PLANT GROWTH TRIALS IN RAPID FILTRATION MEDIA

Dr. J. Cheah, Research and Development Engineer at Stormwater360
Dr. R. Simcock, Ecologist / Soil Scientist at Landcare Research
M. Hannah, Managing Director of Stormwater360

ABSTRACT (300 WORDS MAXIMUM)

Rapid bio filtration treatment systems have gained Washington State Department of Ecology General and Conditional Use Level Designations as basic level and enhanced level stormwater treatment devices in the USA. The media used in rapid bio filtration devices have hydraulic conductivity rates exceeding 2500 mm/hr. Stormwater360 NZ has partnered with Contech USA to develop a local version of this rapid filtration media. One of the reasons current bio retention guidance limit the hydraulic conductivities of media to less than 350 mm/hr is to support plant growth. This research examined the capability of four NZ groundcover plant species to establish in the rapid filtration media made using locally available materials. A typical 'TP10' rain garden mix was used as a control. Both treatments were covered with 7 cm of shredded bark mulch.

The four NZ plant species that were used for the plant growth trials were:-

- *Poa cita* / Silver tussock
- *Hebe speciosa* / NZ hebe
- *Dianella latissima* / Flax lily
- *Carex testacea* / Orange sedge

Over a period of 12 weeks the plants were watered with tap water and stormwater taken from a local carpark sump according to a fixed schedule. Plant root and shoot growth and biomass showed 3 of the 4 species successfully established in both the rapid filtration and TP10 media, developing extensive root systems with markedly different structures. *Carex testacea* did not establish in either media. Hebe foliar growth was greater and visibly greener in the TP10 mix, likely due to significantly higher levels of available nitrogen and phosphorus. *Hebe* and *Dianella* had high root mass, with Hebe having a root:shoot ratio between 1.7 and 2.6.

KEYWORDS

Bio-retention, plant establishment, roots, biomass

PRESENTER PROFILE

Dr. John Cheah

John graduated with his doctorate from the University of Auckland in Civil and Environmental Engineering in 2015. His PhD focused on the development and implementation of a prototype earth housing solution in partnership with a rural Maori community. John is presently working as a R&D engineer to develop Stormwater360 products.

1 AIM

The purpose of this research was to:-

1. determine whether four native NZ plant species were able to establish and grow in a rapid filtration media (NZ Filterra) under typical summer conditions,

2. quantitatively assess the growth and health of the plant species grown in the rapid filtration Filterra media, and to

3. compare plants grown in the rapid filtration media with plants grown in a TP10 approved raingarden mixture.

2 INTRODUCTION

The upper level of hydraulic conductivity (saturated, K_{sat}) of media in bio retention treatment devices is typically limited by two main factors.

1. Adequate contact time for pollutant removal mechanisms. The relationship between pollutant removal and K_{sat} is typically pollutant-dependant, being slowest for nitrogen and fastest for sediment and some metals (Fassman, Simcock, & Wang, 2013).

2. Plant survival (Payne, et al., 2015) and the ability of plants to establish in the media (FAWB, 2009). In particular, the volume of water able to be extracted by plants to support growth between rainfall events.

Typical maximum K_{sat} for media are 300 mm/hr, with Australian guidance allowing higher rates in tropical areas (up to 500 mm/hr), provided plant growth can be supported (Payne, et al., 2015, Woods Ballard, et al., 2015). Recently rapid bio retention treatment devices using media with K_{sat} exceeding 2500 mm/hr have been approved for use in Washington State by Washington State Department of Ecology (WSDOE).

Stormwater360 in partnership with Contech USA have developed a New Zealand equivalent of the Filterra rapid bio retention treatment media (Hannah, et al., 2015). A plant trial has evaluated the ability of four native, locally available groundcover species to establish and grow in the media. The plants have been selected to cover a range of growth forms and rooting strategies including a woody shrub, grass, sedge, and lily.

2.1 FILTERRA®

The Filterra® Bioretention Stormwater Treatment System (Figure 1) consists of a precast concrete curb inlet structure with a tree and/or plants grown in an engineered filter media with a selected mulch and drainage rock layer to support plant growth and provide stormwater treatment.

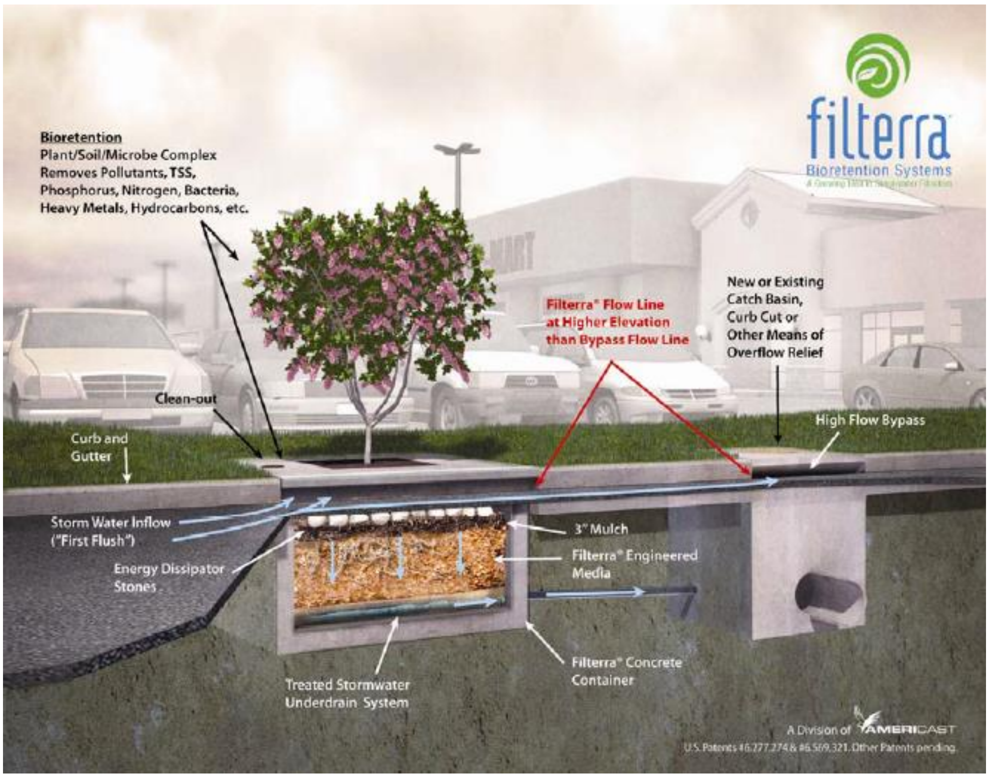

Figure 1: Schematic of a Filterra® Bioretention Stormwater Treatment System

Third-party analyses of the Filterra® system based on five field studies (Lenth & Dugopolski, 2010) showed that at a hydraulic conductivity of at least 2500 mm/hr the device was able to remove:-

- 83-88% TSS
- 9-70% Total Phosphorus
- 40% Total Kjeldahl Nitrogen
- 33-77% Total Copper
- 48-79% Total Zinc

The five studies referred to in the analysis were:-

- TARP study, Oct 2004 – Nov 2005 (Yu & Stanford, 2006)
- TARP addendum study, Dec 2006 – Jan 2007 (ATR Associates, 2009)
- Performance over time study, Jan 2008 – Feb 2010 on 3 Filterra units (Americast Inc, 2009)
- TAPE study May 2008 – May 2009 at two sites (Herrera, 2009)
- Bellingham study Mar 2009 – Apr 2010 (Ruby, 2010)

A study conducted by Geosyntec Consultants compared the pollutant removal performance of Filterra® systems to conventional bio retention systems reported in the International Stormwater Best Management Practices Database (http://www.bmpdatabase.org/) and concluded that Filterra® provided somewhat higher TSS removal across all land uses, and provided similar copper and zinc removal. The Filterra system had better nitrogen and phosphorus performance because it did not leach nutrients during normal operation (after first flush release) whereas the majority of existing bio retention devices were observed to leach nutrients, with some continuing to do so years after installation (Geosyntec Consultants, 2015). Bio retention devices tend to leach nutrients in the establishment phase and at 'first flush' as media generally contain readily-mineralisable organic components that release N and P. At establishment, plants have both relatively low nutrient demand (low leaf area) and ability to uptake nutrients (small root systems).

3 PLANT GROWTH TRIAL - METHOD

Establishment of 4 native NZ plant species was evaluated over a 12 week period. The plants were all groundcover species with rapid growth characteristics. Eight plants were grown in NZ Filterra media, and eight plants grown in an approved TP10 rain garden media and are shown below in Table 1.

The native ground cover species were selected for the trial based on resilience to a wide range of soil moistures, specifically including drought, ability to quickly form a dense (weed suppressing) groundcover size, and ease of maintenance. The groundcover species selected were easily propagated varieties which grew 500 mm to 1 m height in height and thus were generally suitable for devices placed adjacent to a road.

Prior to planting, plants were saturated, then removed from their 1.7 litre plastic bags. Nearly all the potting mix was removed before each plant was carefully planted into the selected media and immediately watered to establish root/media contact. The containers were 38 cm deep and 52 cm in diameter; a coarse shredded bark mulch was then placed over the surface to a depth of about 7 cm (about 8 litres per container).

The plant growth trial was conducted in an outdoor grassed area at the SW360 premises that was fully exposed to sunshine during most of the day. Plant heights were measured weekly and the change in plant biomass at the beginning and end of the 12 week period was measured for each plant.

Table 1: Plant species used for the plant growth trial

			
Poa cita Silver tussock	*Hebe speciosa* NZ hebe	*Dianella latissima* Flax lily	*Carex testacea* Orange sedge

3.1 WATERING SCHEDULE

The plant growth trial began on 5th December 2015 and concluded on 22nd February 2016. Over the first 6 weeks until 18th January 2016, each container was watered with 7L of tap water and between 2-3L of stormwater bi-weekly; typically on a Monday and Thursday morning. For the final 6 weeks (18th January 2016 onwards) plants were not watered.

The volume of water used for watering was calculated based on the amount of water that would pass through a 1.8m X 1.8m treatment unit with a 1011 m^2 impervious catchment during a 2.5 mm rainfall event. For a treatment surface area of 150 mm diameter, this equated to a watering volume of 13.6L. Due to difficulties in obtaining enough stormwater for regular watering purposes, 7L of tap water and 2-3L of stormwater was used at each watering. Stormwater was sourced from sumps in the Stormwater360 carpark.

3.2 HEIGHT MEASUREMENTS

The heights of the plants were measured weekly by straightening (without pulling) the plants vertically and measuring the tallest vegetation. For the Hebe speciosa, as a more rigid bush-like plant, the height and width of the plant was measured without any manipulation. The datum used for all measurements was the rim of the container. Measurements were taken by placing a straight rod across the container and extending a tape measure alongside the plant, perpendicular to the rod.

3.3 MEDIA MOISTURE MEASUREMENTS

Moisture measurements were taken directly before, and 24 hours after, watering (i.e. four times a week during bi-weekly watering, and twice a week during the period when watering ceased). Moisture levels were measured at 20 cm and 30 cm depths below the rim of the container. Moisture measurements were 10-20 cm from the centre of the plant and in new locations. Each subsequent measurement corresponding with the hour positions of a clock using a Frizzell Soil Moisture Probe (Model SMP3A). The probe made measurements by sending many pulses of electricity into the media and using the returning modified signals to predict the percentage of water in the soil. The device automatically compensated for temperature variation.

3.4 CALIBRATION OF MOISTURE METRE

The soil moisture probe was calibrated against the actual gravimetric moisture content of the two media at a range of moisture levels. Gravimetric moisture content was determined by drying media samples at 105 degrees Celsius overnight (minimum 24 hours) on in-situ 100 mm diameter cores taken at depths of 10-20 cm, and 20-30 cm from each container shortly after the final probe measurement, i.e. n=8 for each depth. The deeper measurement probably approximated field capacity for the NZ Filterra media.

Table 2: Moisture probe calibration test results

	NZ Filterra media (±1 S.D.)		TP10 media (±1 S.D.)	
	20 cm depth	30 cm depth	20 cm depth	30 cm depth
n	8	8	8	8
Moisture content (probe)	25.2% (±0.8)	30.4% (±1.2)	30.4% (±1.6)	48.9% (±0.3)
Gravimetric moisture content	16% (±1.0)	19% (±5.8)	53% (±1.4)	61% (±2.2)
Difference	-9%	-11%	+23%	+12%

The over-estimation of moisture content in the NZ Filterra mixture was unexpected and the media component influencing the electric signals emitted and received by the probe needs further investigation. The large under-estimation of actual TP10 media moisture content might be related to the high organic content and bulk density of the mix. Regardless, results illustrates the importance of calibrating measuring devices when comparing different media.

4 RESULTS

4.1 PLANT HEIGHT MEASUREMENTS

Changes in plant height were used to evaluate plant growth. Due to the different starting heights of the plants, a percentage difference in plant height was used to evaluate and compare growth rates.

The growth rates are presented over three periods in Table 3:-

1. The full 12 week period 5/12/15 to 23/02/16,
2. the bi-weekly watering period 5/12/15 to 18/01/16, and
3. the period during which the plants were not watered 18/01/16 to 23/02/16.

Table 3: Percentage height growth rates of plants during the 12 week trial

Growth period	Day	NZFPC	NZFHS	NZFDL	NZFCT	TP10PC	TP10HS	TP10DL	TP10CT
5 Dec '15 to 23 Feb '16	1-82	28.8%	13.5%	7.6%	-9.9%	33.6%	30.9%	-4.9%	-14.9%
5 Dec '15 to 22 Jan '16	1-49	29.5%	6.2%	8.1%	-2.2%	36.2%	14.9%	-4.5%	-10.5%
22 Jan '16 to 23 Feb '16	49-82	-0.7%	7.3%	-0.4%	-7.7%	-2.6%	16.0%	-0.4%	-4.4%

KEY: NZF=NZ Filterra media blend, TP10=TP10 Approved media, PC=*Poa cita*, HS=*Hebe speciosa*, DL=*Dianella latissima*, CT=*Carex testacea*

4.2 PLANT MASS MEASUREMENTS

Changes in biomass were also used to evaluate plant growth. These measurements were obtained by carefully extracting the plant from the media they were growing in, washing the roots of any remaining soil or gravels, and gently drying the roots using paper towels. The plants were removed from the media both at the beginning of the plant growth trial (see Figure 2) and at the end of the experiment (see Figure 3). The weight of the plants were measured on a scale with an accuracy of +/- 0.1g.

Table 4: Plant (wet) biomass at the beginning and end of plant trial, mean of two plants per treatment

	NZFPC	NZFHS	NZFDL	NZFCT	TP10PC	TP10HS	TP10DL	TP10CT
Initial plant weight (g)	119	97	68	26	124	74	143	23
Final plant weight (g)	118	186	136	12	197	246	257	14
Difference	**-1.5%**	**+91%**	**+98%**	**-52%**	**+59%**	**+233%**	**+80%**	**-40%**

Figure 2: Hebe speciosa (left) and Poa cita (right) plant removed from planter bag and being washed at the beginning of the plant growth trial

Figure 3: Hebe speciosa and Poa cita plants removed from media at end of 12 week plant growth trial

4.3 ROOT TO SHOOT RATIO

The plants at the end of the plant growth trial were dried and weighed to evaluate the root to shoot ratio. A high root to shoot ratio indicates that a plant has greater capacity to survive in dry and harsh conditions.

Table 5: Root to shoot ratio of plants

	NZFPC	NZFHS	NZFDL	NZFCT	TP10PC	TP10HS	TP10DL	TP10CT
Dry shoot mass	34	14	15	6	56	21	28	5
Dry root mass	16	38	12	0.5	16	37	27	0.9
Ratio	**0.5**	**2.6**	**0.8**	**0.1**	**0.3**	**1.7**	**0.9**	**0.2**

4.4 MEDIA MOISTURE CONTENT

One of the key media properties with respect to supporting plant growth was the ability of the media to retain water for plant growth. Over the course of the plant growth trial the media received water from rainfall events and watering. Using the council rain gauge at Rosedale treatment plant nearby and by converting the volume watered into an equivalent depth of rainfall, the amount of water the media received was recorded for each day. The moisture levels measured in the media at 20cm and 30cm below the rim of the container were plotted against the rainfall and watering depth (Figure 4).

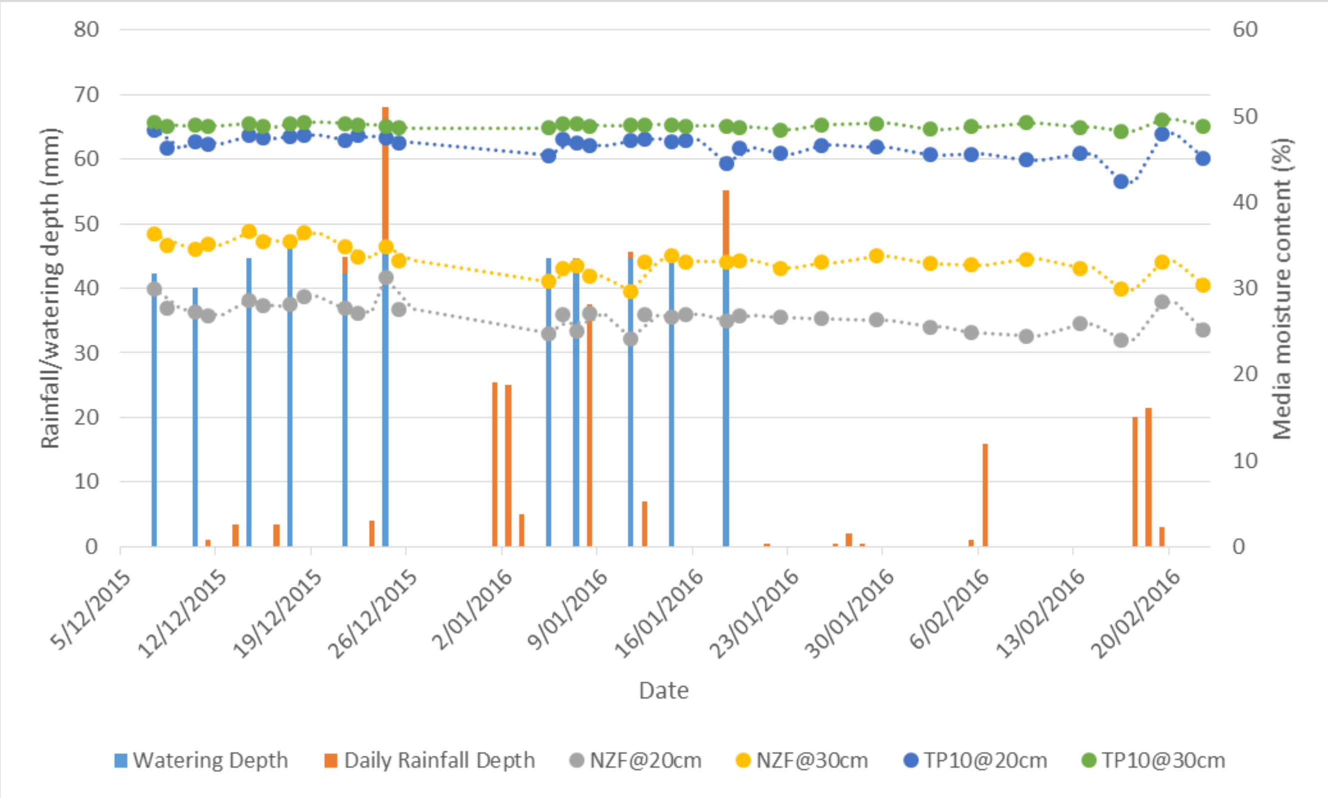

Figure 4: Influence of rainfall and watering of media on moisture content at 20 and 30 cm depths

Of interest was the field capacity and the plant available water of the media. The field capacity is the total amount of water that can be held by the media against gravity. It includes plant available water and hygroscopic water held below the nominal wilting point that is unavailable to plants. From the measurements taken and the graph shown in Figure 4, it seems that the media was at field capacity or near it for the majority of the plant growth trial, and that it was higher for the TP10 media than the NZ Filterra media.

The ability of both media to remain near to field capacity, even across weeks with no rain events or watering was due to the presence of the 75 mm mulch layer which minimized moisture loss (Simcock & Dando, 2013), and low moisture removal by plants, due to their small size.

5 DISCUSSION

5.1 PLANT ESTABLISHMENT AND GROWTH RATE

Vastly different growth performance of plant species in both media highlight the importance of plant selection in implementing a rapid bio retention system. Three native species were able to establish and grow in both the NZ Filterra and TP10 approved media whilst the *Carex testacea* struggled to establish in both media.

Poa cita established the best in both the NZ Filterra media and TP10 approved media after being transplanted. Over the first 6 weeks the plants increased in height by 30% and 36% respectively. Once the watering stopped, the *Poa cita* in both media stopped growing and slightly decreased in height. The stabilization of plant height is likely due to the plants reaching their mature height. The mature height of *Poa cita* in the NZ Filterra media was about 500-600 mm whilst the *Poa cita* in the TP10 media stabilized at 700 mm. Grasses that grew longer than these heights would break in the wind. Poa cita in the Filterra mix developed many more reproductive stems than the TP10 mix.

Hebe speciosa also successfully established in both media, however, plants in the TP10 media grew larger and faster. It was interesting to observe that the Hebe speciosa in both media grew faster during the period when watering had ceased than when being watered twice a week. The increased growth was suspected to be due to the plants having overcome transplant shock in the second half of the trial rather than drier media conditions.

The *Dianella latissima* plants also successfully established and grew in both media. New shoots could be seen growing in all four plants at the end of the plant trial. The plant grew slowly and steadily in the NZ Filterra media during the bi-weekly watering period and stopped growing (but didn’t decrease in height) when watering ceased. Despite the height decrease of the plants grown in the TP10 media over both the first 6 weeks and the last 6 weeks, visually it was clear that the plants had established well in the TP10 media and were growing vibrantly at the end of the 12 week plant trial.

The *Carex testacea* plants did not establish in either media. All four plants had halved in weight by the end of the plant trial, had negligible root systems, and had died or were on the verge of dying by the end of the 12 week plant trial.

Over the 12 week period. *Hebe speciosa* plants in TP10 mix tripled in weight whilst the plants grown in the NZ Filterra media doubled in weight. Biomass of *Dianella latissima* were similar in both media.

5.2 PLANT RESILIENCE

Plants grown in the NZ Filterra media had a higher root to shoot mass ratio than plants grown in the TP10 media. The lower water and nutrient content in the NZ Filterra media likely encouraged the plants to allocate more resources below ground to increase the media volume accessed for water and nutrients.

Despite the lower root to shoot ratio in plants grown in the TP10 media compared with plants grown in the NZ Filterra media, the actual dry mass of roots was similar. The difference was in the mass of shoots. A direct comparison of plant root mass at the end of the plant trial is difficult to make due to the different starting sizes of the plants but it was interesting to observe that regardless of the vegetation observed growing above the surface, the roots in both the media grew to a similar mass. *Hebe speciosa* had the largest root mass made up of fine intertwined roots in a dense mat predominantly below the plant. The roots of the *Dianella latissima* plants in both media, but especially the TP10 media, were observed to spread extensively both laterally and vertically into the media.

6 FUTURE RESEARCH

Long term plant growth trials are continuing on eight more native plants and trees species, and research is also being conducted on the effectiveness of incorporating an internal water storage into the treatment unit to improve the drought resilience of plants grown in the NZ Filterra media.

7 CONCLUSION

The plant growth trial successfully demonstrated that NZ native plants can establish and grow in a rapid infiltration media (NZ Filterra) with a hydraulic conductivity of 2500 mm/hr. Of the four plant species trialed, three were able to establish and grow in the media.

The plants that successfully established in the NZ Filterra media were observed to grow well when watered twice a week (first 6 weeks of the plant trial) and also survive without being stressed when not watered during summer (last 6 weeks of the plant trial). The *Hebe speciosa* plant varieties in fact grew faster during the period when the media was not watered.

Plants grown in the TP10 approved media showed similar results with respect to successful plant establishment. The same three plant species were able to establish in the TP10 approved media whilst the fourth plant species *Carex testacea* was not able to. The *Poa cita* and *Hebe speciosa* plant varieties grew faster in the TP10 approved media whilst *Dianella latissima* plants grew at a similar rate in both media.

Root to shoot ratios were higher in plants grown in NZ Filterra media. Measurements of the dry mass of roots and shoots showed that plants grown in the NZ Filterra media had a lower amount of shoot growth, but a similar amount of root growth.

The field capacity of the TP10 approved media was estimated to be about 60%, more than double the NZ Filterra media (~24%). However, this difference does not reflect the large volume of hygroscopic water that is unavailable to plants in the TP10 mix (due to its high organic content and high silt+clay content – can be 20 to 25% v/v). In contrast, the NZ Filterra media has very low hygroscopic water content; hence nearly all the water held at field capacity is available for plant growth. Some work is still required to be done regarding the calibration of the moisture probe results.

Three species grew well in both media. During the last 6 weeks when the media and plants were not watered, the moisture levels in both media did not decrease significantly and the plants did not show signs of water stress. The presence a 75 mm organic mulch layer over the media was able to reduce and minimize the water loss significantly.

REFERENCES

Americast Inc. (2009). *Filterra® Long Term Field Performance Evaluation Report.* Virginia: Americast Inc.

ATR Associates. (2009). *Technical Report Addendum. Additional Field Testing and Statistical Analysis of the Filterra® Stormwater Bioretention Filtration System. Prepared for Americast, Inc.* Virginia: ATR Associates Inc.

Fassman, E., Simcock, R., & Wang, S. (2013). *Media specification for stormwater bioretention devices TR2013/011.* Auckland: Auckland Council.

FAWB (2009). *Guidelines for Filter Media in Biofiltration Systems (Version 3.01).* Melbourne: Facility for Advancing Water Biofiltration.

Geosyntec Consultants. (2015). *Filterra Equivalency Analysis and Design Criteria.* Portland: CONTECH Engineering Solutions.

Herrera (2009). *Filterra® Bioretention Filtration System Performance Monitoring Technical Evaluation Report. Prepared for Americast, Inc.* Seattle, Washington: Herrera Environmental Consultants.

Lenth, J., & Dugopolski, R. (2010). *Filterra® Bioretention Systems: Technical Basis for High Flow Rate Treatment and Evaluation of Stormwater Quality Performance.* Virginia: Americast Inc.

Payne, E., Hatt, B., Deletic, A., Dobbie, M., McCarthy, D., & Chandrasena, G. (2015). *Adoption guidelines for Stormwater Biofiltration systems.* Melbourne, Australia: Cooperative Centre for Water Sensitive Cities.

Ruby, M. (2010, June 8). Personal communication.

Simcock, R., & Dando, J. (2013). *TR2013/056 Mulch Specification for Stormwater Bioretention Devices. Prepared by Landcare Research New Zealand for Auckland Council.* Auckland: Auckland Council.

Woods Ballard, B., Wilson, U.-C., Illman, S., Scott, T., Ashley, R., & Kellagher, R. (2015). *The SuDS Manual. Chapter 18: Bioretention systems.* London: CIRIA.

Yu, S. L., & Stanford, R. L. (2006). *Field Evaluation of the Filterra® Stormwater Bioretention Filtration System. A Final Technical Report. Prepared for Americast, Inc.* Virginia: Department of Civil Engineering, University of Virginia.