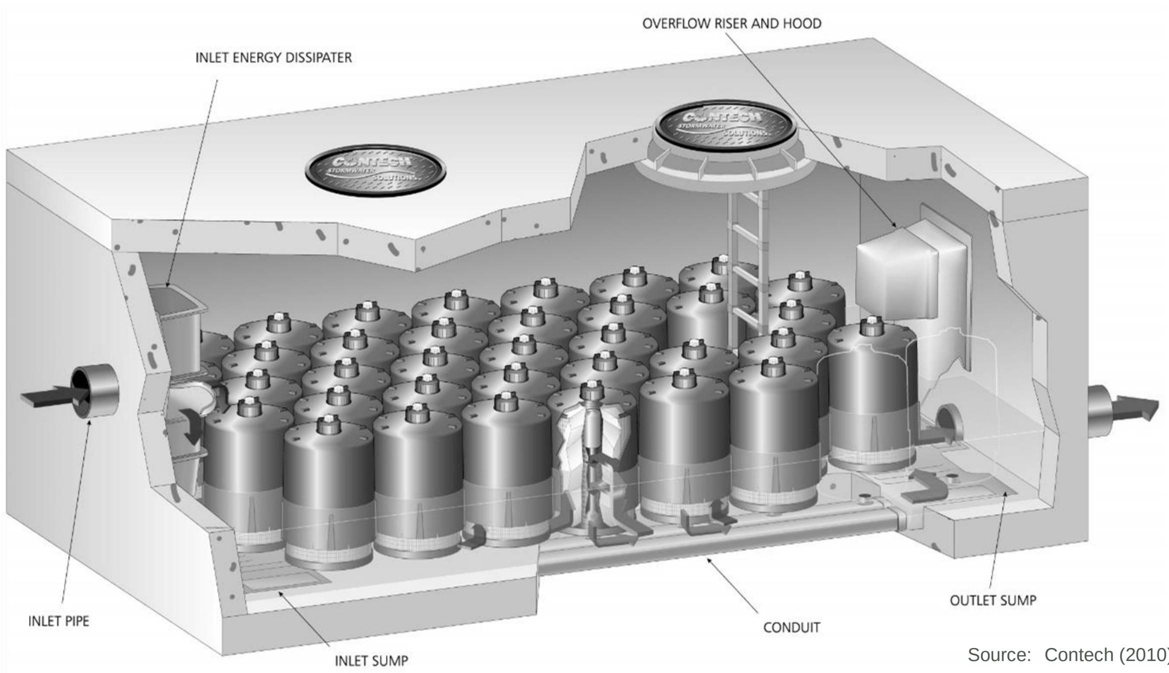
The StormFilter® is a proprietary SCM comprised of one or more structures that house rechargeable, media-filled cartridges that trap particulates and adsorb pollutants from stormwater runoff such as total suspended solids, hydrocarbons, nutrients, metals, and other common pollutants.

Figure 1-1 illustrates the components of a StormFilter®, and Figure 1-2 provides an example section drawing of a StormFilter® installation. Further information in relation to the operation, and media and configuration options is provided in Appendix A.



Source: Ocean Protect (2020)

Figure 1-1 StormFilter® components



Source: Contech (2010)

Figure 1-2 Example conceptual diagram of a StormFilter® system

The key function of StormFilter® is to remove pollutants from stormwater. During a storm, runoff percolates through the filtration media and starts filling the cartridge central tube. The air inside the hood is purged through a one-way check valve as the water rises. When water reaches the top of the float, buoyant forces pull the float free and allow filtered water to exit the cartridge.

A siphon is established within each cartridge that draws water uniformly across the full height of the media profile ensuring even distribution of pollutants and prolonged media longevity.

As the storm subsides and the water level in the structure starts falling, a hanging water column remains under the cartridge hood until the water level reaches the scrubbing regulators at the bottom of the hood. Air then rushes through the regulators breaking the siphon and creating air bubbles that agitate the surface of the filter media causing accumulated sediment to settle on the treatment bay floor. This unique surface-cleaning mechanism helps prevent surface blinding and further extends cartridge life.

Key processes involved in the removal or transformation of stormwater pollutants are summarised in Table 1-1.

Table 1-1 Key processes involved in the removal or transformation of stormwater pollutants within a StormFilter® system

Stormwater pollutant	Key treatment processes
Sediment	• Settlement during ponding within detention chamber • Physical filtration by media
Nitrogen	• Physical filtration of sediment-bound fraction • Adsorption/Absorption
Phosphorus	• Physical filtration of sediment-bound fraction • Adsorption/Absorption
Heavy metals	• Physical filtration of sediment-bound fraction • Oxidation/reduction reactions • Cation Exchange
Pathogens	• Adsorption-desorption • Physical filtration by media
Organic micropollutants*	• Adsorption/Absorption

*: Hydrocarbons, pesticides/herbicides, polycyclic aromatic hydrocarbons (PAHs), phenols, phthalates
Source: Payne et al (2015)

1.3 Report objectives

The objectives of this report are to provide the following:

- A review of the application of StormFilter® technologies within Australia
- A review of the methods for modelling the treatment performance of StormFilter® technologies (and, if appropriate, identify a recommended method).

2 Review of Suitability of StormFilter® in Australia

2.1 Preamble

This section provides a review of the suitability of StormFilter® for Australian conditions, based on the following aspects:

- Research and development
- Government approvals
- Case studies
- Treatment performance monitoring
- Life cycle analyses
- Peer reviews
- Applicability to local conditions.

2.2 Research and development

The design and implementation of StormFilter® technology has been developed by Contech and Ocean Protect based on over twenty years of research and development, testing and field monitoring.

2.3 Case studies

Since 2001, StormFilter® has been installed in a variety of applications to meet regulatory requirements set by authorities throughout Australia. Over 27,000 StormFilter® cartridges have been installed within Australia. Globally, there are over 220,000 StormFilter® cartridges installed.

2.4 Government approvals

StormFilter® has been accepted by many of the most stringent stormwater quality regulators within Australia and overseas, including:

- Brisbane City Council
- City of Gold Coast
- Blacktown City Council
- Washington State Department of Ecology (TAPE) GULD – Basic, Phosphorus
- New Jersey Department of Environmental Protection (NJ DEP)
- North Carolina Department of Environmental Quality (NC DEQ)

2.5 Treatment performance monitoring

Table 2-1 provides a summary of three four (4) examples of StormFilter® operating in 'real world' conditions where treatment performance monitoring has been undertaken.

Table 2-1 Summary of recent treatment performance monitoring case studies of StormFilter®

Location	Site details	Methodology summary	Performance summary	Further information
Kuranda, Queensland	• 220m² road catchment • Gully pit insert and ZPG StormFilter® system • Mean rainfall 2188mm per year	• Monitored by James Cook University • 20-month monitoring period (2008-09) • Influent & effluent analysed for solids, nutrients and metals • 4 sampling events • Flow-rates and volumes measured	• 99%, 47%, and 47% TSS, TP and TN load removal respectively	• Wicks et al (2011) • Appendix F
Zigzag, Oregon, USA	• 260m² road catchment • PSorb StormFilter® system • Mean rainfall 1919mm per year	• Monitored by Contech • 27-month monitoring period (2012-14) • Influent & effluent analysed for solids, nutrients and metals • 23 qualifying sampling events • Flow-rates and volumes measured	• 89%, 82%, and 50% TSS, TP and TN load removal respectively • 89%, 77% and 61% TSS, TP and TN concentration reduction respectively	• Contech (2015) • Appendix F
The International Corporate Center, Portland, USA	• 1130m² pumped to system • PSorb StormFilter® • Mean rainfall 1092mm per year	• Monitored by Contech • 10-month monitoring period • 19 sampling events • Influent & effluent analysed for solids, nutrients and metals • Flow-rates and volumes measured	• 85%, 36% and 43% TSS, TP and TN concentration reduction respectively	• Contech (2010)
Mitchell Community College, Mooresville, North Carolina, USA	• 4370m² catchment (car parking, 68% impervious) • PSorb StormFilter® system • Mean rainfall 1219mm per year	• Monitored by Contech • 20-month monitoring period (2010-12) • Influent & effluent analysed for solid and, nutrients • 13 qualifying sampling events • Flow-rates and volumes measured	• 91%, 87% and 50% TSS, TP and TN load reduction respectively • 90%, 86% and 56% TSS, TP and TN concentration reduction respectively	• Wicks et al (2014) • Contech (2012) • Appendix F

2.6 Longevity analyses

Ocean Protect commissioned Renew Solutions to undertake flow testing of ‘real world’ StormFilter® installations to determine if pollutant accumulation in these devices had caused any significant reduction in flows, and subsequently inform recommended maintenance actions – specifically, how often the StormFilter® media may need replacement due to reduced flow conveyance through the media (due to pollution accumulation).

A key finding of this study (report given in Appendix C) was:

> “if flow rate is used as the indicator of when to replace the StormFilter® cartridges (as recommended by Blacktown City Council (2020), it is anticipated that StormFilters® would not typically require replacement before 3 years of operation (depending on the catchment characteristics)”.

This supports the guidance given by Ocean Protect (2019) that the expected StormFilter® media life is 1 to 3 years, noting that Ocean Protect (2019) also recommend inspections every 6 months and minor service every 12 months. Furthermore, the performance monitoring (summarised in Table 2-1) included studies of up to 27 months (with no replacement of filter media or other components) with no significant deterioration in stormwater treatment performance over time (despite increasing pollution accumulation). As an example, Figure 2-1 provides a graph of recorded concentration reduction efficiency over time at the StormFilter® performance monitoring site at Zigzag, Oregon, USA.

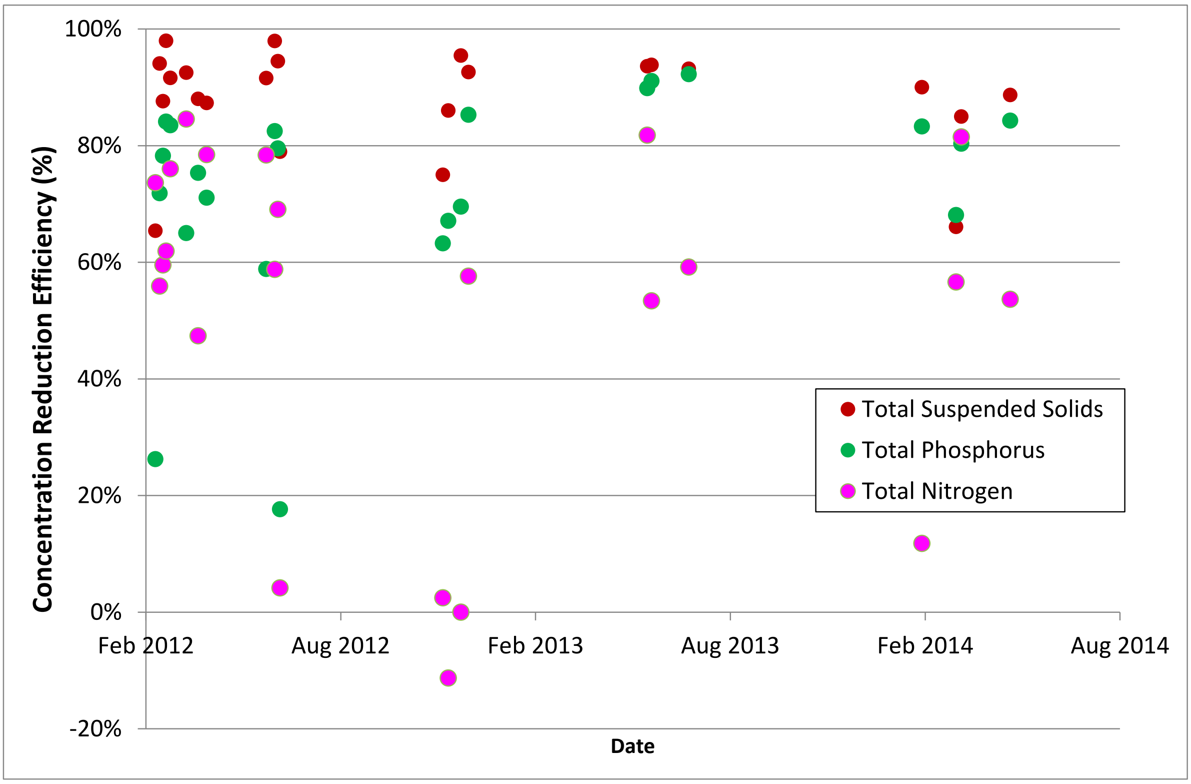


Figure 2-1 Graph of recorded concentration reduction efficiency at StormFilter® performance monitoring site at Zigzag, Oregon, USA

2.7 Peer reviews

Two (2) separate peer reviews have been undertaken in relation to the applicability of StormFilter® as a stormwater improvement device under typical Australian urban runoff conditions. These peer reviews were undertaken by the following personnel:

- Professor Ataur Rahman from the University of Western Sydney
- Damian McCann from AWC

These peer reviews are provided in Appendices A and B respectively, and summarised in the following sub-sections.

2.7.1 Peer review by Professor Ataur Rahman

Professor Ataur Rahman from the University of Western Sydney was commissioned by Ocean Protect to undertake a peer review in relation to the applicability of StormFilter® as a stormwater improvement device under typical Australian urban runoff conditions.

This peer review report is provided in Appendix A, and states that "*It has been found that StormFilter® is likely to achieve pollution (Suspended Solids, Total Phosphorus and Total Nitrogen) removal targets (currently required by various Australian authorities) from typical urban runoff under Australian conditions including Sydney and Melbourne*". Professor Rahman's review is largely based on the treatment performance monitoring from the site at Moorseville described by Wicks et al (2014) and Contech (2012) (given in Appendix F), summarised in Table 2-1.

2.7.2 Peer review by Damian McCann

Damian McCann of AWC undertook a review of StormFilter®, with a particular focus on assessing whether performance monitoring undertaken at the site at Zigzag, Oregon, USA (see Table 2-1) compiles with "*Stormwater Quality Improvement Device Evaluation Protocol*" (Stormwater Australia, 2018 Version 1.3).

Mr McCann's peer review report is provided in Appendix B and confirms that this performance monitoring complies with the aforementioned protocol with pollution concentration reductions as summarised in Table 2-1 (and Table 2 of Appendix B) for this site.

2.8 Applicability to local conditions

Climatic conditions are obviously variable across Australia. However, as described in the peer review by Professor Rahman "*It has been found that StormFilter® is likely to achieve pollution (Suspended Solids, Total Phosphorus and Total Nitrogen) removal targets (currently required by various Australian authorities) from typical urban runoff under Australian conditions including Sydney and Melbourne*".

As described in Table 1-1, StormFilter® uses physical (e.g. sedimentation, filtration) and chemical (e.g. adsorption) treatment processes – and these are highly unlikely to be significantly impacted by differences in climate conditions (e.g. temperatures, rainfall frequencies/ amounts) between the specific project site and the monitoring sites described in Section 2.5.

Regardless of rainfall intensity and duration, the StormFilter® operates with minimum contact time across a fixed bed depth (radial design, no short circuiting). Thus, variations in performance will predominantly be subject to sediment particle size, influent concentrations and speciation (nutrient solubility) rather than locality. For example, as described by Neumann et al (CSIRO 2010). it is easier to achieve higher pollutant load removal rates when runoff has higher pollutant concentrations. However, as noted by Professor Rahman (see Appendix A) "*concentrations of pollutants in the influent of (the Moorseville monitoring site were) found to be much smaller than Australian observed data reported in the literature. Hence, the efficiency ratio for StormFilter® system could be higher for typical Australian conditions*".

Solubility of nutrients is also critically important to the total nutrient pollutant removal performance. The removal of soluble pollutants such as ammonium or ortho-phosphate tend to be more difficult to remove than solids as the removal pathways/mechanisms are not only dictated by media contact time, sediment particle size, sediment density and concentration, but also competing pollutants ie, selective removal of soluble pollutants such as ammonium vs metals (Pb, Cu & Zn etc) typically found in urban runoff. Sites with low Dissolved Inorganic Nitrogen (DIN, sum of Ammonium, Nitrite and Nitrate) tend yield lower Nitrogen removals than sites with higher proportions of Total Kjeldahl Nitrogen (TKN) which is predominantly solid.

2.9 Conclusion

Based on the information presented in the above sections, StormFilter® is considered to be an appropriate stormwater treatment asset type for application in urban environments within Australia. Given stormwater pollution targets for new development in Australia should be achieved by StormFilter® (particularly when used in combination with other asset types in a 'treatment train') when these assets are appropriately designed, installed and managed in accordance with StormFilter® guides and manuals (provided in Appendices B and C).

3 Modelling StormFilter® treatment performance

3.1 Preamble

This section describes and assesses potential methods for modelling the treatment performance of StormFilter®, and identifies the most appropriate method.

3.2 Modelling software

The Model for Urban Stormwater Improvement Conceptualisation (MUSIC) is a software tool that simulates the behaviour of stormwater in urban catchments. MUSIC is the preferred tool for demonstrating the performance of stormwater quality treatment systems (Water By Design 2010, BMT WBM 2015).

Within MUSIC, the user is required to specify source nodes, which represent the stormwater flow and pollutant generating areas of the site being modelled. Treatment nodes can also be included to simulate (and assess) the operation of any stormwater treatment devices (e.g. biofiltration) within the site being modelled.

3.3 Treatment node options

As outlined in the previous section, MUSIC models the performance of stormwater treatment devices using 'treatment nodes'. A range of treatment nodes are available within MUSIC. It is recommended that the StormFilter® technology be modelled using the following treatment nodes within MUSIC:

- Detention basin
- Generic treatment.

The following sections describe the applicability of these node types for modelling StormFilter®.

3.3.1 Detention basin

The detention basin node is used to hydraulically represent the detention tank (or 'vault'/ storage) 'housing' the StormFilter® cartridge systems. However, the 'k' values associated with this system should have no additional treatment (i.e. k value set to 1 or zero). Selection of parameter values (default or otherwise) should not be used to claim additional stormwater treatment when none materially exists. This is consistent with the recommendations of Stormwater Queensland (2019), Brisbane City Council (2017) and the majority of regulatory authorities and local Government (that specify requirements on MUSIC modelling).

The storage assumed in the MUSIC modelling should be consistent with the dimensions (depth, volume, area) of the detention tank, with the design outlet (to the downstream Generic node) sized in accordance with the design flow rate of the StormFilter® systems.

3.3.2 Generic treatment

The pollutant removal provided by the StormFilter® is modelled within MUSIC by adjusting the pollutant removal 'transfer functions' within the generic treatment node for gross pollutants (GPs), total suspended solids (TSS), total phosphorus (TP), and total nitrogen (TN). The high flow bypass rate should equal the maximum treatment flow capacity of the given StormFilter® technologies.

The pollutant removal transfer function values vary across jurisdictions within Australia. Table 3-1 summarises the applied stormwater treatment performance for PSorb StormFilter® in Queensland and NSW (as applied to the MUSIC generic treatment node transfer function values).

Table 3-1 Applied stormwater treatment performances for PSorb StormFilter® in Queensland and NSW

Parameter	% Reduction				Comments
	GPs	TSS	TP	TN	
Queensland					
City of Gold Coast	100%	93.4	86.1	46.3	
Moreton Bay Regional Council	100%	86.8	77.6	51.2	Moreton Bay Regional Council require that StormFilter® apply a Generic Treatment node alone (i.e. no detention basin node)
Logan City Council	100%	88.3	78	53	
All other Councils in Queensland (including Brisbane City, Ipswich City and Sunshine Coast Regional Councils)	100%	90.4	86.1	55.9	
NSW					
Local governments in NSW*	100%	93.4	86.1	55.9	

*: Blacktown City Council approve ZPG StormFilter®, with GP, TSS, TP and TN reductions of 95%, 85%, 59%, and 33% respectively.

As described in Section 2.7.2, Mr McCann's peer review report for the performance monitoring site at Zigzag, Oregon, USA has confirmed that this performance monitoring complies with "*Stormwater Quality Improvement Device Evaluation Protocol*" (Stormwater Australia, 2018 Version 1.3) aforementioned protocol with pollution concentration reductions as summarised in Table 2-1 (and Table 2 of Appendix B) for this site. These concentration reductions may be more appropriate (relative to the values given in Table 3-1) where SQIDEP is applied and endorsed by the given local government.

3.4 Recommendation

It is recommended that the treatment performance of PSorb StormFilter® be modelled using a detention basin node and generic treatment node (as described above), with stormwater treatment performance consistent with the values outlined in Table 3-1.

4 Conclusion

This report has provided a review of the performance of StormFilter, and of their suitability for application within Australia. This review has included the following:

- Overview of case studies of StormFilter® and associated Government approvals
- Review of treatment performance monitoring for StormFilter® operating in 'real world' conditions

This review has shown that StormFilter® is an appropriate stormwater treatment asset type for application in Australian urban environments.

It is recommended that a combination of the detention basin and generic treatment node (in eWater's MUSIC software) be applied in modelling the performance of PSorb StormFilter®, with stormwater treatment performance consistent with that given in Table 3-1.

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Appendix A Peer Review of StormFilter® by Professor Ataur Rahman

This appendix provides the peer review of StormFilter® as a stormwater treatment device in Australia, undertaken by Professor Ataur Rahman from Western Sydney University for Ocean Protect.

School of Engineering
Western Sydney University, Sydney, Australia
Locked Bag 1797, Penrith, NSW 2751, Australia

Date 2 March 2020

Mr Michael Wicks
Technical Director
Stormwater 360, Australia

Dear Sir,

Please find attached a peer review report in relation to the applicability of StormFilter® as a stormwater improvement device under typical Australian conditions.

It has been found that StormFilter® is likely to achieve pollution (Suspended Solids, Total Phosphorus and Total Nitrogen) removal targets (currently required by various Australian authorities) from typical urban runoff under Australian conditions including Sydney and Melbourne. This conclusion is mainly based on the test results carried out by Contech Engineered Solutions (Contech, 2012), which demonstrated the effectiveness of the StormFilter® in treating stormwater runoff with respect to the removal of solid and nutrient pollutants. This twenty month long field study (during 2011-12) was conducted at the Mitchell Community College testing site located in the Town of Mooresville, NC, USA. Furthermore, limited test data from Australian studies reported in scientific literature have been used to arrive at this conclusion.

Yours sincerely,

Professor Ataur Rahman, PhD, FIE Aust.
Water and Environmental Engineering
Civil and Environmental Engineering Discipline
School of Engineering
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Peer Review: StormFilter® as a stormwater improvement device under typical Australian conditions

1. Background

Urban stormwater runoff is a major source of pollutant which can undermine waterway health. A study by Cordery (1976) demonstrated that urban runoff from three urban catchments in Sydney resulted in the wash-off of greater pollutant mass into the waterways than typical sewage effluents subject to secondary treatment. Sartor and Boyd (1972) found that sediments present in urban runoff carried a large quantity of pollutants with them. The loadings and concentrations of suspended solids and nutrients in urban runoff were reported to be much higher than runoff from typical rural areas (Chew et al., 1997). The concentrations of sediment-bound contaminants generally vary with particle size, and generally finer particles carry a larger quantity of contaminants than larger ones (Sartor and Gaboury, 1984). Shartor et al. (1974) found that in urban runoff although less than 10% of particulates are in the silt and clay soil size they contain over 50% of the Phosphorus and 25% of other pollutants. Chew et al. (2004) showed that higher concentrations of heavy metals are also associated with smaller size particles. Results show that almost 50% of the heavy metals found on street sediments are associated with particles of 60–200 µm in size, and 75% are associated with particles finer than 500 µm in size.

Vaze and Chiew (2004) found that about 50% of heavy metals were associated with particles smaller than 200 µm, and 75% with particles smaller than 500 µm. Hence, controlling of finer particles has emerged as a priority in urban stormwater management in Australia similar to other developed countries. In this regard, the particle size distributions (PSD) of urban runoff sediments have been the basis of many urban stormwater management guidelines both in Australia and other countries. New research conducted in Australia and other countries have revealed that the PSD of urban runoff in Australia are not significantly different from international results (e.g. USA) when considering similar collection methods and similar analytical techniques (Drapper, 2014).

This review focuses on StormFilter®, which is a radial cartridge media filter in relation to its pollutant removal efficiency from typical urban runoff under Australian conditions.

2. Review of StormFilter®

StormFilter® is a radial cartridge filtration system (RCFS) that uses an activated alumina media to treat stormwater runoff, particularly to remove solids and nutrients from urban runoff. Activated alumina is made of aluminium oxide (Al_2O_3) and has a very high surface-area-to-weight ratio, due to the many tunnel-like pores within it, which is ideal to remove pollutants from water. The adsorptive capacity of activated alumina is quite high, and hence it is widely used in water treatment process as an adsorptive filter media to enhance the removal of the phosphorus from water (Wang et al., 2015). In a laboratory experiment of treating river water conducted by Wang et al. (2015) in Beijing, China, it was found that activated alumina filter media could remove 70-80% of the Total Phosphorus.

Activated alumina media within StormFilter® has necessary physical and chemical filtration characteristics to promote adsorption of pollutants such as dissolved phosphorus (Ma, 2011). The RCFS system (used at the Mitchell Community College test site located in the town of Mooresville, North Carolina, USA) contained a total of eight, 460mm high, media-filled filter cartridges operating at a flow rate of 0.5L/s per cartridge. Each of the filter cartridges was filled with an activated alumina media (Figure 1). The media used for this study was a granular perlite coated with activated alumina. This was done to aid in the attenuation and/ or capture of nutrient pollutants by cation exchange and adsorption. With the exception of the surface coating, coated and uncoated perlite media were determined to be identical with respect to physical characteristics and therefore the media should be considered equivalent with respect to expected solids removal performance (Wicks et al., 2014).

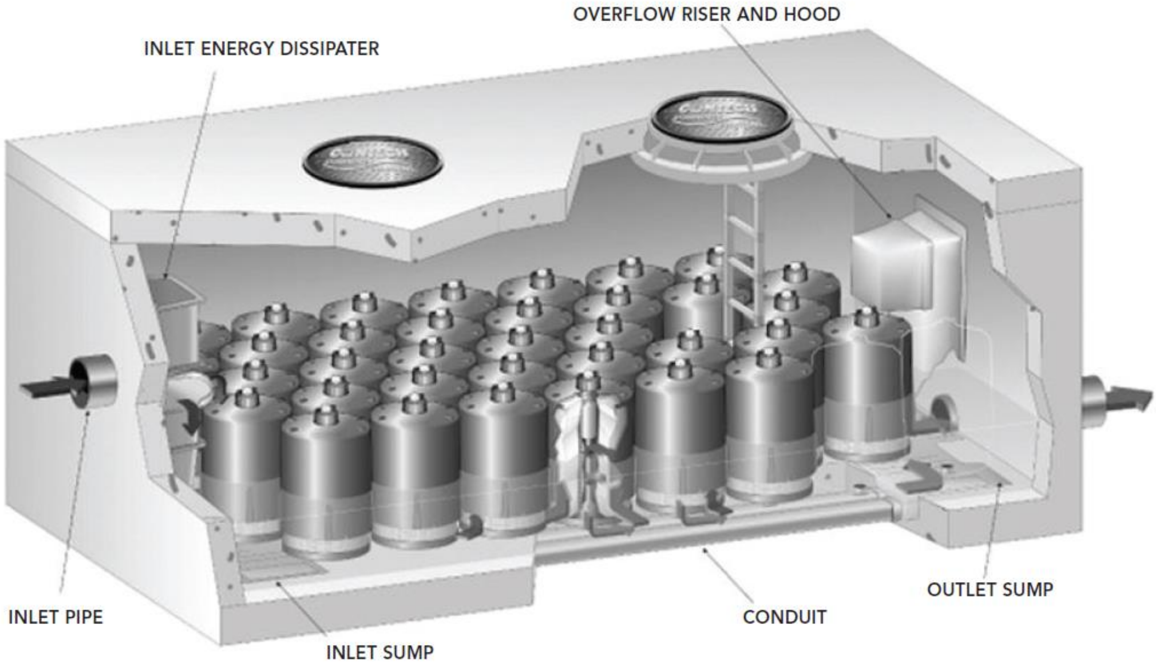

Figure 1. Features of a radial cartridge filtration system (RCFS) (Wickks et al., 2014)

3. Review of Field Testing on StormFilter®

A field testing was carried out by Contech Engineered Solutions (Contech, 2012) to demonstrate the effectiveness of the Stormwater Management StormFilter® Stormwater Treatment System (system) in treating stormwater runoff with respect to the removal of solid and nutrient pollutants. This twenty month’s field study during 2011-12 was conducted at the Mitchell Community College testing site located in the Town of Mooresville, NC, USA. The test site is shown in Figures 2 and 3.

The StormFilter® system described in the report by Contech (2012) consisted of eight cartridge StormFilter® preceded by a detention tank designed to capture 75% of the runoff volume from the 25.4 mm storm event. The carpark catchment area was 0.437 ha, with an equivalent impervious area of 0.297 ha i.e. 68% impervious.

The equipment and sampling techniques used for this study were in accordance with the Project Plan (Contech, 2010) developed by Contech in consultation with local government organisation. Qualified Contech personnel were responsible for the installation, operation, and maintenance of the sampling equipment. Water sample processing and analysis was performed by Pace and Test America. It should be noted that Pace and Test America are accredited laboratories in accordance with the National Environmental Laboratory Accreditation Conference (NELAC) and all samples were tested in accordance with their nationally approved testing protocols as reported by Contech (2010, 2012).

Both the influent and effluent samples were collected using twelve, one litre sample bottles. The collection of flow proportional samples commenced when the flow rate exceeded 0.32 L/s. The sample strainers intakes and flow measurement equipment were secured to the invert of the influent and effluent pipes, which biases the samples towards the larger fraction of the suspended solids (Contech, 2010, 2012).

Testing of the StormFilter® system was conducted to assess the effectiveness of this device to remove Total Suspended Solids (TSS), Suspended Sediment Concentration (SSC), Total Volatile Suspended Solids (TVSS), Total Phosphorus (TP), Dissolved Phosphorus (Diss. P), Ortho-phosphate (Ortho-P), Particulate Phosphorus (PP), Ammonia (NH3+), Total Kjeldahl Nitrogen (TKN), Nitrate plus Nitrite (NO2- plus NO3-), Total Nitrogen (TN), and Organic Nitrogen (ON) in accordance with the approved Project Plan, (Contech, 2010) as well as the conditions outlined in the North Carolina Department of Environment and Natural Resources (NCDENR) Division of Water Quality (DWQ) Preliminary Evaluation Period (PEP) program, (NCDENR, 2007).

Results from the twenty month study, that represented a total of 13 storm events and 70.4 mm of precipitation, showed that the StormFilter® system tested was effective in removing solid and nutrient pollutants from stormwater runoff. The study was completed using the recommended design criteria of a maximum cartridge specific flow rate of 1gpm/ft^2, a coated perlite media, and a volume based design methodology. The StormFilter® system was designed to capture and treat the 25 mm water quality volume, typical for the Piedmont region of North Carolina. The StormFilter system was also designed on a mass-loading basis to meet the annual pollutant loading requirements of the site with a minimum expected interval between maintenance of 1 year (Contech, 2012). Significant reductions for solid and nutrient pollutants were observed in the testing between influent and effluent sampling locations using the Efficiency Ratio (ER) calculation (TSS 90.4%, TP 86.1%, and TN 55.9%) and Summation of Load (SOL) efficiency calculation methods (TSS 90.9%, TP 87.1%, and TN 50.2 %) (Contech, 2012).

The study concluded that the StormFilter® system successfully treated stormwater runoff with respect to removal of solid and nutrient pollutants and was able to meet North Carolina’s 85% TSS pollutant removal requirement, and provided excellent reductions of TP and TN to meet nutrient sensitive watershed nutrient goals (NCDENR, 2007) as reported by Contech (2012).

Figure 2. Picture showing the parking lot at the Mitchell Community College testing site (Contech, 2012)

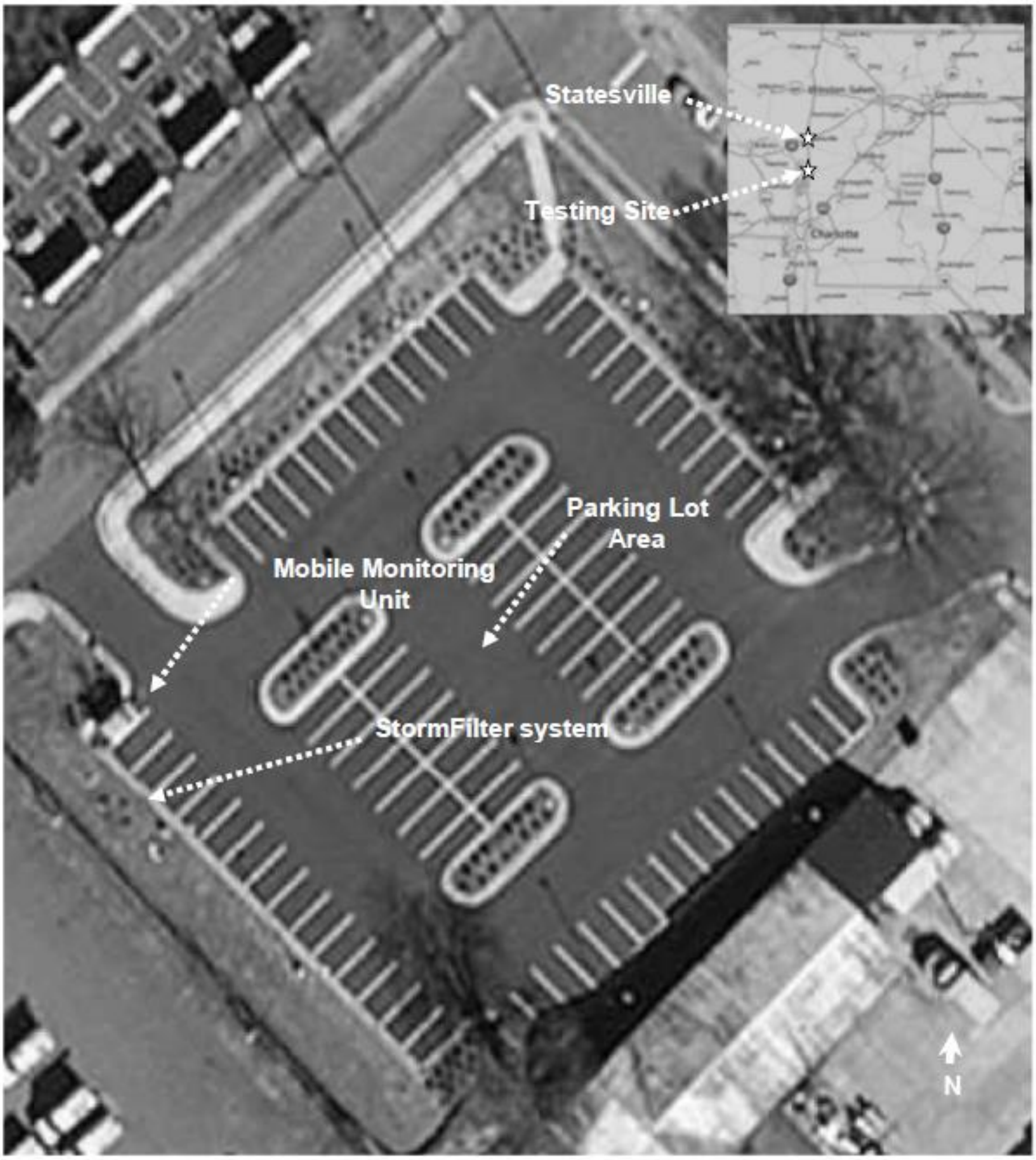

Figure 3. Aerial view of the Mitchell Community College testing site (Contech, 2012)

4. Mitchell Community College testing vs. Australian data

There are little published data on contaminants runoff from carparks in Australia. The contaminant concentrations and load in the carpark runoff depends on factors such as traffic volume in the carpark, surrounding land use, adopted maintenance mode and frequency. The small catchment size of carpark is likely to show a first flush effect after the heavy rainfall events. Hence, comparison of contaminants in the carpark runoff from different studies located in different regions must be interpreted in light of the local conditions.

Fletcher et al. (2004) recommended the event mean concentrations (EMC) for a number of land uses in Australia, which are widely used in design (Table 1). It is found that contaminant concentrations for the case of Mitchell Community College carpark testing are much smaller than reported by Fletcher et al. (2004).

Table 1. EMC for different land uses in Australia (Fletcher et al., 2004) compared with Mitchell Community College carpark testing (values in parentheses indicate Mitchell Community College carpark result)

Contaminant	Range (mg/L)	Typical value (mg/L)
Suspended solids	900-800 (10.30-98.20)	270 (34.60)
Total Nitrogen	1.00-5.00 (0.35-2.95)	2.2 (1.00)
Total Phosphorus	0.15-1.50 (0.07-0.90)	0.50 (0.22)

In another study by Morison (2001) for St Martins Shopping Village carpark in Western Sydney using a rainfall simulator (calibrated for a 1 in six month storm of 15 minutes duration) showed a first flush effect for 10 minutes with an approximate EMC for a duration of 15 minutes of Suspended Solids (95 mg/L), Total Nitrogen (1.85 mg/L) and Total Phosphorus (0.15 mg/L). The results from Morison (2001) and Fletcher et al. (2004) when compared with Mitchell Community College carpark testing exhibit a large difference, which perhaps are due to different land use characteristics and traffic volume representing local conditions.

It should be highlighted that if the EMC in the influent is higher, the contaminant removal efficiency by a stormwater quality improvement device should be higher. Hence, it is highly likely that the efficiency ratio for StormFilter® observed for the Mitchell Community College system would be much higher if the influent EMCs were higher as reported in Australia.

In relation to the constituent species of the contaminants in the runoff from carparks and roads in Australia, there is little measured data available except for Ammonia. Data from Sydney and the Illawarra (based on urban runoff) have shown a mean concentrations in the range of 0.02 and 0.54 mg/L and data from Hornsby showed a mean Ammonia EMC in the range of 0.01 and 0.11 mg/L, and in the case of Grafton it has been found to be in the range of 0.02 and 0.41 mg/L (Fletcher et al., 2004). These Australian values of Ammonia do compare well with the EMC range of 0.05 mg/L and 0.72 mg/L (mean: 0.27 mg/L) from the Mitchell Community College carpark testing.

The Contech (2012) did not include a PSD breakdown of the suspended solid load and only refers to the < 2000 µm fraction and the < 500 µm fraction. Pace and Test America referred to the texture of the suspended solids sampled as loamy sand.

However, additional sieve analyses of the sediment, captured within the system, undertaken by GeoTesting Express on 5 September 2014, determined that in excess of 80% of the sediment was < 75 μm in diameter. This is consistent to the suspended solid loads used in Australian design (≤ 125 μm) (Brodie & Rosewell, 2008, Hunter, 2008).

5. Conclusion

Based on this literature review, the following conclusions can be made:

- The sampling and monitoring protocol of the Mitchell Community College carpark undertaken by the Contech Engineered Solutions are largely consistent with the Australian and New Zealand Guidelines, NQWMS (2000). Hence, the test results from Mitchell Community College carpark are deemed to be reliable.

- The concentrations of pollutants in the influent of the Mitchell Community College carpark testing are found to be much smaller than Australian observed data reported in the literature. Hence, the efficiency ratio for StormFilter® system could be higher for typical Australian conditions.

- StormFilter uses activated alumina as filter media, which has a very high surface-area-to-weight ratio due to the many tunnel-like pores within it, and hence it is ideal to remove significant proportion of pollutants from urban runoff.

- StormFilter system is used with a storage tank, which allows releasing of appropriate volume of runoff to the StormFilter, and hence its performance is unlikely to be affected by rainfall intensity at the site of interest.

- Significant reductions for solid and nutrient pollutants were observed in the Mitchell Community College carpark testing between influent and effluent sampling locations using the Efficiency Ratio (ER) calculation (TSS 90.4%, TP 86.1%, and TN 55.9%). This compares very well for typical Australian design criteria of removing minimum 85% of the Suspended Solids, 65% of the Total Phosphorus and 45% of the Total Nitrogen average annual loads. Hence, StormFilter is likely to achieve pollution removal targets from typical urban runoff required by local councils in Australia including Sydney and Melbourne.

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Appendix B Peer Review of StormFilter® by Damian McCann

This appendix provides the peer review of StormFilter® undertaken by Damian McCann from AWC for Ocean Protect.

Brad Dalrymple

Ocean Protect

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16th June 2021

AWC Reference: 1-201279_Stormfilter_SQIDEP_Review_Final

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Dear Brad

RE: StormFilter SQIDEP Review

Australian Wetlands Consulting (AWC) was commissioned to audit the performance monitoring of the StormFilter System in Australia and confirm compliance with two Stormwater Australia's *SQIDEP (Version 1.3).*

Ocean Protect supplied the following materials pertaining to the performance monitoring:

- *A review of the application of StormFilter® in Victoria, Australia* (Dalrymple and Wicks, 2020), which includes information on current approvals, case studies, performance monitoring, review of applicability to local conditions in Victoria
- Product evaluation *The Stormwater Management StormFilter with PhosphoSorb Media Performance Evaluation Study, Lolo Pass Road, Zigzag, Oregon*)
- Supporting information for the Lolo Pass Road, Zigzag, Oregon site, including a copy of approved QAPP, technical papers and laboratory and individual storm reports (ISR) reports
- A Microsoft excel file *StormFilter Psorb LPR SQIDEP Compliance 210519* containing data and statistical analysis from the monitoring of StormFilter system with Psorb media at operational flow rate 12.5gpm (0.79L/s for standard 460mm cartridge)

Based on a review of the information provided and the remote site inspection, AWC confirm that the field testing of the StormFilter System conducted at Lolo Pass Road (LRP), Zigzag Oregon, USA between February 2012 and April 2014 complies with the requirements of SQIDEP (v1.3) Field Evaluation pathway as shown in Table 3 attached.

Pollutant inflow concentrations observed during the trial are consistent with ranges reported in the literature and suggested ranges within the Water by Design MUSIC Guideline (2010). A comparison has been made in Table 1.

Table 1 Comparison of pollutant inflow concentrations across 21 storm events at Zigzag, Oregon with precedent studies and the Water by Design (2010) MUSIC Modelling Design Guidelines

Analyte	Duncan (1999) study	Drapper and Lucke (2015) study	Water By Design (2010)	Current study – Stormfilter, Zigzag
TSS (mg/L)	60 – 700 (n=42)	1.45 – 5800 (n=325)	269	302
TP (mg/L)	0.1 – 0.8 (n=25)	0.08 – 26 (n=325)	0.501	0.254
TN (mg/L)	1 – 9 (n=17)	0.38 - 8.5 (n=325)	1.82	0.921

The following key information needs to be highlighted with regards to any Treatment Claims that can be made for the Stormfilter system evaluated under the SQIDEP framework:

- Pollutant concentration reduction claims that can be made as a result of the field trials are shown in Table2
- A treatable flow rate of 0.9L/s for a 460mm cartridge at the crest of the overflow weir (535mm driving head - 460mm driving head equates to 0.79L/s treatable flow rate)

Table 2 Summary of pollution reduction of Stormfilter at the Lolo Pass Road (Zigzag Oregon, USA

Analyte	Median CRE (%)	Efficiency Ratio (%)
TSS	90	88.6
TP	78.3	77.1
TN	59.2	61.9

I hope this summary is clear but please contact me with any questions.

Your sincerely,

Damian McCann

Director

Attachment 1

Table 3 Assessment of the Stormfilter system performance monitoring undertaken at Oregon USA against SQIDEP (v1.3) requirements (the respective page number where the requirement is discussed in SQIDEP v1.3 is shown for ease of reference).

SQIDEP Requirement	Initial AWC comments	Compliance	Ocean Protect Response	Final AWC comments / compliance
Catchment area (p14)	260m^2	Y		
Land Use (p14)	Used Road	Y		
Percentage Impervious cover (p14)	100%	Y		
Aerial photos (p14)	Figure 2	Y		
Site Photos (p14)	Figures 2 and 3	Y		
Potential pollutant sources (p14)	Vehicles, leaves, grass, human litter.	Y		
Site map showing: (p14) • Catchment area • Drainage system layout • Treatment device • Sampling points	Catchment area with drainage layout and sampling points are not clearly defined by land survey or distinguished on site mapping provided	Y		
Treatable flow rate (TFR) (p14)	0.9L/s. observed within flow data	**Y**		
Rainfall ≤ 5 min time interval (p15)	Measured at 5minute intervals. Details provided in LPR hydro data QA review	**Y**		
Rainfall ≤ 0.25mm increments (p15)	0.25mm tip bucket rain gauges	Y		
Rainfall - Location shown on site map (p15)	Location of rain gauge shown in Figure 6 of QAPP report	**Y**		
Rainfall - Checked, cleared of debris and calibrated at least two times during the testing period (p15)	Calibrated 2x during monitoring period (LPR hydro report) and maintenance of rain gauge within Field forms Appendix C of TAPE_Contech-StormFilter-PhosphoSorb_TER.pdf	Y		
Rainfall - Protected from excessive wind velocities (p15)	Rain gauge was installed in accordance with manufactures instructions. The tipping bucket itself is designed to be shielded	**Y**		

SQIDEP Requirement	Initial AWC comments	Compliance	Ocean Protect Response	Final AWC comments / compliance
	from the wind. Detail provided page 3 of LPR report.			
Min 15 events (p15-16)	Results for all 21 qualifying events are provided in shown in table 4 of LPR data and Hydrographs of individual storm events provided within Appendix A	Y		
Achieve at least 90% statistical significance between paired samples of influent and effluent (p15-16)	Paired t test calculation on influent and effluents concentrations of TSS<TP and TN show >90% statistically significant was achieved	Y		
Each monitoring program will need to identify the period delineating the end of one event and beginning of the next – typically 24hrs or the time taken to reset monitoring equipment (p15-16)	Table 4 within provided excel file provides date of each event and the sampling duration in hours coinciding with time between rainfall events The LPR report page 4 states that a minimum inter-event period was equal or greater than 6hrs	Y		
Hydrographs for each event to demonstrate the program has representatively captured the event (p15-16)	Hydrographs of individual storm events provided within Appendix A of LPR report sampling had correctly captured event	**Y**		
Min 2 peak inflows from the sampled events should exceed 75% of the design TFR of the device + 1 ≥ than its design TFR (p15-16)	TFR is 0. 9L/s. Table 4 within provided excel file indicate that 9 events exceeded TFR within the monitoring period	Y		
Events to be sufficiently distributed throughout the monitoring period to capture seasonal	Monitoring occurred between Oct 2012 and April 2014 with a range of rainfall event	**Y**		

SQIDEP Requirement	Initial AWC comments	Compliance	Ocean Protect Response	Final AWC comments / compliance
influences on storm conditions & The independent evaluation panel must be satisfied that the qualifying storms includes a good range of storm event (longer and shorter duration) (p15-16)	characteristics sampled across monitoring Rainfall durations ranged from 4-47hr with peak inflows ranging from 0.16-5.06L/s Number of events per season: • Summer: 4 • Autumn: 4 • Winter: 6 • Spring: 9			
50% of qualifying storms should include the first 70% storm hydrograph coverage (p15-16)	Hydrographs have been provided within LPR reports with plotted aliquots within first 70% of hydrograph cover with 19 of 23 events meeting this criteria.	Y		
Flow measurement at the inlet and outlet are recommended. Monitoring of bypass flows is optional, however, at a minimum the monitoring information should be sufficient to identify periods when device is operating in bypass (p17)	Influent and effluent flows were monitored using primary and secondary measurement devices page 3 LPR report and presented in Individual storm reports Appendix A along with flow and sampling data provided in supporting excel folder. Bypass occurs when total flow is more than the treatment flow, except a very small part of the catchment contributes to the bypass without going to the treatment. This information has been provided in ISR's Appendix A	Y		
The QAPP should identify	Figure 7 of the QAPP	Y		

SQIDEP Requirement	Initial AWC comments	Compliance	Ocean Protect Response	Final AWC comments / compliance
whether effluent characterization accounts for total storm flow, including bypass if it occurs (p17)	shows t sampling locations and illustrates that flow bypass are not included in effluent samples within system			
Outlet flow should be sampled either prior to or after mixing with bypass flow and Claims identify the inclusions/exclusion of bypass flows (p17)	Sampling was conducted prior to mixing with bypass flows as stipulated by Washington Department of Ecology TAPE (TAPE, 2011) pages 3 of the LPR report	Y		
Make, model and procedures and schedule for calibration, inspection and cleaning shall be provided (p20)	Influent and effluent sampler: ISCO 6712 Portable Automated sampler configured for 1L wide-mouthed bottles Influent and effluent flows were measured using Large 60°V Trapezoidal Flumes (primary measurement device) in conjunction with individual ISCO 730 Bubbler Flow Modules (secondary measurement devices Contech personnel would visit the site to retrieve samples and reset the automated sampling equipment. Equipment installations and Calibration details provided in table 6 of QAPP report	Y		
Rainfall (p20)	The rain gauge is factory-calibrated and needs no further calibration (As manufactures	Y		

SQIDEP Requirement	Initial AWC comments	Compliance	Ocean Protect Response	Final AWC comments / compliance
	recommendations). Routine maintenance is required to check for debris and blockage, with details provided in Appendix C 'field forms' of "TAPE Contech Stormfilter PhosphoSor_TER			
Flow proportional sampling requires at least 80% of the submitted events have at least 8 aliquots collected from both the rising and falling limbs of the hydrograph to form the composite sample (p21)	Table 4 within provided excel file provides evidence that 8 aliquots were collected in over 80% of events sampled with Evidence of aliquots sampling points are also shown on hydrographs within ISR in Appendix A	Y		
Sample blanks for field and analytical testing to be supplied (p21)	Provided in LPR Lab reports	Y		
COC documents identifying sample collection, collection agency, collection time, preservation used, laboratory receipt of sample and sample collection shall be provided (p21)	Provided	Y		
NATA accreditation (p21)	Study was undertaken in Washington State, USA by a NATA equivalent Laboratory.	Y	As outlined in "TAPE_Contech-StormFilter-PhosphoSorb_TER.pdf" (page 24 of PDF) "All Analytical Laboratories selected for this evaluation are Ecology-accredited." Further information in relation to this accreditation is available from https://ecology.wa.gov/Regulations-Permits/Permits-certifications/Laboratory-Accreditation We suggest that this is a sufficient equivalent to NATA accreditation for the purposes of the given study.	AWC confirm that both Test America and APEX Labs that were used for lab analysis for the study are both listed as accredited laboratories on Ecology WA website.

SQIDEP Requirement	Initial AWC comments	Compliance	Ocean Protect Response	Final AWC comments / compliance
Method of analysis detailed (p21)	Analytical methods for tested parameters are detailed in table 1 of LPR report	Y		
Non-detects (p23) Effluent sample results below the limit of detection (LOD) shall be set at 0.5 x LOD and must be accompanied by a sensitivity analysis showing impact on performance metrics of adopting both LOD and 0).	Table 3 within the LPR report provides information on non-detects within the study	Y		
Performance metrics (p25) Analysis should clearly indicate how treatment and bypass flows (either external or internal to the device) have been accounted for in the presentation of results.	Monitoring of flows at inlet and outlet coinciding with bypass flows are shown in ISR and details on how treatment and bypass flows have been accounted for is provided within LPR data table 4 of excel data	Y		
Average and Median Concentration Removal Efficiency (p25)	Details are provided in table 4 of LPR data within supporting excel file along with results presented in table of LRP report	Y		
Event Mean Concentration and Mass Discharge (p30) The event mean concentration and Mass Discharge variability are required to verify the ability of the device to manage large variability in EMCs and mass discharges. Box and whisker plots should be prepared for influent and effluent EMCs as well as mass loads (where presented).	The required results including EMCs, mass discharge, and box and whisker plots are provided in results section of the report and accompanying excel spreadsheet. Box and whisker plots for influent and effluent EMCs are presented in figure and are clearly show EMCs in scatter plot graphs in Figure C-	Y		

SQIDEP Requirement	Initial AWC comments	Compliance	Ocean Protect Response	Final AWC comments / compliance
The number of EMCs and mass loads contributing to each distribution should be clearly indicated.	6			

References

Contech Engineered Solutions (2013), Quality Assurance Project Plan: The Stormwater Management StormFilter® PhosphoSorb® at a Specific Flow Rate 1.67 gpm/ft2 Performance Evaluation

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Appendix C Flow testing study of StormFilter® by Renew Solutions

This appendix provides the report by Renew Solutions for Ocean Protect, describing the methodology and results of flow testing of ‘real world’ StormFilter® installations to determine if pollutant accumulation in these devices had caused any significant reduction in flows, and subsequently inform recommended maintenance actions.

StormFilter Flow Test

Ocean Protect
R&D11373

Document Information

Document Name	StormFilter Flow Test	Date	19/07/21
Author(s)	Samuel Loder	Version	V3
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Document Distribution History

Version #	Issue Date	Distribution	Reviewer	Issuer
1	24/05/21	Ocean Protect	CC	SL
2	07/06/21	Ocean Protect	CC	SL
3	22/07/21	Ocean Protect	CC	SL

Non-disclosure Statement

Renew Solutions Pty Ltd (hereafter Renew Solutions) retains ownership of the content and intellectual property contained within this document. The document has been prepared for use by and distribution within Ocean Protect (hereafter the client).

Integrated Management System

Renew Solutions is certified by Atlas Certification Pty Ltd for the International Organisation Standards (ISO) for Quality, Safety, and Environmental (QSE) management. Further information can be supplied upon request.

EXECUTIVE SUMMARY

The StormFilter® is a proprietary stormwater quality improvement device (SQID) comprised of one or more structures that house rechargeable, media-filled cartridges that trap particulates and adsorb pollutants from stormwater runoff such as total suspended solids, hydrocarbons, nutrients, metals, and other common pollutants. As the StormFilter® cartridges capture pollutants, the media will eventually become occluded and require replacement. Maintenance requirements and frequencies are dependent on the pollutant load characteristics of each site, and Ocean Protect (2019a) recommend inspection every 6 months, minor service every 12 months, and media replacement 'as required' but approximately every 1 to 3 years to ensure the continuing operation of the device is in line with the original design specification.

Ocean Protect commissioned Renew Solutions PTY LTD to undertake flow testing of 'real world' StormFilter® installations to determine if pollutant accumulation in these devices had caused any significant reduction in flows, and subsequently inform recommended maintenance actions – specifically, how often the StormFilter® media may need replacement due to reduced flow conveyance through the media (as a result of pollution accumulation).

StormFilters® were selected by Renew Solutions PTY LTD for subsequent flow testing from five (5) different locations within Gold Coast City. At each location, the StormFilters® had been designed, installed and maintained by Ocean Protect in accordance with typical guidance, as outlined in Ocean Protect (2019a, 2019b) guidelines. Each StormFilter® had been operating (with no media replacement) for between 1.5 and 3 years, and the presence of pollution (e.g. sediment) was observed within the StormFilter® cartridge (and associated chamber housing the StormFilter®) at each site. Two flow tests were also undertaken by Renew Solutions PTY LTD on two different, new (unused) StormFilter® cartridges.

When the flow tests were performed by Renew Solution PTY LTD, the flow tests were undertaken without the flow restrictor (orifice) disk, allowing the total reduction of flow in the StormFilter® cartridges media to be observed. In real world applications, the flow rate through each cartridge media option is controlled by a flow restrictor disc (orifice) that is located at the base of each cartridge. Reducing the flow rate across the uniform media depth increases pollutant removal and the mass load capacity of each cartridge.

Blacktown City Council allows for a reduction of 10% in flow rate before StormFilter® cartridges must be serviced. For the Spelfiter, Spel (n.d.) recommends replacing the Spelfilter if flow rates across the entire chamber are reduced by approximately 40%.

Observed flow rates for the tested StormFilter® cartridges were significantly higher than the StormFilter® cartridge design flow rate (if the flow restrictor (orifice) disc was present) – demonstrating that, despite pollution accumulation observed in all tested StormFilter® cartridges, this accumulation would cause zero reduction in flow through the StormFilter® cartridges.

Our assessment has not reviewed stormwater treatment performance of the StormFilter (and potential reductions in performance with increased pollution accumulation). Nevertheless, if flow rate is used as the indicator of when to replace the StormFilter® cartridges (as recommended by Blacktown City Council (2020), it is anticipated that StormFilters® would not typically require replacement before 3 years of operation (depending on the catchment characteristics).

TABLE OF CONTENTS

INTRODUCTION

Stormwater quality improvement devices (SQIDs) are commonly applied in urban areas to mitigate the water quality and hydrologic impacts of urbanisation on waterway health. The StormFilter® is a proprietary stormwater quality improvement device (SQID) comprised of one or more structures that house rechargeable, media-filled cartridges that trap particulates and adsorb pollutants from stormwater runoff such as total suspended solids, hydrocarbons, nutrients, metals, and other common pollutants.

As the StormFilter® cartridges capture pollutants, the media will eventually become occluded and require replacement. Like any SQID, the maintenance requirements and frequencies of StormFilter® are dependent on the pollutant load characteristics of each site. To ensure the continuing operation of the StormFilter® cartridges consistent with its original design specification, Ocean Protect (2019a) recommends the inspection of StormFilters® cartridges every 6 months, a minor service every 12 months, and media replacement 'as required' but approximately every 1 to 3 years.

Ocean Protect commissioned Renew Solutions PTY LTD to undertake flow testing of 'real world' StormFilter® installations to determine if pollutant accumulation in these devices had caused any significant reduction in flows, and subsequently inform recommended maintenance actions – specifically, how often the StormFilter® cartridge media may need replacement due to reduced flow conveyance through the media (as a result of pollution accumulation).

The purpose of this report is to describe the flow testing investigations undertaken by Renew Solutions PTY LTD, and associated results – and subsequently inform recommended maintenance actions for StormFilter® cartridges.

METHODOLOGY

Trigger Point

When reviewing data provided by SPEL Stormwater in regards to their SPEL Filter, they state '*applications are designed to treat the WQv in 24 hours initially. Later in the cycle these cartridges will flow at a slower rate, and when the WQv does not drain down within +/- 40 hours after the storm event, the system must be maintained.*' (SPEL Stormwater, n.d.). From this, we can assume once the flow rate of SPEL filters has been reduced by 40%, the filter media is exhausted and should be replaced.

Blacktown City Council allows for a reduction of 10% in flow rate before the filter must be serviced. The trigger point can be site specific, depending on the WQv needing to be treated during a specific ARI event. However, Renew Solutions PTY LTD have assumed the trigger point for a media filter clean should be a reduction of flow by 40%, which is the maximum reduction that can occur before the filter media is exhausted.

For the purpose of this test and to understand the reduction in flow caused by sediment accumulation within the device, the flow restrictor (orifice) disk was removed from the StormFilter® cartridges to allow free flow of water through the device. In real world applications, the flow rate through each StormFilter® cartridge is controlled by a flow restrictor disc (orifice) that is located at the base of each cartridge. This disc reduces the flow rate across the uniform media depth, increases pollutant removal and the mass load capacity of each StormFilter® cartridge.

Clean, unused StormFilters® cartridges were tested, so the maximum flow rate without any sediment accumulation could be determined. The results of the used StormFilters® were compared against the clean StormFilters® results.

Site selection

StormFilters® cartridges at five (5) different locations within Gold Coast City were selected for testing. Table 1 provides a summary of the sites.

Table 1 Summary of StormFilter test sites

Site ID	Site address	Filter size (mm)	Filter media	Time since media replacement (years)
1	36 Hammond Drive, Gaven	690	PSorb	1.5
2	5 Harbour Side Court, Biggera Waters	460	PSorb	3
3	Sunkids, 259 Scottsdale Drive, Robina	690	PSorb	2.3
4	296 Esplanade, Burleigh Heads	690	PSorb	1.7
5	192 Marine Parade, Rainbow Bay (The Garland)	690	PSorb	2.2

As described in Table 1, at each site, StormFilter® cartridges had been operating (with no media replacement) for between 1.5 and 3 years.

The presence of pollution (e.g. sediment) was observed within the StormFilter® cartridges (and associated chamber housing the StormFilters) at each site. Figure 1 provides example photos of a StormFilter® cartridges removed for testing.

Figure 1: Example of selected StormFilter® cartridge for testing

At each location, the StormFilters® had previously been designed, installed and maintained by Ocean Protect in accordance with recommended procedures, as outlined in Ocean Protect (2019a, 2019b) guidelines.

To avoid potential 'cherry picking' of potentially cleaner StormFilter® cartridges at each site, Renew Solutions PTY LTD personnel were responsible for randomly selecting one StormFilter® cartridge for testing at each site. Renew Solutions PTY LTD also allocated tag numbers to each StormFilter® cartridge for identification and traceability. Ocean Protect personnel removed the selected StormFilter® cartridges for transport by Renew Solutions PTY LTD to the flow testing facility. The StormFilters® were removed and transported on 13 April 2021.

Ocean Protect also provided Renew Solutions PTY LTD with a new (unused) 460mm StormFilter® cartridge as well as a 690mm StormFilter® cartridge to act as a reference point for the flow tests.

Flow testing

Figure 2- Volumetric weir in use during flow test

Flow testing was undertaken by Renew Solutions PTY LTD at their offices. A volumetric weir (see Figure 2) was used to record the flow rates across each filter. With the flow restrictor (orifice) disc removed from the devices, the flow rates expected were to be between 3 and 5 L/s. The following methodology was used to test the filters:

1. Filter devices were loaded into the test chamber and attached to underdrainage.
2. Using a transfer pump, water was directed from the intermediate bulk container to the testing chamber.
3. Once the water level in the testing chamber reached the desired height to mimic a typical StormFilter® weir (as seen in Figure 3), the return valve was opened next to the flow meter and the water was allowed to begin flowing through the filter device, its media, and the flow meter.
4. The flow test was conducted over 5 minutes, recording the flow every minute.
5. Once the 5 minutes had passed, the pump was switched off and the water was drained from the testing chamber.
6. Once drained, the test was repeated 3 times for each StormFilter® cartridge .
7. Once all flow testing was completed and the testing chamber was drained, the StormFilter® cartridge was removed.

Figure 3: StormFilter® installed in testing rig with desired head achieved.

RESULTS

Table 2 provides a summary of the StormFilter® flow test results.

Table 2 Summary of StormFilter flow test results

Filter #	Filter Code	Filter Location	Filter size (mm)	Filter Material	Years since replaced	Recorded Average Flow rate (L/s)	Design Flow rate (L/s)[1]	Pass/ Fail[2]
Clean Filter-460	-	-	460	Psorb	-	3.1	0.46	-
Clean Filter-690	-	-	690			4.3	0.90	-
Filter 1	B653661	36 Hammond Drive, Gaven	690	Psorb	1.5	3.7	0.90	Pass
Filter 2	B653670	5 Harbour Side Court, Biggera Waters	460	Psorb	3	3.0	0.46	Pass
Filter 3	B653662	Sunkids, 259 Scottsdale Drive, Robina	690	Psorb	2.3	3.9	0.90	Pass
Filter 4	B653663	296 The Esplanade, Burleigh Heads	690	Psorb	1.7	3.9	0.90	Pass
Filter 5	B653664	192 Marine Pde, Rainbow Bay (The Garland)	690	Psorb	2.2	3.6	0.90	Pass

1: with flow restrictor (orifice) disc.

2: 'Pass' means flow rate of StormFilter® complies with Blacktown City Council (2020) requirements (i.e. recorded average flow rate is not less than 10% below design flow rate).

Key findings from the results were:

- The observed flow rates were significantly higher than the design flow rate if the flow restrictor (orifice) disc was present – being 0.9L/s for a 690 PSorb StormFilter and 0.46L/s for a 460 PSorb StormFilter (see Appendix B)
- The unrestricted flow rates recorded in the used cartridges were between 3% and 16% lower than that recorded in the new (unused) cartridge
- The highest reduction in flow (relative to a clean/ unused device) was Filter 5 (690 PSorb StormFilter®, operating for 2.2 years), which recorded a flow reduction of 16% and an average flow rate of 3.6L/s
- The lowest reduction in flow was Filter 2 (460 PSorb StormFilter) with a flow reduction of 3% (to 3.0L/s), despite being in operation for the longest (3 years) of the tested filters.

DISCUSSION

Blacktown City Council allows for a reduction of 10% in flow rate before StormFilters® must be serviced (Blacktown City Council, 2020). For the Spelfiter®, Spel recommends replacing the Spel filter if flow rates exiting the cartridge chamber are reduced by 40% (SPEL Stormwater, n.d.).

The results of the flow test suggest that a reduction in the unrestricted flow rate of the device will be observed over a period of time in operation, however this will not affect the actual operational flow rate, as the flow restrictor (orifice) disc will cause a greater reduction in flow.

Of the observed flow rate reduction percentage, the greatest reduction observed was 16% for a 690 Psorb filter. As the flow reduction percentage due to the orifice disc for a 690mm Psorb filter is 80%, it is likely that the sediment accumulation within the filters will not have an effect on the operational flow rate. For the 460mm Psorb filter, the observed reduction percentage in flow rate caused by sediment accumulation was 3%. As the flow reduction percentage due to the orifice disk is 33%, it is likely that the operational flow rate will not be affected by sediment accumulation.

The results demonstrate that flow rate reductions are not entirely dependent on the amount of time they have been in operation. Filter 1 had been operating for longer than filter 3 and filter 4, however filter 1 observed the largest flow rate reduction. This is likely due to the different pollutant loads for each catchment area, and higher pollutant loads would be expected to result in a higher flow rate reduction in a shorter time frame.

Our assessment has not reviewed stormwater treatment performance of the StormFilter (and potential reductions in performance with increased pollution accumulation). Nevertheless, if flow rate is used as the indicator of when to replace the StormFilter cartridges (as recommended by Blacktown City Council (Blacktown City Council, 2020)), it is anticipated that StormFilters® would not typically require media replacement before 3 years of operation (depending on catchment characteristics).

CONCLUSION AND RECOMMENDATIONS

Flow testing of StormFilter® cartridges was undertaken at five (5) locations within Gold Coast City operating in 'real world' conditions with between 1.5 and 3 years since the cartridge media was replaced. Flow tests were undertaken without the flow restrictor (orifice) disk located at the base of StormFilter, allowing the total reduction of flow in the StormFilter® cartridges to be observed. Observed flow rates for the tested StormFilter® cartridges were significantly higher than the StormFilter® cartridge design flow rate (if the flow restrictor (orifice) disc was present) – demonstrating that, despite pollution accumulation observed in all tested StormFilter® cartridges, this accumulation would cause zero reduction in flow through the StormFilter® cartridges.

Our assessment has not reviewed stormwater treatment performance of the StormFilter® (and potential reductions in performance with increased pollution accumulation). Nevertheless, if flow rate is used as the indicator of when to replace the StormFilter cartridges (as recommended by Blacktown City Council (2020), it is anticipated that StormFilters would not typically require media replacement before 3 years of operation.

REFERENCES

Blacktown City Council, 2020, WSUD *developer handbook MUSIC modelling and design guide 2020*.

Ocean Protect, 2019a, *StormFilter Operations & Maintenance Manual*.

Ocean Protect, 2019b, *StormFilter Technical Design Guide*.

SPEL Stormwater. (n.d.). *SPEL Filter Manual*. Chapter 4, Maintenance.,

http://www.aksindustries.com.au/wp-content/uploads/2017/06/SPEL-Filter-Manual-Full-Res_Maintenance.pdf

APPENDIX A - Flow Testing Raw Results

Raw data recorded in Gallons per day and converted to L/s.

STORMFILTER FLOW TEST									
	CLEAN FILTER 460			CLEAN FILTER 690			FILTER 1		
TIME	TEST 1 (GPD)	TEST 2 (GPD)	TEST 3 (GPD)	TEST 1 (GPD)	TEST 2 (GPD)	TEST 3 (GPD)	TEST 1 (GPD)	TEST 2 (GPD)	TEST 3 (GPD)
1	72810	76760	68940	106160	106160	97460	84850	84850	80770
2	68940	72810	68940	97460	97460	88990	84850	84850	84850
3	72810	68940	72810	97460	97460	93910	84850	88990	84850
4	68940	72810	68940	97460	93190	97460	84850	88990	84850
5	68940	68940	72810	101780	97460	93910	80770	84850	84850
AVERAGE (GPD)	70488	72052	70488	100064	98346	94346	84034	86506	84034
FILTER AV (GPD)	71009.33			97585.33			84858.00		
FILTER AV (L/s)	3.1			4.3			3.7		

STORMFILTER FLOW TEST												
	FILTER 2			FILTER 3			FILTER 4			FILTER 5		
TIME	TEST 1 (GPD)	TEST 2 (GPD)	TEST 3 (GPD)	TEST 1 (GPD)	TEST 2 (GPD)	TEST 3 (GPD)	TEST 1 (GPD)	TEST 2 (GPD)	TEST 3 (GPD)	TEST 1 (GPD)	TEST 2 (GPD)	TEST 3 (GPD)
1	72810	68940	68940	88990	93190	88990	97460	88990	88990	80770	84850	80770
2	65140	68940	68940	93190	88990	84850	93190	84850	84850	84850	80770	84850
3	65140	65140	65140	88990	93190	84850	88990	88990	88990	80770	80770	84850
4	68940	65140	68940	97460	84850	93190	88990	88990	93190	80770	80770	80770
5	68940	68940	72810	88990	97460	84850	93190	88990	93190	84850	84850	84850
AVERAGE	68194	67420	68954	91524	91536	87346	92364	88162	89842	82402	82402	83218
FILTER AV	68189.33			90135.33			90122.67			82674.00		
FILTER AV (L/s)	3.0			3.9			3.9			3.6		

APPENDIX B - StormFilter® Specifications and Site Characteristics

STORMFILTER SPECS				
	Units	StormFilter® 1	StormFilter® 2	StormFilter® 3
Cartridge height	mm	690	460	310
Physical Height	mm	840	600	600
Head Loss	mm	920	690	540
Flow Rate (ZPG)	L/s	1.6	1.1	0.7
Flow Rate (Psorb)	L/s	0.9	0.46	0.39

APPENDIX C - Filter Locations and Site Characteristics

FILTER #	FILTER CODE	FILTER LOCATION	SITE CHARACTERISTICS
1	B653661	36 Hammond Drive, Gaven	- Located in the carpark of an early education centre. - Surrounded by leafy vegetation. - Site surrounded by bushland.
2	B653670	5 Harbour Side Court, Biggera Waters	- Located within a large apartment complex. - Storm chamber was submerged, suggesting the system is influenced by tides, or there are blockages downstream. - Significant number of trees, hedges and leafy vegetation on site.
3	B653662	Sunkids, 259 Scottsdale Drive, Robina	- Located in the carpark of an early education centre. - Site surrounded by bushland. - Cark surrounded by garden beds.
4	B653663	296 The Esplanade, Burleigh Heads	- Located within an apartment complex. - Small site with low surface area. Filter expected to be relatively clean. - Filter media falling out of device. Pre-treatment through silt/ sediment trap.
5	B653664	192 Marine Pde, Rainbow Bay (The Garland)	- Located in Large apartment complex. - Minimal leafy vegetation on site. - Large impervious areas throughout the site.

Appendix D StormFilter® Technical Design Guide

This appendix provides a technical design guide for StormFilter®, produced by Ocean Protect.

StormFilter

Technical Design Guide

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***Rev:** 1 **Last Updated:** March 2019*

Introduction

The Ocean Protect StormFilter® is an underground stormwater treatment device comprised of one or more structures that house rechargeable, media-filled cartridges that trap particulates and adsorb pollutants from stormwater runoff such as total suspended solids, hydrocarbons, nutrients, metals, and other common pollutants.

With media options to target multiple or specific pollutants, multiple system configurations, and field and laboratory performance verified by the most stringent stormwater technology evaluation organisations, the StormFilter provides engineers with the most flexible and reliable manufactured treatment technology available.

Operational Overview

During a storm, runoff percolates through the filtration media and starts filling the cartridge central tube. The air inside the hood is purged through a one-way check valve as the water rises. When water reaches the top of the float, buoyant forces pull the float free and allow filtered water to exit the cartridge.

A siphon is established within each cartridge that draws water uniformly across the full height of the media profile ensuring even distribution of pollutants and prolonged media longevity.

As the storm subsides and the water level in the structure starts falling, a hanging water column remains under the cartridge hood until the water level reaches the scrubbing regulators at the bottom of the hood. Air then rushes through the regulators breaking the siphon and creating air bubbles that agitate the surface of the filter media causing accumulated sediment to settle on the treatment bay floor. This unique surface-cleaning mechanism helps prevent surface blinding and further extends cartridge life.

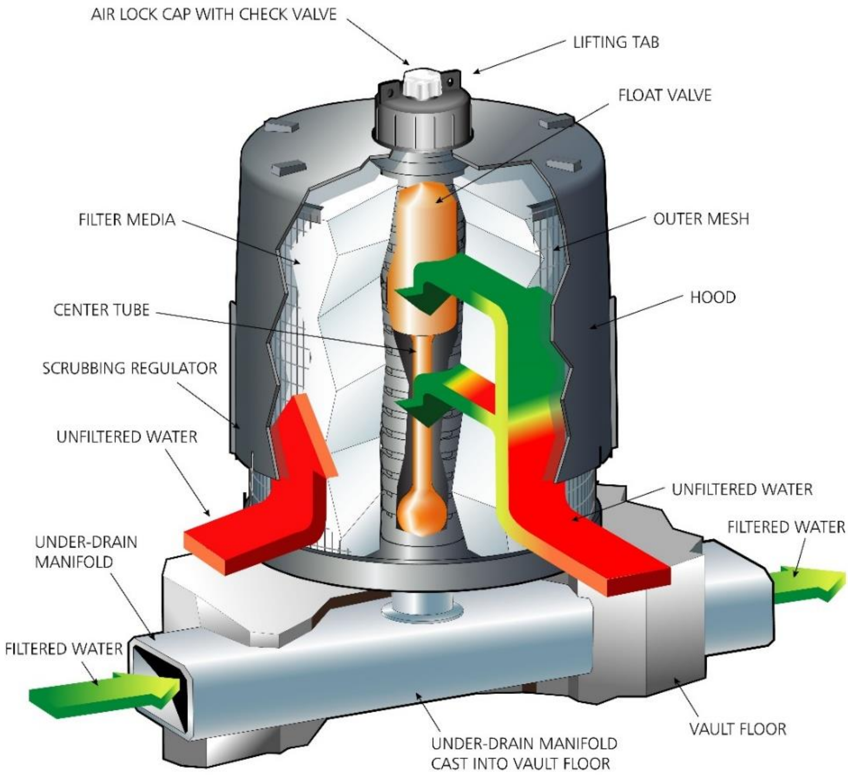

Figure 1: StormFilter cartridge components

Features

Media Options

The StormFilter system has the ability to operate with a variety of media options. These options are designed to target site or regulatory specific requirements. The current range of options is as follows:

- PhosphoSorb™
- ZPG™
- Perlite

PhosphoSorb™ (PSorb) media is the most advanced option available and is suited to most applications. Produced locally in Australia by Ocean Protect, PSorb achieves the optimum combination of pollutant removal and cost-effective treatment.

PSorb is a lightweight Perlite-based media coated in activated alumina. It removes Total Suspended Solids and Nutrients including some soluble forms of both Nitrogen and Phosphorus. PSorb media was developed to improve not only performance but also to provide a longer service life and to reduce OH&S risk by drastically reducing cartridge weight.

The other primary media option utilised by Ocean Protect is our ZPG™ media. It consists of Perlite, Zeolite and Granular Activated Carbon and was Ocean Protects original regulatory approved media for treating Total Suspended Solids and Nutrients.

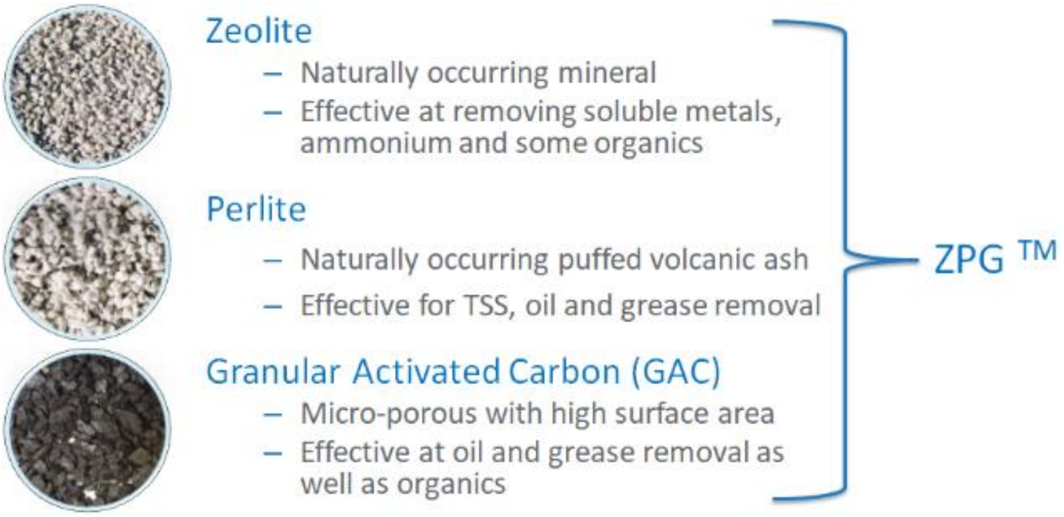

Figure 2: ZPG Media Overview

Cartridge Options

The StormFilter cartridge is available in three size options 310, 460 and 690 (Refer Table 1). The 690 StormFilter cartridge delivers most cost effective solution within these options. It has the highest flow rate and the largest filtration surface area and sediment capacity, however it requires a greater head loss and physical height to achieve this. In comparison the 460 and 310 cartridge options are best utilised when either physical height or head loss are a limiting factor.

The physical height of the cartridge must not be confused with the cartridge naming convention. Refer to table 1 for the physical cartridge height when needing to utilise the StormFilter cartridges in a shallow height unit.

The flow rate through each cartridge media option is controlled by a flow restrictor disc (orifice) that is located at the base of each cartridge. Reducing the flow rate across the uniform media depth increases pollutant removal and the Mass Load Capacity of each cartridge.

Cartridge Name / Siphon Height (mm)	690	460	310
Physical Height (H) mm	840	600	600
Typical Weir Height from outlet (Head Loss, mm)	920	690	540
Flow Rate ZPG (L/s)	1.60	1.10	0.70
Flow Rate PSorb (L/s)	0.90	0.46	0.39

Table 1: StormFilter cartridge details

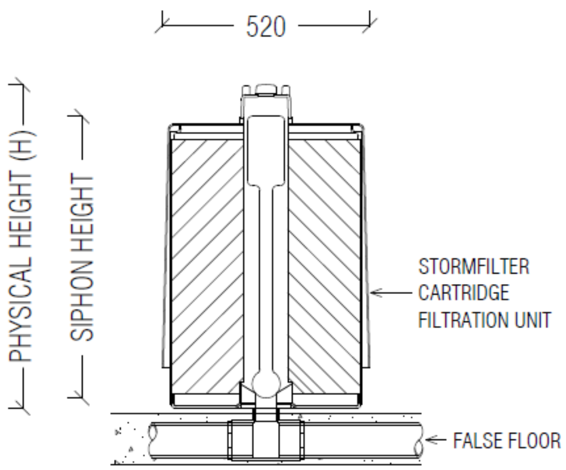

Figure 3: StormFilter cartridge dimensions

Configurations

The StormFilter cartridge system can be housed in a variety of ways such that it suits the site specific requirements for flowrate, hydraulics, accessibility and footprint restrictions. The standard configurations offered by Ocean Protect include pre-cast concrete tanks, detention and above ground pre-fabricated tanks.

Pre-cast concrete StormFilter systems can house the cartridges within manholes, pits or vaults. These systems are simple to install, as they arrive on site after being manufactured offsite to suit site specific requirements (pipe size, inlet/outlet orientation, levels etc.).

Figure 4: Pre-cast concrete manholes

Alternatively detention tanks constructed for water quantity requirements, can incorporate the StormFilter system into the design. Typically a separated water quality chamber (cartridge bay area) is constructed inside the larger tank. With this approach Ocean Protect performs the installation of the underdrain pipework manifold within the chamber, including the encasement of it in a concrete false floor.

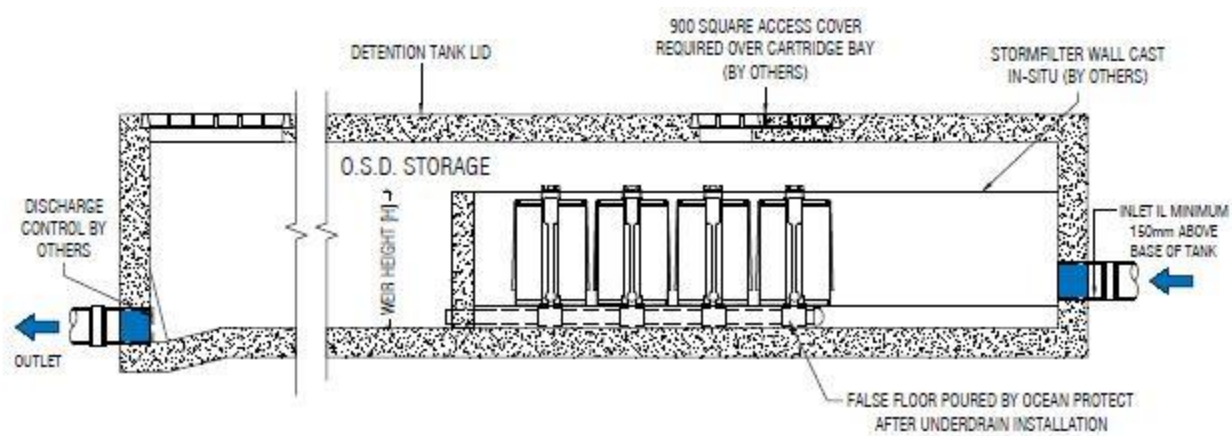

Figure 5: Detention system, sectional view

Above ground pre-fabricated tanks are also available, and are ideal for utilisation when treating downpipe flows. Often utilised when space is limited (boundary to boundary) they are available in both aluminium and HDPE and are custom built to suit the site specific requirements.

Figure 6: Aluminium StormFilter tank

Performance and Select Approvals

While laboratory testing provides a means to generate hydraulic and basic performance data, all filtration devices should also be complemented with long-term field data evaluations. As a minimum, field studies should generally comply with a recognised field testing protocol, for example, the Technology Acceptance Reciprocity Partnership (TARP) or the Technology Assessment Protocol – Ecology (TAPE) in the USA.

To be considered valid, all field monitoring programs should be peer reviewed by a reputable third party and replicate local pollutant concentrations including soluble fractions of nutrients together with rainfall. Ocean Protect has undertaken such field testing both locally in Australia and overseas, copies of the supporting articles are available upon request.

Globally there are over 220,000 StormFilter cartridges installed and since 2001 the StormFilter system has been successfully installed in a variety of applications to meet regulatory requirements set by authorities throughout Australia.

Specifically StormFilter has been accepted by some of the most stringent stormwater quality regulators around the globe including;

- Brisbane City Council
- Gold Coast City Council
- Blacktown City Council
- Washington State Department of Ecology (TAPE) GULD – Basic, Phosphorus
- New Jersey Department of Environmental Protection (NJ DEP)
- North Carolina Department of Environmental Quality (NC DEQ)
- Maine Department of Environmental Protection (ME DEP)

Please contact your Ocean Protect representative to obtain the StormFilter approval status in your area.

Maintenance

All stormwater quality improvement devices require routine maintenance. The question is how often and how much it will cost. Proper evaluation of long-term maintenance costs should be a consideration when selecting a treatment device. The StormFilter has been optimized to reduce long-term maintenance costs with proven, repeatable performance in the laboratory and in the field.

Reduce Life Cycle Costs

StormFilter has been designed for predictable maintenance intervals ranging from 1 to 3 years, resulting in fewer maintenance events and reduced life-cycle costs compared to other filtration devices.

Easy to maintain

All StormFilter structures provide access for inspection, media replacement, and washing of the structure. Visual indicators for maintenance are observable from the surface. Our Cartridge replacement program provides refurbished cartridges that are shipped to your site ready to install. Ocean Protect arranges for empty cartridges to be picked up and shipped back, reducing cartridge costs and environmental impact.

Maintenance support

Ocean Protect provides flexible options and contract terms. A detailed maintenance guide and mass load calculation spreadsheet is available upon request.

For further information please refer to the StormFilter Operations and Maintenance Manual (**click here**).

Design Basics

The design requirements of any StormFilter system is detailed in 3 typical steps.

1. Hydraulic Design
2. Water Quality Design
3. Mass Load Design

1. Hydraulic Design

All StormFilters must be designed to ensure that the hydraulic requirements of the system are met without adversely impacting the upstream hydraulics (limiting the likelihood of localised flooding). Table 1 (page 4) details the head loss for each cartridge size option. The designer must initially select a cartridge option and ensure the corresponding head loss can be catered for.

For a StormFilter system head loss does not have to equal head drop. If the head loss is not able to be fully achieved through a differential of height between the inlet and outlet pipes, then a minimum head drop of 100mm is required across the system with the balance of the head loss being impacted upstream. The minimum head drop is required to ensure that all inlet pipes enter the chamber above the concrete false floor.

StormFilter cartridges have a unique backflush mechanism that is passively activated at the end of each storm peak to increase the longevity of each cartridge. Consequently, captured pollutants are stored within the system and in order to minimise scour peak flows into the cartridge bay need to be limited. Specifically when peak flows surpass 80-100L/s StormFilter cartridges need to be arranged off-line.

It is also necessary to consider the impacts that tail water/submergence has on all stormwater treatment devices. In order to maintain an effective driving head for the StormFilter system the weir height should be adjusted accordingly. Please be aware that permanent submergence will blind all stormwater treatment devices utilising media. In the case of the StormFilter system, regardless of the storm intensity/duration the system will always drain relatively dry.

2. Water Quality Design

Ocean Protect recommends and uses the widely endorsed Model for Urban Stormwater Improvement Conceptualisation (MUSIC), which makes it easy to correctly sizing an appropriate StormFilter system for your site.

A complimentary design service which includes MUSIC modelling is provided by the Ocean Protect engineering team. Simply email your project details to design@oceanprotect.com.au or alternatively you can always call one of our engineers for a discussion or to arrange a meeting in your office. The team will provide you with an efficient design containing details of the devices required to meet your water quality objectives together with budget estimates, product drawings and the MUSIC (.sqz) file.

Alternatively, you can download the MUSIC treatment nodes for the Ocean Protect products from our website (www.oceanprotect.com.au).

When designing/modelling a StormFilter system for water quality purposes in MUSIC, two (2) treatment nodes are typically utilised in series. These are the detention/sedimentation node located immediately upstream of a generic treatment node.

For the detention node there are a number of parameters that need to be entered to ensure the node is representative of its effectiveness within the treatment train: surface area, extended detention depth, k-values, equivalent pipe diameter etc. For guidance on all of these variables please refer to the StormFilter design pack or contact Ocean Protect.

For the StormFilter system the generic treatment node is utilised with relevant removal efficiencies inserted. These parameters can vary based on the jurisdiction (authority) of your project, relevant details can be obtained from Ocean Protect. The high-flow bypass figure is adjusted within the node to represent the treatable flow rate required to obtain water quality targets. Once finalised this figure can be divided by the relevant cartridge flow rate to obtain the number of cartridges.

All details such as drawings, specifications and maintenance manuals can also be downloaded for integration into your project's documentation. Additionally the Ocean Protect team is available to review your model and provide additional assistance and guidance on the configuration of the StormFilter system(s) for your project.

3. Mass Load Design

At the completion of your water quality design process (as above) it is necessary that maintenance frequency is considered in order to prevent excessive ongoing maintenance requirements. Ocean Protect recommends a minimum maintenance frequency of 12 months.

All filtration devices occlude overtime, consequently they have a maximum sediment capacity (TSS load). By analysing the mean annual load figures for the StormFilter generic treatment node, the total annual retained TSS can be determined. To determine the minimum cartridge quantity required by mass load design, the annual retained TSS should be divided by the relevant cartridge sediment capacity. The Ocean Protect team can provide assistance and details on this process.

In determining the final cartridge quantity for your project, you must utilise the largest number of cartridges obtained from undertaking Water Quality and Mass Load design steps.

Appendix E StormFilter® Operation & Maintenance Manual

This appendix provides an operation and maintenance manual for StormFilter®, produced by Ocean Protect.

OCEAN PROTECT

StormFilter

Operations & Maintenance Manual

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Introduction

The primary purpose of stormwater treatment devices is to capture and prevent pollutants from entering waterways, maintenance is a critical component of ensuring the ongoing effectiveness of this process. The specific requirements and frequency for maintenance depends on the treatment device and pollutant load characteristics of each site. This manual has been designed to provide details on the cleaning and maintenance processes for the StormFilter as recommended by the manufacturer.

The StormFilter is designed and sized to meet stringent regulatory requirements. It removes the most challenging target pollutants (including fine solids, soluble heavy metals, oil, and soluble nutrients) using a variety of media. For more than two decades, StormFilter has helped clients meet their regulatory needs and, through ongoing product enhancements, the design continues to be refined for ease of use and improved performance.

Why do I need to perform maintenance?

Adhering to the inspection and maintenance schedule of each stormwater treatment device is essential to ensuring that it functions properly throughout its design life.

During each inspection and clean, details of the mass, volume and type of material that has been collected by the device should be recorded. This data will assist with the revision of future management plans and help determine maintenance interval frequency. It is also essential that qualified and experienced personnel carry out all maintenance (including inspections, recording and reporting) in a systematic manner.

Maintenance of your stormwater management system is essential to ensuring ongoing at-source control of stormwater pollution. Maintenance also helps prevent structural failures (e.g. prevents blocked outlets) and aesthetic failures (e.g. debris build up), but most of all ensures the long term effective operation of the StormFilter.

Health and Safety

Access to a StormFilter unit requires removing heavy access covers/grates, and it is necessary to enter into a confined space. Pollutants collected by the StormFilter will vary depending on the nature of your site. There is potential for these materials to be harmful. For example, sediments may contain heavy metals, carcinogenic substances or objects such as broken glass and syringes. For these reasons, all aspects of maintaining and cleaning your StormFilter require careful adherence to Occupational Health and Safety (OH&S) guidelines.

It is important to note that the same level of care needs to be taken to ensure the safety of non-work personnel. As a result, it may be necessary to employ traffic/pedestrian control measures when the device is situated in, or near areas with high vehicular/pedestrian activity.

Personnel health and safety

Whilst performing maintenance on the StormFilter, precautions should be taken in order to minimise (or, if possible, prevent) contact with sediment and other captured pollutants by maintenance personnel. The following personal protective equipment (PPE) is subsequently recommended:

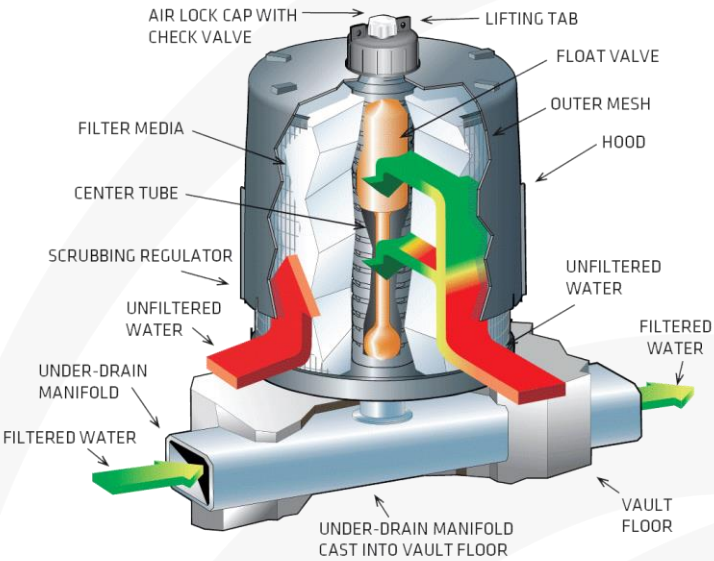
- Puncture resistant gloves
- Steel capped safety boots
- Long sleeve clothing, overalls or similar skin protection
- Eye protection
- High visibility clothing or vest

During maintenance activities, it may be necessary to implement traffic control measures. Ocean Protect recommend that a separate site-specific traffic control plan is implemented as required to meet the relevant governing authority guidelines.

Whilst some aspects of StormFilter maintenance can be performed from surface level, there will be a need to enter the StormFilter system (confined space) during a major service. It is recommended that all maintenance personnel evaluate their own needs for confined space entry and compliance with relevant industry regulations and guidelines. Ocean Protect maintenance personnel are fully trained and carry certification for confined space entry applications.

How does it Work?

Stormwater enters the cartridge chamber, passes through the filtration media and begins filling the cartridge center tube. When water reaches the top of the cartridge the float valve opens and filtered water is allowed to drain at the designed flow rate. Simultaneously, a one-way check valve closes activating a siphon that draws stormwater evenly throughout the filter media and into the center tube. Treated stormwater is then able to discharge out of the system through the underdrain manifold pipework.



As the rain event subsides, the water level outside the cartridge drops and approaches the bottom of the hood, air rushes through the scrubbing regulators releasing the water column and breaking the siphon. The turbulent bubbling action agitates the surface of the cartridge promoting trapped sediment to drop to the chamber floor. After a rain event, the chamber is able to drain dry by way of an imperfect seal at the base of the float valve.

Maintenance Procedures

To ensure optimal performance, it is advisable that regular maintenance is performed. Typically, the StormFilter requires an inspection every 6 months with a minor service at 12 months. Additionally, as the StormFilter cartridges capture pollutants the media will eventually become occluded and require replacement (expected media life is 1-3 years).

Primary Types of Maintenance

The table below outlines the primary types of maintenance activities that typically take place as part of an ongoing maintenance schedule for the StormFilter.

	Description of Typical Activities	Frequency
Inspection	Visual Inspection of cartridges & chamber Remove larger gross pollutants Perform minimal rectification works (if required)	Every 6 Months
Minor Service	Evaluation of cartridges and media Removal of accumulated sediment (if required) Wash-down of StormFilter chamber (if required)	Every 12 Months
Major Service	Replacement of StormFilter cartridge media	As required

Maintenance requirements and frequencies are dependent on the pollutant load characteristics of each site. The frequencies provided in this document represent what the manufacturer considers to be best practice to ensure the continuing operation of the device is in line with the original design specification.

Inspection

The purpose of the inspecting the StormFilter system is to assess the condition of the StormFilter chamber and cartridges. When inspecting the chamber, particular attention should be taken to ensure all cartridges are firmly connected to the connectors. It is also an optimal opportunity to remove larger gross pollutants and inspect the outlet side of the StormFilter weir.

Minor Service

This service is designed to ensure the ongoing operational effectiveness of the StormFilter system, whilst assessing the condition of the cartridge media.

1. Establish a safe working area around the access point(s)
2. Remove access cover(s)
3. Evaluate StormFilter cartridge media (if exhausted schedule major service within 6 months)
4. Measure and record the level of accumulated sediment in the chamber
   (if sediment depth is less than 100 mm skip to step 9)
5. Remove StormFilter cartridges from the chamber
6. Use vacuum unit to removed accumulated sediment and pollutants in the chamber
7. Use high pressure water to clean StormFilter chamber
8. Re-install StormFilter cartridges
9. Replace access cover(s)

Major Service (Filter Cartridge Replacement)

For the StormFilter system a major service is reactionary process based on the outcomes from the minor service, specifically the evaluation of the cartridge media.

Trigger Event	Maintenance Action
Cartridge media is exhausted[1]	Replace StormFilter cartridge media[2]

[1] Multiple assessment methods are available, contact Ocean Protect for assistance
[2] Replacement filter media and components are available for purchase from Ocean Protect.

This service is designed to return the StormFilter device back to optimal operating performance

1. Establish a safe working area around the access point(s)
2. Remove access cover(s)
3. By first removing the head cap, remove each individual cartridge hood to allow access to the exhausted media.
4. Utilise a vacuum unit to remove exhausted media from each cartridge
5. Use vacuum unit to remove accumulated sediment and pollutants in the chamber
6. Use high pressure water to clean StormFilter chamber
7. Inspect each empty StormFilter cartridges for any damage, rectify damage as required
8. Re-fill each cartridge with media in line with project specifications
9. Re-install replenished StormFilter cartridges
10. Replace access cover(s)

Additional Types of Maintenance

Occasionally, events on site can make it necessary to perform additional maintenance to ensure the continuing performance of the device.

Hazardous Material Spill

If there is a spill event on site, the StormFilter unit should be inspected and cleaned. Specifically, all captured pollutants and liquids from within the unit should be removed and disposed in accordance with any additional requirements that may relate to the type of spill event. Additionally, it will be necessary to inspect the filter cartridges and assess them for contamination, depending on the type of spill event it may be necessary to replace the filtration media.

Blockages

In the unlikely event that flooding occurs upstream of the StormFilter system the following steps should be undertaken to assist in diagnosing the issue and determining the appropriate response.

1. Inspect the upstream diversion structure (if applicable) ensuring that it is free of debris and pollutants
2. Inspect the StormFilter unit checking the underdrain manifold as well as both the inlet and outlet pipes for obstructions (e.g. pollutant build-up, blockage), which if present, should be removed.

Major Storms and Flooding

In addition to the scheduled activities, it is important to inspect the condition of the StormFilter after a major storm event. The focus is to inspect for damage and higher than normal sediment accumulation that may result from localised erosion. Where necessary damaged components should be replaced and accumulated pollutants should be removed and disposed.

Disposal of Waste Materials

The accumulated pollutants found in the StormFilter must be handled and disposed of in a manner that is in accordance with all applicable waste disposal regulations. When scheduling maintenance, consideration must be made for the disposal of solid and liquid wastes. If the filter media has been contaminated with any unusual substance, there may be additional special handling and disposal methods required to comply with relevant government/authority/industry regulations.

Maintenance Services

With over a decade and a half of maintenance experience Ocean Protect has developed a systematic approach to inspecting, cleaning and maintaining a wide variety of stormwater treatment devices. Our fully trained and professional staff are familiar with the characteristics of each type of system, and the processes required to ensure its optimal performance.

Ocean Protect has several stormwater maintenance service options available to help ensure that your stormwater device functions properly throughout its design life. In the case of our StormFilter system we offer long term pay-as-you-go contracts, pre-paid once off servicing and replacement media for cartridges.

For more information please visit www.OceanProtect.com.au

Appendix F Technical Papers Describing Stormwater Treatment Performance Monitoring of StormFilter®

Table 2-1 provides a summary of four (4) recent examples of StormFilter® operating in ‘real world’ conditions where treatment performance monitoring has been undertaken. This appendix provides technical papers describing the stormwater treatment performance monitoring undertaken for each of these sites.

Volume 38 No 6 SEPTEMBER 2011
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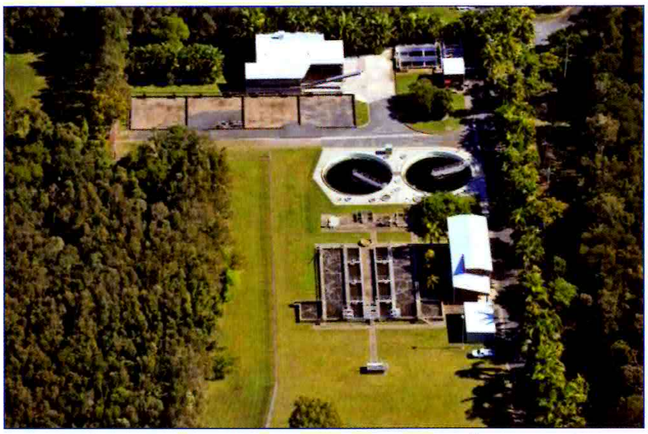
contents

Residents at Buru in Queensland map their water system. See page 73.



An aerial view of the Suncoast Sewage Treatment Plant. See page 58.

TECHNICAL FEATURES (INDICATES THE PAPER HAS BEEN REFEREED)

NUTRIENTS AND SOLIDS REMOVAL BY AN ENGINEERED TREATMENT TRAIN

Field evaluation of a gully pit insert and cartridge media filter

M Wicks, N Vigar, M Hannah

Abstract

The performance claims for individual stormwater treatment devices is often open to debate, as much of the data available has not been subjected to robust scrutiny and/or the claims are unable to be replicated. The following article summarises the results from a field trial of two such devices: an EnviroPod® and a StormFilter®, arranged in series (or a 'treatment train') treating runoff from a small road catchment on Streets Creek, Kuranda, west of Cairns in Far North Queensland.

This field trial complements an earlier research project undertaken on the same system by James Cook University. Data was collected from six storm events, predominantly during the dry seasons of 2008 and 2009, and includes simultaneous sampling of both the flow rate and water quality on the inflows to, and outflows from, the treatment train for a suite of particulate and soluble stormwater pollutants. Influent concentrations for both Phosphorus and Nitrogen were found to be half to one-third of concentrations reported in the literature as typical for urban catchments in Australia.

One storm was also analysed for an expanded suite of nitrogen analytes, which determined that more than half the load was in soluble form. Furthermore, results from the field trial and research project indicated that this treatment train system has the potential to achieve meaningful load reductions of Suspended Solids (up to 99%), Phosphorus (up to 70%) and Nitrogen (up to 45%) through the use of conventional screening, filtration and ion-exchange removal technologies.

Introduction

Livingston and McCarron (1992) identified that pollution loads (gross pollutants, sediment and nutrients) in stormwater increase proportionally with the degree of urbanisation in the catchment. Most consent authorities in Australia have established pollution removal efficiencies to be achieved prior to discharge from the urban catchment (eg, NSW Department of Environment and Climate Change (DECC) 2007 recommends Suspended Solids (SS) 85%, Total Phosphorus (TP) 65%, and Total Nitrogen (TN) 45%) and/or Event Mean Concentrations (EMCs) in any stormwater discharged into natural ecosystems (e.g. ANZECC 2000 recommends turbidity 2-15 Nephelometric Turbidity Units (NTU), TP 0.01 mg/L and TN 0.15 mg/L for river systems in tropical Australia).

In general, each pollutant is removed from the water column using a specific physical, chemical or biological process. Arranging these processes in sequence provides a treatment train approach that addresses and treats the whole pollutant load. There is, however, a paucity of published peer-reviewed scientific information validating the removal efficiency of each element or device used within a treatment train – let alone the performance of the treatment train itself. The research referred to herein provides information to validate the performance claims of an EnviroPod® gully trap and a StormFilter ® cartridge arranged in series as a treatment train.

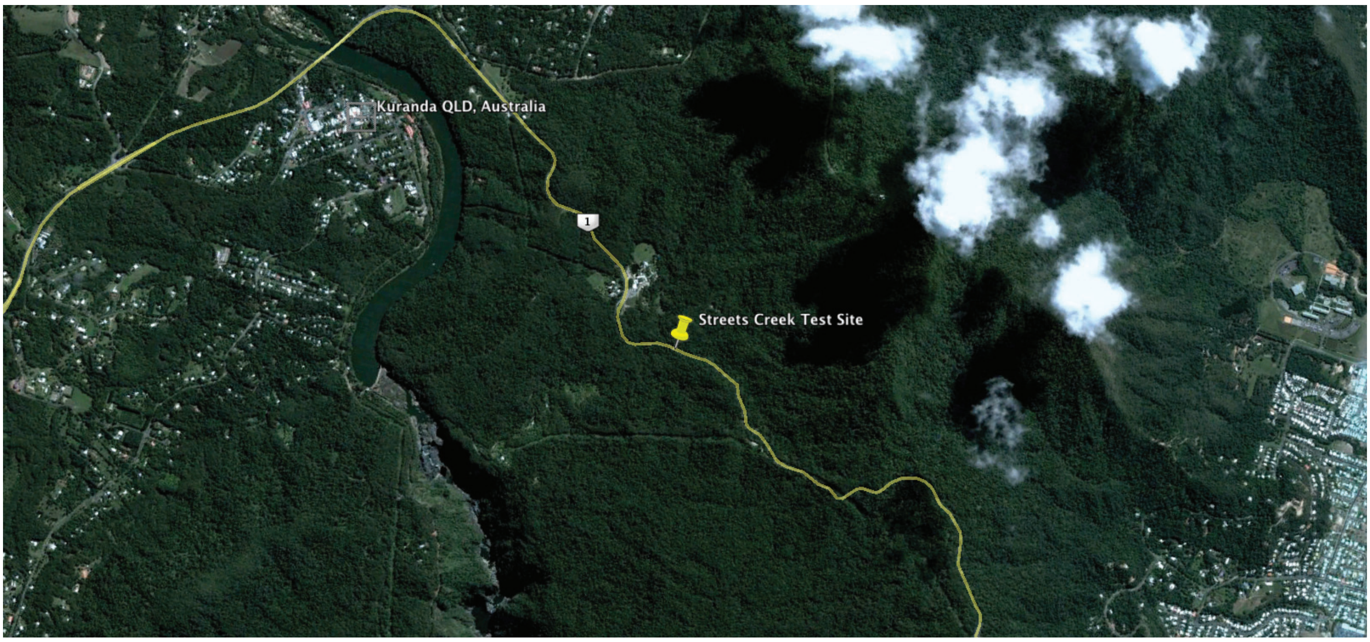


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Figure 1. Location of the Kuranda Test Site.

Background

This field trial follows a previous research project undertaken by the School of Earth and Environmental Sciences, James Cook University (JCU), as part of a wider investigation into the impacts of road runoff on the Kuranda Range Road watershed, near Cairns (Munksgaard and Lottermoser, 2008), which discharges into the sensitive environment of Streets Creek. JCU reported on the quality of the watershed's receiving waters, the chemical characterisation of the road runoff and the performance of the system over four runoff events.

JCU found that the system "had a high retention capacity for suspended sediment and by implication particulate metals". Conversely, they reported that the "treatment train" had only a "modest retention capability for dissolved (filtered) metals". In addition, JCU identified that the treatment train system was, in fact, responsible for a significant net export of zinc. On the basis of their data, nutrient levels in the road runoff were low, and do not constitute a water quality concern at Streets Creek. However, they also reported significant retention of both TN and TP. The JCU study, which, in their own words "do[es] not constitute a full evaluation of the EnviroPod/StormFilter treatment system", found the system achieved substantial removal of Total Nitrogen (45%), Total Phosphorus (70%), Total Aluminium (71%), Total Nickel (73%), Total Lead (60%) and Total Copper (58%). On the other hand, it identified potential releases of Suspended Solids under 500 microns, as well as dissolved zinc and copper.

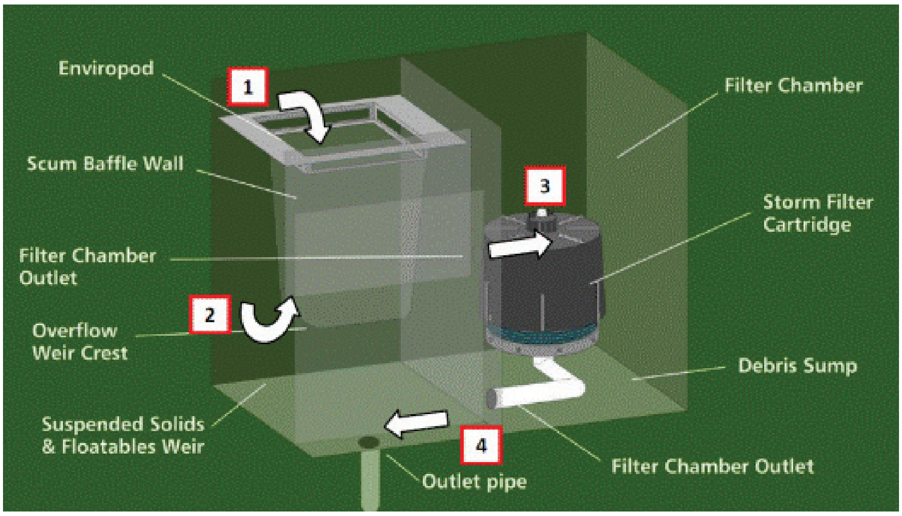

Figure 2. Schematic of the SYSTEM treatment train.

One explanation for the above-mentioned releases is that they could be related to the anaerobic conditions present in either the standing water within the wet-sump or, in the case of zinc, corrosion of the exposed galvanised protection on the steel components. Given the substantial removal of suspended solids, nutrients and total metals, it appears unlikely that the dissolved copper and zinc, observed in the outflows, was associated with a release of the under-500 micron sediment fraction.

It was largely to address these issues and better understand the sources of these copper and zinc releases that Stormwater360 undertook a further field evaluation of the treatment train system, which is the subject of this evaluation.

Table 1. Water quality analytical parameters.

Parameter	Abbreviation	Analytical Method*	Units	Limit of Reporting	Analysed by
Electrical Conductivity	EC	APHA 2510B	µS/cm	1	Cairns Water
pH	pH	APHA 4500-H+	-	0.1	Cairns Water
Suspended Solids above 500 microns	SS > 500 micron	500 micron sieve & APHA 2540B	mg/L	1	Cairns Water
Volatile Suspended Solids above 500 microns	SS Vol. > 500 micron	500 micron sieve & APHA 2540E	mg/L	0.1% Dry Solids	Cairns Water
Suspended Solids below 500 microns	SS < 500 micron	APHA 2540B; equiv. ASTM D-3977-97	mg/L	1	Cairns Water
Volatile Suspended Solids below 500 microns	SS Vol. < 500 micron	APHA 2540E	mg/L	0.1% Dry Solids	Cairns Water
Suspended Solids	SS	Calculated	mg/L	-	-
Volatile Suspended Solids	SS Vol.	Calculated	mg/L	-	-
Total Phosphorus	TP	APHA 4500-P	mg/L P	0.02	Cairns Water
Total Nitrogen	TN	APHA 4500-N	mg/L N	0.05	Cairns Water
Total Kjeldahl Nitrogen	TKN	Calculated	mg/L N	-	-
Ammonia Nitrogen (Ammonium Nitrogen)	NH3-N	APHA 4500-NH3	mg/L N	0.05	Cairns Water
Nitrate/Nitrite (Total Oxidised Nitrogen)	NO3-/NO2--N	APHA 4500-NO3	mg/L N	0.01	Cairns Water
Total Organic Carbon	TOC	APHA 5310-B	mg/L	1	ALS
Dissolved Organic Carbon	DOC	APHA 5310-B	mg/L	1	ALS
Particle Size Distribution (Laser Diffraction)	PSD	Malvern Mastersizer S	micron	0.05	QUT

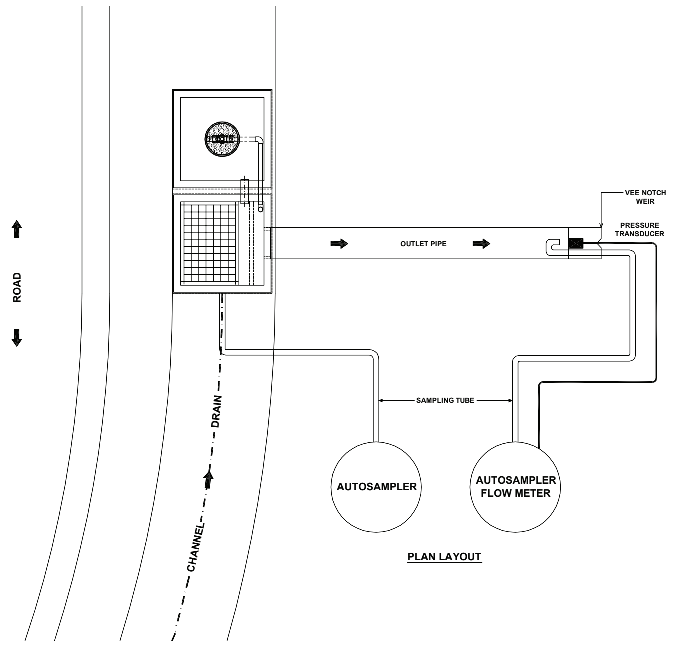

Figure 3. Schematic of the sampling location.

Sampling Procedure and Equipment

A graphical representation of the system is shown in Figure 2. The direction of flow through the gully pit insert (EnviroPod®) and into the cartridge media filter (StormFilter®) is shown in sequence from 1 to 4. The gully pit insert is intended to treat most flows and filter solids above 100 µm while containing contaminants in a dry state.

After treatment by the gully pit insert, water is filtered radially through the media cartridge (outside to inside). The media cartridge had a nominal flow rate of 0.95 L/s (at 46 cm head, when the cartridge is primed) and a peak flow rate of *ca.* 1.3 L/s (at maximum 0.88 m head prior to bypass). The ZPG™ media used was a proprietary blend containing perlite (50%), granular activated carbon (GAC, 10%) and zeolite (40%).

The system samples were collected using automated influent and effluent samplers (Figure 3), collecting continuous flow and precipitation data and water quality simultaneously. The influent sampler was programmed to send an SMS alert to Stormwater360, via the GSM cellular network, when the sampling program was triggered. A dial-up connection was then made to each sampler to download data for analysis.

To qualify as a representative sample, the following criteria were specified.

I. Collection of at least three simultaneous influent and effluent samples per storm;

II. Samples must have been collected while the treatment system operated within design flow rates (not in bypass);

III. The sampled portion of the storm event must represent at least 60% of the storm total flow volume;

IV. A minimum of six data sets must be collected for a full performance evaluation.

Antecedent dry period was not identified as a constraint, due to the impervious nature of the catchment and the absence of a base flow; however, at least a three-day antecedent dry period was preferred. If the storm was deemed to qualify, Stormwater360 would inform Cairns Water and Waste Laboratory Services (Cairns Water, NATA accreditation # 14204) that samples required collection and analysis. Analysis was performed by Cairns Water and Waste Laboratory Services, ALS Laboratory Group – Brisbane (ALS, NATA accreditation # 825). All water quality parameters for qualifying storms were sent to an independent peer reviewer at Queensland University of Technology (QUT), ensuring transparency of data. Test methods for water quality analysis used for this study are provided in Table 1.

Gross pollutants were not monitored as part of this study, although significant quantities were captured. Previous monitoring by White *et al*. (2001) demonstrated that the Enviropod® filter retained all (100%) litter up to an approach flow of 100L/sec.

Results and Discussion

The system was installed at the Streets Creek site in March 2006 and remained an active treatment and sampling site for four years until being decommissioned in March 2010. Stormwater360 monitored the system from April 2008 to December 2009. During this time, the unit was maintained annually, prior to the onset of each dry season. Complete maintenance involved removing all sediments and debris from the system, gully pit insert and replacing the cartridge media. The gully pit insert required additional manual maintenance approximately once per year.

Maintenance frequencies for the study were conducted in line with the systems standard operational lifecycle. Due to the nature of the catchment and size, there was an absence of a base flow or dry weather flows. Potential pollutant leaching of soluble contaminants was, however, still accounted for; organic debris left within the system was allowed to break down between maintenance periods and permitted to be sampled by the effluent sampler during storm events.

A summary of the principal analytes sampled is contained in Table 2.

Suspended Solids

ANZECC (2000), DECC (2007) and Fletcher *et al*. (2004) have identified suspended solids as a stressor of aquatic ecosystems. In addition, many of the other pollutants, such as metals, hydrocarbons etc, are transported attached to the suspended solids and sediment. The system achieved an SSC

Table 2. Summary of results.

Analyte	No. of events	Range of Influent EMCs (mg/L)	Median Influent EMC (mg/L)	Range of Effluent EMCs (mg/L)	Median Effluent EMC (mg/L)	Mean Removal Efficiency (Sum of Loads)
SSC	6	75 to 4384	1181	8 to 63	20	99%
SSC < 500 micron	6	48 to 180	105	8 to 62	20	78%
TP	6	0.08 to 0.19	0.123	0.02 to 0.15	0.055	47%
TN	6	0.6 to 1.5	1.045	0.2 to 0.9	0.615	44%
TKN	6	0.6 to 1.2	1.007	0.175 to 0.800	0.515	49%
NH3-N	6	0.05 to 0.15	0.050	0.05 to 0.07	0.050	31%
TOC	6	3 to 16	7	3 to 10	5	32%
DOC	6	3 to 12	7	3 to 11	6	21%

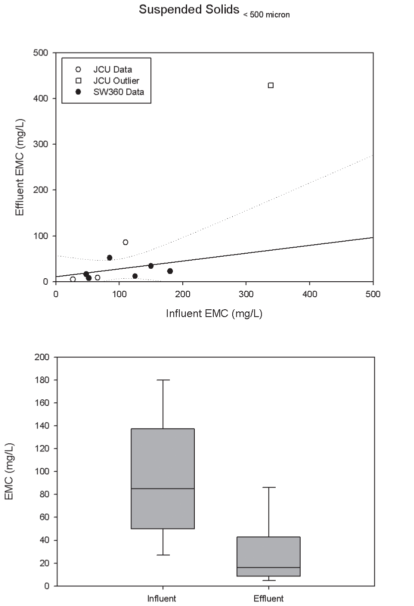

Figure 4. SS <500micron data (JCU + SW360).

aggregate load reduction of 99%. SSC (ie, SSC is defined as the sum of SS <500 micron and SS >500 micron) is 'suspended' in the sense that all these particles were sufficiently suspended to reach the system. However, SS <500 micron represents what is more commonly understood by the term 'suspended solids'. It excludes coarse settleable sediment, which, while being a management issue, does not represent such an acute threat to water quality.

Figure 4 shows influent and effluent data (Stormwater360) for SS <500 micron, together with the results published by JCU. In the scatter plot, the filled-in circles represent data from the trial reported herein, and open circles represent data from the previous JCU's research project. The exception is the JCU outlier represented as an open square, which has not been included in this evaluation. The line of best fit shown as a solid straight line was calculated by a least squares linear regression for all data points except the JCU outlier (intended to be informational only). Its relative slope provides an appreciation of the trend of the removal efficiency for the treatment train. The dotted curves represent the 95% confidence limits for these same data points. The true statistical significance of the regression lines is open to interpretation and requires further investigation, due to the limited number of data points available for this analysis.

Over the six storms analysed by Stormwater360, the influent EMC for SS <500 micron was in the range of 48 to 180 mg/L with a median influent EMC of 105 mg/L. Duncan (1999) literature review determined that the median concentration for most land uses (roofs excepted) lies between 71 mg/L (forested catchments) and 232 mg/L (urban roads). Fletcher *et al*. (2004) recommend using a value of *ca.* 120 mg/L for roads and *ca.* 100 mg/L for most other land uses. Both sources propose a median value of *ca.* 40 mg/L for forested catchments. The influent concentration of Suspended Solids at Streets Creek is within the typical range of average annual EMCs proposed within the literature; however, no data was collected during large wet-season storm events. Consequently, the median influent EMC reported herein should not be regarded as indicative of an annual median value.

Effluent EMCs recorded for SS <500 micron were in the range of 8 to 62 mg/L. The median effluent EMC was 20 mg/L. Mean removal efficiency for SS<500 micron, calculated by aggregate load reduction, was 78%. It is evident from Figure 4 that the Stormwater360 and JCU data sets are in relatively good agreement with each other, with the exception of the JCU outlier, which represents the first storm from JCU's research project. This storm was deemed an outlier for all water quality parameters due to possible sampling errors and has been removed from the analyses. The box plot in Figure 4 shows that the combined dataset is also clustered around an influent EMC of *ca.*100 mg/L and an effluent EMC of *ca.*20 mg/L. In practical terms, 10 mg/L approximates the system's irreducible EMC for under-500 micron suspended solids. The box plot in Figure 4 indicates that, over the course of two trials, the effluent EMCs from the system, were typically within the range of 10 to 40 mg/L.

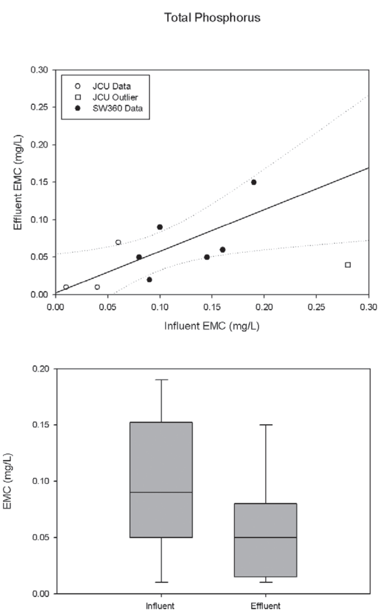

Figure 5. Total Phosphorus (SW360 and JCU combined).

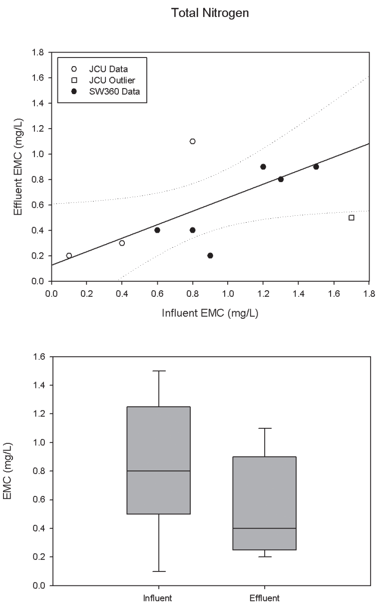

Figure 6. Total Nitrogen (SW360 and JCU combined).

Particle size distribution (PSD) by laser diffraction was performed for the SS <500 micron fraction for three storms during the Stormwater360 evaluation. Inspection of the three cases analysed consists of particles between *ca.* 10 microns and 200 microns in diameter. There is substantial variation between the three events.

- Storm 2 influent PSD centred at *ca.* 20 microns for a removal efficiency of approximately 65%;
- Storm 3 influent PSD centred at *ca.* 100 microns for a removal efficiency of approximately 85%;
- Storm 6 influent PSD centred at *ca.* 35 microns for a removal efficiency of approximately 75%.

Generally, the higher removal efficiency would be expected for the coarser samples, and this was the case for all three storms sampled.

Total Nutrients

The system achieved an aggregate load reduction for total phosphorus (TP) of 47% (note, JCU recorded a load reduction of 70%), the median influent and effluent EMCs for TP were 0.123 mg/L and 0.055 mg/L respectively (refer to Table 2). Duncan (1999) and Fletcher *et al.* (2004) recorded EMCs within a similar range and Fletcher (2004) recommends mean TP concentrations of between 0.25 and 0.50 mg/L for most land uses. Similarly, BMP Database (2010) suggests that a typical range for TP concentrations in stormwater is from 0.11 to 0.38 mg/L, across a range of land uses. In this context it is apparent that the influent TP concentration at the Kuranda site is towards the very low end of published data. Consequently, the 47%

Table 3. Nitrogen results from Storm 6.

Phase	Analyte	Influent EMC (mg/L)	Effluent EMC (mg/L)	Mean Removal Efficiency (Sum of Loads)
Total (dissolved and particulate)	TN	0.8	0.4	50%
	TKN	0.8	0.34	58%
	NH3-N	0.15	0.07	53%
	Org-N	0.65	0.27	58%
	NO3-/NO2--N	0.01	0.06	-500%
Dissolved	TN	0.4	0.3	25%
	TKN	0.39	0.23	41%
	NH3-N	0.16	0.073	54%
	Org-N	0.23	0.157	32%
	NO3-/NO2--N	0.01	0.07	-600%
Particulate (by calculation)	TN	0.4	0.1	75%
	TKN	0.41	0.11	73%
	NH3-N	0	0	N/A
	Org-N	0.41	0.11	73%
	NO3-/NO2--N	0	0	N/A

reduction recorded in the Stormwater360 trial could be related to the difficulty in removing TP at very low influent EMCs, and a much higher removal rate (similar to the 70% recorded by JCU) could be expected as the influent EMC increased.

The system achieved an aggregate load reduction for total nitrogen (TN) of 44%, while the median influent and effluent EMCs for TN were 1.045 mg/L and 0.615 mg/L respectively (Table 2). Again, this influent EMC is low with respect to most of the published data and, according to Duncan (1999), it correlates well with the median for data from forested catchments (0.95 mg/L), but is significantly lower than the median for roads (2.2 mg/L) or urban catchments (2.5 mg/L). Fletcher *et al*. (2004) recommends using a typical total nitrogen value of at least 2 mg/L for most land uses, with the exception of forested catchments.

The total nitrogen results from JCU and SW360 are presented in Figure 6. The spread of influent EMCs is broad, but removal efficiency appears relatively consistent and substantial. This is in spite of the low influent concentrations. TN is generally considered to be predominantly soluble, which is best removed by biological uptake or denitrification (in an anaerobic environment). Consequently, the consistent removal of TN exhibited by the system deserves further consideration. The majority (*ca.* 95%) of the total nitrogen load at Kuranda is TKN and a breakdown of TN species is contained in Table 3.

A small proportion of this TKN load (*ca.* 5%) is ammonia nitrogen, which implies that *ca.* 90% of the total nitrogen load is present as organic nitrogen, in either soluble or particulate forms. An expanded nitrogen suite analysis was conducted for Storm 6, and filtered (0.45 micron) and unfiltered samples were processed in order to establish whether the removal processes, for this event, involved particulate removal or removal of dissolved species. Essentially, the entire TN load was present as TKN and *ca.* 20% of this was ammonia-N (Table 3).

The entire ammonia-N load was soluble, and the treatment train system achieved 54% removal of this species. The remainder (*ca.* 80%) of the TN/TKN load was present as organic nitrogen, of which *ca.* 35% was dissolved. Overall, 73% removal of particulate organic nitrogen and 32% removal of dissolved organic nitrogen was achieved.

Given the removal efficiency for suspended solids, the high removal of particulate organic nitrogen is understandable. Removal mechanisms for dissolved organic nitrogen are less obvious. It is possible that there is some adsorption to the 'schmutzdecke' (bio-film) that develops on the cartridge; another possibility is removal under the anaerobic conditions within the standing water within the wet-zones, being the wet-sump and around the base of the cartridge.

When runoff first enters the StormFilter®, it initially displaces the standing water in the wet-zones. Any pollutants in the standing water are sampled by the effluent sampler (once they have passed through the StormFilter® cartridge), but they are not sampled by the influent sampler. Furthermore, the last of the runoff to enter the cartridge during a storm event does not necessarily pass through the filter cartridge during that event and may be retained within the wet-sump until the next storm event, whereupon it is displaced. When the (particulate or dissolved) organic nitrogen converts to ammonia in the anaerobic wet sump, it can be removed as ammonia-N by the zeolite.

Table 4. Grab samples from wet sump.

Date	Antecedent Dry Period (days)	Report #	Diss. Cu (mg/L)	Diss. Zn (mg/L)	DOC (mg/L)	Diss. N (mg/L)	Diss. NH3-N (mg/L)	Diss. NOx--N (mg/L)
07/07/2008	8	40627	0.011	0.053	17	-	-	-
20/02/2009	6	42998	0.001	0.016	-	2.4	2.39	<0.01
06/05/2009	19	43826	0.005	0.082	16	7.2	5.85	0.72
21/07/2009	79	44703	0.004	0.083	20	3.4	2.24	0.025

Periodic grab samples from the wet-sump indicate that most of the TN load in the standing water is present as ammonia-N at concentrations that are two orders of magnitude higher than typical influent ammonia-N concentrations. As such, ammonia-N is, possibly, generated in the wet-zones by anaerobic decomposition of organic nitrogen in the inter-storm event periods. This has two important implications: 1): the load of ammonia-N passed to the StormFilter® cartridge is significantly higher than is suggested by the influent EMC, which implies that the removal rates for ammonia-N removal may be an under-estimate; and 2): by converting organic nitrogen to ammonia-N in the wet-zones and then removing this ammonia, the system has the potential to remove soluble organic-N.

Discussion

The results for Storm 6 represent a snapshot of one storm, and should not be considered as comprehensive; they do suggest, however, that the main TN removal pathways for the treatment train is the efficient removal of particulate organic nitrogen, complemented by the sorptive removal of soluble ammonia-N and organic-N.

Very often TN removal is treated as a key performance benchmark for stormwater treatment practices. This is potentially problematic, given the apparent variation in the nature of the TN load. In a comprehensive study of nitrogen composition in Melbourne (Taylor *et al*., 2005), *ca.* 25% of the load was present as particulate organic nitrogen. The remainder was soluble and, of these species, oxidised nitrogen predominated over dissolved organic nitrogen and ammonia-N.

Taylor *et al*. (2005) inferred that either 'removing' the water by infiltration or denitrification (ie, in the anaerobic zone of bio-retention practices) would be necessary to achieve significant TN reduction. Fletcher *et al*. (2004) reported that the TN composition measured in wet weather samples for various land uses in the Sydney and Illawarra regions was extremely variable. For urban catchments, median oxidised nitrogen concentrations were in the range 0.09 to 0.42 mg/L, while the median TN concentration range was 0.65 to 2.32 mg/L.

The oxidised nitrogen represents a much smaller proportion of the TN load than was observed by Taylor *et al*. (2005) for Melbourne data. In a study of nutrient build-up on urban roads in the Gold Coast, Miguntanna *et al*. (2010) found that oxidised nitrogen comprised only *ca.* 10% of the TN load, across three different land uses, and most of the TN load was present as TKN and a significant proportion of this was particulate in nature. Consequently, the measured TN load from the Gold Coast catchments is similar to that measured at the Streets Creek, Kuranda site, providing applicability of Nitrogen removals to various urban land uses.

Conclusions

The results from this field trial generally correlate well with an earlier study at this site by JCU (Munksgaard and Lottermoser, 2008). The data collection from this study has been based on a rigorous and technically demanding monitoring program, which adds further credibility of the results (Goonetilleke, 2010). From an operational perspective, the system captured an appreciably large sediment load requiring annual cleaning to maintain its operational effectiveness.

The EnviroPod®/StormFilter® treatment train achieved 78% removal for suspended solids under 500 microns, which approximates the long-term environmental target recommended by NSW DECC (2007), QLD DERM (2010) for South East Queensland (SEQ) and consistent with the 80% reduction target of many consent authorities in the US.

The runoff at Streets Creek contained very low levels of phosphorus and nitrogen. Total Phosphorus removal was between 45% and 70% respectively in both the Stormwater360 field trial and the JCU research project, which approximates the NSW DECC (2007) and QLD DERM (2010) SEQ long-term environmental targets of 65% and 60% respectively, and is better than expected given the low influent EMCs. Total Nitrogen removal was consistent, substantial and in agreement with the NSW DECC (2007) and QLD DERM (2010) SEQ 45% long-term environmental target, despite the proximity of the influent EMC to the irreducible concentration of the treatment train. The removal of nitrogen was particularly noteworthy, given that the debris captured and stored within the treatment train was not included in the influent load into the system, but may have been sampled as a soluble leachate by the effluent sampler.

Acknowledgements

The authors would like to acknowledge the support of and contributions by Professor Ashantha Goonetilleke and Geoffrey Hunter.

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SOLID AND NUTRIENT POLLUTANT REMOVAL BY AN ENGINEERED STORMWATER FILTRATION MEDIA

Field evaluation of a radial cartridge media filter

M Wicks, J Lenhart, J Pedrick

ABSTRACT

This paper provides a summary of the results associated with a 20-month field study conducted at the Mitchell Community College test site located in the town of Mooresville, North Carolina, USA. The study was conducted to demonstrate the effectiveness of a radial cartridge filtration system (RCFS) using an activated alumina media, treating stormwater runoff with respect to the removal of solid and nutrient pollutants.

Testing of the RCFS was conducted for a suite of pollutants, including Total Suspended Solids (TSS), Total Phosphorus (TP) and Total Nitrogen (TN) in accordance with an approved Project Plan.

Results from the study indicated that the RCFS, operating at 0.5L/s per cartridge, successfully treated stormwater runoff with significant reductions for solid and nutrient pollutants that were observed between influent and effluent sampling locations using the Efficiency Ratio (ER) calculation (TSS 90%, TP 86%, and TN 56%) and Summation of Load (SOL) efficiency calculation methods (TSS 91%, TP 87%, and TN 50%). These results demonstrate that the radial cartridge filter system was able to successfully meet the current load-based objectives from the NSW DECC (2007) and QLD Single State Planning Policy (2014) for all relevant pollutants, including TSS, TP and TN.

Keywords: BMP, stormwater, TP, TN, TSS, activated alumina, media filter cartridge.

INTRODUCTION

This field trial complements previous studies undertaken on the RCFS utilising alternative filtration media in both North America and Australia. RCFS have previously demonstrated significant removal of both phosphorus and nitrogen (about 44%) on a SOL basis (Wicks *et al.*, 2011) using a granular perlite, zeolite and carbon filtration media blends. Similar to blended filtration media, activated alumina media employs both physical as well as chemical filtration characteristics to promote adsorption of pollutants such as dissolved phosphorus (Ma, 2011). The legislated removal requirements of both phosphorus and nitrogen have become commonplace in Australia, for example the Queensland Planning Policy (DSDIP, 2014) for the treatment of stormwater from development sites.

Although the stormwater treatment objectives for TSS, TP and TN have been commonplace in Australia, reliable and transferrable data from robust field assessments in other regions can seldom be accomplished due to variations in climatic conditions, particle size distribution of solids and soluble fractions of nutrients. For example, Wong and Walker (2009) found that the particle size distributions range on Australian roadways were between approximately 2 and 500 microns.

This research provides information for a range of particle size distributions for suspended solids, together with both soluble and particulate fractions of both phosphorus and nitrogen at mean concentrations that can be compared to the Australia context, to validate the performance of the activated alumina in the RFCS.

The RCFS, as seen in Figure 1, is typically comprised of a vault that houses rechargeable, media-filled filter cartridges. Stormwater entering the system percolates horizontally through these media-filled cartridges, where pollutant removal processes occur. Once filtered through the media, the treated stormwater is directed to a collection pipe and/or discharged to the receiving water.

The Mitchell Community College testing site is located in the town of Mooresville, North Carolina; it is owned and operated by Mitchell Community College and is used for parking. The site is 68% impervious and the total drainage area for the site is 4,370m^2. A view of the finished parking lot located on site can be seen in Figure 2. Stormwater runoff from the contributing drainage area is directed to the RCFS for treatment before eventually discharging.

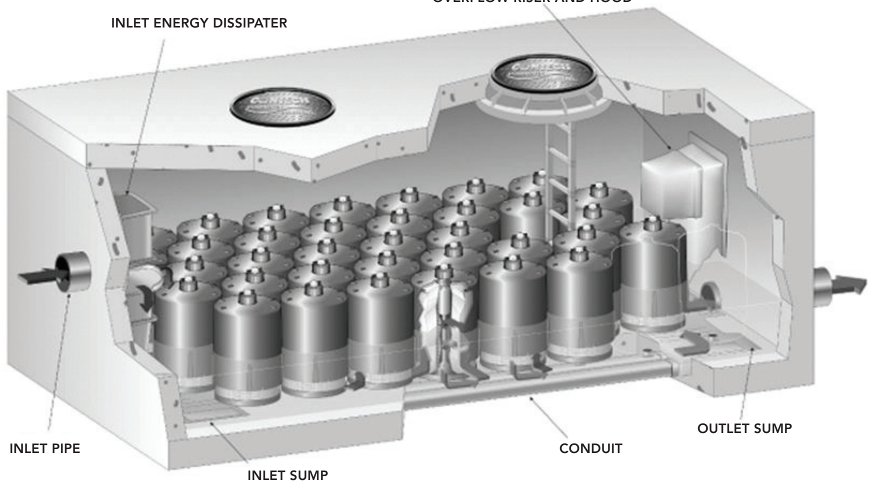

Figure 1. Diagram of an RFCS system.

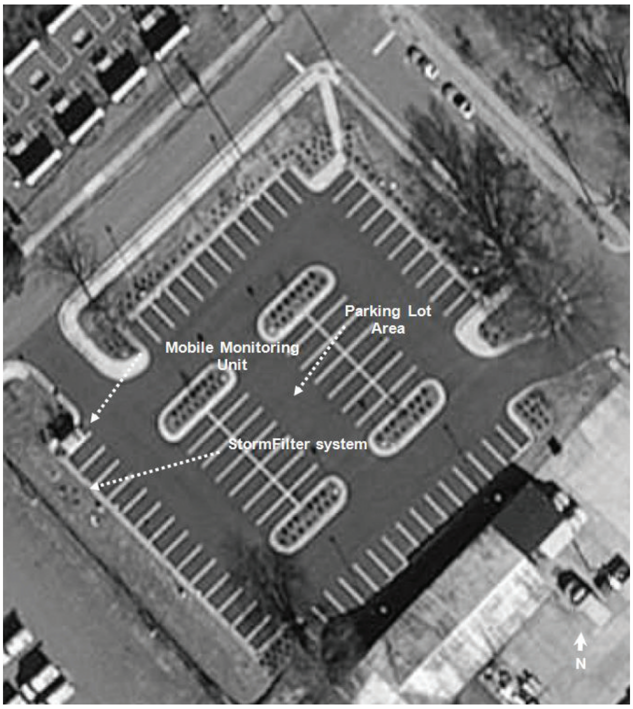

Figure 2. Aerial view of the testing site.

The RCFS was designed as a capture-and-treat system. The storage component of the system (tank) is a 750mm diameter corrugated metal pipe (CMP) network designed to capture 75% of the calculated water quality volume (i.e. the runoff associated with a 25mm event).

The treatment component (StormFilter) was designed on a mass-loading basis required to meet the annual pollutant loading requirements of the site with a minimum estimated interval between maintenance of one year. The estimation of the yearly maintenance was based on a predictive probabilistic assessment of the sediment load entrained within the stormwater runoff from the site. Although the cartridges were maintained on a yearly basis, a qualitative assessment undertaken at the time of the cartridge exchange did not indicate that any bypassing of treatment occurred due to filter occlusion. The yearly maintenance frequency is unremarkable, given the detention tank upstream and the RCFS's passive surface cleaning mechanism, which activates at least once during every runoff event and deposits the waste on the floor of the cartridge bay.

The RCFS system contained a total of eight, 460mm high, media-filled filter cartridges operating at a flow rate of 0.5L/s per cartridge. Each of the filter cartridges was filled with an activated alumina media. The media used for this study was a granular perlite coated with activated alumina; this was done to aid in the attenuation and/or capture of nutrient pollutants by cation exchange and adsorption. With the exception of the surface coating, coated and uncoated perlite media were determined to be identical with respect to physical characteristics and therefore the media should be considered equivalent with respect to expected solids removal performance.

METHOD

The Mitchell Community College RCFS installation was evaluated over a 20-month period following system maintenance in November 2010. Independent oversight of all aspects of the project was provided by Ryan Winston, MS, Extension Associate Engineer in the Department of Biological and Agricultural Engineering at North Carolina State University.

Sample handling services (sample retrieval, system reset and sample submittal) were provided by Pace Analytical Services (Pace) and laboratory work was conducted by Pace and Test America. Precipitation was measured with a tipping bucket-type rain gauge. Influent and effluent water quality samples were collected by portable automated samplers simultaneously collecting flow, precipitation and water quality samples. Each automatic sampler was connected to the cellular network for remote communication and data access.

The influent sampler was equipped with an area velocity flow module with low profile sensor for flow analysis and influent sample pacing. The effluent sampler was equipped with a bubbler flow module used in conjunction with a weir for flow analysis and effluent sample pacing. Sample strainers and flow

measurement equipment were secured to the invert of the influent and effluent pipes using stainless steel spring rings.

Following a precipitation event, composite samples were submitted for analysis according to accepted, relevant EPA, ASTM (Suspended Sediment Concentration) and SM254D (TSS) methods. The field monitoring methods used for this study represent the current state-of-the-art practice and are similar to those used by researchers in North Carolina to evaluate vegetated stormwater treatment systems.

To obtain a better understanding of RCFS performance with respect to solids, the portion of SSC (Suspended Sediment Concentration) particles smaller than 500µm and 2000µm was also determined.

For each of the 13 qualifying storm events sampled between November of 2010 and June of 2012:

1. The total rainfall was greater than 2.5mm for each event sampled;
2. The minimum inter-event period was greater than six hours for all storm events sampled;
3. The minimum number of influent and effluent aliquots collected per storm event was five;
4. Seven influent flow-weighted composite samples covered ≥ 50% of the total storm flow, while six covered between 34% and 49%; effluent flow-weighted composite samples covered ≥ 50% of the total storm flow for all storm events sampled.

Performance was calculated using the Efficiency Ratio (ER) efficiency calculation method. The ER method defines the efficiency as the average event mean concentration of pollutants over some time period.

$$ER = 1 - \frac{mean\ effluent\ EMC}{mean\ influent\ EMC}$$

The ER method assumes: 1) The weight of all storm events is equal, regardless of the relative magnitude of the storm event; and 2) that if all storm events at the site had been monitored, the average inlet and outlet EMCs would be similar to those that were monitored (URS/ EPA, 1999). ER results for each parameter in the 13 events sampled are summarised in Table 1.

Performance was also calculated using the Summation of Loads (SOL) efficiency calculation method. The SOL method defines the efficiency as a percentage based on the ratio of the summation of all influent loads to the summation of all effluent loads.

$$SOL = 1 - \frac{sum\ of\ all\ effluent\ loads}{sum\ of\ all\ influent\ loads}$$

The SOL method assumes: 1) Monitoring data accurately represents the actual entire total loads in and out of the BMP for a period long enough to overshadow any temporary storage or export of pollutants; and 2) Any significant storm events that were not monitored had a ratio of inlet to effluent loads similar to the storms events that were monitored (URS/EPA, 1999). In an effort to eliminate the introduction of potential bias associated with observed discrepancies between influent and effluent measured volumes, it was assumed that the influent volume was equal to the effluent volume. Measured effluent volume was used to calculate loads for both the influent and effluent sample locations.

RESULTS AND DISCUSSION

Monitoring 13 storm events over a 20-month period resulted in the collection of cumulative rainfall representing 704mm. Comparison of the measured rainfall intensities is not wholly representative of that found in Australia due to varying climatic regions. The presence, however, of upstream storage attenuates flows from all storms such that differences in rainfall intensities are not a significant factor on treatment performance and pollutant wash-off. Full treatment flow through each RCFS is not achieved until the water level inside the chamber reaches a height of 460mm. At this water elevation a siphon is activated and the cartridge throughput of 0.5L/s per cartridge is achieved, regardless of the rainfall intensity.

Non-parametric statistical methods were used to evaluate correlations and differences between non-transformed influent and effluent event mean concentrations (EMCs), since influent and effluent EMCs were generally not from the same statistical distribution due the complex nature and variability of stormwater monitoring. To test for positive correlations between influent and effluent EMCs, the Spearman Rank Order Correlation test was used (USGS, 1991). To evaluate the significance of differences between influent and effluent EMCs, the Mann-Whitney Rank Sum Test was used (USGS, 1991).

For the Mann-Whitney Rank Sum Test the null hypothesis was that the two samples were not drawn from populations with different medians. A significant difference between influent and effluent EMCs was concluded when $P<0.05$. Based on the use of the

Table 1. Summary of results.

Analyte	no. of events	Range of Influent EMCs (mg/L)	Median Influent EMC (mg/L)	Mean Influent EMC (mg/L)	Range of Effluent EMCs (mg/L)	Median Effluent EMC (mg/L)	Mean Effluent EMC (mg/L)	Mean Removal Efficiency (Sum of Loads)	Efficiency Ratio (ER)
SSC < 2000 micron	12	17.7 - 2080.0	53.4	231	1.9 - 7.2	3.4	3.9	98.3%	98.3%
SSC < 500 micron	12	9.0 - 393.0	28.6	66.1	1.7 - 10.0	2.8	4.4	93.7%	93.4%
TP	11	0.065 - 0.9	0.14	0.223	0.025 - 0.058	0.025	0.031	87.1%	86.1%
PP	9	0.019 - 0.225	0.06	0.083	0.0 - 0.033	0.0	0.007	96.4%	91.3%
DP	9	0.025 - 0.850	0.054	0.155	0.025 - 0.160	0.025	0.04	67.3%	74.2%
TN	10	0.035 - 2.95	0.85	1.00	0.35 - 0.82	0.35	0.44	50.2%	55.9%
TKN	11	0.25 - 2.70	0.72	0.94	0.25 - 0.58	0.25	0.28	60.9%	70.2%
NH3-N	11	0.05 - 0.72	0.21	0.27	0.05 - 0.24	0.05	0.10	60.0%	62.8%
NOx	10	0.10 - 0.35	0.16	0.17	0.10 - 0.35	0.10	0.16	11.2%	9.8%

Spearman Rank Order correlation test, positive correlations ($P<0.05$) were determined between influent and effluent EMCs for Ortho-P and NH_3+. Based on the use of the Mann-Whitney Rank Sum test, the difference in the median values between the influent and effluent EMCs is greater than would be expected by chance. Therefore, a statistically significant difference ($P<0.05$) was observed for TSS, SSC (<2000µm), SSC (<500µm), TP, PP, TKN, TN, and ON.

SUSPENDED SOLIDS PARAMETERS

Under Australian conditions Walker and Wong (1999) found that most suspended solids in stormwater runoff is smaller than 500µm. In this study the closest parameter was SSC<500µm. Influent EMCs for SSC <500µm ranged from 9mg/L to 393mg/L with a median of 29mg/L and a mean of 66mg/L. Corresponding effluent EMCs ranged from 2mg/L to 10mg/L with a median of 3mg/L and a mean of 4mg/L, resulting in an ER of 93% and a SOL efficiency of 94%.

This result needs to be explained in context with lower than expected influent concentrations. High pollutant concentrations lead to high percentage reductions and tend to over-estimate the removal efficiency of pollutants from stormwater treatment systems (CSIRO, 2010). A literature review by Duncan (1999) showed that the median influent concentration for total suspended solids ranged from the lowest 41mg/L for roofs to 232mg/L for urban roads. Fletcher (2004) found that mean influent concentrations for roofs to roadways ranged from 20mg/L to 270mg/L.

PHOSPHORUS PARAMETERS

Given that the phosphorus removal target in the Australian context is based solely on TP load removal efficiency, the review of additional data was required to further demonstrate the significance of the RCFS TP removal efficiencies obtained. In an effort to isolate phosphorus removal efficiency based on solubility of TP, dissolved phosphorus was also measured. Removal efficiencies for TP and dissolved P were 86% and 74%, respectively, using the ER method *cf* 87% and 67%, using the SOL efficiency calculation method.

The removal of dissolved phosphorus is unsurprising but warrants further discussion. Traditional forms of treatment such as settling and inert filtration are able to remove particulate bound phosphorus, but are ineffective at removing soluble phosphorus. The absorptive filtration properties of the activated alumina media provides further removal mechanisms of total phosphorus in stormwater through the synergistic effects of precipitation, adsorption and filtration (Ma, 2009).

These results not only demonstrate that the system was able to provide substantial and consistent removal, given the high solubility of phosphorus and at low mean influent concentration for the study of 0.22mg/L, but was able to attenuate TP captured by the system over the entire course of the study. The soluble fraction appears to be higher than found by Vaze and Chew (2004) under Australian conditions; they estimated that 20 to 30% of the phosphorus is soluble. It would be expected, given the primary removal mechanism of the RCFS is physical filtration, that a higher particulate fraction of phosphorus would yield a similar result.

Fletcher *et al.* (2004) measured mean TP concentrations of between 0.25 and 0.50mg/L for most land uses while the BMP Database (2010) suggests a typical TP range 0.11 to 0.38mg/L, across a variety of land uses. Clearly the mean influent TP concentration of 0.22mg/L for this study correlates well with the published data from Australia. In addition, the removal processes of physical straining and adsorption are independent of location and solely a function of water chemistry, filtration media and associated hydraulic conductivity. Hence our results should apply to Australian stormwater.

NITROGEN PARAMETERS

Given that the nitrogen removal target in the Australian context is based solely on TN load removal efficiency, the review of additional data was required to further demonstrate the significance of the RCFS TN removal efficiencies obtained in this study. In an effort to further isolate nitrogen removal efficiency NH_3+ was also measured. Removal efficiencies based on NH_3+, led to overall removal efficiency of 63% based on the ER and 60% using the SOL efficiency calculation method.

There are several pathways in which ammonium reduction may be occurring in the RCFS system that require further discussion. During the manufacturing process of the activated alumina media, aluminium oxide powder is mixed with clay to form a slurry, which is coated and then baked onto the perlite media. In operational conditions at low cartridge flow rates, the RCFS also has the ability to physically remove clay particles in addition to the clay found within the media from the manufacturing process. Substitution of silica by aluminum in soil clay particles causes clays to have a negative charge (Cornell University, 2007). Because of this negative charge at sites on or within the media structure, we expect that the media would provide some sorptive capacity and affinity for ammonium. The characteristics of the media would also result in an increase in pH. This increase in pH would cause the ammonium to convert to ammonia and then volatilise into the atmosphere.

Fletcher *et al*. (2004) measured nitrogen concentrations of at least 2mg/L for most urban land uses within Australia, while Duncan (1999) determined median concentrations for roads and urban catchments of 2.2 to 2.5mg/L. In Melbourne, Taylor *et al*. found that, for TN in stormwater, 49% consisted of dissolved inorganic nitrogen (NH_3+ and NO_x), which compares well with the 44% dissolved inorganic nitrogen load from the RCFS study. The soluble component of nitrogen in stormwater found by Wicks *et al*. (2011) and Miguntanna *et al*. (2010) from roadways and commercial areas in Queensland was 50 to 60%. Vaze and Chew (2004), also under Australian conditions, found that the soluble portion of nitrogen in stormwater can be up to 50%. In the RCFS study, soluble organic nitrogen was not measured; however, assuming a modest allowance for soluble organic nitrogen the soluble component of nitrogen in stormwater for the RCFS study would be expected to be similar to results from Australian studies.

CONCLUSIONS

Between April 2011 and June 2012, 13 storm events were monitored and were determined to meet the relevant USA storm data collection requirements. Significant reductions in sediment and nutrient pollutant concentrations were measured between influent and effluent sampling locations using the Efficiency Ratio (ER) calculation method (TSS 90%, TP 86%, and TN 56%) and Summation of Load (SOL) efficiency calculation method (TSS 91%, TP 87%, and TN 50%). These results demonstrate that the radial cartridge filter system was able to successfully meet the current load-based objectives from the NSW DECC (2007) and QLD Single State Planning Policy (2014) for all relevant pollutants, including TSS, TP and TN.

Results from the 20-month study, that represented 704mm of precipitation, show that the RCFS tested was effective in removing solid and nutrient pollutants from the stormwater runoff. This study was completed using the recommended design criteria based on an individual cartridge flow rate of 0.5L/s, activated alumina media, and a volume-based design methodology. The RCFS was designed to capture and treat 75% of the calculated water quality volume (i.e. the runoff volume associated with a 25mm event). The RCFS was also designed on a mass-loading basis to meet the annual pollutant loading requirements of the site with a minimum expected interval between maintenance of one year.

The fraction of soluble nitrogen found in this study is in good agreement with the Australian data. The influent concentrations, however, are at the lower end of the Australian data. CSIRO (2010) found that higher influent concentrations lead to higher percentage removals and, in this context, we would expect results of the RCFS study to be conservative when applied under Australian conditions.

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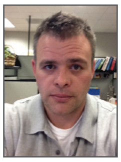

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Mitchell Community College
Stormwater Treatment System Field Evaluation:

Stormwater Management StormFilter® with PhosphoSorb Media at 1 gpm/ ft^2

Abstract

This report presents the results of a twenty month field study conducted at The Mitchell Community College testing site located in the Town of Mooresville, NC. The study was conducted in an effort to demonstrate the effectiveness of The Stormwater Management StormFilter® (StormFilter) Stormwater Treatment System (system) in treating stormwater runoff with respect to the removal of solid and nutrient pollutants.

Testing of the StormFilter system was conducted for Total Suspended Solids (TSS), Suspended Sediment Concentration (SSC), Total Volatile Suspended Solids (TVSS), Total Phosphorus (TP), Dissolved Phosphorus (Diss. P), Ortho-phosphate (Ortho-P), and Particulate Phosphorus (PP) in accordance with the approved Project Plan, (Contech, 2010) as well as the conditions outlined in the North Carolina Department of Environment and Natural Resources (NCDENR) Division of Water Quality (DWQ) Preliminary Evaluation Period (PEP) program, (NCDENR, 2007).

Results from the twenty month study, that represented a total of 13 storm events and 23.73 inches of precipitation, show that the StormFilter system tested was highly effective in removing solid and nutrient pollutants from stormwater runoff. Significant reductions for solid and nutrient pollutants were observed between influent and effluent sampling locations using the Efficiency Ratio (ER) efficiency calculation (TSS 90.4% and TP 86.1%) and Summation of Load (SOL) efficiency calculation methods (TSS 90.9% and TP 87.1%).

Keywords

BMP; stormwater; TP; TSS; NCDENR DWQ PEP; StormFilter; media filter cartridge

Introduction

Contech Engineered Solutions LLC (formerly Contech Construction Products Inc., Stormwater360 Inc., and Stormwater Management Inc.) is the leading provider of innovative, long-term, stormwater treatment solutions, offering a variety of products, maintenance, laboratory, and engineering support to meet stormwater treatment needs. Contech Engineered Solutions LLC's patented product, the Stormwater Management StormFilter® (StormFilter) Stormwater Treatment System (system) is a Best Management Practice (BMP) designed to meet federal, state, and local requirements for treating stormwater runoff in compliance with the Clean Water Act. The StormFilter system improves the quality of stormwater runoff before it enters receiving waterways through the use of customizable filter media, which removes non-point source pollutants, including sediment particles, oil and grease, soluble metals, nutrients, and organics.

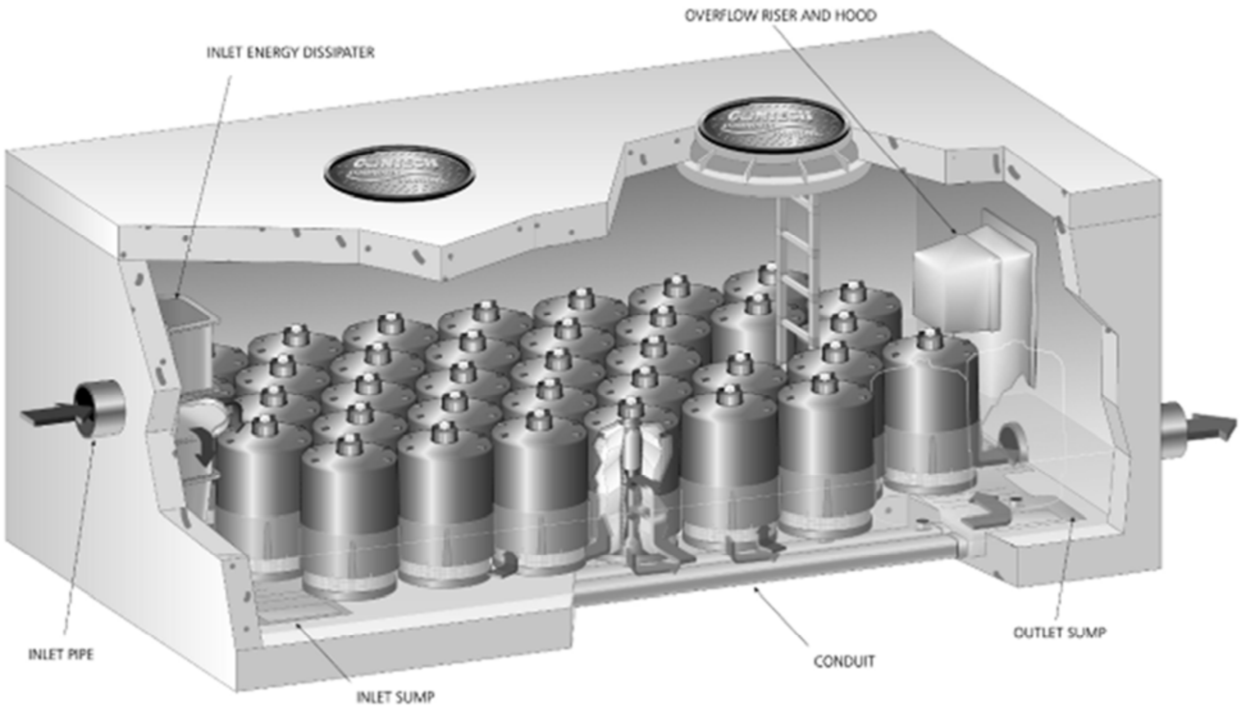

Figure 1. Standard StormFilter® Configuration.

The StormFilter system, as seen in Figure 1, is typically comprised of a vault that houses rechargeable, media-filled, filter cartridges. Stormwater entering the system percolates horizontally through these media-filled cartridges, where pollutant removal processes occur. Once filtered through the media, the treated stormwater is directed to a collection pipe and discharged to an open channel drainage way or storm sewer.

The StormFilter system is offered in a variety of configurations or containers depending on the specific application and site conditions: precast vault, box culvert vault, panel vault, manhole, and cast-in-place concrete. The StormFilter system is also offered in a steel catch basin or a concrete curb inlet configuration. The precast, manhole, and inlet configuration models utilize standard pre-manufactured units and arrive at the construction site with the filter cartridges and other internal components already in place to ease the installation process; the box culvert, panel vault, and cast-in-place units are customized for larger flows and require installation of cartridges at the site.

The Mitchell Community College StormFilter system installation (located in Mooresville, NC) was evaluated over a twenty month period following system maintenance in November of 2010. This project was managed by Contech in cooperation with the site owner and the North Carolina Department of Environment and Natural Resources (NCDENR) Division of Water Quality (DWQ). Independent oversight of all aspects of the project was provided by Ryan Winston, M.S., Extension Associate Engineer in the Department of Biological and Agricultural Engineering at North Carolina State University. Independent sample handling services were provided by Pace Analytical Services (Pace) of Huntersville, NC, and independent laboratory work was conducted by Pace and Test America of Beaverton, OR. Monitoring over a twenty month period resulted in the collection of 13 qualified storm events representing 23.73 inches of cumulative precipitation.

Site and System Description

The Mitchell Community College testing site is located in the Town of Mooresville, NC. Mooresville is located in southern Iredell County in the Piedmont region of North Carolina. The town is located between the Charlotte metropolitan area and the city of Statesville, the County seat. Mooresville is located within 15 miles of three interstate highways and is approximately 23 miles from the Charlotte-Douglas International Airport. The testing site was located at the intersection of West Moore Avenue and North Academy Street, (Lat: 35°35'3.60"N, Lon: 80°48'47.76"W, Elevation AMSL: 862ft). The site was owned and operated by Mitchell Community College and used primarily for parking. The site was swept periodically, however minor amounts of sediment and organic debris were typically present on site. Based on information provided by the design engineer, the site was 68% impervious and the total drainage area for the site was 1.08 acres. An aerial view of the site from 2010 is shown in Figure 2. Stormwater runoff from the contributing drainage area was directed to the StormFilter system before eventually discharging into Reed’s Creek Basin and ultimately Lake Norman.

Stormwater treatment for the site was provided by a StormFilter system, designed as a capture-and-treat system. The storage component of the system (tank) was comprised of a 30 inch diameter corrugated metal pipe (CMP) network designed to capture 75% of the calculated water quality volume (i.e. the runoff volume associated with the 1.0 inch event). The treatment component (StormFilter) was designed on a mass-loading basis and was required to meet the annual pollutant loading requirements of the site with a minimum estimated interval between maintenance of 1 year. The StormFilter contained a total of eight 18 inch tall, media filled filter cartridges operating at a maximum surface area specific flow rate of 1 gpm/ft^2 (7.5 gpm/cartridge). Each of the filter cartridges was filled with an innovative coated reactive perlite media (PhosphoSorb). The PhosphoSorb media employs both physical straining and adsorption as primary and secondary pollutant removal mechanisms respectively thus allowing the media to sequester both particulate and dissolved pollutants.

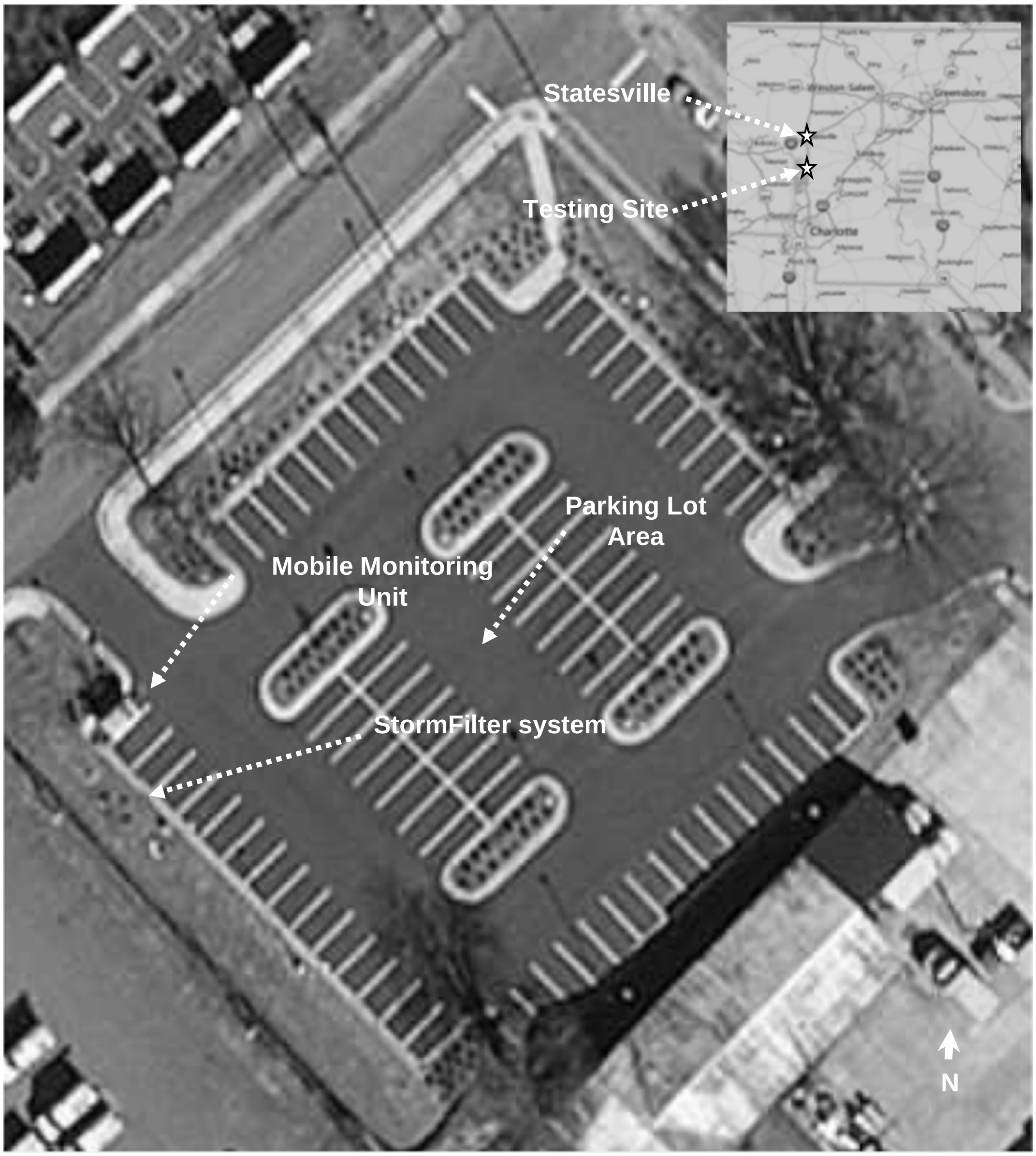

Figure 2. Aerial view of the Mitchell Community College testing site.

Sampling Design

The equipment and sampling techniques used for this study were in accordance with the Project Plan (Contech, 2010) developed by Contech in consultation with NCDENR DWQ. The Project Plan met the conditions outlined in the NCDENR DWQ preliminary evaluation period (PEP) program. Contech personnel were responsible for the installation, programming, and maintenance of the sampling equipment. Pace analytical provided independent sample retrieval, system reset, and sample submittal activities. Water sample processing and analysis was performed by Pace and Test America.

A Mobile Monitoring Unit (MMU) was provided, installed, maintained, and operated by Contech for sampling purposes. The MMU is a towable, fully enclosed, self-contained stormwater monitoring system specially designed and built by Contech for remote, extended-deployment stormwater monitoring. The design allows for remote control of sampling equipment, eliminates confined space entry requirements, and streamlines the sample and data collection process. The MMU installed at the Mitchell Community College testing site is shown in Figure 3.

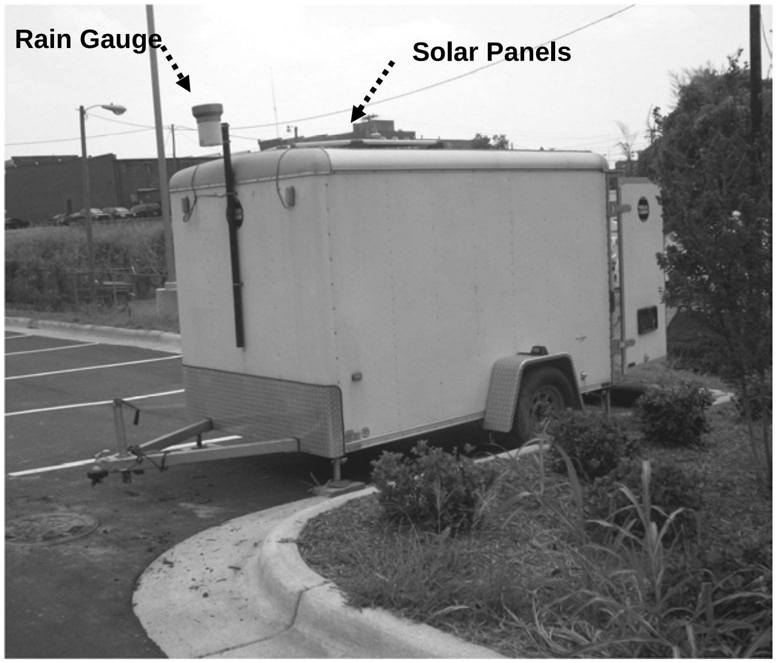

Figure 3. View of the Mobile Monitoring Unit (MMU) installed at the Mitchell Community College testing site.

Influent and effluent water quality samples were collected using individual ISCO 6712 Portable Automated Samplers configured for standard, individual, round, 1 liter wide-mouth HDPE bottles with sample bottles in the 1 through 12 positions for sample collection. The samplers were connected to individual 12V DC batteries recharged with solar panels. The influent sampler was equipped with an ISCO 750 Area Velocity Flow Module with a Low Profile Area Velocity Flow Sensor for flow analysis and influent sample pacing. The effluent sampler was equipped with an ISCO 730 Bubbler Flow Module used in conjunction with a 6 inch diameter Thel-Mar Weir for flow analysis and effluent sample pacing. Each sampler was also connected to an ISCO SPA 1489 Digital Cell Phone Modem to allow for remote communication and data access. Rainfall was measured using a 0.01-in resolution Texas Electronics TR-4 tipping bucket-type rain gauge. The sample intake for each automated sampler was connected to a stainless steel sample strainer (9/16″ diameter, 6″ length, with multiple ¼″ openings) via a length of 3/8″ ID Acutech Duality FEP/LDPE tubing. Sample strainers and flow measurement equipment were secured to the invert of the influent and effluent pipes using stainless steel spring rings.

Following a precipitation event, Contech personnel remotely communicated with the automated sampling equipment to confirm sample collection and dispatch personnel from Pace to retrieve the samples and reset the automated sampling equipment. Samples were delivered to Pace and Test America on ice (<4 degrees C) and accompanied by chain-of-custody documentation. Sample bottles were combined by Pace to create composite samples. Sample bottles were thoroughly shaken and sieved through a 2000µm sieve. Samples were then emptied into a cone splitter to obtain a single, composite sample (USGS, 1980). Composite samples were then submitted for analysis according to the analytical methods specified in Table 1. The field monitoring methods used for this study represent the current state-of-the practice, and are very similar to those used by researchers in North Carolina and elsewhere to evaluate Stormwater BMPs.

Table 1. Analytical methods used for analytical parameters of interest.

Parameter	Analytical Method
Total Suspended Solids (TSS)	SM2540 D
Suspended Sediment Conc. (SSC)	ASTM D3977
Total Volatile Suspended Solids (TVSS)	EPA 160.4
Total Phosphorus (TP)	EPA 365.1
Dissolved Phosphorus (Diss. P)	EPA 365.1

As per the Project Plan, the following quality control samples were used to assess the quality of both field sampling and analytical activities: equipment rinsate blanks, equipment field blanks, method blank, and duplicate analysis. Sample processing blank samples were not taken. Except for solids analyses that employ the use of the whole sample volume (SSC), all method blanks and duplicate analyses were handled by Pace and Test America. Since solids analyses that employ the use of whole sample volume (SSC) consume the entire sample volume, replicate samples were prepared in place of duplicate samples and analyzed to allow for the assessment of analytical accuracy. The results of equipment rinsate blanks and equipment field blanks are shown in Table 2 accompanied by associated decisions and action items for instances of detection. Equipment rinsate blanks and equipment field blanks were submitted for analysis of the following parameters TSS, TVSS, and TP.

Table 2. Instances of detection in equipment rinsate blank and equipment field blank samples.

Date	Blank Type	Detections	Action	% of Sample Pairs Affected
7/8/2011	Rinsate	None	None	0
6/28/2011	Field	None	None	0
6/14/2012	Field	None	None	0

Precipitation Measurement

Precipitation was measured with a Texas Electronics TR-4 tipping bucket-type rain gauge. The rain gauge was connected to an ISCO 6712 Automated Sampler programmed to record the total number of tips (0.01 inch per tip) every 5 minutes. Equipment calibrations performed on site during the monitoring period indicated that the rain gauge was working properly during the monitoring period.

A comparison of monthly precipitation totals measured at the NOAA NWS COOP weather station in Statesville, NC during the monitoring period to the 30 year monthly mean precipitation totals shows that precipitation in the area was below normal in 15 of the 20 months studied (Table 3). Rainfall was above normal in March (2011), July (2011), September (2011), November (2011), and May (2012) as seen in Table 3.

Table 3. Monthly precipitation totals compared to 30 year monthly mean precipitation totals (NOAA NWS COOP Weather Station Statesville, NC)

Month	NOAA NWS COOP Station Statesville, NC Precipitation Total (in.)	Percent of Monthly Precipitation Total Normal (%)	30 Year Monthly Precipitation Total Normal (in.)
November (2010)	1.08	33	3.30
December (2010)	2.63	72	3.64
January (2011)	1.59	42	3.83
February (2011)	1.76	50	3.55
March (2011)	5.66	127	4.45
April (2011)	2.72	80	3.42
May (2011)	3.82	92	4.15
June (2011)	1.78	40	4.49
July (2011)	6.26	158	3.95
August (2011)	3.29	90	3.67
September (2011)	4.89	120	4.07
October (2011)	2.39	69	3.45
November (2011)	4.14	125	3.30
December (2011)	3.32	91	3.64
January (2012)	1.8	47	3.83
February (2012)	1.81	51	3.55
March (2012)	2.64	59	4.45
April (2012)	1.77	52	3.42
May (2012)	6.43	155	4.15
June (2012)	4.36	97	4.49

For sampled storm events, rainfall durations ranged from 8 to 36 hours, rainfall depth ranged from 0.85 to 4.41 inches, and 15 and 30 minute maximum intensities were 3.28 and 1.90 inches/hour respectively. Based on design information provided by the design engineer, runoff was calculated using the Curve Number Method using a CN of 89. Calculated runoff volumes ranged from 5796 to 94,133 gallons as seen in Table 4.

Table 4. Precipitation and runoff statistics for sampled events at the Mitchell Community College testing site.

Event ID	Duration of storm event (hours)	Total Precipitation (in.)	P15 (in/hr)	P30 (in/hr)	Calculated Runoff Volume (gal)
MCC041611	8	1.04	1.32	0.96	9086
MCC051011	8	0.93	1.24	0.80	7126
MCC051611	22	1.04	0.40	0.26	9086
MCC062811	24	2.06	1.36	1.00	31611
MCC070811	13	4.41	3.28	1.90	94133
MCC073111	19	1.37	2.04	1.88	15674
MCC090511	36	1.94	1.92	0.96	28694
MCC092111	13	3.75	2.16	1.60	75933
MCC110311	24	1.40	0.56	0.50	16316
MCC111611	14	1.01	1.68	1.34	8538
MCC051312	21	1.82	1.28	0.92	25828
MCC052112	30	0.85	1.68	0.86	5796
MCC060612	30	2.11	1.00	0.88	32841

Flow Measurement

An ISCO 750 Area Velocity Flow Module with a Low Profile Area Velocity Flow Sensor was used to measure flow and pace sample collection at the influent sample location. An ISCO 730 Bubbler Flow Module was used in conjunction with a 6 inch diameter Thel-Mar Weir to measure flow and pace sample collection at the effluent sample location. Level measurements were adjusted by applying corrections that reflected differences between recorded and measured water surface elevations at the influent and effluent sampling locations. On average, 105% of the calculated total rainfall volume as runoff was measured, as effluent for the monitored events, as shown in Table 5.

Table 5. Percentage of calculated rainfall runoff volumes represented by actual measured runoff volumes at the Mitchell Community College testing site.

Event ID	Calculated Runoff Volume (gal)	Effluent Volume (gal)	Effluent Volume / Calc. Runoff Volume (%)
MCC041611	9086	12748	140
MCC051011	7126	9392	132
MCC051611	9086	18104	199
MCC062811	31611	26364	83
MCC070811	94133	49090	52
MCC073111	15674	16093	103
MCC090511	28694	35039	122
MCC092111	75933	67321	89
MCC110311	16316	20220	124
MCC111611	8538	9926	116
MCC051312	25828	13154	51
MCC052112	5796	4879	84
MCC060612	32841	21569	66

Stormwater Data Collection Requirements

Of the 13 qualifying storm events sampled; 1) the total rainfall was greater than 0.1 inches for all storm events sampled, 2) the minimum inter-event period was greater than 6 hours for all storm events sampled, 3) the minimum number of influent and effluent aliquots collected per storm event was ≥ 5, 4) influent flow-weighted composite samples covered ≥ 50% of the total storm flow for all storm events sampled with the exception of the MCC070811, MCC090511, MCC092111, MCC110311,MCC051312, and MCC060612 events, and 5) effluent flow-weighted composite samples covered ≥ 50% of the total storm flow for all storm events sampled. All events have been determined to meet the conditions outlined in the PEP program as shown in Table 6.

Table 6. Stormwater data collection requirement results.

Event ID	Influent Coverage	Effluent Coverage	Influent Number of Aliquots	Effluent Number of Aliquots	Antecedent Dry Period > 6 hours	Event Depth (in.)
MCC041611	101%	100%	18	14	√	1.04
MCC051011	91%	79%	6	6	√	0.93
MCC051611	79%	90%	8	8	√	1.04
MCC062811	98%	97%	19	13	√	2.06
MCC070811	41%	98%	24	24	√	4.41
MCC073111	97%	98%	16	16	√	1.37
MCC090511	46%	90%	29	26	√	1.94
MCC092111	49%	93%	48	48	√	3.75
MCC110311	34%	60%	48	48	√	1.40
MCC111611	100%	100%	39	40	√	1.01
MCC051312	36%	92%	28	48	√	1.82
MCC052112	100%	74%	31	5	√	0.85
MCC060612	46%	73%	42	48	√	2.11

Data Analysis

Of the 13 qualifying storm events sampled, data verification and validation did not lead to the outright disqualification of any events due to obvious monitoring, handling or analytical errors, or the substantial exceedance of the design operating parameters. Event Mean Concentrations (EMC) from influent and effluent samples are summarized in Table 7-9.

Using SSC (<500µm) EMC results, the percent of corresponding SSC (<2000µm) EMC results was calculated. The calculated percentages of corresponding SSC (<2000µm) EMC results indicated the portion of material that was less than 500µm in size and are summarized in Table 10.

Using TVSS EMC results, the percent of corresponding SSC results was calculated. The calculated percentages of corresponding SSC (<2000µm) and SSC (<500µm) results indicated the percent of combustible materials that are assumed to be organic in nature and are summarized in Table 11.

Non-parametric statistical methods were used to evaluate correlations and differences between non-transformed influent and effluent EMCs since influent and effluent EMCs were generally not from the same statistical distribution. To test for positive correlations between influent and effluent EMCs, the Spearman Rank Order Correlation test was used (USGS, 1991). To evaluate the significance of differences between influent and effluent EMCs, the Mann-Whitney Rank Sum Test was used (USGS, 1991). For the Mann-Whitney Rank Sum Test the null hypothesis was that the two samples were not drawn from populations with different medians. A significant difference between influent and effluent EMCs was concluded when $P<0.05$.

Detectible concentrations were observed for all parameters analyzed except for TSS for the MCC051011, MCC051611, MCC062811, MCC073111, MCC090511, MCC092111, MCC110311, and MCC060612 events; SSC (<2000µm) for the MCC073111, MCC051312, and MCC060612 events; SSC (<500µm) for the MCC051611, MCC051312, and MCC060612 events; TVSS (<2000µm) for the MCC111611 event; TVSS (<500µm) for the MCC110311 and MCC111611 events; TP for the MCC05161, MCC062811, MCC070811, MCC092111, MCC110311, MCC111611, MCC051312, MCC052112, and MCC060612 events ; Diss. P for the MCC041611, MCC062811, MCC070811, MCC073111, MCC092111, MCC110311, MCC111611, MCC051312, and MCC060612 events; Ortho-P for the MCC041611, MCC062811, MCC070811, MCC073111, MCC092111, MCC110311, MCC111611, MCC051312, and MCC060612 events; For values that were reported as non-detect, substitutions were made using half of the Method Reporting Limit (MRL) for statistical testing and calculation of efficiencies. For calculated parameters values calculated as ≤ 0 were reported as 0 for statistical testing and calculation of efficiencies.

Performance was calculated using the Efficiency Ratio (ER) efficiency calculation method. The ER method defines the efficiency as the average event mean concentration of pollutants over some time period.

$$ER = 1 - \frac{mean\ effluent\ EMC}{mean\ influent\ EMC}$$

The ER method assumes; 1) The weight of all storm events is equal regardless of the relative magnitude of the storm event and 2) that if all storm events at the site had been monitored, the average inlet and outlet EMCs would be similar to those that were monitored (URS/ EPA 1999). ER efficiency calculations for the 13 events sampled at the Mitchell Community College testing site are summarized in Tables 7-19.

Performance was also calculated using the Summation of Loads (SOL) efficiency calculation method. The SOL method defines the efficiency as a percentage based on the ratio of the summation of all influent loads to the summation of all effluent loads.

$$SOL = 1 - \frac{sum\ of\ all\ effluent\ loads}{sum\ of\ all\ influent\ loads}$$

The SOL method assumes; 1) monitoring data accurately represents the actual entire total loads in and out of the BMP for a period long enough to overshadow any temporary storage or export of pollutants and 2) any significant storm events that were not monitored had a ratio of inlet to effluent loads similar to the storms events that were monitored (URS/ EPA 1999). In an effort to eliminate the introduction of potential bias associated with observed discrepancies between influent and effluent measured volumes it was assumed that the influent volume was equal to the effluent volume. Measured effluent volume was used to calculate loads for both the influent and effluent sample locations. Sum of Loads (SOL) Efficiency Calculations for the 13 events sampled at the Mitchell Community College testing site are summarized in Tables 12,13, and 14.

Results

Based on the use of the Spearman Rank Order correlation test, positive correlations (P<0.05) were determined between influent and effluent EMCs for Ortho-P.

Based on the use of the Mann-Whitney Rank Sum test, the difference in the median values between the influent and effluent EMCs is greater than would be expected by chance. Therefore, a statistically significant difference (P<0.05) was observed for TSS, SSC (<2000µm), SSC (<500µm), TVSS (<2000µm), TP, and PP as seen in Tables 7, 8, and 9.

Based on the use of the Mann-Whitney Rank Sum test, the difference in the median values between the influent and effluent EMCs is not great enough to exclude the possibility that the difference is due to random sampling variability. A statistically significant difference ($P > 0.05$) was not observed for TVSS (<500µm), Diss. P, and Ortho-P as seen in Tables 7, 8, and 9.

Suspended Solids Parameters

Influent EMCs for TSS ranged from 10.3 mg/l to 98.2 mg/l with a median of 27.6 mg/l and a mean of 34.6 mg/l. Corresponding effluent EMCs ranged from 1.3 mg/l to 6.6 mg/l with a median of 2.8 mg/l and a mean of 3.3 mg/l, resulting in an ER efficiency of 90.4%. Total event loadings for the study were 32.7 kg at the influent and 3.0 kg at the effluent sampling location, resulting in an SOL TSS efficiency of 90.9%.

Influent EMCs for SSC (<2000µm) ranged from 17.7 mg/l to 2080.0 mg/l with a median of 53.4 mg/l and a mean of 231.0 mg/l. Corresponding effluent EMCs ranged from 1.9 mg/l to 7.2 mg/l with a median of 3.4 mg/l and a mean of 3.9 mg/l, resulting in an ER efficiency of 98.3%.Total event loadings for the study were 222.0 kg at the influent and 3.9 kg at the effluent sampling location, resulting in an SOL SSC efficiency of 98.3%. In general, the relationship between TSS and SSC (<2000µm) was determined not to be significant based on the linear regression results for both influent (R^2 =0.0130) and effluent (R^2 =0.410) EMCs.

Influent EMCs for SSC (<500µm) ranged from 9.0 mg/l to 393.0 mg/l with a median of 28.6 mg/l and a mean of 66.1 mg/l. Corresponding effluent EMCs ranged from 1.7 mg/l to 10.0 mg/l with a median of 2.8 mg/l and a mean of 4.4 mg/l, resulting in an ER efficiency of 93.4%.Total event loadings for the study were 63.3 kg at the influent and 4.0 kg at the effluent sampling location, resulting in an SOL efficiency of 93.7%. For each storm event, the percent of SSC (<2000µm) represented by SSC (<500 µm) was calculated (Table 11). Influent and effluent median percentages of SSC (<2000µm) were 68.0% and 94.2%, respectively. The percentage of corresponding SSC (<2000µm) results indicated the portion of material that were less than 500µm in size.

Volatile Suspended Solids Parameters

Influent EMCs for TVSS (<2000µm) ranged from 1.1 mg/l to 99.2 mg/l with a median of 11.9 mg/l and a mean of 23.8 mg/l. Corresponding effluent EMCs ranged from 0.5 mg/l to 6.7 mg/l with a median of 3.0 mg/l and a mean of 2.9 mg/l, resulting in an ER efficiency of 87.7%.Total event loadings for the study were 24.6 kg at the influent and 2.9 kg at the effluent sampling location, resulting in an SOL efficiency of 88.2%. For each storm event, the percent of SSC (<2000 µm) represented by TVSS (<2000µm) was calculated (Table 12). Influent and effluent median percentages of SSC (<2000µm) were 29.0% and 65.1%, respectively. Percentage of corresponding SSC (<2000µm) results indicated the percent of combustible materials that were assumed to be organic in nature.

Influent EMCs for TVSS (<500µm) ranged from 1.1 mg/l to 48.0 mg/l with a median of 7.3 mg/l and a mean of 11.6 mg/l. Corresponding effluent EMCs ranged from 0.6 mg/l to 5.3 mg/l with a median of 3.4 mg/l and a mean of 3.1 mg/l, resulting in an ER efficiency of 73.4%.Total event loadings for the study were 9.9 kg at the influent and 3.3 kg at the effluent sampling location, resulting in an SOL efficiency of 67.1%. For each storm event, the percent of SSC (<500µm) represented by TVSS (<500µm) was calculated (Table 12). Influent and effluent median percentages of SSC (<500µm) were 31.4% and 86.4% respectively. Percentage of corresponding SSC (<500µm) results indicated the percent of combustible materials that were assumed to be organic in nature.

Phosphorus Parameters

Influent EMCs for TP ranged from 0.07 mg/l to 0.90 mg/l with a median of 0.14 mg/l and a mean of 0.22 mg/l. Corresponding effluent EMCs ranged from 0.03 mg/l to 0.06 mg/l with a median of 0.03 mg/l and a mean of 0.03 mg/l, resulting in an ER efficiency of 86.1%. Total event loadings for the study were 218.6 g at the influent and 28.1 g at the effluent sampling location, resulting in an SOL efficiency of 87.1%.

Influent EMCs for Diss. P ranged from 0.03 mg/l to 0.85 mg/l with a median of 0.05 mg/l and a mean of 0.16 mg/l. Corresponding effluent EMCs ranged from 0.03 mg/l to 0.16 mg/l with a median of 0.05 mg/l and a mean of 0.04 mg/l, resulting in an ER efficiency of 74.2%. Total event loadings for the study were 109.6 g at the influent and 35.9 g at the effluent sampling location, resulting in an SOL efficiency of 67.3%.

Influent EMCs for Ortho-P ranged from 0.03 mg/l to 0.86 mg/l with a median of 0.03 mg/l and a mean of 0.14 mg/l. Corresponding effluent EMCs ranged from 0.03 mg/l to 0.03 mg/l with a median of 0.03 mg/l and a mean of 0.03 mg/l, resulting in an ER efficiency of 82.5%. Total event loadings for the study were 102.8 g at the influent and 22.4 g at the effluent sampling location, resulting in an SOL efficiency of 78.2%.

Calculated influent EMCs for PP, calculated as the difference between TP and Diss. P, ranged from 0.02 mg/l to 0.23 mg/l with a median of 0.06 mg/l and a mean of 0.08 mg/l. Corresponding effluent EMCs ranged from 0.03 mg/l to 0.00 mg/l with a median of 0.00 mg/l and a mean of 0.01 mg/l, resulting in an ER efficiency of 91.3%. Total event loadings for the study were 97.7 g at the influent and 3.5 g at the effluent sampling location, resulting in an SOL efficiency of 96.4%.

Table 7. Suspended Solids Efficiency Ratio (ER) Efficiency Calculations and Statistical Testing for the 13 events sampled at the Mitchell Community College testing site.

Event ID	TSS (mg/l)		SSC (<2000µm) (mg/l)		SSC (<500µm) (mg/l)	
	Influent	Effluent	Influent	Effluent	Influent	Effluent
MCC041611	21.2	6.2	55.7	7.2	45.8	7.3
MCC051011	98.2	5.1	90.6	4.6	104.0	5.1
MCC051611	21.8	2.8	51.0	6.2	9.6	1.9
MCC062811	10.3	1.4	18.0	3.0	9.0	2.6
MCC070811	18.2	3.3	29.7	3.8	16.0	3.0
MCC073111	28.4	2.5	17.7	2.7	29.1	4.0
MCC090511	25.1	2.5	81.8	2.5	74.5	2.4
MCC092111	27.6	1.3	86.0	1.9	20.4	1.7
MCC110311	23.6	1.3	2080.0	2.4	393.0	1.8
MCC111611	56.9	3.4	186.0	2.7	16.3	2.5
MCC051312	52.4	5.7	27.0	5.0	28.0	10.0
MCC052112	28.2	6.6	NT	NT	NT	NT
MCC060612	38.0	1.3	48.0	5.0	48.0	10.0
Min	10.3	1.3	17.7	1.9	9.0	1.7
Max	98.2	6.6	2080.0	7.2	393.0	10.0
Median	27.6	2.8	53.4	3.4	28.6	2.8
Mean	34.6	3.3	231.0	3.9	66.1	4.4
Efficiency Ratio	90.4%		98.3%		93.4%	
Mann-Whitney U statistic	0.000		0.000		4.000	
P value for U statistic	<0.001		<0.001		<0.001	

NT = Not tested
QC DQ = Quality Control Disqualification

Table 8. Total Volatile Suspended Solids Efficiency Ratio (ER) Efficiency Calculations and Statistical Testing for the 13 events sampled at the Mitchell Community College testing site.

Event ID	TVSS (<2000µm) (mg/l)		TVSS (<500µm) (mg/l)	
	Influent	**Effluent**	**Influent**	**Effluent**
MCC041611	30.8	4.1	24.0	5.3
MCC051011	53.0	6.7	48.0	4.2
MCC051611	13.0	3.1	10.4	3.6
MCC062811	10.8	3.4	4.8	4.3
MCC070811	8.0	2.1	7.6	3.3
MCC073111	19.6	3.8	3.4	3.9
MCC090511	7.4	2.8	4.2	3.4
MCC092111	27.3	1.7	6.1	1.5
MCC110311	99.2	1.6	13.3	1.0
MCC111611	1.1	0.5	1.1	0.6
MCC051312	8.4	3.2	9.2	3.2
MCC052112	NT	NT	NT	NT
MCC060612	7.2	2.2	7.0	2.8
Min	1.1	0.5	1.1	0.6
Max	99.2	6.7	48.0	5.3
Median	11.9	3.0	7.3	3.4
Mean	23.8	2.9	11.6	3.1
Efficiency Ratio	87.7%		73.4%	
Mann-Whitney U statistic	11.000		0.000	
P value for U statistic	<0.001		0.667	

NT = Not tested
QC DQ = Quality Control Disqualification

Table 9. Phosphorus Efficiency Ratio (ER) Efficiency Calculations and Statistical Testing for the 13 events sampled at the Mitchell Community College testing site.

Event ID	TP (mg/l)		Diss. P (mg/l)		Ortho-P (mg/l)		PP (mg/l)	
	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
MCC041611	0.160	0.058	0.025	0.025	0.025	0.025	0.135	0.033
MCC051011	NT	NT	NT	NT	NT	NT	NT	NT
MCC051611	0.110	0.025	NT	NT	NT	NT	NT	NT
MCC062811	0.130	0.025	0.025	0.160	0.025	0.025	0.105	0.000
MCC070811	0.065	0.025	0.025	0.025	0.025	0.025	0.040	0.000
MCC073111	0.140	0.057	0.061	0.025	0.025	0.025	0.079	0.032
MCC090511	NT	NT	NT	NT	NT	NT	NT	NT
MCC092111	0.250	0.025	0.025	0.025	0.025	0.025	0.225	0.000
MCC110311	0.900	0.025	0.850	0.025	0.860	0.025	0.050	0.000
MCC111611	0.100	0.025	0.081	0.025	0.063	0.025	0.019	0.000
MCC051312	0.088	0.025	0.054	0.025	0.025	0.025	0.034	0.000
MCC052112	0.200	0.025	NT	NT	NT	NT	NT	NT
MCC060612	0.310	0.025	0.250	0.025	0.210	0.025	0.060	0.000
Min	0.065	0.025	0.025	0.025	0.025	0.025	0.019	0.000
Max	0.900	0.058	0.850	0.160	0.860	0.025	0.225	0.033
Median	0.140	0.025	0.054	0.025	0.025	0.025	0.060	0.000
Mean	0.223	0.031	0.155	0.040	0.143	0.025	0.083	0.007
Efficiency Ratio	86.1%		74.2%		82.5%		91.3%	
Mann-Whitney U statistic	0.000		23.000		27.000		2.000	
P value for U statistic	<0.001		0.074		0.077		<0.001	

NT = Not tested
QC DQ = Quality Control Disqualification

Table 10. Calculated Percentages of material less than 500µm for the 13 events sampled at the Mitchell Community College testing site.

Event ID	SSC (<500µm)/ SSC (<2000µm) (%)	
	Influent	**Effluent**
MCC041611	82.2	100.0
MCC051011	100.0	100.0
MCC051611	18.9	31.1
MCC062811	49.8	86.0
MCC070811	53.9	79.9
MCC073111	100.0	100.0
MCC090511	91.1	98.4
MCC092111	23.7	85.9
MCC110311	18.9	75.2
MCC111611	8.8	90.1
MCC051312	100.0	100.0
MCC052112	NT	NT
MCC060612	100.0	100.0
Min	8.8	31.1
Max	100.0	100.0
Median	68.0	94.2
Mean	62.3	87.2

NT = Not tested
QC DQ = Quality Control Disqualification

Table 11. Calculated percentages of combustible materials that were assumed to be organic in nature for the 13 events sampled at the Mitchell Community College testing site.

Event ID	TVSS (<2000µm)/ SSC (<2000µm) (%)		TVSS (<500µm)/ SSC (<500µm) (%)	
	Influent	**Effluent**	**Influent**	**Effluent**
MCC041611	55.3	56.9	52.4	72.6
MCC051011	58.5	100.0	46.2	81.9
MCC051611	25.5	50.0	100.0	100.0
MCC062811	60.0	100.0	53.6	100.0
MCC070811	26.9	55.6	47.5	100.0
MCC073111	100.0	100.0	11.7	98.7
MCC090511	9.0	100.0	5.6	100.0
MCC092111	31.7	88.5	29.9	90.9
MCC110311	4.8	66.1	3.4	54.9
MCC111611	0.6	18.3	6.7	22.4
MCC051312	31.1	64.0	32.9	32.0
MCC052112	NT	NT	NT	NT
MCC060612	15.0	44.0	14.6	28.0
Min	0.6	18.3	3.4	22.4
Max	100.0	100.0	100.0	100.0
Median	29.0	65.1	31.4	86.4
Mean	34.9	70.3	33.7	73.5

NT = Not tested
QC DQ = Quality Control Disqualification

Table 12. Suspended Solids Summation of Loads (SOL) Efficiency Calculations for the 13 events sampled at the Mitchell Community College testing site.

Event ID	TSS (kg)		SSC (<2000µm) (kg)		SSC (<500µm) (kg)	
	Influent	Effluent	Influent	Effluent	Influent	Effluent
MCC041611	1.0	0.3	2.7	0.3	2.2	0.4
MCC051011	3.5	0.2	3.2	0.2	3.7	0.2
MCC051611	1.5	0.2	3.5	0.4	0.7	0.1
MCC062811	1.0	0.1	1.8	0.3	0.9	0.3
MCC070811	3.4	0.6	5.5	0.7	3.0	0.6
MCC073111	1.7	0.2	1.1	0.2	1.8	0.2
MCC090511	3.3	0.3	10.8	0.3	9.9	0.3
MCC092111	7.0	0.3	21.9	0.5	5.2	0.4
MCC110311	1.8	0.1	159.2	0.2	30.1	0.1
MCC111611	2.1	0.1	7.0	0.1	0.6	0.1
MCC051312	2.6	0.3	1.3	0.2	1.4	0.5
MCC052112	0.5	0.1	NT	NT	NT	NT
MCC060612	3.1	0.1	3.9	0.4	3.9	0.8
Sum	32.7	3.0	222.0	3.9	63.3	4.0
SOL Efficiency	90.9%		98.3%		93.7%	

NT = Not tested
QC DQ = Quality Control Disqualification

Table 13. Total Volatile Suspended Solids Summation of Loads (SOL) Efficiency Calculations for the 13 events sampled at the Mitchell Community College testing site.

Event ID	TVSS (<2000μm) (kg)		TVSS (<500μm) (kg)	
	Influent	Effluent	Influent	Effluent
MCC041611	1.5	0.2	1.2	0.3
MCC051011	1.9	0.2	1.7	0.1
MCC051611	0.9	0.2	0.7	0.2
MCC062811	1.1	0.3	0.5	0.4
MCC070811	1.5	0.4	1.4	0.6
MCC073111	1.2	0.2	0.2	0.2
MCC090511	1.0	0.4	0.6	0.5
MCC092111	7.0	0.4	1.6	0.4
MCC110311	7.6	0.1	1.0	0.1
MCC111611	0.0	0.0	0.0	0.0
MCC051312	0.4	0.2	0.5	0.2
MCC052112	NT	NT	NT	NT
MCC060612	0.6	0.2	0.6	0.2
Sum	24.6	2.9	9.9	3.3
SOL Efficiency	88.2%		67.1%	

NT = Not tested
QC DQ = Quality Control Disqualification

Table 14. Phosphorus Summation of Loads (SOL) Efficiency Calculations for the 13 events sampled at the Mitchell Community College testing site.

Event ID	TP (g)		Diss. P (g)		Ortho-P (g)		PP (g)	
	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
MCC041611	7.7	2.8	1.2	1.2	1.2	1.2	6.5	1.6
MCC051011	NT	NT	NT	NT	NT	NT	NT	NT
MCC051611	7.5	1.7	NT	NT	NT	NT	NT	NT
MCC062811	13.0	2.5	2.5	16.0	2.5	2.5	10.5	0.0
MCC070811	12.1	4.6	4.6	4.6	4.6	4.6	7.4	0.0
MCC073111	8.5	3.5	3.7	1.5	1.5	1.5	4.8	1.9
MCC090511	NT	NT	NT	NT	NT	NT	NT	NT
MCC092111	63.7	6.4	6.4	6.4	6.4	6.4	57.3	0.0
MCC110311	68.9	1.9	65.1	1.9	65.8	1.9	3.8	0.0
MCC111611	3.8	0.9	3.0	0.9	2.4	0.9	0.7	0.0
MCC051312	4.4	1.2	2.7	1.2	1.2	1.2	1.7	0.0
MCC052112	3.7	0.5	NT	NT	NT	NT	NT	NT
MCC060612	25.3	2.0	20.4	2.0	17.1	2.0	4.9	0.0
Sum	218.6	28.1	109.6	35.9	102.8	22.4	97.7	3.5
SOL Efficiency	87.1%		67.3%		78.2%		96.4%	

NT = Not tested
QC DQ = Quality Control Disqualification

Residual Solids Assessment Results

In an effort to verify the capture of materials by the StormFilter system over the course of the monitoring period, a qualitative assessment of materials captured by the StormFilter system was performed during the site visit conducted on November 3, 2011. The mass of materials contained in the system was estimated using a mean depth measurement and a texture based bulk density estimate. The mean depth of material captured by the StormFilter at the time of inspection was determined to be approximately 3 inches. A composite sample of the material captured by the StormFilter was collected and texture was determined in the field by hand texturing of the sample. Hand texture analysis of the composite sample revealed that the materials captured by the StormFilter had a loamy sand texture (USDA classification). The estimated mass of materials contained in the StormFilter, using the mean depth of material captured by the StormFilter and a bulk density assumption for loamy sand texture soils of 1.65 gm/cc, was approximately 150 kg.

Following the maintenance of the system on November 3, 2011 which involved the removal of accumulated solids from the system as well as the replacement of cartridges, a qualitative assessment of materials captured by the StormFilter system was performed during the site visit conducted on June 14, 2012. The mass and texture of materials contained in the system was estimated as described above. The mean depth of material captured by the StormFilter was determined to be approximately 0.5 inches; and had a loamy sand texture (USDA classification). The estimated mass of materials was approximately 25 kg.

Summary and Conclusion

The primary purpose of this report was to document StormFilter system performance with respect to solid and nutrient pollutant removal and quantify performance in accordance with the conditions outlined in the NCDENR DWQ PEP program. Between November (2010) and June (2012), a total of 13 qualifying storm events were monitored and were determined to meet the storm data collection requirements as per the conditions outlined in the NCDENR DWQ PEP program.

Significant reductions for solid and nutrient pollutant concentrations were observed between influent and effluent sampling locations using the Efficiency Ratio (ER) efficiency calculation (TSS 90.4% and TP 86.1%) and Summation of Load (SOL) efficiency calculation methods (TSS 90.9% and TP 87.1%). The capture of solids by the system was verified as part of the residual solids assessment during site visits conducted on November 3, 2011 and June 14, 2012.

Given that the solid performance standard for this project is based solely on TSS removal efficiency, the review of additional data was required to further understand removal efficiency results. In an effort to isolate suspended sediment removal efficiency based on specific particle size ranges, SSC samples were sieved prior to analysis. The particle size ranges that were isolated for this study included 2000µm to 1.5µm and 500µm to 1.5µm. The isolation of suspended solids removal efficiencies based on particles 2000µm to 1.5µm and particles between 500µm and 1.5 µm resulted in an overall removal efficiency of 98.3% and 93.4% respectively using the ER efficiency calculation method and 98.3% and 93.7% respectively using the SOL efficiency calculation method. These results demonstrate performance greater than the performance goal of 85% removal of TSS. In addition to these results demonstrating performance greater than the performance goal of 85% removal of TSS, research by (Rutgers/ NJDEP, 2006) suggests the difference between TSS and SSC results becomes smaller as the particle size of the material analyzed becomes finer.

Given that the phosphorus removal performance standard for this project is based solely on TP removal efficiency, the review of additional data was required to further understand removal efficiency results. In an effort to isolate phosphorus removal efficiency based on speciation TP, Diss. P, Ortho-P, and PP results were isolated. TP, Diss. P, and Ortho-P results were provided by the analytical lab. PP was calculated as the difference between TP and Diss. P. Removal efficiencies for TP, Diss. P, Ortho-P, and PP results resulted in an overall removal efficiency 86.1%, 74.2%, 82.5%, and 91.3% respectively using the ER efficiency calculation method. Removal efficiencies for TP, Diss. P, Ortho-P, and PP results resulted in an overall removal efficiency of 87.1%, 67.3%, 78.2%, and 96.4% using the SOL efficiency calculation method. These results not only demonstrate that the system was able to meet the performance goal but was able to attenuate TP captured by the system over the course of the study.

Results from the twenty month study, that represented a total of 13 storm events and 23.73 inches of precipitation, show that the StormFilter system tested was highly effective in removing solid and nutrient pollutants from the stormwater runoff.

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Revision History

Original

The Int'l Corporate Center Stormwater Treatment System Field Evaluation:

The Stormwater Management StormFilter® (StormFilter) with PhosphoSorb and Sintered Perlite Media at specific flow rate of 0.67 gal/min/ft²

Introduction

Phosphorus is the twelfth most abundant elemental component of the Earth and it is a critical component of life on this planet. Biological processes such as the development of cellular tissue (cell walls, bones, teeth, DNA) and the biochemical transfer of energy (ATP) are all very sensitive to both the presence and absence of phosphorus. Thus ecosystem characteristics, particularly those of terrestrial and freshwater systems, are largely defined by a balance of phosphorus within these systems.

The deliberate upset of this balance can have beneficial effects for mankind. For example, the terrestrial application of phosphorus-rich fertilizer is used to boost agricultural yields and maintain aesthetically pleasing landscapes. Upsetting this balance, however, can also have detrimental effects. Through runoff and erosion, elevated levels of phosphorus in the landscape ultimately increases phosphorus levels in surrounding waterways, often resulting in biological problems such as algal blooms and the subsequent decline of dissolved oxygen. The most abundant forms of phosphorus found in stormwater include organic phosphorus, polyphosphates and orthophosphate. This evaluation will focus on removal efficiency of total phosphorus in stormwater.

The Stormwater Management StormFilter®, a Best Management Practice (BMP) designed to meet federal, state, and local requirements for treating stormwater runoff in compliance with the Clean Water Act. The StormFilter improves the quality of stormwater runoff before it enters receiving waterways through the use of its customizable filter media, which removes non-point source pollutants, including sediments (TSS), oil and grease, soluble metals, nutrients, and organics. The StormFilter is typically comprised of a vault that houses rechargeable, media-filled, filter cartridges. Stormwater from storm drains is percolated through these media-filled cartridges, which trap particulates and remove pollutants such as dissolved metals, nutrients, and hydrocarbons. During the filtering process, the StormFilter system also removes surface scums and floating oil and grease. Once filtered through the media, the treated stormwater is directed to a collection pipe or discharged to an open channel drainage way. For detailed information on the StormFilter, please refer to the www.contech-cpi.com.

The purpose of this project is to demonstrate the total phosphorus removal efficiency of the Stormfilter system using with PhosphoSorb media as compared to Sintered Perlite Media at specific flow rate of 0.67 gal/min/ft^2 .Solids, metals, and additional water quality parameters were evaluated simultaneously.

Site and System Description

The Int'l Corporate Center No 3 Lot 7&8 TL 201 (ICC) site is an office building complex located at 11835 NE Glenn Widing Drive (Long -122.54140 Lat 45.57031). The site is located in Portland OR, covers 7.62 acres, and is adjacent to the Columbia River. An aerial photo of the site is shown in Figure 1. The site consists of 1.99 acres of finished buildings (two 36,500 ft^2 buildings and one 13,520 ft^2 building), 1.52 acres of landscaped area, and 4.07 acres of paved impervious area. Stormwater from this complex ultimately drains to the Columbia River. The site receives moderate traffic during normal business hours consisting of employee vehicles, company vehicles, and delivery trucks. An aerial photograph of the study site is shown in Figure 1 and additional photographs of the study site are provided in Figures 3 and 4.

For this study storm water runoff was pumped from a catch basin inlet located between buildings E and F to a StormFilter located inside building E, as shown in Figures 3 and 4. The StormFilter tested consisted of a 2.5 ft by 3 ft plastic Catchbasin StormFilter unit located inside of building E. The system was designed in an online configuration with an internal weir overflow capacity of 0.5 cfs. The contributing drainage area to the catch basin inlet being pumped from was estimated to be 0.28 acres.

Two different media types were tested during this evaluation; Sintered Perlite and PhosphoSorb an experimental media designed for enhanced phosphorus removal. A total of two cartridges were installed in the system; one Sintered Perlite media filled cartridge designed to operate at 5 gpm and one cartridge filled with PhosphoSorb media designed to operate at 5.0 gpm. To directly compare the performance of each media type effluent samples were collected directly from the under drain manifolds plumbed separately to the cartridges installed in the Stormfilter being tested.

Figure 1. Ariel view of the ICC site showing site boundary (solid white line), study drainage area, and buildings E and F

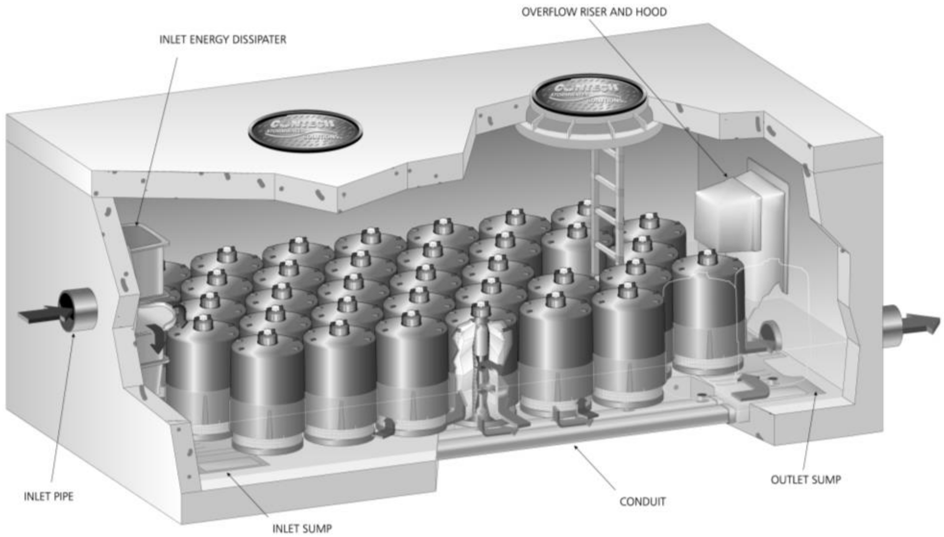

Figure 2. Standard System Illustration

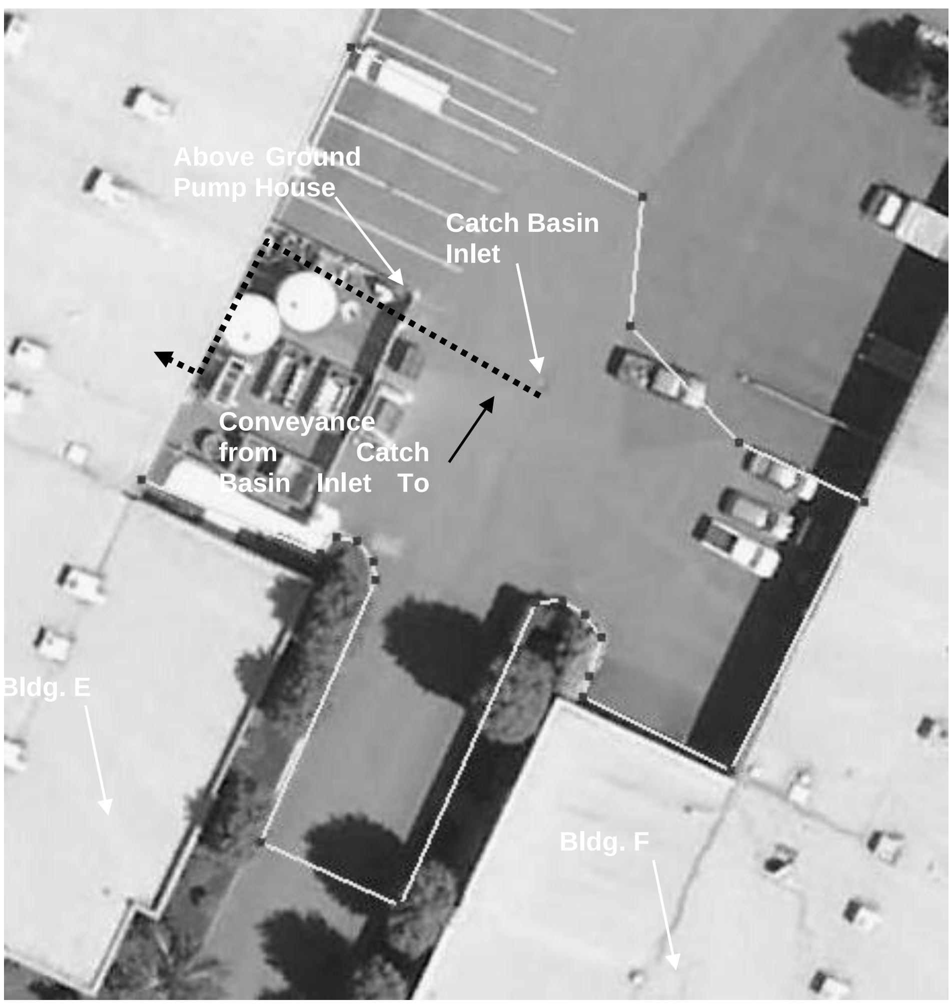

Figure 3. Ariel view of the ICC site showing study drainage area boundary (solids white line) between buildings E and F, catch basin inlet being pumped from, above ground pump house, and path of conveyance

Figure 4. View of ICC site looking north across drainage area

Sampling Design

The equipment and sampling techniques used for this study are in accordance with the Quality Assurance Project Plan (CONTECH, 2009). CONTECH personnel were responsible for the installation, operation, and maintenance of the sampling equipment. CONTECH personnel were also utilized for sample retrieval, system reset, and sample submittal activities. Water sample analysis was performed by Test America. A general overview of methodology is provided.

Influent and effluent samples were collected using individual ISCO 6700 Portable Automated Samplers configured for standard, individual, round, wide-mouth 1L HDPE sample bottle use. Samplers were connected to individual 12VDC power supplies. All samplers were independently flow paced using orifice flow meters installed at the sample location. Head measurements made using an Omega PX429-2.5-GI Pressure Sensors were recorded by a Campbell CR1000. Recorded measurements were converted into flow measurements and transmitted to the automated sampler for sample collection pacing. The sample intake from each automated sampler pump was connected to a sample port via a length of 3/8" ID Acutech Duality FEP/LDPE tubing.

Samplers were programmed to collected samples on a volume paced basis allowing for a specified volume to pass before taking a sample. The sample collection program input into each automated sampler was developed to maximize the number of water quality samples collected as well as storm event coverage. Influent and effluent sample collection programs were configured to collect multiple aliquots per bottle. Due to the variability among precipitation events, the sample pacing was variable on a continuous basis.

Upon the collection of samples following a precipitation event, CONTECH personnel confirmed sample collection, retrieved the samples, and reset the automated sampling equipment. Sample bottles were combined to create composite samples through identification of those bottles best representing the storm event based upon the storm event hydrograph. Selected sample bottles were then thoroughly shaken and emptied into a cone splitter. Samples were preserved and delivered to Test America using cold transport and accompanied by chain-of-custody documentation.

Due to low solids concentrations on site, solids were applied to the drainage area during the monitoring period. Solids were collected from catch basin sumps on the ICC site and applied to the drainage area prior to storm events. A total of 31 kg of sediment was applied to the site during the monitoring period, Table 6. The collected sediment was never dried out, coarse solids were removed (>2000-um), and collected sediments were amended with phosphorus salts to increase total phosphorus concentrations as well.

Table1. Analytical methods used for analytical parameters of interest.

Parameter	Analytical Method
Total Suspended Solids (TSS-SM)	SM2540 D
Susp. Sediment Conc. (SSC)	ASTM D3977
Tot. Susp. Solids (TSS)	SM2540D
Tot. Vol. Susp. Solids (TVSS)	SM2540E
SSC <500-um	ASTM D3977
TVSS <500-um	SM2540G
Particle Size Distribution	ASTM A4464
Total Phosphorus	EPA 365.2
Total Dissolved Phosphorus	EPA 200.7
Orthophosphate	EPA 365.2
TKN	EPA 351.2
Ammonia	EPA 350.1
Nitrate/Nitrite-N	EPA 353.2
Total Copper	EPA 200.8
Total Zinc	EPA 200.8
Aluminum	EPA 200.7
Hardness	SM 2340B
pH	EPA 150.1

The following quality control samples were used to assess the quality of both field sampling and analytical activities: equipment field blanks, method blank, and duplicate analysis. Sample processing blank samples were not taken. Except for solids analyses that employ the use of the whole sample volume (SSC), all method blanks and duplicate analyses were handled by Test America. Since solids analyses that employ the use of whole sample volume (SSC) consume the entire sample volume, replicate samples were prepared in place of duplicate samples and analyzed to allow the assessment of analytical accuracy. The results of equipment field blanks are shown in Table 2 accompanied by associated decisions and action items for instances of detection.

Table 2. Instances of contaminant detection in equipment rinsate blank and equipment field blank samples.

Date	Blank Type	Detections	Level (mg/L)	Action	% of Sample Pairs Affected
11/03/09	Field	ND		None	0
06/29/10	Field	ND		None	0

Residual Solids Assessment Methods.

Residual solids captured by the system were assessed at the end of the monitoring phase of the project. The assessment involved the estimation of captured material found inside the system and the collection of a composite sample of the residual solids. The composite sample of residual solids was homogenized and representatively subsampled for analysis. Samples were submitted to Test America for analysis. Results were used to characterize residual solids.

Precipitation Measurement

Rainfall was analyzed with a ISCO 674 tipping bucket-type rain gauge. A comparison of data collected during the monitoring period at the National Weather Service (NWS) cooperative station located at Portland International Airport Portland, Oregon (PDX) to monthly normals. Table 3 shows that rainfall in the area was below normal in September 2009, November 2009, December 2009, January 2010, February 2010, and March 2010. Rainfall was above normal in October 2009, April 2010, May 2010, and June 2010.

Table 3. Comparison of monthly rainfall data between National Weather Service (NWS) cooperative station and Monthly Normals.

Month	PDX rain gage (in.)	Percent of normal (%)	Monthly normals (1971-2000)
September 2009	1.4	85	1.65
October 2009	3.02	105	2.88
November 2009	5.13	91	5.62
December 2009	3.76	66	5.71
January 2010	4.94	97	5.07
February 2010	2.76	66	4.18
March 2010	3.58	96	3.71
April 2010	2.92	111	2.64
May 2010	4.68	197	2.38
June 2010	4.27	269	1.59

A total of 19 storm events that were successfully sampled during the monitoring period between September of 2009 and June of 2010. Collection of storm events commenced after the review and conditional approval of the Quality Assurance Project Plan by project stake holders. Storm event durations ranged from 1 to 40 hours, rainfall depth for sampled events ranged from 0.08 to 1.43 inches, and 15 and 30 minute maximum intensities were 0.13 and 0.14 inches/hour respectively. Based on the estimated drainage area of 0.28 acres the calculated total rainfall volume ranged from 608 to 10871 gallons, Table 4.

Table 4. Rainfall and runoff statistics for sampled events at the ICC site

Event ID	Duration of storm event (hours)	Total rainfall (in.)	P15 (in/hr)	P30 (in/hr)	Total rainfall volume (gallons)
PNT090509	9	0.76	0.05	0.09	5778
PNT102109	5	0.23	0.05	0.08	1749
PNT102309	8	0.40	0.06	0.06	3041
PNT102909	9	0.27	0.04	0.04	2053
PNT110509	17	0.49	0.09	0.09	3725
PNT011510	39	0.86	0.03	0.05	6538
PNT012210	13	0.22	0.02	0.04	1673
PNT012410	18	0.68	0.05	0.08	5170
PNT020110	40	0.18	0.02	0.03	1368
PNT020210	16	0.12	0.01	0.02	912
PNT020410	12	0.39	0.03	0.05	2965
PNT031110	12	0.56	0.04	0.05	4257
PNT032510	6	0.25	0.03	0.03	1901
PNT032610	17	0.37	0.06	0.10	2813
PNT032810	31	1.43	0.13	0.14	10872
PNT051910	1	0.08	0.04	0.04	608
PNT052010	16	0.29	0.07	0.11	2205
PNT061010	3	0.11	0.04	0.04	836
PNT061510	18	0.28	0.04	0.06	2129

Table 5. Percentage of calculated rainfall runoff volumes measured at the ICC site

Event ID	Event depth (in)	Influent volume (gal)	Calc. flow volume (gal)	Percent runoff (%)
PNT090509	0.76	4916	5778	85
PNT102109	0.23	1596	1749	91
PNT102309	0.4	1472	3041	48
PNT102909	0.27	1481	2053	72
PNT110509	0.49	2948	3725	79
PNT011510	0.86	7118	6538	109
PNT012210	0.22	1211	1673	72
PNT012410	0.68	5523	5170	107
PNT020110	0.18	1445	1368	106
PNT020210	0.12	1024	912	112
PNT020410	0.39	3395	2965	115
PNT031110	0.56	4017	4257	94
PNT032510	0.25	1405	1901	74
PNT032610	0.37	2544	2813	90
PNT032810	1.43	6209	10872	57
PNT051910	0.08	600	608	99
PNT052010	0.29	243	2205	11
PNT061010	0.11	780	836	93
PNT061510	0.28	1295	2129	61

Flow Measurement

An orifice flow meter was used at the influent and effluent sample locations in conjunction with a Campbell CR1000 to measure flow and pace sample collection. Head measurements were adjusted by applying corrections that reflected differences between recorded and measured water surface elevations. On average 83 percent of the calculated total rainfall volume was measured as runoff for the events monitored, Table 5.

Stormwater Data Collection

Of the 19 storm events sampled between September of 2008 and April of 2010; 1) the total rainfall was greater than 0.1 inch for all storm events sampled except for the PNT051910 storm event (0.08), 2) the minimum inter-event period was greater than 6 hours for all storm events sampled except the except for the PNT102909 storm event (I hour) and PNT031110 storm event (6 hours), 3) flow-weighted influent composite samples covered greater than 50% of the total storm event volume for all storm events sampled except for the PNT090509 storm event (12%), 4) the average number of samples collected per storm event was 27 at the Influent, 19 at Sintered Perlite effluent, and 23 PhosphoSorb effluent sampling locations. 5) The total sampled rainfall was 8.0 inches, 6) internal bypass was detected for 12 of storm events sampled 6) solids, metals, and nutrient water quality parameters were evaluated simultaneously for all storm events sampled. All sampled storm events were used to demonstrate the total phosphorus removal efficiency of the Stormfilter system using the PhosphoSorb media as compared to Sintered Perlite Media, Table 6.

Table 6. Stormwater data collection results for the ICC site

				Influent				Sintered Perlite				PhosphoSorb						
Event (ID)	**Event Depth (in)**	**Antecedent Dry Period (hours)**	**Mass of solids seeded prior to storm event (kg)**	**Coverage**	**Number of Aliquots**	**Influent Volume (gal)**	**Peak Flow (gpm)**	**Coverage**	**Number of Aliquots**	**Effluent Volume (gal)**	**Peak Flow (gpm)**	**Coverage**	**Number of Aliquots**	**Effluent Volume (gal)**	**Peak Flow (gpm)**	**Calculated Runoff Volume**	**Measured/ Calc. Runoff Ratio**	***Bypass Volume (gal)**
PNT090509	0.76	40	0.0	12	23	4916	44	11	22	1989	6	11	20	1847	5	5778	0.9	1113
PNT102109	0.23	60	0.0	67	18	1596	44	64	16	842	8	65	11	523	5	4621	0.3	316
PNT102309	0.4	41	0.0	94	18	1472	35	93	12	633	6	89	14	780	6	8037	0.2	38
PNT102909	0.27	1	0.0	100	11	1481	18	95	12	935	6	99	8	653	5	5425	0.3	0
PNT110509	0.49	94	0.0	100	22	2948	44	100	14	1354	7	100	15	1432	7	9845	0.3	84
PNT011510	0.86	43	2.0	75	32	7118	30	81	24	3264	6	100	31	3018	6	17280	0.4	0
PNT012210	0.22	72	1.0	91	11	1211	7	94	8	478	4	99	9	536	5	4420	0.3	0
PNT012410	0.68	26	1.0	67	40	5523	32	84	30	1878	5	72	29	2409	6	13663	0.4	1149
PNT020110	0.18	24	2.0	83	23	1445	17	91	17	451	6	92	33	757	5	3617	0.4	8
PNT020210	0.12	26	1.0	93	23	1024	18	100	8	235	5	100	19	453	6	2411	0.4	0
PNT020410	0.39	26	4.0	65	35	3395	18	68	25	1269	5	68	33	1441	6	7836	0.4	294
PNT031110	0.56	6	8.0	57	48	4017	39	100	42	1058	5	58	44	2007	6	11252	0.4	22
PNT032510	0.25	66	2.0	63	26	1405	18	87	14	351	4	93	33	770	5	5023	0.3	0
PNT032610	0.37	10	3.5	91	21	2544	42	94	10	570	5	92	12	743	6	7434	0.3	653
PNT032810	1.43	7	3.5	66	46	6209	43	98	33	1719	5	92	37	2112	6	28733	0.2	1450
PNT051910	0.08	21	1.5	93	34	600	31	92	21	210	5	99	29	250	6	1607	0.4	0
PNT052010	0.29	13	0.0	48	8	243	18	92	12	104	4	82	9	99	4	5827	0.0	0
PNT061010	0.11	9	1.5	98	39	780	45	93	22	237	5	93	21	228	6	2210	0.4	168
PNT061510	0.28	119	0.0	49	31	1295	50	50	21	383	5	56	24	409	6	5626	0.2	274

*Bypass Volume = Influent Volume-(Sintered Perlite Effluent Volume + PhosphoSorb Effluent Volume) when flow over internal weir detected

Table 7. **Solids Event Mean Concentrations (EMCs) for the 19 events sampled at the ICC site using Sintered Perlite Media**

Event ID	TSS (SM) (mg/l)		SSC (mg/l)		TVSS (mg/l)		SSC<500-um (mg/l)		TVSS<500-um (mg/l)	
	Influent	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**
PNT090509	40.0	10.0	93.1	7.0	24.1	3.5	NT	NT	NT	NT
PNT102109	80.0	10.0	130.0	14.0	23.1	5.4	79.8	14.6	15.6	5.6
PNT102309	30.0	10.0	45.3	4.5	11.3	2.2	28.0	4.6	9.3	2.3
PNT102909	10.0	10.0	19.7	1.7	9.9	3.3	5.7	1.7	3.8	3.1
PNT110509	20.0	10.0	14.7	4.6	7.9	3.1	14.1	4.8	8.2	3.2
PNT011510	20.0	10.0	20.0	8.5	9.1	4.2	15.3	9.1	7.6	4.6
PNT012210	10.0	10.0	12.4	6.3	8.3	6.3	10.8	8.1	5.4	8.1
PNT012410	20.0	10.0	21.7	5.4	10.8	4.0	19.4	6.0	8.8	4.0
PNT020110	20.0	10.0	22.3	5.8	12.4	2.9	19.4	7.0	11.1	3.5
PNT020210	30.0	30.0	32.7	31.3	20.4	21.9	32.7	33.0	19.6	23.1
PNT020410	90.0	60.0	100.0	55.3	49.1	31.9	91.3	55.3	45.6	31.0
PNT031110	50.0	10.0	55.1	12.0	25.4	6.0	50.8	13.3	20.3	6.7
PNT032510	40.0	10.0	45.8	8.8	24.1	5.9	36.9	7.3	15.8	7.3
PNT032610	180.0	30.0	196.0	30.2	96.9	16.5	169.0	30.2	74.3	16.5
PNT032810	90.0	20.0	94.3	15.8	45.7	8.6	88.6	16.4	40.0	8.2
PNT051910	190.0	10.0	197.0	12.7	72.0	7.6	156.0	13.5	52.8	6.8
PNT052010	1210.0	70.0	1350.0	69.0	552.0	30.2	679.0	62.8	244.0	29.0
PNT061010	220.0	40.0	429.0	40.0	87.0	20.0	339.0	38.2	89.0	22.3
PNT061510	40.0	10.0	36.7	8.6	16.7	5.7	33.3	5.9	16.7	5.9
Min	10.0	10.0	12.4	1.7	7.9	2.2	5.7	1.7	3.8	2.3
Max	1210.0	70.0	1350.0	69.0	552.0	31.9	679.0	62.8	244.0	31.0
Median	40.0	10.0	45.8	8.8	23.1	5.9	35.1	11.2	16.3	6.7
Mean	125.8	20.0	153.5	18.0	58.2	10.0	103.8	18.4	38.2	10.6

Table 8. **Solids Event Mean Concentrations (EMCs) for the 19 events sampled at the ICC site PhosphoSorb Media.**

Event ID	TSS (SM) (mg/l)		SSC (mg/l)		TVSS (mg/l)		SSC<500-um (mg/l)		TVSS<500-um (mg/l)	
	Influent	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**
PNT090509	40.0	10.0	93.1	10.3	24.1	3.4	NT	NT	NT	NT
PNT102109	80.0	10.0	130.0	4.6	23.1	1.5	79.8	4.7	15.6	1.6
PNT102309	30.0	10.0	45.3	3.3	11.3	1.6	28.0	3.3	9.3	1.7
PNT102909	10.0	10.0	19.7	3.3	9.9	3.3	5.7	3.1	3.8	3.1
PNT110509	20.0	10.0	14.7	4.5	7.9	3.0	14.1	4.8	8.2	3.2
PNT011510	20.0	10.0	20.0	8.9	9.1	4.5	15.3	7.8	7.6	3.9
PNT012210	10.0	10.0	12.4	5.6	8.3	5.6	10.8	7.5	5.4	7.5
PNT012410	20.0	10.0	21.7	5.1	10.8	3.4	19.4	5.3	8.8	2.6
PNT020110	20.0	10.0	22.3	8.0	12.4	4.5	19.4	7.6	11.1	4.6
PNT020210	30.0	20.0	32.7	24.5	20.4	13.4	32.7	25.6	19.6	14.2
PNT020410	90.0	30.0	100.0	36.4	49.1	21.8	91.3	38.0	45.6	20.8
PNT031110	50.0	10.0	55.1	7.4	25.4	3.7	50.8	7.1	20.3	3.6
PNT032510	40.0	10.0	45.8	8.6	24.1	4.9	36.9	8.0	15.8	4.8
PNT032610	180.0	40.0	196.0	42.0	96.9	22.0	169.0	41.2	74.3	21.6
PNT032810	90.0	20.0	94.3	21.6	45.7	11.4	88.6	23.0	40.0	12.2
PNT051910	190.0	20.0	197.0	22.9	72.0	11.4	156.0	21.4	52.8	10.7
PNT052010	1210.0	60.0	1350.0	63.2	552.0	26.3	679.0	54.4	244.0	27.2
PNT061010	220.0	40.0	429.0	33.9	87.0	19.1	339.0	34.7	89.0	17.3
PNT061510	40.0	10.0	36.7	7.4	16.7	4.9	33.3	7.9	16.7	5.3
Min	10.0	10.0	12.4	3.3	7.9	1.5	5.7	3.1	3.8	1.6
Max	1210.0	60.0	1350.0	63.2	552.0	26.3	679.0	54.4	244.0	27.2
Median	40.0	10.0	45.8	8.6	23.1	4.9	35.1	7.8	16.3	5.0
Mean	125.8	18.4	153.5	16.9	58.2	8.9	103.8	17.0	38.2	9.2

Table 9. Nutrient Event Mean Concentrations (EMCs) for the 19 events sampled at the ICC site using Sintered Perlite Media

Event ID	Total Dissolved P (TDP) (mg/l)		Ortho-P (mg/l)		Total Phos (mg/l)		TKN (mg/l)		Nitrate/Nitrite-N (mg/l)		Ammonia (mg/l)	
	Influent	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**
PNT090509	NT	NT	NT	NT	0.075	0.029	1.73	1.58	0.66	0.63	0.40	0.40
PNT102109	ND	ND	ND	ND	0.115	0.032	0.81	0.76	0.16	0.15	ND	ND
PNT102309	ND	ND	ND	ND	0.045	0.020	ND	ND	0.05	0.05	ND	ND
PNT102909	ND	ND	ND	ND	0.025	0.022	ND	ND	0.04	0.05	ND	ND
PNT110509	ND	ND	ND	ND	ND	ND	ND	ND	0.05	0.06	ND	ND
PNT011510	ND	ND	ND	ND	ND	ND	0.78	0.50	ND	ND	ND	ND
PNT012210	ND	ND	ND	ND	0.033	0.040	ND	ND	ND	ND	ND	ND
PNT012410	ND	ND	ND	ND	0.040	0.026	0.52	0.50	ND	ND	ND	ND
PNT020110	ND	ND	ND	ND	0.049	0.026	0.53	0.50	ND	ND	ND	ND
PNT020210	0.50	0.59	0.12	0.22	0.332	0.503	0.87	0.94	ND	ND	ND	ND
PNT020410	ND	ND	0.01	0.01	0.166	0.140	1.70	1.30	ND	ND	0.05	0.06
PNT031110	0.10	0.03	ND	ND	ND	ND	1.07	0.65	ND	ND	NT	ND
PNT032510	ND	ND	ND	ND	0.060	0.037	1.11	1.05	ND	ND	0.10	0.05
PNT032610	ND	ND	ND	ND	0.161	0.055	2.11	0.98	0.03	0.03	NT	ND
PNT032810	ND	ND	ND	ND	0.118	0.039	1.21	0.67	0.04	0.04	ND	ND
PNT051910	ND	ND	0.01	0.01	0.161	0.066	2.08	0.85	0.04	0.46	ND	ND
PNT052010	ND	ND	ND	ND	0.485	0.174	10.20	2.02	0.05	0.12	0.26	0.12
PNT061010	ND	ND	ND	ND	0.169	0.131	2.28	1.27	0.03	0.18	ND	ND
PNT061510	ND	ND	ND	ND	0.095	0.037	0.76	0.56	0.05	0.26	0.05	0.11
Min	0.10	0.03	0.01	0.01	0.025	0.020	0.52	0.50	0.03	0.03	0.05	0.05
Max	0.50	0.59	0.12	0.22	0.485	0.503	10.20	2.02	0.66	0.63	0.40	0.40
Median	0.30	0.31	0.01	0.01	0.105	0.038	1.11	0.85	0.05	0.12	0.10	0.11
Mean	0.30	0.31	0.05	0.08	0.133	0.086	1.85	0.94	0.11	0.18	0.17	0.15

Table 10. Nutrient Event Mean Concentrations (EMCs) for the 19 events sampled at the ICC site using PhosphoSorb Media

Event ID	Total Dissolved P (TDP) (mg/l)		Ortho-P (mg/l)		Total Phos (mg/l)		TKN (mg/l)		Nitrate/Nitrite-N (mg/l)		Ammonia (mg/l)	
	Influent	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**
PNT090509	NT	NT	NT	NT	0.075	0.020	1.73	1.51	0.66	0.77	0.40	0.34
PNT102109	ND	ND	ND	ND	0.115	0.026	0.81	0.54	0.16	0.16	ND	ND
PNT102309	ND	ND	ND	ND	0.045	0.020	0.50	0.51	0.05	0.05	ND	ND
PNT102909	ND	ND	ND	ND	0.025	0.022	ND	ND	0.04	1.02	ND	ND
PNT110509	ND	ND	ND	ND	ND	ND	ND	ND	0.05	0.05	ND	ND
PNT011510	ND	ND	ND	ND	ND	ND	0.78	0.50	ND	ND	ND	ND
PNT012210	ND	ND	ND	ND	0.033	0.020	ND	ND	ND	ND	ND	ND
PNT012410	ND	ND	ND	ND	0.040	0.022	0.52	0.50	ND	ND	ND	ND
PNT020110	ND	ND	ND	ND	0.049	0.029	0.53	0.50	ND	ND	ND	ND
PNT020210	ND	ND	0.12	0.06	0.332	0.174	0.87	0.67	0.03	0.04	ND	ND
PNT020410	ND	ND	ND	ND	0.166	0.091	1.70	0.91	ND	ND	ND	ND
PNT031110	0.10	0.50	ND	ND	0.057	0.020	1.07	0.56	ND	ND	NT	NT
PNT032510	ND	ND	ND	ND	0.060	0.030	1.11	0.79	0.06	0.08	0.10	0.05
PNT032610	ND	ND	ND	ND	0.161	0.084	2.11	1.20	0.03	0.03	ND	ND
PNT032810	ND	ND	ND	ND	0.118	0.053	1.21	0.80	0.04	0.04	ND	ND
PNT051910	ND	ND	ND	ND	0.161	0.097	2.08	1.19	0.04	0.45	0.05	0.10
PNT052010	ND	ND	ND	ND	0.485	0.146	10.20	1.64	0.05	0.10	0.26	0.18
PNT061010	ND	ND	ND	ND	0.169	0.107	2.28	0.90	0.03	0.24	ND	ND
PNT061510	ND	ND	ND	ND	0.095	0.030	0.76	0.50	0.05	0.27	ND	ND
Min	0.10	0.50	0.12	0.06	0.025	0.020	0.50	0.50	0.03	0.03	0.05	0.05
Max	0.10	0.50	0.12	0.06	0.485	0.174	10.20	1.64	0.66	1.02	0.40	0.34
Median	0.10	0.50	0.12	0.06	0.095	0.030	1.09	0.73	0.05	0.10	0.18	0.14
Mean	0.10	0.50	0.12	0.06	0.129	0.058	1.77	0.83	0.10	0.25	0.20	0.17

Table 11. Total Metals Event Mean Concentrations (EMCs) for the 19 events sampled at the ICC site using Sintered Perlite Media

Event ID	Total Aluminum (mg/l)		Total Magnesium (mg/l)		Total Copper (mg/l)		Total Zinc (mg/l)		Hardness (mg/l)		pH	
	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
PNT090509	0.717	0.185	0.627	0.424	0.019	0.015	0.069	0.045	12.7	11.9	6.0	6.2
PNT102109	1.230	0.277	0.521	0.285	0.011	0.006	0.055	0.029	8.9	6.1	6.9	7.0
PNT102309	0.518	0.100	0.289	0.174	0.007	0.004	0.026	0.039	5.0	3.5	6.9	6.9
PNT102909	ND	ND	0.163	0.131	0.005	0.005	0.012	0.031	4.0	3.3	7.1	7.0
PNT110509	0.150	0.100	0.250	0.231	0.004	0.003	0.017	0.015	5.2	5.3	7.0	6.9
PNT011510	0.294	0.100	0.189	0.137	0.006	0.004	0.022	0.015	4.5	3.8	6.8	6.9
PNT012210	0.186	0.100	0.209	0.155	0.004	0.002	0.017	0.012	4.9	4.1	6.8	6.7
PNT012410	0.266	0.100	0.148	0.113	0.003	0.002	0.022	0.012	3.8	3.2	6.7	6.7
PNT020110	0.280	0.100	0.183	0.146	0.005	0.002	0.023	0.011	4.4	4.2	7.6	7.5
PNT020210	0.458	0.498	0.258	0.255	0.009	0.010	0.044	0.047	5.9	5.1	6.7	6.6
PNT020410	1.300	0.860	0.453	0.327	0.016	0.014	0.087	0.076	8.1	6.0	6.9	6.9
PNT031110	0.597	0.151	0.266	0.143	0.011	0.004	0.035	0.019	5.6	3.5	6.6	6.5
PNT032510	0.353	0.101	0.362	0.289	0.010	0.008	0.040	0.032	7.3	6.4	6.7	6.7
PNT032610	1.650	0.388	0.656	0.247	0.025	0.007	0.128	0.037	9.9	4.6	6.7	6.7
PNT032810	1.030	0.214	0.375	0.172	0.016	0.004	0.077	0.025	6.7	4.1	6.8	6.8
PNT051910	1.700	0.138	0.643	0.193	0.014	0.002	0.094	0.035	10.0	5.2	6.5	6.7
PNT052010	9.610	1.110	3.210	0.589	0.087	0.012	0.493	0.089	44.5	10.7	6.5	6.6
PNT061010	2.880	0.696	1.020	0.275	0.022	0.009	0.101	0.051	12.4	5.1	6.2	6.4
PNT061510	0.484	0.100	0.319	0.229	0.007	0.004	0.034	0.035	6.7	6.4	6.5	6.8
Min	0.150	0.100	0.148	0.113	0.003	0.002	0.012	0.011	3.8	3.2	6.0	6.2
Max	9.610	1.110	3.210	0.589	0.087	0.015	0.493	0.089	44.5	11.9	7.6	7.5
Median	0.558	0.145	0.319	0.229	0.010	0.004	0.040	0.032	6.7	5.1	6.7	6.7
Mean	1.317	0.295	0.534	0.238	0.015	0.006	0.073	0.034	9.0	5.4	6.7	6.8

Table 12. Total Metals Event Mean Concentrations (EMCs) for the 19 events sampled at the ICC site using PhosphoSorb Media

Event ID	Total Aluminum (mg/l)		Total Magnesium (mg/l)		Total Copper (mg/l)		Total Zinc (mg/l)		Hardness (mg/l)		pH	
	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
PNT090509	0.717	0.322	0.627	0.522	0.019	0.010	0.069	0.016	12.7	10.0	6.0	6.2
PNT102109	1.230	0.119	0.521	0.264	0.011	0.003	0.055	0.036	8.9	5.8	6.9	6.8
PNT102309	0.518	0.115	0.289	0.225	0.007	0.003	0.026	0.061	5.0	4.6	6.9	7.0
PNT102909	ND	ND	0.163	1.520	0.005	0.004	0.012	0.006	4.0	3.9	7.1	7.1
PNT110509	0.150	0.100	0.250	0.234	0.004	0.003	0.017	0.008	5.2	5.6	7.0	7.0
PNT011510	0.294	0.115	0.189	0.151	0.006	0.002	0.022	0.010	4.5	4.2	6.8	7.0
PNT012210	0.186	0.100	0.209	0.154	0.004	0.002	0.017	0.010	4.9	4.2	6.8	6.8
PNT012410	0.266	0.100	0.148	0.115	0.003	0.002	0.022	0.016	3.8	3.2	6.7	6.7
PNT020110	0.280	0.166	0.183	0.151	0.005	0.002	0.023	0.010	4.4	4.0	7.6	7.5
PNT020210	0.458	0.382	0.258	0.228	0.009	0.007	0.044	0.028	5.9	5.1	6.7	6.7
PNT020410	1.300	0.518	0.453	0.257	0.016	0.009	0.087	0.047	8.1	5.4	6.9	6.8
PNT031110	0.597	0.100	0.266	0.140	0.011	0.002	0.035	0.010	5.6	3.7	6.6	6.5
PNT032510	0.353	0.100	0.362	0.228	0.010	0.005	0.040	0.014	7.3	5.3	6.7	6.7
PNT032610	1.650	0.057	0.656	0.327	0.025	0.009	0.128	0.040	9.9	5.8	6.7	6.6
PNT032810	1.030	0.333	0.375	0.206	0.016	0.005	0.077	0.031	6.7	4.7	6.8	6.8
PNT051910	1.700	0.311	0.643	0.349	0.014	0.003	0.094	0.022	10.0	10.3	6.5	6.9
PNT052010	9.610	0.973	3.210	0.550	0.087	0.009	0.493	0.052	44.5	10.5	6.5	6.8
PNT061010	2.880	0.580	1.020	0.267	0.022	0.007	0.101	0.029	12.4	5.3	6.2	6.5
PNT061510	0.484	0.100	0.319	0.218	0.007	0.003	0.034	0.014	6.7	5.7	6.5	6.8
Min	0.150	0.057	0.148	0.115	0.003	0.002	0.012	0.006	3.8	3.2	6.0	6.2
Max	9.610	0.973	3.210	1.520	0.087	0.010	0.493	0.061	44.5	10.5	7.6	7.5
Median	0.558	0.117	0.319	0.228	0.010	0.003	0.040	0.016	6.7	5.3	6.7	6.8
Mean	1.317	0.255	0.534	0.321	0.015	0.005	0.073	0.024	9.0	5.6	6.7	6.8

Table 13. Dissolved Metals Event Mean Concentrations (EMCs) for the 19 events sampled at the ICC site using Sintered Perlite Media

Event ID	Dissolved Aluminum (mg/l)		Dissolved Copper (mg/l)		Dissolved Zinc (mg/l)	
	Influent	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**
PNT090509	NT	NT	NT	NT	NT	NT
PNT102109	NT	NT	NT	NT	NT	NT
PNT102309	NT	NT	NT	NT	NT	NT
PNT102909	ND	ND	0.0029	0.0021	0.01	0.01
PNT110509	ND	ND	0.0030	0.0027	0.01	0.01
PNT011510	ND	ND	ND	ND	0.01	0.01
PNT012210	ND	ND	0.0030	0.0021	0.01	0.01
PNT012410	ND	ND	ND	ND	ND	ND
PNT020110	ND	ND	ND	ND	ND	ND
PNT020210	ND	ND	0.0027	0.0031	0.01	0.02
PNT020410	ND	ND	ND	ND	0.01	0.02
PNT031110	ND	ND	0.0023	0.0020	0.01	0.01
PNT032510	ND	ND	0.0041	0.0040	ND	ND
PNT032610	ND	ND	ND	ND	0.02	0.01
PNT032810	ND	ND	ND	ND	ND	ND
PNT051910	ND	ND	ND	ND	0.01	0.03
PNT052010	ND	ND	ND	ND	0.01	0.04
PNT061010	ND	ND	0.0025	0.0025	0.13	0.03
PNT061510	ND	ND	0.0023	0.0026	0.01	0.03
Min	NA	NA	0.002	0.002	0.01	0.01
Max	NA	NA	0.004	0.004	0.13	0.04
Median	NA	NA	0.003	0.003	0.01	0.02
Mean	NA	NA	0.003	0.003	0.02	0.02

Table 14. Dissolved Metals Event Mean Concentrations (EMCs) for the 19 events sampled at the ICC site using PhosphoSorb Media

Event ID	Dissolved Aluminum (mg/l)		Dissolved Copper (mg/l)		Dissolved Zinc (mg/l)	
	Influent	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**
PNT090509	NT	NT	NT	NT	NT	NT
PNT102109	NT	NT	NT	NT	NT	NT
PNT102309	NT	NT	NT	NT	NT	NT
PNT102909	ND	ND	0.003	0.002	0.009	0.007
PNT110509	ND	ND	0.003	0.002	0.013	0.007
PNT011510	ND	ND	ND	ND	0.011	0.010
PNT012210	ND	ND	0.003	0.002	0.012	0.010
PNT012410	ND	ND	ND	ND	ND	ND
PNT020110	ND	ND	ND	ND	ND	ND
PNT020210	ND	ND	0.003	0.002	0.013	0.012
PNT020410	ND	ND	ND	ND	0.014	0.012
PNT031110	ND	ND	0.002	0.002	0.013	0.010
PNT032510	ND	ND	0.004	0.003	ND	ND
PNT032610	ND	ND	ND	ND	0.015	0.010
PNT032810	ND	ND	ND	ND	ND	ND
PNT051910	ND	ND	ND	ND	0.011	0.010
PNT052010	ND	ND	ND	ND	0.010	0.011
PNT061010	ND	ND	0.002	0.002	0.134	0.011
PNT061510	ND	ND	0.002	0.002	0.012	0.010
Min	NA	NA	0.002	0.002	0.009	0.007
Max	NA	NA	0.004	0.003	0.134	0.012
Median	NA	NA	0.003	0.002	0.012	0.010
Mean	NA	NA	0.003	0.002	0.022	0.010

Data Analysis

Of the 19 storm events captured between September of 2009 and June of 2010, data verification and validation did not lead to the outright disqualification of any events due to obvious monitoring, handling, or analytical errors, or the substantial exceedance of the design operating parameters. No instances were encountered that suggested the disqualification or separation of select analytical results from the data set. Disqualification of either an influent or effluent result would result in the elimination of the paired data from the final data set. Event mean concentrations (EMCs) from influent and effluent samples are summarized in Tables 7 thru 14.

In order to determine if data was normally or log-normally distributed the Kolmogorov-Smirnov test was used. EMCs for all parameters analyzed were tested.

Influent EMCs for Total Dissolved P (TDP), Ortho-P, Dissolved Copper, Ammonia, and pH were normally distributed. Influent EMCs for TSS (SM), SSC, TVSS, SSC<500-um,TVSS<500-um,Total Dissolved P (TDP), Ortho-P, Dissolved Copper, Total Phosphorus, TKN, Ammonia, Total Aluminum, Total Magnesium, Total Copper, Total Zinc, Hardness, and pH were log normally distributed.

Sintered Perlite effluent EMCs for Total Dissolved P (TDP), Ortho-P, Dissolved Copper, Dissolved Zinc, TKN, Nitrate/Nitrite-N, Total Magnesium, Total Zinc, and pH were normally distributed. Sintered Perlite effluent EMCs for SSC, TVSS, SSC<500-um, TVSS<500-um,Total Dissolved P (TDP), Ortho-P, Dissolved Copper, Dissolved Zinc, TKN, Nitrate/Nitrite-N, Ammonia, Total Magnesium, Total Copper, Total Zinc, Hardness, and pH were log-normally distributed.

PhosphoSorb effluent EMCs for TKN, Ammonia, and pH were normally distributed. PhosphoSorb effluent EMCs for SSC, TVSS, TVSS<500-um, TKN, and Nitrate/Nitrite-N, Ammonia, Total Copper, Total Zinc, and pH were log-normally distributed.

Non-parametric statistical methods were used to evaluate correlations and differences between influent and effluent EMCs since influent and effluent EMCs were generally not from the same statistical distribution. To test for positive correlations between influent and effluent EMCs, the Spearman Rank Order Correlation test was used (USGS, 1991). To evaluate the significance of differences between influent and effluent EMCs, the Mann-Whitney Rank Sum Test was used (USGS, 1991). For the Mann-Whitney Rank Sum Test the null hypothesis was that the two samples were not drawn from populations with different medians. A significant difference between influent and effluent EMCs was concluded when $P<0.05$.

Performance was calculated using the summation of loads (SOL) method. The SOL method defines the efficiency as a percentage based on the ratio of the summation of all incoming loads to the summation of all outlet loads. The SOL method assumes; 1) monitoring data accurately represents the actual entire total loads in and out of the BMP for a period long enough to overshadow any temporary storage or export of pollutants and 2) any significant storm events that were not monitored had a ratio of inlet to outlet loads similar to the storms events that were monitored (URS/ EPA 1999). Sum of Loads (SOL) Efficiency Calculations for the 19 events sampled at the ICC site are summarized in Tables 15 thru 21.

For values that were reported as non-detect, substitutions were made using the Method Reporting Limit (MRL) for statistical testing or calculation of event loads.

Under the assumption that measured effluent volumes are equal to influent volumes, effluent volumes were used for the calculation of loads for both influent and effluent sample locations.

Results

Based on the use of the Spearman Rank Order correlation test, positive correlations (P<0.05) were determined between Influent and Sintered Perlite effluent EMCs for TSS (SM), SSC, TVSS, SSC<500-um,TVSS<500-um, Dissolved Aluminum, Total Phosphorus, TKN, Total Aluminum, Total Magnesium, Total Copper, Total Zinc, Hardness, and pH.

Based on the use of the Spearman Rank Order correlation test, positive correlations (P<0.05) were determined between Influent and PhosphoSorb effluent EMCs for Total Phosphorus, TKN, Total Aluminum, Total Magnesium, Total Copper, Total Zinc, Hardness, and pH.

Based on the use of the Mann-Whitney Rank Sum test the difference in the median values between the influent and Sintered Perlite effluent EMCs is greater than would be expected by chance; there is a statistically significant difference (P< 0.05) for TSS (SM), SSC, TVSS, SSC<500-um, TV<500-um, Dissolved Copper, Dissolved Zinc, Total Phosphorus, TKN, Total Aluminum, Total Copper, and Total Zinc.

Based on the use of the Mann-Whitney Rank Sum test the difference in the median values between the influent and Sintered Perlite effluent EMCs is greater than would be expected by chance; there is a statistically significant difference (P< 0.05) TSS (SM), SSC, TVSS, SSC<500-um, TVCC<500-um, Dissolved Copper, Dissolved Zinc, Total Phosphorus, TKN, Total Aluminum, Total Copper, and Total Zinc.

Table 15. **Suspended Solids Event Sum of Loads (SOL) Efficiency Calculations for the 19 events sampled at the ICC site using Sintered Perlite**

Event ID	TSS (SM) (g)		SSC (g)		TVSS (g)		SSC<500-um (g)		TVSS<500-um (g)	
	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
PNT090509	280	70	651	49	168	25	0	0	0	0
PNT102109	158	20	258	28	46	11	158	29	31	11
PNT102309	89	30	134	13	33	7	83	13	28	7
PNT102909	25	25	49	4	24	8	14	4	9	8
PNT110509	108	54	80	25	43	17	76	26	45	17
PNT011510	228	114	228	97	104	48	175	104	87	52
PNT012210	20	20	25	13	17	13	22	16	11	16
PNT012410	182	91	198	49	98	37	177	55	80	36
PNT020110	57	29	64	17	36	8	56	20	32	10
PNT020210	51	51	56	54	35	38	56	57	34	40
PNT020410	491	327	546	302	268	174	498	302	249	169
PNT031110	380	76	419	91	193	46	386	101	154	51
PNT032510	117	29	133	26	70	17	107	21	46	21
PNT032610	506	84	551	85	272	46	475	85	209	46
PNT032810	719	160	754	126	365	69	708	131	320	66
PNT051910	180	9	187	12	68	7	148	13	50	6
PNT052010	452	26	504	26	206	11	253	23	91	11
PNT061010	190	35	370	35	75	17	293	33	77	19
PNT061510	62	15	57	13	26	9	51	9	26	9
Total	4296	1266	5262	1063	2149	607	3737	1043	1577	596
SOL Efficiency	71		80		72		72		62	

Table 16. **Solids Event Sum of Loads (SOL) Efficiency Calculations for the 19 events sampled at the ICC site using PhosphoSorb**

Event ID	TSS (SM) (g)		SSC (g)		TVSS (g)		SSC<500-um (g)		TVSS<500-um (g)	
	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
PNT090509	301	75	701	78	181	26	0	0	0	0
PNT102109	255	32	414	15	74	5	254	15	50	5
PNT102309	72	24	108	8	27	4	67	8	22	4
PNT102909	35	35	70	12	35	12	20	11	13	11
PNT110509	102	51	75	23	41	15	72	24	42	16
PNT011510	247	124	247	110	113	55	189	96	94	48
PNT012210	18	18	22	10	15	10	20	13	10	13
PNT012410	142	71	154	36	77	24	138	37	63	19
PNT020110	34	17	38	14	21	8	33	13	19	8
PNT020210	27	18	29	22	18	12	29	23	17	13
PNT020410	432	144	480	175	236	105	439	183	219	100
PNT031110	200	40	221	30	102	15	204	28	81	14
PNT032510	53	13	61	11	32	7	49	11	21	6
PNT032610	388	86	423	91	209	47	364	89	160	47
PNT032810	586	130	614	141	297	74	577	150	260	79
PNT051910	151	16	157	18	57	9	124	17	42	9
PNT052010	478	24	533	25	218	10	268	21	96	11
PNT061010	198	36	385	30	78	17	305	31	80	16
PNT061510	58	14	53	11	24	7	48	11	24	8
Total	3778	969	4787	858	1855	462	3200	783	1315	426
SOL Efficiency	74		82		75		76		68	

Table 17. Nutrient Event Sum of Loads (SOL) Efficiency Calculations for the 19 events sampled at the ICC site using Sintered Perlite

Event ID	Total Dissolved P (TDP) (g)		Ortho-P (g)		Total Phosphorus (g)		TKN (g)		Nitrate/Nitrite-N (g)		Ammonia (g)	
	Influent	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**
PNT090509	0.00	0.00	0.00	0.00	0.52	0.20	12.09	11.05	4.64	4.43	2.76	2.77
PNT102109	0.00	0.00	0.00	0.00	0.23	0.06	1.60	1.51	0.31	0.30	0.00	0.00
PNT102309	0.00	0.00	0.00	0.00	0.13	0.06	0.00	0.00	0.15	0.15	0.00	0.00
PNT102909	0.00	0.00	0.00	0.00	0.06	0.05	0.00	0.00	0.10	0.11	0.00	0.00
PNT110509	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.26	0.33	0.00	0.00
PNT011510	0.00	0.00	0.00	0.00	0.00	0.00	8.88	5.76	0.00	0.00	0.00	0.00
PNT012210	0.00	0.00	0.00	0.00	0.07	0.08	0.00	0.00	0.00	0.00	0.00	0.00
PNT012410	0.00	0.00	0.00	0.00	0.37	0.24	4.74	4.56	0.00	0.00	0.00	0.00
PNT020110	0.00	0.00	0.00	0.00	0.14	0.07	1.51	1.43	0.00	0.00	0.00	0.00
PNT020210	0.86	1.01	0.20	0.38	0.57	0.86	1.49	1.61	0.00	0.00	0.00	0.00
PNT020410	0.00	0.00	0.05	0.07	0.91	0.76	9.28	7.09	0.00	0.00	0.27	0.32
PNT031110	0.76	0.23	0.00	0.00	0.00	0.00	8.13	4.97	0.00	0.00	0.00	0.00
PNT032510	0.00	0.00	0.00	0.00	0.17	0.11	3.23	3.06	0.00	0.00	0.29	0.15
PNT032610	0.00	0.00	0.00	0.00	0.45	0.15	5.93	2.75	0.09	0.08	0.00	0.00
PNT032810	0.00	0.00	0.00	0.00	0.94	0.31	9.67	5.34	0.33	0.30	0.00	0.00
PNT051910	0.00	0.00	0.01	0.01	0.15	0.06	1.97	0.81	0.03	0.44	0.00	0.00
PNT052010	0.00	0.00	0.00	0.00	0.18	0.06	3.81	0.75	0.02	0.05	0.10	0.05
PNT061010	0.00	0.00	0.00	0.00	0.15	0.11	1.97	1.10	0.03	0.15	0.00	0.00
PNT061510	0.00	0.00	0.00	0.00	0.15	0.06	1.17	0.87	0.08	0.41	0.08	0.16
Total	1.62	1.23	0.26	0.46	5.19	3.27	75.47	52.65	6.04	6.75	3.50	3.44
SOL Efficiency	24		-74		37		30		-12		2	

Table 18. Nutrient Event Sum of Loads (SOL) Efficiency Calculations for the 19 events sampled at the ICC site using PhosphoSorb

Event ID	Total Dissolved P (TDP) (g)		Ortho-P (g)		Total Phosphorus (g)		TKN (g)		Nitrate/Nitrite-N (g)		Ammonia (g)	
	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
PNT090509	0.00	0.00	0.00	0.00	0.56	0.15	13.02	11.37	5.00	5.83	2.97	2.52
PNT102109	0.00	0.00	0.00	0.00	0.37	0.08	2.58	1.72	0.50	0.52	0.00	0.00
PNT102309	0.00	0.00	0.00	0.00	0.11	0.05	1.20	1.23	0.12	0.12	0.00	0.00
PNT102909	0.00	0.00	0.00	0.00	0.09	0.08	0.00	0.00	0.15	3.61	0.00	0.00
PNT110509	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.28	0.00	0.00
PNT011510	0.00	0.00	0.00	0.00	0.00	0.00	9.60	6.23	0.00	0.00	0.00	0.00
PNT012210	0.00	0.00	0.00	0.00	0.06	0.04	0.00	0.00	0.00	0.00	0.00	0.00
PNT012410	0.00	0.00	0.00	0.00	0.28	0.15	3.70	3.55	0.00	0.00	0.00	0.00
PNT020110	0.00	0.00	0.00	0.00	0.08	0.05	0.90	0.85	0.00	0.00	0.00	0.00
PNT020210	0.00	0.00	0.10	0.06	0.30	0.15	0.77	0.60	0.03	0.03	0.00	0.00
PNT020410	0.00	0.00	0.00	0.00	0.80	0.44	8.17	4.35	0.00	0.00	0.00	0.00
PNT031110	0.40	2.00	0.00	0.00	0.23	0.08	4.29	2.25	0.00	0.00	0.00	0.00
PNT032510	0.00	0.00	0.00	0.00	0.08	0.04	1.48	1.05	0.08	0.11	0.13	0.07
PNT032610	0.00	0.00	0.00	0.00	0.35	0.18	4.55	2.59	0.07	0.06	0.00	0.00
PNT032810	0.00	0.00	0.00	0.00	0.77	0.34	7.87	5.18	0.27	0.26	0.00	0.00
PNT051910	0.00	0.00	0.00	0.00	0.13	0.08	1.66	0.95	0.03	0.36	0.04	0.08
PNT052010	0.00	0.00	0.00	0.00	0.19	0.06	4.03	0.65	0.02	0.04	0.10	0.07
PNT061010	0.00	0.00	0.00	0.00	0.15	0.10	2.05	0.81	0.03	0.21	0.00	0.00
PNT061510	0.00	0.00	0.00	0.00	0.14	0.04	1.09	0.72	0.08	0.40	0.00	0.00
Total	0.4	2.0	0.10	0.06	4.7	2.1	66.95	44.09	6.60	11.83	3.25	2.74
SOL Efficiency	-400		45		55		34		-79		16	

Table 19. Total Metals Event Sum of Loads (SOL) Efficiency Calculations for the 19 events sampled at the ICC site using Sintered Perlite

Event ID	Total Aluminum (g)		Total Magnesium (g)		Total Copper (g)		Total Zinc (g)	
	Influent	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**
PNT090509	5.01	1.29	4.38	2.96	0.13	0.11	0.48	0.31
PNT102109	2.44	0.55	1.03	0.56	0.02	0.01	0.11	0.06
PNT102309	1.53	0.30	0.85	0.51	0.02	0.01	0.08	0.11
PNT102909	0.00	0.00	0.40	0.32	0.01	0.01	0.03	0.08
PNT110509	0.81	0.54	1.36	1.25	0.02	0.02	0.09	0.08
PNT011510	3.36	1.14	2.16	1.56	0.06	0.05	0.25	0.17
PNT012210	0.38	0.20	0.42	0.31	0.01	0.00	0.04	0.02
PNT012410	2.42	0.91	1.35	1.03	0.03	0.02	0.20	0.11
PNT020110	0.80	0.29	0.52	0.42	0.01	0.01	0.07	0.03
PNT020210	0.78	0.85	0.44	0.44	0.02	0.02	0.08	0.08
PNT020410	7.09	4.69	2.47	1.78	0.08	0.07	0.47	0.41
PNT031110	4.54	1.15	2.02	1.09	0.08	0.03	0.26	0.14
PNT032510	1.03	0.29	1.05	0.84	0.03	0.02	0.12	0.09
PNT032610	4.64	1.09	1.84	0.69	0.07	0.02	0.36	0.10
PNT032810	8.23	1.71	3.00	1.37	0.13	0.03	0.62	0.20
PNT051910	1.61	0.13	0.61	0.18	0.01	0.00	0.09	0.03
PNT052010	3.59	0.41	1.20	0.22	0.03	0.00	0.18	0.03
PNT061010	2.49	0.60	0.88	0.24	0.02	0.01	0.09	0.04
PNT061510	0.75	0.15	0.49	0.35	0.01	0.01	0.05	0.05
Total	51.50	16.31	26.49	16.16	0.81	0.45	3.66	2.18
SOL Efficiency	68		39		45		40	

Table 20. Total Metals Event Sum of Loads (SOL) Efficiency Calculations for the 19 events sampled at the ICC site using PhosphoSorb

Event ID	Total Aluminum (g)		Total Magnesium (g)		Total Copper (g)		Total Zinc (g)	
	Influent	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**
PNT090509	5.40	2.42	4.72	3.93	0.14	0.07	0.52	0.12
PNT102109	3.92	0.38	1.66	0.84	0.03	0.01	0.17	0.12
PNT102309	1.24	0.28	0.69	0.54	0.02	0.01	0.06	0.15
PNT102909	0.00	0.00	0.58	5.38	0.02	0.02	0.04	0.02
PNT110509	0.77	0.51	1.28	1.20	0.02	0.01	0.09	0.04
PNT011510	3.63	1.42	2.34	1.87	0.07	0.03	0.28	0.12
PNT012210	0.34	0.18	0.38	0.28	0.01	0.00	0.03	0.02
PNT012410	1.89	0.71	1.05	0.82	0.02	0.01	0.15	0.12
PNT020110	0.48	0.28	0.31	0.26	0.01	0.00	0.04	0.02
PNT020210	0.41	0.34	0.23	0.20	0.01	0.01	0.04	0.02
PNT020410	6.24	2.49	2.18	1.23	0.07	0.04	0.42	0.23
PNT031110	2.39	0.40	1.07	0.56	0.04	0.01	0.14	0.04
PNT032510	0.47	0.13	0.48	0.30	0.01	0.01	0.05	0.02
PNT032610	3.56	0.12	1.41	0.70	0.05	0.02	0.28	0.09
PNT032810	6.70	2.17	2.44	1.34	0.10	0.04	0.50	0.20
PNT051910	1.35	0.25	0.51	0.28	0.01	0.00	0.07	0.02
PNT052010	3.80	0.38	1.27	0.22	0.03	0.00	0.19	0.02
PNT061010	2.59	0.52	0.92	0.24	0.02	0.01	0.09	0.03
PNT061510	0.70	0.14	0.46	0.32	0.01	0.00	0.05	0.02
Total	45.88	13.14	23.97	20.50	0.71	0.31	3.22	1.40
SOL Efficiency	71		14		57		57	

Table 21. Dissolved Metals Event Sum of Loads (SOL) Efficiency Calculations for the 19 events sampled at the ICC site using Sintered Perlite

Event ID	Dissolved Aluminum (g)		Dissolved Copper (g)		Dissolved Zinc (g)	
	Influent	Effluent	Influent	Effluent	Influent	Effluent
PNT090509	0.00	0.00	0.00	0.00	0.00	0.00
PNT102109	0.00	0.00	0.00	0.00	0.00	0.00
PNT102309	0.00	0.00	0.00	0.00	0.00	0.00
PNT102909	0.00	0.00	0.01	0.01	0.02	0.02
PNT110509	0.00	0.00	0.02	0.01	0.07	0.07
PNT011510	0.00	0.00	0.00	0.00	0.12	0.11
PNT012210	0.00	0.00	0.01	0.00	0.02	0.03
PNT012410	0.00	0.00	0.00	0.00	0.00	0.00
PNT020110	0.00	0.00	0.00	0.00	0.00	0.00
PNT020210	0.00	0.00	0.00	0.01	0.02	0.03
PNT020410	0.00	0.00	0.00	0.00	0.08	0.09
PNT031110	0.00	0.00	0.02	0.02	0.10	0.10
PNT032510	0.00	0.00	0.01	0.01	0.00	0.00
PNT032610	0.00	0.00	0.00	0.00	0.04	0.04
PNT032810	0.00	0.00	0.00	0.00	0.00	0.00
PNT051910	0.00	0.00	0.00	0.00	0.01	0.03
PNT052010	0.00	0.00	0.00	0.00	0.00	0.01
PNT061010	0.00	0.00	0.00	0.00	0.12	0.02
PNT061510	0.00	0.00	0.00	0.00	0.02	0.04
Total	0.00	0.00	0.07	0.06	0.63	0.60
SOL Efficiency	NA		10		4	

Table 22. Dissolved Metals Event Sum of Loads (SOL) Efficiency Calculations for the 19 events sampled at the ICC site using PhosphoSorb

Event ID	Dissolved Aluminum (g)		Dissolved Copper (g)		Dissolved Zinc (g)	
	Influent	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**
PNT090509	0.00	0.00	0.00	0.00	0.00	0.00
PNT102109	0.00	0.00	0.00	0.00	0.00	0.00
PNT102309	0.00	0.00	0.00	0.00	0.00	0.00
PNT102909	0.00	0.00	0.01	0.01	0.03	0.02
PNT110509	0.00	0.00	0.02	0.01	0.07	0.04
PNT011510	0.00	0.00	0.00	0.00	0.13	0.12
PNT012210	0.00	0.00	0.01	0.00	0.02	0.02
PNT012410	0.00	0.00	0.00	0.00	0.00	0.00
PNT020110	0.00	0.00	0.00	0.00	0.00	0.00
PNT020210	0.00	0.00	0.00	0.00	0.01	0.01
PNT020410	0.00	0.00	0.00	0.00	0.07	0.06
PNT031110	0.00	0.00	0.01	0.01	0.05	0.04
PNT032510	0.00	0.00	0.01	0.00	0.00	0.00
PNT032610	0.00	0.00	0.00	0.00	0.03	0.02
PNT032810	0.00	0.00	0.00	0.00	0.00	0.00
PNT051910	0.00	0.00	0.00	0.00	0.01	0.01
PNT052010	0.00	0.00	0.00	0.00	0.00	0.00
PNT061010	0.00	0.00	0.00	0.00	0.12	0.01
PNT061510	0.00	0.00	0.00	0.00	0.02	0.01
Total	0.00	0.00	0.05	0.04	0.57	0.37
SOL Efficiency	NA		25		35	

Residual Solids Assessment Results

In an effort to verify the capture of materials by the system over the course of the monitoring period a qualitative assessment of materials captured by the system was performed during the final maintenance. Following the dewatering of the system, a sediment sample was collected of materials contained in the system and a sediment depth measurement taken. Subsamples were then taken from the collected sediment sample and analyzed for bulk density and particle size distribution. Particle size analysis of materials revealed that the materials contained in the system had a Loamy Sand texture (USDA classification). The estimated mass of materials contained in the system, after dewatering, was approximately 11 kg. The accuracy of the estimated mass of materials contained in the system should be considered limited, due to the non uniform distribution of materials contained in the system.

Summary and Conclusion

Between September of 2009 and June of 2010, 19 storm events were monitored and were determined to meet the storm data collection requirements for this study by the project stake holders. Total rainfall depth for the qualified storm events was 8.00 inches and bypass was detected for 12 of the 19 storm events sampled.

Significant reductions for loads were observed between influent and PhosphoSorb effluent sampling locations: TSS (SM) (74%) , SSC (82%), TVSS (75%), SSC<500-um (76%), TVSS<500-um (68%) ,Total Aluminum (71%), Total Copper (57%), Total Zinc (57%), Dissolved Copper (25%), Dissolved Zinc (35%), Total Phosphorus (55%), and TKN (34%).

Significant reductions for suspended solids loads were observed between influent and Sintered Perlite effluent sampling locations: TSS (SM) (71%), SSC (80%), TVSS (72%), SSC<500-um (72%), TVCC<500-um (62%), Total Aluminum (68%), Total Copper (45%), Total Zinc (40%), Dissolved Copper (10%), Dissolved Zinc (4%), Total Phosphorus (37%), and TKN (30%).

The capture of solids by the system was verified as part of the residual solids assessment during the final maintenance. Comparison of the estimated mass of material contained in the system to calculated loads using water quality results was determined to be within the realm of expectations for the study.

The primary purpose of this project was to document the total phosphorus removal efficiency of the Stormfilter system using with PhosphoSorb media as compared to Sintered Perlite Media. Although the difference between Effluent EMCs was not statistically significant, the total phosphorus load reduction by the PhosphoSorb media observed appears to be greater than that of the Sintered Perlite media.

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Revision History

Original

The Stormwater Management StormFilter®- PhosphoSorb®

Field Performance Summary

A three year field performance evaluation of The Stormwater Management StormFilter® (StormFilter) with PhosphoSorb® media operating at a specific flow rate of 1.67 gpm/ft^2 was completed at a 0.06 acre roadway site in Zigzag, Oregon. The Quality Assurance Project Plan (QAPP) for this evaluation followed the Guidance for Evaluating Emerging Stormwater Treatment Technologies: Technology Assessment Protocol – Ecology (TAPE, 2011). The StormFilter with PhosphoSorb Technical Evaluation Report resulted in a General Use Level Designation from Washington State Department of Ecology for Total Suspended Solids (TSS) and Total Phosphorus removal.

Results of the field performance evaluation for 17 qualified events are provided in Table 1.

Table 1. StormFilter with PhosphoSorb Field Evaluation Results

	Parameter	Sample population (n)	Average Influent (mg/L)	Average Effluent (mg/L)	Average Removal (%)	Aggregate Pollutant Load Reduction [1] (%)
Solids	TSS	17	380	40	88	89
	SSC<500 µm	15	325	40	87	89
	Silt and Clay[2]	16	153	32	78	82
Nutrients	Total Phosphorus	17	0.33	0.07	73	82
	Total Nitrogen	17	1.14	0.57	43	50
Metals	Total Zinc	15	0.129	0.024	78	81
	Dissolved Zinc	7	0.016	0.01	28	32
	Total Copper	15	0.026	0.005	79	82
	Dissolved Copper	7	0.004	0.003	30	28
	Total Aluminum	16	5.85	1.08	83	83
	Total Lead	15	0.009	0.003	64	70

[1] Treatment Efficiency Calculation, Method #2 (TAPE, 2008)
[2] Suspended Solids less than 62.5 microns

Load Reduction

89% TSS

82% Total Phosphorus

50% Total Nitrogen

Data were analyzed using the TAPE bootstrap confidence interval calculator for TSS and Total Phosphorus. The lower 95% confidence interval for TSS removal efficiency was 85%. The lower 95% confidence interval for total phosphorus removal efficiency was 67%. The upper 95% confidence interval for total phosphorus effluent concentration was 0.084 mg/L.

Over the entire 37 month evaluation period, the total effluent volume recorded at the site was 376,244 gallons. A total of 14,060 gallons were bypassed through the system accounting for 4% of the total recorded volume. A total of 26 events contained bypass flow, with 23 of those events producing peak flows exceeding the design treatment capacity of the system. The three events with bypass flows occurring below the design treatment capacity triggered maintenance. During the evaluation period, the system lasted between 10 and 12 months between maintenance events and retained an average of 291 pounds of sediment per maintenance event.

References

Contech Engineered Solutions, LLC. (2015). The Stormwater Management StormFilter® PhosphoSorb® at a Specific Flow Rate of 1.67 gpm/ft^2 General Use Level Designation Technical Evaluation Report. Portland, OR. Author.

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