Development of a test method for micro-bioretention treatment devices and media

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Abstract
Micro-bioretention devices operate at a hydraulic conductivity of >2500 mm/hr whilst maintaining similar levels of pollutant removal to conventional bioretention devices which operate considerably slower (typically 100-300 mm/hr). At SW360 we are seeing a growing market for micro-bioretention treatment devices both locally and internationally. To meet this demand media blends made from locally sourced materials need to be developed. Agreement on a standardised test method would support the development and regulation of micro-bioretention media blends and devices.

An ideal test method needs to:-
- produce results which measure real world performance,
- produce results which are comparable with other scientific studies, and
- be practical to conduct from a time and cost perspective.

Stormwater360 has conducted tests to evaluate the performance of micro-bioretention media and devices made using locally available materials in New Zealand. In the process of evaluating different media, different regulatory guidelines were compared and test methods trialled.

Using the review of US, Australian and New Zealand regulatory requirements for bioretention treatment devices, existing research literature, and experience gained from trialling different test methods, a lab based column test method was advocated for the evaluation of micro-bioretention devices and media.

Keywords
Bioretention, micro-bioretention, hydraulic conductivity, test methods, stormwater, rapid filtration, standards, regulatory

INTRODUCTION

As a result of climate change, extreme rainfall events occur more frequently (Easterling, et al., 2000) and treatment capacity for higher peak and total stormwater volumes are required to ensure water quality standards are maintained and local water bodies are protected. Due to the limited space available in urban centres and more stringent stormwater treatment requirements becoming more stringent in many jurisdictions, treating stormwater to the effluent quality level required by the local governing bodies is expensive and require the use and development of new and innovative treatment technologies.

Bioretention treatment devices such as raingardens, swales, green roofs and filter strips, have been shown to be an effective treatment method to remove suspended sediment, metals (e.g. zinc and copper) and nutrients (e.g. phosphorus and nitrogen). One of the main disadvantages of bioretention devices however is that they require considerable amounts of space due to low infiltration rates (typically 100-300 mm/hr) (FAWB, 2009). Micro-bioretention devices are an emerging class of treatment devices which achieve similar pollutant treatment performance of existing bioretention devices, but uses media with a much higher infiltration rate (1250-3250 mm/hr) (Geosyntec Consultants, 2008). Currently the Washington State Department of Ecology (Ecology) has granted General Use Level approval for Enhanced treatment approval for one micro-bioretention device and several other micro-bioretention devices are currently at a conditional or pilot level of approval (WSDOE, 2015). Enhanced treatment is defined as “providing a higher rate of removal of dissolved metals than basic treatment facilities."

There is a demand for micro-bioretention in New Zealand and other countries but the methods currently used and specified to evaluate and measure bioretention media differs between organisations, is not very practical to conduct, is not repeatable, and does not necessarily measure the real world performance. Common differences between regulatory processes from different organisations and countries include laboratory vs field tests, synthetic vs real stormwater influent, short term vs long term tests. Cost of media development and testing is also an issue. The Ecology approved devices were developed in the USA using field tests which cost in excess of $200,000 USD per test to conduct. Getting devices and media tested in the US is cost prohibitive and more cost effective ways of evaluating the pollutant removal performance of micro-bioretention devices are required.

This paper documents the variation in test methods and parameters for evaluating bioretention devices from regulatory organization in the USA, Australia and New Zealand. The goal of this research was to determine a test method for micro-bioretention media that is both practical to conduct and is able to provide an accurate indication of media and device performance in the field.

Performance of micro and conventional bioretention devices

A review of the bioretention device performance recorded in the International Stormwater Best Management Practice Database (www.bmpdatabase.org) is shown in **Table 1** and is compared with pollutant removal rates from five field studies of micro-bioretention devices available in the US (Lenth & Dugopolski, 2010) in **Table 2**.

Table 1 Pollutant removal characteristics of bioretention devices reported in the BMP database (Geosyntec Consultants, 2015)

	Commercial		High density single family residential		Light industrial		Multi-family residential		**Average**
	Median influent	% removal	Median influent	% removal	Median influent	% removal	Median influent	% removal	**% removal**
TSS (mg/L)	53	77%	61	80%	129	88%	24	55%	**75%**
Total Phosphorus (mg/L)	0.27	-70%	0.32	-47%	0.3	-57%	0.14	-179%	**-88%**
Total Nitrogen (mg/L)	2.3	30%	2	20%	2.4	33%	1.5	-7%	**19%**
Copper (µg/L)	22	45%	11	52%	21	43%	12	53%	**48%**
Zinc (µg/L)	192	82%	66	70%	366	90%	89	78%	**80%**

Table 2 Pollutant removal rates of micro and conventional bio-retention devices (Lenth & Dugopolski, 2010; FAWB, 2009)

	Bioretention device (BMP Database)	Micro-bioretention		FAWB mixture
	Field test	Field test	Lab test	Guidelines
Hydraulic conductivity (mm/hr)	100-300	>2500	2500	100-300
Suspended sediment (TSS)	55-88%	83-88%		90%
Nutrients				
- Phosphorus	-179 to -49%	9-70%	26-75%	80%
- Nitrogen	-7 to 33%	40%	42-48%	50%
Metals				
- Zinc	70-90%	48-79%	82-90%	90%
- Copper	43-53%	33-77%	74-83%	60%

Field measurements of micro-bioretention devices in the US have shown high TSS removal across all land uses, and provided similar levels of copper and zinc removal to conventional bioretention treatment devices. Nitrogen and phosphorus performance was also better that conventional systems. The better nutrient removal performance was attributed to the lower organic composition of micro-bioretention media which decreased the amount of nutrients leached into the effluent during normal operation. The majority of conventional bioretention devices reported in the BMP database were observed to leach nutrients, with some treatment devices continuing to do so years after installation (Geosyntec Consultants, 2015). Use of the certain types of vegetation was observed to contribute to Nitrogen and Phosphorus removal (FAWB, 2009).

SELECTING A TEST METHOD

In determining a suitable test method to advocate and use, emphasis was placed in identifying a test method which was:-

- repeatable,
- practical to conduct (from a cost and time requirement perspective),
- produced results which were a fair representation of field performance, and which
- produced results which were able to be meaningfully compared with results from other bioretention devices.

REGULATORY PROTOCOLS FOR EVALUATING BIORETENTION TREATMENT DEVICES – LABORATORY TESTING VS FIELD TESTING

There are a number of regulatory agencies which have developed protocols for evaluating and approving the use of bioretention devices around the world. A review of protocols in the US, Australia and New Zealand showed a clear preference towards full scale field testing of treatment devices (see Table 3).

Table 3 Summary of regulatory authority approval methods for evaluating the performance of bioretention treatment devices

	Field or Laboratory testing	Comments
Washington State Department of Ecology (WSDOE, 2008)	Field testing	Laboratory tests can only supplement field test results
New Jersey Technology Acceptance Reciprocity Partnership (NJCAT, 2003)	Field testing	
NJDEP laboratory assessment of a Filtration Manufactured Treatment Device (NJDEP, 2013)	Lab testing	Only tests for TSS
Proprietary Devices Evaluation Protocol (Wong, Ansen, & Fassman, 2012)	Lab or field testing	Laboratory tests can only claim half the demonstrated performance.
Goldcoast City Council (GCCC, 2015)	Lab or field testing	

Field testing was preferred because it measured real world performance in a dynamic natural setting. Laboratory based measurement in contrast was not preferred due to likely elevated pollutant removal measurements arising from the controlled and targeted test setup. Advantageous pollutant removal in laboratory settings arises mainly from stable flow testing conditions and the absence of pollutants which are not of interest such as organic matter, debris and oil (Miller, 2011). In cases where laboratory based assessment was allowed by regulatory authorities, limitations were often placed on what could be claimed based off laboratory obtained results. A common limitation stipulated was that only part of the removal performance measured in the laboratory could be claimed or that the test results were only able to assess specific pollutants (TSS). One of the main arguments for laboratory based assessment however was due to the cost and time requirements of field based assessment. Based on field assessment reports on bioretention units, reports by other companies and quotes SW360 have received to assess bioretention devices, we have found the cost of a field test can be upwards of $200,000 and takes between 12-24 months to complete (Miller, 2011).

Despite field testing being the preferred method of evaluation by the majority of regulatory authorities at present, apart from cost there are issues with the credibility and accuracy of field testing as well. An analysis of field and laboratory obtained data showed that field test data is not necessarily more accurate than laboratory data (Miller, 2011). The main issues raised with regard to field testing were that the test results were not repeatable and that influent compositions had a high degree of variability between storms and across seasons. Field results were also not comparable between sites as each site had unique conditions.

It is not clear whether field based testing is better than laboratory based assessment from a scientific or regulatory perspective. SW360 has conducted testing to evaluate the effect of varying test parameters to identify if a robust laboratory test method can be defined that can overcome the limitations of laboratory based assessment of bioretention treatment devices and provide repeatable and representative measurements (of real world pollutant removal performance).

SYNTHETIC VS SEMI-SYNTHETIC VS REAL STORMWATER

Influent composition greatly influences the removal performance of devices observed in tests. The concentration and form (e.g. dissolved or particulate) of pollutants of interest is the a key variable but the presence of other pollutants can have a large effect as well. Other pollutants in the influent can reduce the media or device's removal capacity, clog the treatment mechanism and interact with the pollutant of interest. As a result, concentration and size ranges are often specified for pollutants of interest in influent. NJCAT requires influent TSS concentration to between 100-300 mg/L and the particles to be <100 microns in diameter (NJCAT, 2003). Other regulatory protocols allow some degree of synthetic pollutants to be used or added to ensure the target pollutant or particle side distribution (PSD) of influent sediment to be within a specified range. A brief summary of influent specifications is provided below in `Table 4`.

Table 4 Influent specification of regulatory authorities

	Influent	Comments
Washington State Department of Ecology (WSDOE, 2008)	Lab tests – synthetic Field - natural	Required to raise TSS concentrations using Sil-Co-Sil 106 or OK-110 to typical runoff PSD for target land use.
New Jersey Technology Acceptance Reciprocity Partnership (NJCAT, 2003)	Field - natural	
Proprietary Devices Evaluation Protocol (Wong, Ansen, & Fassman, 2012)	Field tests – synthetic Lab tests – not specified	Clean water from hydrants for flow with pollutants of interest spiked to required concentrations
NJDEP laboratory assessment of a Filtration Manufactured Treatment Device (NJDEP, 2013)	Lab tests – synthetic	Only tests for TSS

Experimental evidence

Laboratory experiments conducted over the past 3 years at SW360 have shown synthetic influent to result in unrealistically high removal rates, whilst use of semi-synthetic stormwater (made in accordance with the FAWB method) on similar media resulted in a removal performance which was within the expected range for the media tested.

A laboratory based column test was conducted at SW360 on four different micro-bioretention media to evaluate a proven US media (Media A) alongside three locally made (NZ) micro-bioretention media. From past field studies conducted on Media A, the pollutant removal capabilities were known and are listed in Table 5 (Contech, 2012). Using a synthetic stormwater influent comprising of dissolved Copper and Zinc, the media were tested and effluent samples were sent to an accredited laboratory (Hill Laboratories) for analysis. Media A performed much better than expected based on the field study results and the other three media performed very well also (Hannah, Simcock, Cheah, & Curry, 2015). The results were clearly unrealistically high.

Table 5 Pollutant removal performance of micro-bioretention media using synthetic influent

	Media A	Media A	Media B	Media C	Media D
	Field test	Lab test	Lab test	Lab test	Lab test
Total Zn	85.2%	99-100%	98-100%	99-100%	99-100%
Dissolved Zn	76.3%	99-100%	99-100%	99-100%	99-100%
Total Cu	72%	92-96%	94-97%	93-97%	94-98%

In an attempt to improve the representativeness of the laboratory column tests, SW360 trialled the use of semi-synthetic influent using the FAWB method which required the use of real stormwater sediment. The same column test described previously was repeated on the four media (1 US media, 3 NZ media) using the semi-synthetic blend of real stormwater sediment, tap water, and synthetic chemicals to ensure the key pollutants (TSS, Zinc, Copper) in the influent were within ranges that mimicked Auckland stormwater.

The pollutant removal performance observed from these tests were within the ranges that were expected for the media. Media A test results were similar to the performance measured in US field studies. The pollutant removal performance of Media B, C and D were close to the expected performance of bioretention treatment devices (see Table 2) (Cheah, Hannah, & Simcock, 2015).

Table 6 Pollutant removal performance of micro-bioretention media using semi-synthetic influent

	Media A	Media A	Media B	Media C	Media D
	Field test	Lab test	Lab test	Lab test	Lab test
Total Zn	85.2%	88.0%	88.9%	82.2%	90.4%
Dissolved Zn	76.3%	59.1%	77.6%	86.6%	66.6%
Total Cu	72%	80.2%	73.9%	76.6%	83.4%

The use of semi-synthetic stormwater influent for testing lab purposes was deemed to be a reasonable compromise between using fully synthetic influent or only real stormwater. Use of semi-synthetic stormwater influent retains the whole range of constituents of stormwater in the test influent (and their associated interactions) whilst allowing key pollutant concentrations to be artificially increased to be within a range in which removal efficacy can be measured fairly and meaningfully.

PERFORMANCE CONSISTENCY - TEST REPETITION AND MEDIA SATURATION

The performance and characteristics of treatment media changes over time, and with the level of water saturation at time of testing. The performance measured in the test should be of the normal operating performance of the media in the field during a design rain event. Media performance changes over time. New media was observed to change significantly in terms of hydraulic conductivity as the media was compacted by water and porosity decreased. Over the longer term, the performance of media decreases due to clogging on the media the surface and active sites (i.e. cation exchange) in the media being exhausted and breakthrough being achieved.

Two experiments conducted at SW360 submitted micro-bioretention media to daily wetting over 5 weeks. The data (see Figure 1) showed that media hydraulic conductivity rates stabilised 2 weeks (or 14 wet-dry cycles) into the test. Initial measurements of hydraulic conductivity would have underestimated the mature rate by 10-30%.

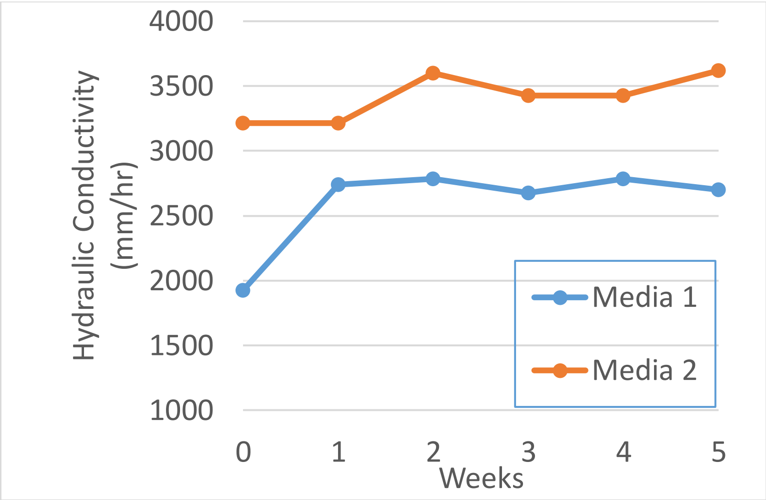

Figure 1 Weekly hydraulic conductivity of a micro-bioretention media tested over 5 weeks

Another area of variability observed arose from the saturation state of media. When dry media was tested, the hydraulic conductivity of media was found to vary erratically throughout the 5 week test period. Tests on saturated media were found to be a lot more consistent in contrast. The variability between the datasets is shown below in **`Table 7`**.

Table 7 Weekly hydraulic conductivity test data summary

	Media condition*	n	Mean (mm/hr)	Range (mm/hr) Min	Max	COV (mm/hr)	SD (mm/hr)
Media 1	Wet	6	2603	1928	2785	4378	333
	Dry	5	3817	3426	4258	5452	372
Media 2	Wet	6	3417	3213	3620	1241	178
	Dry	3	3963	3475	4208	7036	423

*Wet condition = fully saturated before test, Dry condition = 24 hour dry antecedent period before test

CONCLUSION

Micro and conventional bioretention devices are stormwater treatment devices which can achieve high pollutant removal rates and provide aesthetic benefits as well. Micro-bioretention devices enable catchments to be treated using a smaller footprints due to the higher hydraulic conductivity of the media used.

Whilst micro-bioretention devices have been tested and approved in the US, there is need to develop local micro-bioretention media and devices in other countries using locally available materials. The standardising of a test method for bioretention devices is needed and would both assist in the development of new bioretention media and in the regulation of the treatment devices.

Current regulatory processes available in the US, Australia and New Zealand prefer field based assessment however such assessments require considerable cost (up to $200,000 USD) and time (12-24 months) to conduct.

At SW360 we have found that laboratory based assessment of micro-bioretention devices can produce results similar to that obtained in the field, but at much lower cost and with greater reliability. With adequate consideration of the influent composition, test setup and duration of a test, the pollutant removal advantages of laboratory based testing (as compared to field testing) can be minimised and a repeatable and credible measure of real world performance can be obtained.

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