FEATURES OF (RESILIENT) WYNYARD QUARTER BIORETENTION MEDIA

R. Simcock, soil scientist& ecologist, Landcare Research NZ
J. Dando, soil physics technician, Landcare Research NZ

ABSTRACT

The media used in bioretention influence hydraulic, chemical and plant growth performance. Resilient media have characteristics that resist or buffer changes to maintain design performance over the life of a device. We followed the performance of Wynyard Quarter raingardens installed between 2007 and 2013. Three contrasting media were used; two are soil-like with >20% fines and organic contents (Auckland Council 'TP10' media); one is 85% v/v sand with low fines and organic matter (Melbourne 'FAWB-type' medium).

Infiltration rates generally increased as plant cover increased. The initial infiltration rate was influenced by each media's response to compaction at installation. The 'TP10' media with infiltration closest to design after 1 to 4 years were rejected at installation in favour of the 'FAWB-type' medium with high infiltration rates that likely exacerbated drought-related mortality, despite high water storage, due to uneven water distribution across individual raingardens.

The organic content of raingardens may be moving towards equilibrium now a dense plant cover is maintained. Organic matter is probably increasing in the FAWB-specified media, and may be decreasing in media with high initial organic matter contents. The FAWB-type media is poorly buffered. Further, the low nitrogen content lead to some groundcover and tree species exhibiting signs of nitrogen stress.

The resilience of rain garden media infiltration rates to compaction and changes in organic content, and the impact of sustained plant growth on infiltration and permeability should be considered. Adequate organic contents are needed to support acceptable plant growth in environments where storm water nutrient inputs are low. Alternatively, mulches can be selected to provide nutrition and organic matter.

KEYWORDS

Bio-retention, Media, Infiltration, Development, Resilience

PRESENTER PROFILE

Dr. Robyn Simcock

Robyn has researched bioretention: raingardens, swales and living (green) roofs since about 2007. Much of this research has been in partnership with Stormwater engineer Dr. Elizabeth Fassman-Beck (formerly at University of Auckland). Research outcomes have been applied in Auckland guidance on living roofs (TR2013/045), selecting bioretention mulches (TR2013/056) and ecological values within storm water management (lead by Mark Lewis, TR2009/023).

1 INTRODUCTION

Auckland, Tamaki Makaurau is a region under pressure. Imperviousness is rapidly increasing in the fastest growing city in Australasia. A forecast 6000 ha of its high quality, most permeable soils is predicted to be urbanised in green field development (Curran-Cournane et al. 2014). Stormwater runoff from impervious surfaces is recognised as a predominant contributor to water quality, stream and coastal ecosystem health. In the central city, 122 active overflow points discharge 1,200,000 m^3 of wastewater on an average annual basis into streams and harbours (Watercare, 2012). Sediment, metals and other contaminants degrade some estuaries and fisheries; while gross pollutants, such as plastics, impact both aesthetics and sea life. Recreational fishing and watersports are important recreational activities – Auckland has an estimated 132,000 boats (in 2011) with 15–19% of households owning one or more boats, canoes or windsurfers (Beca, 2012). The Manukau Harbour is an internationally–important feeding and breeding–ground for migratory birds; the Waitemata Harbour includes the Hauraki Gulf Marine Park and 22 dolphin and whale species.

A key way to mitigate impacts of the stormwater generated from increased imperviousness is implementation of Water Sensitive Design (WSD, previously Low Impact Design). WSD is defined in the proposed Auckland Unitary Plan (PAUP) (Auckland Council 2013) as *'An approach to freshwater management… applied to land use planning and development at complementary scales including region, catchment, development and site. Water sensitive design seeks to protect and enhance natural freshwater systems, sustainably manage water resources, and mimic natural processes to achieve enhanced outcomes for ecosystems and our communities'*.

The PAUP may increase the focus on both reducing the generation of stormwater and managing it at or near source. Auckland's geography and climate is ideally suited to WSD using plant–based, at–source devices. Auckland's estimated 16,500 km networks of streams (Storey and Wadhwa, 2009) are typically small, short and low–gradient, fed by small catchments (Kanz, 2013). The majority of individual rainfall events are small storms; 80% of individual events are less than 22 mm on average across the region, while 90% of events are less than 31 mm (Shamseldin, 2010). A long growing season allows year–round plant growth and water uptake by evergreen tree species. Bioretention, either as planted stormwater devices (raingardens, bioswales, planter boxes, or living roofs) or stormwater-receiving landscaped areas is therefore a highly effective mitigation method.

Water Sensitive Design is also fundamental to delivering the vision of Auckland as the 'world's most livable city' on land, as WSD stormwater underpins self-watering, self-fertilising open space. Such spaces have been called a 'hybrid park typology', where stormwater treatment is integrated with high aesthetics, recreational values and ecosystem restoration. In the best examples, all landscaping contributes to stormwater management – Wynyard Quarter's Jellico Street is one such place; an international–award–winning, brownfield development constructed in 2011. WSD was embedded in the site to deliver a highly–aesthetic environment creating a uniquely 'Auckland' sense of place. Boulevards of raingardens and swales are being used to anchor the 30-year development where new buildings must meet high sustainability ratings.

1.1 WYNYARD QUARTER

Wynyard Quarter is a 45 hectare precinct of retail, hotel, office and intensive housing developed within, and alongside, established light marine industries enabled by the removal of bus and bulk petro–chemical storage areas; the so-called 'tank farm'. The transformation of this reclaimed brownfield area to desirable work and play spaces started with Jellico Street in 2011 (Figure 1) and should be complete by 2030. The land is owned by Auckland Council. The Council's development agency was tasked with leading and delivering projects in waterfront consistent with the city's vision, building on the 2007 urban design framework for Wynyard Quarter, developed by Sea+City projects Ltd.

The Wynyard Quarter development aimed to be *'NZ's premier example of environmentally responsible development'*, and to *'showcase world–class strategic and design responses to local and global environmental issues'* (SDF, 2009). An over–arching objective was to create a 'blue–green', public waterfront recognised for the natural environmental quality of public spaces. Managing stormwater was a critical component. The site is almost flat, close to sea level and some parts are contaminated, so water is unable to be drained into the ground. Stormwater discharges to the harbour. Public spaces encourage direct contact with the harbour through broad steps leading into the water. The sea is also used for public events such as international multi–sport triathlons.

The intent of the raingarden design was to implement the latest, international best practice 'Water Sensitive Urban Design'. Specific success measures were a 42% reduction in stormwater discharge and exceeding the (then) statutory requirement of 75% removal of Total Suspended Solids. The stormwater mitigation approach adopted was to capture and reuse roof–water within buildings (e.g. for flushing toilets) and to treat runoff at the surface in raingardens.

Auckland Council initially proposed treatment in sub-surface sand filters with individual trees within pavements creating boulevards. However, this conventional approach was shifted with input from landscape architects Wraight + Architects to an adaptive landscape where trees were part of raingardens with a dense native groundcover based on interpretation of local ecology. The raingardens are very large, almost–continuous, and indistinguishable from landscaping. Continuous simulation modelling of the 10–year, 6–minute rainfall indicated 78% TSS removal could be achieved; the 'over–sized' raingardens helping compensate for areas that would not get treated (Allison 2009).

Figure 1: Wynyard Quarter pre-reinstatement and artist's impression of mature, post-reinstatement landscape (Matthews 2010)

The raingardens along Jellico Street have high in–built resilience provided through: a relatively large volume of media per tree (10m^3, Howell Davies pers. comm.); over 30 species of tree and groundcover species in a complex planting pattern (generally avoiding single species clusters); and, a three year maintenance requirement during which the growth of each tree was measured annually. Additional root volume was achieved by extending media under the impervious area of carparks and some pedestrian pavements and walkways. This additional root volume allowed clusters of trees to be planted. Unusually for urban landscaping, six native evergreen tree species were used together, as they might be found in a native forest. Many of the species had rarely been used in raingardens, nor planted so close to the harbour. The approach reduced the risk of any one tree species not performing on the overall landscape and helped create self-sheltering microsites[1]. At Karanga Plaza, some older pohutukawa trees were salvaged from streets being renovated. This was particularly effective at creating a variation of canopy and more 'natural' outcome. Raingarden groundcover plants are particularly diverse, dense and textured, ranging from 1.4 m tall native lilies to 50 mm carpets. By 2015, about half these plants produced seedlings that have themselves successfully established, as have four tree species.

[1] In Auckland, most raingarden and street tree plantings use evenly spaced, evenly –aged and single–species of trees. This increases the risking of failure of the overall design with tree disease or uneven growth rates.

Figure 2: Wynyard Quarter's Jellico Street in early 2012

1.2 BIORENTENTION MEDIA SELECTION

The bioretention at Wynyard Quarter required imported soils, as existing soils were unsuitable, and some were contaminated. At the time Wynyard Quarter gained resource consents, there was fierce debate over the media that should be used in the raingardens, and in particular its permeability. In this case infiltration rate had no bearing on raingarden size, as the raingardens had a much greater area than needed for Stormwater treatment. Council stormwater engineers preferred at 'TP10'mix with 12.5 to 40 mm/hr, and up to 25% clay content. They were concerned the proposed mix (permeability 100 mm/hr) would not be able to support adequate plant growth. They also considered raingarden maintenance costs would be too high (compared to sand filters).

The applicants' Stormwater engineer (Robin Alison) stated that the loamy sand media with 100 to 300 mm/hr infiltration rate, had a minimum moisture content and minimum organic matter content (typically 5%), that plants were selected to match the climate and soil, and that organic material combined with nutrients and organic matter within stormwater entering the raingardens would be sufficient to plant growth. He added that the infiltration rate was expected to reduce over time as sediment accumulated (Alison 2009).

Mr Alison did not support TP10 filter media based on the potential for extended surface ponding, boggy conditions created not being suited to the coastal plants, and potential failure of the media by structural collapse (which had been observed in some Auckland raingardens, and reported in a 6 month glasshouse trial laboratory where North Shore topsoils high in silt and clay had been mixed with sand to achieve the 'sandy loam' textural classification' of TP10).

A loamy sand media made from compost, pumice sand and ash soil was installed in 2011 to raingardens near Karanga Plaza. In Table 1 and throughout this paper it is referred to as 'TP10' mix as it confirms to TP10 (2003) in terms of textural analysis. Following surface ponding in some raingardens, this mix was removed from most of the raingardens in Jellico Street, and replaced with more permeable sand containing a small proportion of ash soil and no compost (Table 1). This mix is referred to as an 'FAWB' mix, as it resembles the Melbourne FAWB (2007) standards.

*Table 1: Particle size (% w/w) for the two media used on Jellico Street, grab samples from two sites per medium. *is taken from the sole remaining raingarden on Jellico St.*

	Sand	Silt	Clay
'TP10' medium A*	53	24	23
'TP 10' medium B	52	30	18
'FAWB' medium A	82	15	3
'FAWB' medium B	73	21	6

The purposes of this research were to:-

1. Compare physical and chemical properties of the two contrasting bioretention media, from 2011 installation through to full plant cover
2. Identify the characteristics of resilient media that meet both hydrological requirements and support acceptable plant growth through the installation and growth of a bioretention cell.

2 METHOD

Soil physical and chemical properties were monitored about a year after construction and again in 2013-2015. Although only one raingarden with the TP10 mix to the surface remains, a very similar 'tree mix' was used in 'Titoki Plaza' – raingardens in this area were used to expand the data on the performance of the TP10 mix. The 'FAWB' mix was measured in at least four raingardens in two general locations, opposite the playground, and beside what is now the ASB building.

Infiltration measurements were generally made using the double ring method. This method uses two rings of different diameters pressed concentrically about 50 mm into the media. Ring dimensions ranged from 500 mm and 300 mm diameter for 'slower' soils (TP10 mix) to 300 mm and 100 mm for the 'faster' FAWB mix. Water is ponded in both rings to 20-50 mm depth. Water in the outside ring reduces lateral flow in the central (measurement) ring. Rings were placed between plants to avoid the influence of potting mix (and killing plants), and to avoid corners where people or vehicles may have compacted the surface. Care was taken to ensure the soil surface remained undisturbed throughout the measurements. The double ring method is simple, portable and samples a relatively large surface area of soil (compared to cores). In some cases it was possible to flood a whole raingarden; in this case the infiltration rate was measured by measuring the rate at which the height of ponded water dropped over 30 to 50 mm, in 10 mm increments. On one occasion the falling head method was applied to twin rings as vessels with Mariotte siphons were not available.

Soil pore volume distribution and dry bulk density was measured on hand-carved, intact soil cores 75 mm depth and 100 mm diameter taken between 10 and 100 mm depth. The cores were sampled from within the area an infiltration measurement was made. Cores were then trimmed in the laboratory, saturated, and subjected to tensions; smaller 50 mm diameter and 20 mm deep cores were either taken in the field or sub sampled from the larger cores for measurement of air-filled pore volume at 100 kPa tension; loose soil was used to measure water held at -1500 kPa and particle density.

Chemistry analyses were made on bulked samples, each of which was a minimum of 10 bulked cores taken with a 25 mm corer across the raingardens from 5-100 mm depth. Sampling was done in 2011, 2012, 2014 and 2015. Surface leaf litter and stones were removed prior to measurement to avoid including fertilizer granules. If potting mix was identified in a core, it was discarded.

3 RESULTS

3.1 INFILTRATION RATE

The infiltration rate of the TP10 mix increased markedly over 12 months, and again over the subsequent 2 years to a level significantly greater than the maximum recommended rate in literature of c. 500 mm/hr. Infiltration rates of the FAWB media exceeded 2 m per hour measured using double rings and using a flood test (Table2).

Table 2: Infiltration rate (mm/hr) measured in situ at Wynyard Quarter. is the sole remaining 'TP10' raingarden*

Media	range mm/hr	median	comments
'TP10' Mix			
2011	0 to 120	n.a.	Reported across several gardens
May 2012*	70 to 710	260	4 locations (twin ring, constant head)
May 2012 (site B)	180 to 540		4 locations
2015	790 to 4400	4170	4 locations (twin ring, falling head)
'FAWB' Mix			
May 2012	2300 to 6000		6 locations (twin ring, constant head)
May 2012	2800 to 3900		4 locations (Twin ring, constant head)
May 2012	2400 to 2590		Single raingarden flood test
'Amended TP10' Mix			
2013 immediately post planting	1 to 80 mm	6	Surface 'puddled' during planting; measured between plants by double ring method
2013 post surface forking	75 to 190	105	Measured by flood test (five raingardens)
2015 full plant cover	320 to 1800	1470	Three of four raingardens were 300-400 mm/hr; the last was much higher

The infiltration rate of an 'amended TP10' mix was able to be followed from the week of installation for two years. Immediately following planting, infiltration rates were low (Table 2). This was found to be due to shallow surface compaction (in the absence of a protective mulch), as observed natural flooding drained relatively rapidly. The surface was forked, and infiltration measurements confirmed the median infiltration rate was within the target range.

Results indicate that as plant cover increases, infiltration rates of these two 'TP10' mixes, which are somewhat vulnerable to surface compaction, increase. Infiltration has not decreased over time, except in (unmeasured) placed where vehicle or people have created ongoing, repeated compaction.

3.2 MEDIA WATER STORAGE

Measuring media pore volumes at 10, 100 and 1500 kPa tension allows comparison of the volume of air and water stored in the media. Both 'TP10' and 'FAWB' mixes had high volume of air-filled pores at nominal field capacity (Figure 3, dark blue bars), i.e. Plants in both mixes are unlikely to suffer from waterlogging. Somewhat surprisingly, both media, the 'Retrofit ('FAWB' mix) and 'TP10' mixes store and supply similar volumes of water for plant growth. The relatively high clay and moderate organic matter content of the 'TP10' mix mean that although it stores more water overall, so has higher moisture content, much of this is unavailable for plant growth – instead it is tightly bound to soil surfaces. In contrast, the water held in the pumice sand, the dominant component of the 'FAWB' mix, is nearly all available for plant extraction. Pumice sand behaves quite differently to non-vesicular Beach Sand, which stores a very low volume of water.

Both media will supply about 160 mm of plant-available water in 800 mm depth. At summer evapotranspiration rates of 5 to 10 mm /day, this mean plants are very well-buffered, needing only rainfall events every 2 to 4 weeks. The single-grained, non-cohesive, weak structure of the media combined with high air-filled pore volume means plant roots readily penetrate throughout the media to access water and nutrients.

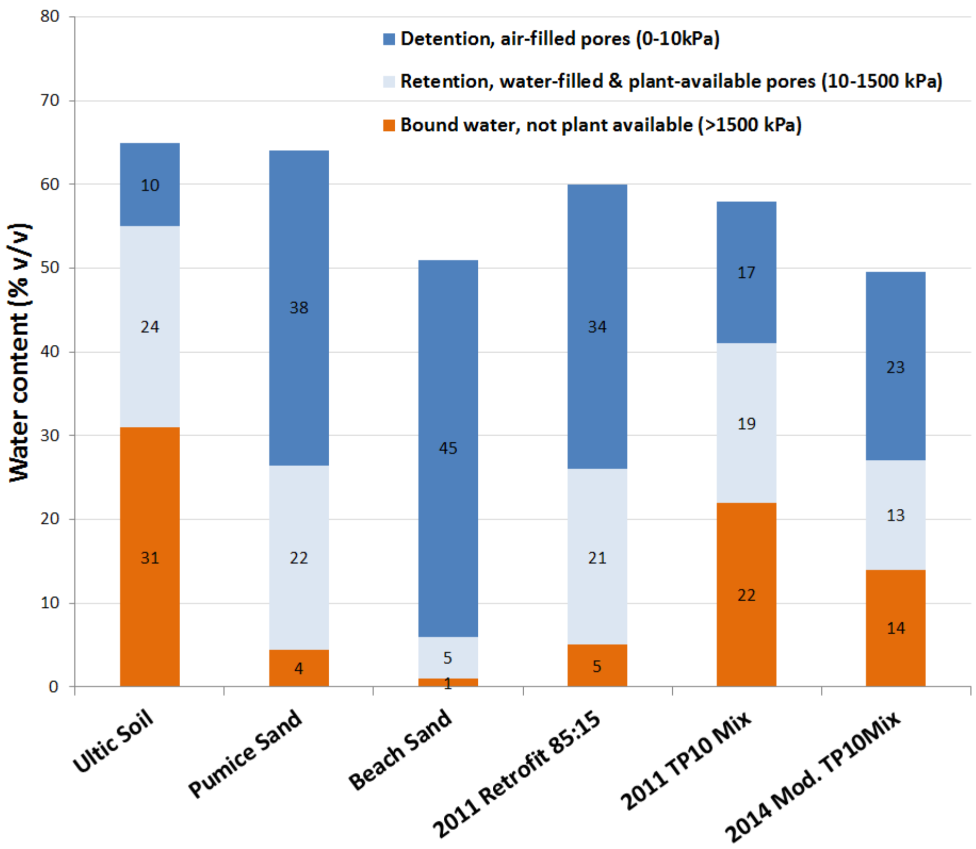

Figure 3: Pore size distribution by volume; the three Wynyard Quarter media on the far right are contrasted with sands, and a natural silt & clay-rich Ultic Soil.

3.3 PLANT NUTRITION

Wynyard Quarter is an area of high aesthetic requirements; landscaping must be lush to achieve the vision of 'an urban oasis'. The plants and trees selected include a high proportion of plants that respond strongly to nitrogen and are naturally found in fertile, organic-rich soils, for example puriri, nikau and rengarenga. The Wynyard Quarter raingardens probably have low nutrient inflow. The area has a high proportion of hard surface (sediment generation is low), street/pavement sweeping is done at least weekly and traffic volumes are low (low NOx emissions).

The two media have very different nitrogen availability and nitrogen turnover, driven by differences in organic carbon content. The 'FAWB' mix has <1% carbon, <0.1% nitrogen, and some C: N ratios that indicate N limitation. Olsen P levels are likely adequate for native plants in both media. The very low Cation Exchange Capacity of the 'FAWB' mix means applied nutrients are more prone to leaching as there is little storage ability; the capacity of the soil to buffer spills is likely also reduced. Some plants are visibly greener in the remaining 'TP10' raingarden and Titoki Plaza, and the higher nitrogen levels have allowed different ground cover species to dominate. The organic content of raingardens would be expected to move towards equilibrium now a dense plant cover is maintained. Organic matter is probably increasing in the FAWB-specified media, and may be decreasing in media with high initial organic matter contents.

Table 1: Media chemistry, 5-100 mm depth. Letters 'A' and 'B' represent different sites along Jellico St. Green indicates favourable, resilient levels.

Media	pH (2:5 water)	Organic Carbon (%)	Total Nitrogen (%)	C/N ratio	Olsen P (mg/kg)	CEC cmol(+)/kg
'TP10' Mix						
2011 at installation	7.4	4.67	0.35	13	56	26.1
2012 A	7.1	5.10	0.43	12	39	26.0
2015 A	6.8	4.82	0.41	12	57	
2011 B	6.5	4.66	0.40	12	49	19.6
2012 B	6.6	4.10	0.39	10	35	16.0
2015 B	6.4	3.79	0.37	10	40	
MEAN	**6.8**	**4.5**	**0.39**	**11**	**46**	**22**
'FAWB' Mix						
2011 at installation	7.3	0.47	0.02	19	11	4.4
2012 A	6.7	0.80	0.08	10	6	5.0
2014 A	6.8	2.66	0.15	18	27	12.9
2015 A	6.8	0.66	0.06	11	12	
2011 B	6.8	0.68	0.07	10	25	6.3
2012 B	7.4	0.50	0.06	8	20	4.0
2015 B	6.7	0.83	0.06	13	45	
MEAN	**6.9**	**0.96**	**0.08**	**12**	**20**	**7**
TP10 C @ 12 months	6.9	2.17	0.13	17	22	
Tree potting mix 2012	5.0	20.60	0.66	31	42	59
Road sediment 2012	7.1	1.00	0.07	14	7	5
Auckland Bot Gardens	6.6	4.85	0.41	12	70	
Pumice+10% compost	7.2	1.52	0.06	27	26	6.3

4 DISCUSSION

Vegetation is the main indicator of the health of the system (Allison 2009). Wynyard Quarter raingardens indicate that media with infiltration rates in excess of 500 mm/hr can support a dense plant growth, given plant available water supply of about 150 mm. However, infiltration rates in excess of 2 m probably contributed to drought stress, as areas away from edges did not receive water regularly enough (the water storage volume was not adequately replenished). Drought stress was particularly noted in shallow-rooted groundcovers and trees (which were generally furthest from inflows) during establishment. Relatively thin gravel mulch may have exacerbated water stress by allowing soil warming and not effectively reducing water evaporation from soil. However, the clustered planting of trees may have reduced individual tree and vegetation stress by decreasing heat stress and increasing wind shelter. Summer drought stress resulted in significant cost of hand-watering specimen trees over the first 2 to 3 years, groundcover dieback and death of some groundcover species. Raingarden designs with high-K media should specifically consider how storm water can be distributed across a device, especially for larger landscaped areas to ensure adequate recharge of plant available water. Larger, deeper-rooted plants are more able to survive in conditions where water distribution is unequal.

A low infiltration rate at construction can be ameliorated by plant growth in as little as 12 months, as long as the plants can survive and grow to develop a dense cover. Such conditions are most likely where the infiltration is limited by surface compaction or crusting, and underlying permeability is adequate. Bioretention mixes that are vulnerable to compaction should therefore be monitored during construction to ensure over-compaction does not occur. In the clean, low-sediment generating Wynyard environment, infiltration rates did not drop over time as reported in Australian literature for high-permeability mixes, nor was the inflow of nutrients likely adequate to support luxuriant plant growth for a mix that had very low organic carbon and nitrogen levels.

5 CONCLUSION

Wynyard Quarter’s Jellico ‘spine’ is an example of large-scale, highly-aesthetic water-sensitive landscaping. All planted areas were designed to receive stormwater runoff. Raingardens are almost–continuous, and indistinguishable from landscaping. The rain gardens along Jellico and Halsey Street have demonstrated mitigation of acute oils and detergent spills that in the past may have been washed directly into the harbour.

Because Wynyard Quarter was designed to be maintained to a high standard by frequent street sweeping and litter management there are probably inadequate nutrients entering the raingardens in Stormwater to support the required plant growth, particularly for the trees. Bioretention media need to have enough initial organic matter to support plant growth for the location. Organic matter can be supplied both in compost-containing organic mulch, or increasing organic matter in the mix

Media with ‘established’ infiltration rates >500 mm/hr can support adequate plant growth under Auckland conditions if:

- An adequate water volume can be held in the root zone, and
- water is evenly distributed across the device to enable adequate recharge,
- mulch is applied to a depth that aids moisture conservation during plant establishment

Water volume storage is effectively increased per unit of media by using pumice sand as a component and providing large root volumes; along Jellico Street this has been achieved using Silva cells and board walks.

Infiltration rates increased as plant cover increased. The initial infiltration rate was influenced by each media's response to compaction at installation (or its absence). Raingarden media design should consider the resilience of rain garden media infiltration rates to compaction, and the impact of sustained plant growth on infiltration and permeability. Adequate plant-available water storage volumes and organic contents are needed to support acceptable plant growth in environments where storm water nutrient inputs are low. Alternatively, mulches can be selected to provide nutrition and organic matter.

REFERENCES

Allison R 2009. Statement of Evidence. In the matter of the Resource management Act 1991 and in the matter of a hearing by submission by Auckland City Council and Auckland Regional Council on resource consent applications by Sea+City Projects Ltd for upgrading of Jellico Street. 27 January 2009.

Curran-Cournane F, Vaughan M, Mermon A Fredrickson C. 2014. *Trade-offs between high class land and development: Recent and future pressures on Auckland's valuable soil resources*. Land Use Policy 39:146-154

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

Fassman-Beck E, Wang S, Simcock R, Liu R. 2015. *Assessing the effects of bioretention's engineered media composition and compaction on hydraulic conductivity and water holding capacity*. Journal of Sustainable Water in the Built Environment.

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

Matthews S 2010. Wynyard Quarter-Jellico Street. Auckland Regional Council Stormwater Seminar. 21 July 2010. (web download)

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.

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.