ARE QUALITY CONTROL/ASSURANCE PROCEDURES NEEDED FOR BIORETENTION TREATMENT DEVICES?

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ABSTRACT

Bioretention treatment devices are an effective stormwater Best Management Practice for the removal of total suspended solids, nutrients and dissolved metals. They are advantageous because they can treat and attenuate stormwater runoff whilst also providing aesthetic amenity to a site. However, to realise the high treatment performance in practice, stringent quality controls and assurance processes need to be in place during the design, manufacture, installation, commissioning and maintenance stages.

Unfortunately, many bioretention devices fail to perform to their design specifications with respect to pollutant removal and infiltration rates. The international stormwater BMP database shows that most installed bioretention devices perform lower than the pollutant removal capacities touted for bioretention on average. A survey of raingardens in Auckland showed raingardens to be clogged and in need of maintenance. In some instances, maintenance may never have been carried out. This raised the question: Are quality control/assurance procedures needed for bioretention devices beginning at design through to implementation and operation?

Based on observations of bioretention devices in Auckland, as well as having visited major bioretention media manufacturing plants in the USA, Stormwater360 New Zealand built and tested their own bioretention devices and media. This research has identified several quality control and assurance processes, and maintenance practices and checks.

The purpose of this paper is to identify design, manufacturing, implementation and maintenance procedures that enhance bioretention treatment device performance in regard to maintaining pollutant removal and hydraulic conductivity rates.

KEYWORDS

Bioretention, biofiltration, quality control, quality assurance, maintenance, monitoring, infiltration, hydraulic conductivity, media manufacture

PRESENTER PROFILE

Dr. John Cheah graduated with his doctorate from the University of Auckland in Civil and Environmental Engineering in 2015. In 2016, he was selected as a finalist for the IPENZ Young Engineer of the Year award. Over the past two years John has been working as a R&D engineer for Stormwater360 to develop engineered bioretention media and conduct laboratory and field tests on stormwater treatment technologies.

1 INTRODUCTION

Bioretention (also associated with biofiltration) treatment devices are an increasingly popular Best Management Practice (BMP) used in stormwater management and water sensitive design (WSD). They are effective for removing of total suspended solids, nutrients and dissolved metals contaminants from stormwater runoff. They are advantageous because they can treat and attenuate stormwater flows whilst also providing aesthetic amenity to a site. These commonly take the form of raingardens, swales, filter strips and living roofs. This paper will focus solely on bioretention gardens.

Quality assurance (QA) checks ensure a desired level of quality is met in a service or product. Quality control (QC) ensures the product delivered meets the requirements of the client. The goal of QA/QC processes are to deliver a product or service that is free of defects and fit for purpose. In the case of bioretention stormwater treatment, the QA/QC process ensures the device installed achieves its pollutant removal and hydraulic conductivity specifications, provides aesthetic amenity, and continues to maintain these outcomes.

A QA/QC process for bioretention devices that ensures the client's or project's requirements are met begins at the design phase, continues throughout the media production and product manufacture stages, checks for proper installation and device operation, and ensures the device continues to perform via ongoing maintenance.

The focus of this paper is on stressing the need for QA/QC throughout all stages of the device life to ensure long term treatment objectives are continually met. The paper will have an emphasis on device design, media manufacture, installation, and commissioning and finally maintenance.

2 BACKGROUND

2.1 BENEFITS OF BIORETENTION

As previously mentioned Bioretention treatment BMPs are an increasingly popular method for the treatment of stormwater for the following reasons: -

- Flow attenuation
  The rate in which influent stormwater exits the bioretention device is limited to the saturated hydraulic conductivity of the media. It takes time for the water to percolate through the media.

- Volume reduction
  Some level of volume reduction also occurs via water retention in the media and evapotranspiration. Hatt, Fletcher, & Deletic (2009) monitored three field scale biofiltration systems and found the biofilters to reduce runoff volumes by 33% on average through a lined biofilter and reduced peak flows by at least 80%. Similarly, Simcock & Trowsdale, (2011) monitored a bioretention system in a light industrial catchment with a busy road over 12 storm events and found that both peak flows and volumes were reduced for every storm event.

- Treatment performance (Sediment and metals)
  Bioretention treatment devices are capable of high suspended solid and heavy metal removal percentages. Hatt, Fletcher, & Deletic (2009) found load reductions of over 90%. Simcock & Trowsdale, (2011) found that the bulk of zinc, lead and suspended sediment from a heavily polluted catchment was removed by the bioretention device.

- Treatment performance (Nutrients and bacteria)
  Bioretention treatment devices have the potential to remove nitrogen, phosphorus and bacteria (Lake Superior Streams, 2017). The nitrogen and phosphorus is absorbed by the plants in the bioretention device and the microbial life that live around plant roots (Shanstrom, 2012; Henderson, 2009). In experiments lasting between 17 days and 6 months using influent containing fecal coliform bacteria, bacteria counts were observed to be reduced 66-92% when passed through a bioretention device (Thomas, Aston, Woodruff, & Cullinan, 2009).

- Social and ecological value
  They demonstrate how the landscape can be used to protect ecosystem integrity as well as providing aesthetic benefits and space efficiency by using a land area both as a treatment system and to provide aesthetic amenities. Through good design, bioretention BMPs can blend into the site environment, provide for increased biodiversity, and add tangible and intangible value to the local community.

- Cultural values
  Māori culture recognizes that environmental management has integral links with the mauri (life force) of the environment and concepts of kaitiakitanga (guardianship); principles which are echoed throughout the Resource Management Act and consenting process. The Māori world view regarding relationships with the natural environment promotes stewardship and protection. The use of bioretention and WSD have the potential to acknowledge and include mātauranga Māori (Māori knowledge), kaitiakitanga, and promotion of mauri (Brockbank & Jonathan, 2017, Auckland Council, 2015).

2.2 PERFORMANCE OF BIORETENTION IN PRACTICE

The actual performance of bioretention devices in practice frequently does not achieve the high performing potential expected of the BMP.

The international stormwater BMP database provides the measured performance of bioretention devices and other stormwater BMPs so that the treatment devices can be improved. As of 2017, data has been collected from over 600 BMP studies. The median influent and effluent values measured for key pollutants from bioretention BMPs is summarised in Table 1.

The Facility for Advancing Water Biofiltration (FAWB), a research centre based in Australia, has provided an indication of the pollutant removal capacity of bioretention BMPs based off their extensive research and knowledge. FAWB's pollutant removal values for bioretention devices and Auckland Council's stormwater treatment requirements are included in the two right-hand columns in Table 1.

Table 1 International BMP database for Bioretention BMPs (median values) (International Stormwater BMP Database, 2014)

	In	Out	Percentage removal (%)	FAWB guidelines (FAWB, 2008)	TP10 (Auckland Council, 2003)
TSS (mg/L)	38.1	9.9	74%	90%	75%
Dissolved Copper (ug/L)	5.21	5.79	-11%	-	-
Total Copper (ug/L)	8.75	5.33	39%	60%	-
Dissolved Zinc (ug/L)	19.7	12.2	38%	-	-
Total Zinc (ug/L)	48.1	12.0	75%	90%	-
Total Phosphorus (mg/L)	0.120	0.240	-100%	80%	-
Total Nitrogen (mg/L)	1.16	0.92	21%	50%	-

Across all pollutant categories, the average performance of bioretention devices was less than that commonly expected of the treatment BMP. In terms of individual studies and treatment devices, a few well designed and maintained devices performed as expected, while the rest did not.

2.3 THE DIFFERENCE BETWEEN CONVENTIONAL AND RAPID BIORETENTION

Conventional bioretention treatment in NZ is typically designed to operate between 12.5 mm/hr and 300 mm/hr (Auckland Council, 2003, Auckland Council, 2013, NZTA, 2010). The lower limit is specified in Auckland Council's TP10 design guidelines, while the upper limit is recommended by FAWB because a saturated hydraulic conductivity of greater than 300 mm/hr creates issues with plant establishment (FAWB, 2008).

Rapid bioretention has media with a saturated hydraulic conductivity of greater than 2500 mm/hr. While the saturated hydraulic conductivity of rapid bioretention is 8 to 200 times faster than convention bioretention, the pollutant removal capacities are the same or better (Geosyntec Consultants, 2008, Stanford, 2007). The increases in pollutant removal efficiencies are due to more efficient treatment device design and the use of highly engineered media. Many independent tests have been done on rapid bioretention devices which support the pollutant removal claims as does the successful acquisition of Washington State Department of Ecology (WSDOE) approvals. WSDOE approvals are commonly used for regulatory product approvals in New Zealand (Wells, J. et al., 2015).

As of March 2017, two proprietary rapid bioretention systems have been approved by the WSDOE for General Use in the Enhanced Treatment category (WSDOE, 2017). Enhanced treatment is a category above "Basic Treatment" for systems with a proven capacity to remove dissolved metals. Basic treatment is required to remove 80% TSS (when the influent suspended solid concentration is 100 mg/L – 200 mg/L).

3 RESEARCH

To address this apparent disparity, research was undertaken by Stormwater360 New Zealand; a specialist stormwater management company. This research was conducted in both New Zealand and in the United States of America (USA) alongside American-based Contech Engineered Solutions, LLC. The research explored how to achieve consistency in pollutant removal and hydraulic conductivity rates in the design, manufacture and maintenance of rapid bioretention systems.

Contech is a provider of site solution products and services to the civil construction industry, and is the largest stormwater management provider in the USA. Their stormwater management division have been installing Filterra™, a rapid bioretention stormwater treatment device, for the last 15 years. There are currently over 7000 Filterra devices installed in the US, and the inground data shows that Filterra devices continually remove pollutants at their claimed pollutant removal percentages, even after 10 years of service (Geosyntec Consultants Inc and Wright Water Engineers Inc, 2014). Observations of their QA/QC processes are included below.

Between 2013 and 2017 Stormwater360 undertook research and development of rapid bioretention media using locally sourced media (Cheah, Hannah, & Simcock. 2015). The research focused on three primary areas; testing, monitoring and installation research.

Numerous laboratory column tests were undertaken on more than 10 different rapid bioretention media. The media was tested to measure saturated hydraulic conductivity rates, and pollutant removal rates for suspended sediments, nutrients, and metals. Following testing, rapid bioretention devices were installed and monitored at the Auckland Botanic Gardens and three other locations in Auckland to further evaluate the bioretention media.

Further to this, the research team travelled to Contech, to receive training on the manufacture and installation of Filterra. This included intensive training on the various quality assurance checks undertaken in their manufacturing and maintenance processes.

4 QUALITY CONTROL AND QUALITY ASSURANCE STAGES

4.1 DESIGN

Good design involves selecting a stormwater treatment method that is suitable for the environment in which it is built (e.g. stormwater volumes and flow rates, site hydraulics, budget) and for the outcomes that are required (e.g. peak flow attenuation, stream protection, removal of specific pollutants). This approach should also be applied to the bioretention media.

Several studies have identified the potential for bioretention treatment devices to leach nitrogen, phosphorus, and copper. In these studies, the compost being used as the treatment media was identified as the primary source of all three pollutants (Herrera Environmental Consultants, 2015, Herrera Environmental Consultants, 2015b). The city of Redmond, Washington monitored a bioretention device over a 12 month period and used a bioretention media that used a high fraction of compost (40%) (the use and proportion of compost was a required specification of bioretention in Washington). The device was observed to export nitrogen, phosphorus and copper continually, even a year after construction (Rheaume et al. 2015). The nutrients were released in the media as the compost broke down and the dissolved copper was suspected to be from herbicides applied on the plants composted.

For compost to not leach nutrients and copper in a bioretention device, it needs to be a well decomposed compost made from an organic source matter (California Regional Water Quality Control Board, 2012). To achieve the outcome required, a specific compost needs to be specified or the amount of compost should be minimized or excluded from the media specification.

A water quality study reported in Auckland Council TR2013/011 showed a similar result in that all 5 of their bioretention media (organic content of at least 10% v/v) were found to leach phosphorus (Auckland Council, 2013).

From these studies, it is evident that, while bioretention treatment devices may have superior pollutant removal capability and potential, only a small proportion of the bioretention devices installed in practice achieve their actual design specification with respect to pollutant removal and flow rates.

4.2 MEDIA MANUFACTURE

Having a stringent QA/QC process for media blending, especially when mixed on a large scale, is the most critical criterion to achieve a consistently performing rapid bioretention device in the field. The media specification directly controls the saturated hydraulic conductivity rate, and indirectly influences the pollutant removal capacity by controlling the contact time between the stormwater influent and media. Plant support capacity, leaching potential and susceptibility to clogging are all dependent on media design, blend constituents used, and the homogeneity of the final product.

During the five years of research Stormwater360 have conducted laboratory column tests on more than 10 different rapid bioretention media. The media was observed to be sensitive to small changes in media composition and ingredient sources.

These tests have shown that certain ingredients in the blend can negatively impact on the hydraulic conductivity and the removal characteristics of some pollutants. The tests included various combinations of compost, zeolite, biochar, sands and gravels, and found in particular, the inclusion of compost in bioretention media needed to be treated with caution. There was a strong correlation between the proportion of compost in the media blend and phosphorus concentrations increasing in the effluent (Hannah et al., 2015). It was also discovered that softer materials broke down over time and introduced fines in to the media thus reducing the long term hydraulic conductivity of the media (Roelofs R. , 2016).

Further more conducting regular checks (e.g. twice a year or before blending a batch of media) on source ingredients was found to be important. Carrying out a Particle Size Distribution (PSD) check occasionally was prudent to ensure material specifications had not changed. A few materials obtained from quarries were found to change over time. In one instance it was discovered that one supplier sourced the same product from two different quarries. The presence of a few particles larger than the orginal specification PSD range and a higher proportion of fines in the media was not an issue for gardening purposes but it affected the media flow rates significantly.

This can be avoided by keeping in contact with material suppliers and informing them of the stringent media requirements. Not only does this help suppliers to better understand the importance of maintaining specification, notifying personnel of changes, and understanding that switching between equivalent products is not acceptable.

The blending method also influenced media performance. In laboratory scale columns the same media blend was tested twice (Figure 1 & Figure 2). The first blend was hand mixed and the second was mixed on a large scale with machinery. The machine blended media had a higher hydraulic conductivity. It was suspected that the machine blended material was less homogenous and led to the formation of preferential flow paths in the media (Cheah, 2016).

Figure 1 Four column laboratory test setup (left)

Figure 2 Two column laboratory test setup (right)

The research process has identified that that checking the media ingredients, carefully controlling the media blending process and testing the final product are all essential steps in the QA/QC process for bioretention media to ensure the media will perform to specification. These findings are echoed in the media blending QA/QC processes undertaken by Contech.

Contech send their personnel to blending sites around the country to pre-qualify raw materials prior to blending at each of their sites around the country. This pre-qualification ensures that raw materials used in blending will yield a final product that meets Filterra media performance specifications. Due to changes in quarry material over time and the stringent specifications they have for their media, it is necessary for them to recalibrate blending ratios for each blend. Onsite media evaluations including PSD and flow tests are conducted to confirm media performance meets specifications. The onsite testing and blending process takes them one working week, during which time up to 2000 tons of Filterra rapid bioretention media is made. One of their media production rigs is shown in Figure 3.

Figure 3 Pug mill used to blend Contech Filterra rapid bioretention media

4.3 INSTALLATION AND COMMISSIONING

Bioretention devices are frequently installed and commissioned inadequately due to a lack of understanding regarding their treatment function and design (e.g. finished media level and live storage volumes), the unique properties of the specified media, and the devices' susceptibility to clogging when subjected to construction site runoff and unstable catchments (Ansen J, 2010). Rapid bioretention devices are particularly susceptible to clogging when subjected to influent with extremely high sediment concentrations due to their high saturated hydraulic conductivity rate and small catchment footprint. Without proper installation and commissioning, the devices are unlikely to meet treatment outcomes and the devices themselves are at risk of incurring permanent damage. In many cases of poor installation and construction, the only recourse is to dig out the whole bioretention device and install it again. Good QA/QC procedures during the installation and commissioning stage will reduce contractor error and ensure the treatment device operates under the conditions it was designed for.

A unique QA/QC process that Contech employs, that is key to maintaining their good track record, is their installation and commissioning process. Their Filterra treatment devices are all officially commissioned by Contech following several checks. Contech prefabricate the treatment device offsite and transport it to site with all inlets and outlets boarded up and closed off. The commissioning process involves a Contech personnel member visiting site to check that the soils onsite and in the catchment are stable, and that the device has been installed as per specification. If the site and treatment device pass these QA/QC checks, the device is unblocked and treatment of stormwater commences.

4.4 FIELD EVALUATION

From a QA/QC perspective, it is important to have a field test method which can be carried out easily and quickly to evaluate the performance of a treatment device. Surface infiltration tests are practical test methods to use to evaluate bioretention BMPs because access to the surface is easy. The surface is also often the location where flow through the device is the most constricted as sediment and gross pollutants build-up on that layer.

Stormwater360 has installed five rapid bioretention devices in the field which have been tested and monitored over the course of this research. One of the devices is shown below in Figure 4.

Figure 4 Filterra rapid bioretention device at the Auckland Botanic Gardens

At the Auckland Botanic Garden site, single ring infiltrometer tests were conducted during the second half of 2016. Double ring tests were also conducted at the end of the monitoring period. The results are listed below in Table 2.

Table 2 Surface infiltration rate of Auckland Botanic Garden rapid bioretention device (Cheah & Roelofs, 2016)

Date	Single ring @ 150 mm head	Double ring @ 150 mm head
4th July, 2016	**2602**	
21st July, 2016	**1914**	
8th August, 2016	**2390**	
24th August, 2016	**2425**	
7th September, 2016	**2215**	
22nd September, 2016	**2728**	
5th October, 2016	**2918**	**2589**

* **green** represents an infiltration rate above the design rate of 2190 mm/hr

4.4.1 LABORATORY VS FIELD VARIATIONS

The results showed that the treatment device was performing hydraulically as designed but that there was a large variance in the rates measured. These variations have been attributed to several aspects.

Some locations in the treatment device were compacted by members of the public entering the device. On one occasion, during a site visit, children were observed jumping into the device, onto the mulch. As the treatment device was in a highly trafficked public area near to both a road and a pedestrian walkway, it is likely that persons have entered the device and compacted the media at discrete points around the device thus potentially reducing the flow rate at certain locations.

In the laboratory, it was observed that the hydraulic conductivity of bioretention media increased to some extent in proportion to antecedent dry period (Hannah et al., 2015). 20 litres of water was poured onto the media at each point where infiltration tests were conducted but this may not have been enough to fully saturate the media. Similarly, some tests were conducted during rainy conditions with the media having no antecedent dry period before the infiltration test was conducted.

A layer of loamy material developed on top of the media and was full of worms. While this was good for supporting plant growth, the effect on infiltration rate was unknown.

User error in the test method may also be a contributing factor. The single and double ring test methods rely on human judgement pertaining to when to take time or water level readings. While these test methods are practical to use to measure the infiltration rate of rapid bioretention media, user introduced variability can be considerable due to the relatively fast infiltration rate of rapid bioretention devices (which infiltrate 8-200 times faster than conventional bioretention media).

The field based tests showed that laboratory determined performance can predict well the field performance. The strong correlation was achieved because of the many checks that were made during device manufacture, installation, media production and regular device maintenance of the device at the Auckland Botanic Gardens. With a stringent

QA/QC process, the performance of the device in the field can be checked, errors can be easily and quickly identified (and fixed) and device performance can be guaranteed.

4.5 MAINTENANCE (ONGOING)

Bioretention devices need to be maintained in order to ensure that device operation is not impaired. Over time sediment and pollutants accumulate in these devices and need to be removed to keep pollutant removal and hydraulic conductivity rates above the design level. Plants and trees have maintenance requirements too and may need to be replaced to retain their functions of retaining stormwater through evapotranspiration, providing long term infiltration, dissolved nutrient removal, and other functions (Barrett et al., 2013, Henderson 2009). Without regular maintenance, bioretention devices lose their treatment capability and function.

In Auckland, the infiltration rate of 6 raingardens was measured using double ring infiltrometer tests. Using the minimum permeability of a raingarden in Auckland specified in TP10 of 12.5 mm/hr, only three out of the six raingardens passed (Roelofs et al., 2017). The results of the double ring infiltration tests are shown in Table 3.

Table 3 Permeability of 6 Auckland raingardens using a double ring infiltrometer test (Roelofs, Simcock, & Cheah, 2017)

Rain garden	Permeability (mm/hr)	Design rate (mm/hr)	Design Standard
Olympic Park, New Lynn	0.5	12.5	TP10
Rangitoto College	1.0	12.5	TP10
Paul Matthews, Albany	8	50	North Shore City Council
Albany Centre	18	12.5	TP10
Waitakere Vehicle Testing Station	66	12.5	TP10
Wynyard Quarter	3382	300	FAWB

At the time of testing, five out of the six raingardens needed maintenance. Due to inadequate maintenance plans, inlets were blocked, there were prolonged periods of ponding, and the devices often bypassed. There may have been no intent to maintain some of the devices.

Contech’s maintenance QA/QC procedures specify that their Filterra devices need to be maintained every 6 months (12 months in drier climates). For most maintenance appointments, old mulch is simply removed and replaced with new mulch. If the Filterra devices are maintained, they perform as expected. Where the devices are not maintained, the performance observed greatly varies. In these cases, the semi-annual inspections have at times revealed that some media or plant replacements may be required. Some devices continued to perform while others deteriorated. The oldest Filterra devices have been in the ground for over 10 years now and have been shown to consistently perform to their design specifications (International Stormwater BMP Database, 2014).

5 CONCLUSIONS

Bioretention treatment systems have high pollutant removal potential and are a common BMP to use in water sensitive urban design. However, many bioretention systems do not perform to their design specification due to poor device design and installation, uncontrolled media manufacture, exposure to construction site waste and catchments with unstable soils, and lack of maintenance.

This paper has demonstrated that bioretention devices can perform consistently where: -

1. a stringent QA/QC process is followed during design and media manufacture,
2. devices are checked upon commissioning to ensure proper device installation, and that the devices will operate under the conditions they were designed for,
3. field testing can be conducted in a practical and meaningful way to check device performance, and
4. a regulatory environment exists wherein owners are required to maintain their treatment devices and the policy is actively enforced.

Without adequate QA/QC processes adhered to across all the stages of implementing a bioretention treatment device, achieving treatment outcomes and improving the health of receiving water catchments using bioretention devices is unlikely. With more enforcement from regulatory authorities regarding the ongoing performance of bioretention units in New Zealand, a culture can be developed where the treatment potential of bioretention devices can be fully and consistently realised and maintenance of the devices is the norm.

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