RESILIENT RAIN GARDENS: SELECTING FILL MEDIA AND MULCH, AND INFLUENCES OF URBAN DESIGN

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ABSTRACT

Rain gardens are Water Sensitive Design devices that use bioretention to retain, and reduce pollutants in, stormwater runoff. Resilient rain gardens consistently attenuate pollutants, volume, and peak flows from small rain events. Research projects investigated combinations of readily available materials in the Auckland region that have consistent physical and chemical properties suitable for bioretention. The mulch and filter (or fill) media used influence rain garden performance – mulches must not float and must have high permeability. Bioretention media must have permeability low enough to achieve adequate contact time (for effective pollutant removal), but high enough to minimize (untreated) overflow from water quality volume events, and avoid excessive ponding duration. Mulch and media chemistry influences effluent water quality and plant growth.

Results of two studies are summarised. The studies guide development of fit-for-purpose rain garden mulches and bioretention media in Auckland. Application at large Auckland rain gardens is reviewed. Although not part of the research, the potential effects of urban design priorities on rain garden resilience at these sites are discussed, including trading rain garden area for depth, increasing rain garden volume to support large trees, desiring lush growth and consistent landscape aesthetics, creating rain gardens 'in series', and 'invisible' inlets.

KEYWORDS

Rain garden, bioretention, mulch, media, substrate, urban design

PRESENTER PROFILE

Robyn Simcock is a soil scientist and ecologist working to understand the inter-relationship of plants, media, and stormwater in bioretention devices with colleagues and students from the University of Auckland, School of Engineering. The team's design, construction, and monitoring of devices over the last nine years provided data and experience that underpins revised recommendations for bioretention in Auckland.

Sam Blackbourn, a stormwater engineer with Auckland Council, is applying the research in bioretention with industry experience to develop the updated Rain garden design guidelines.

1 INTRODUCTION

In Auckland, the key contaminants in urban stormwater runoff are sediment and heavy metals, including zinc (Zn) and copper (Cu). Suspended and deposited sediments degrade waterways though physical smothering, reducing water clarity and light, and reducing food quality and the feeding efficiency of aquatic fish and invertebrates. Cu and Zn are toxic at low concentrations in the aquatic (but not terrestrial) environment. As both metals persist in the environment, small amounts can accumulate through the food chains and over many years before reaching levels with adverse effects. Surveys of Auckland's estuary sediments show increasing levels of Zn with the highest concentrations in the upper reaches of estuaries receiving runoff from intensely urbanised and/or older industrialised catchments (Miles et al. 2012). Zinc is the metal that most often reached concentrations where adverse effects on benthic ecology would be expected to occur more frequently. Runoff from galvanised steel roofs is probably the major source of Zn entering Auckland's harbours (Timperley et al. 2005; ARC 2004); however, road runoff also contributes Zn and Cu (Depree 2008). Other contaminants from impervious surfaces are elevated temperature (Young et al. 2013 [TR2013/044]) and nutrients. Effects of high temperature discharges are exacerbated in urban streams due to reduced base flows and reduced riparian vegetation. Stormwater is probably a minor <u>direct</u> contributor to nutrient loads in Auckland, as the main source is from sewage entering surface waters from damaged pipes and combined sanitary / stormwater overflows during larger rainfall events (Kelly 2010 [TR2010/021]).

The introduction of Water Sensitive Design (WSD) focuses on managing urban stormwater on-site through small-scale hydrologic controls that aim to mimic the pre-development hydrologic condition of a green-field site, and enhance the hydrologic condition of brown-field sites. Bioretention systems aim to mimic the natural hydrological cycle by slowing and filtering stormwater through biologically active plants and media. At-grade bioretention cells are a popular WSD device also known as a rain garden, biofilter, bioswale or biocell. A bioretention device is a terrestrial device typically placed close to a source of runoff, with an area of 2–10% of a catchment. Devices generally comprise a drainage layer, sand or transition layer, filter media and surface mulch with a dense cover of perennial plants (Figure 1).

The materials used in rain garden media greatly influence its performance and maintenance requirements. Media and mulch can be selected to target site-specific contaminants of concern and match site-specific environmental conditions. Site-specific conditions include drought (plant water stress) or inundation (plant oxygen stress), contaminant loads (both acute and chronic), and maintenance (e.g., inlet and vegetation management, street sweeping). Media and mulch must also help establishment and maintenance of a resilient plant cover that meets specified landscape outcomes. Landscaping and urban design needs can influence the selection of mulch directly (on aesthetic grounds) and indirectly, particularly through rain garden location, connectivity and accessibility to people and vehicles, and inlet design.

This paper summarises two bioretention studies. The first study investigated engineered rain garden media. Experimental results were presented by Simon Wang in NZWWA 2012 conference (Fassman et al. 2012). The complete report is now available online as Auckland Council Technical Report, AC TR 2013/011 (Fassman et al. 2013). The second study investigated rain garden mulches, particularly on identification of non-floating organic mulches. The report is available as AC TR 2013/056 (Simcock and Dando 2013). During the latter study, an extensive range of rain gardens throughout Auckland were visited. Although not part of the research, this provided case studies that demonstrated the influences of urban and landscape design on aspects of rain garden resilience. These influences include the selection of media and mulch as well as inlet design, and rain garden size, depth, and location.

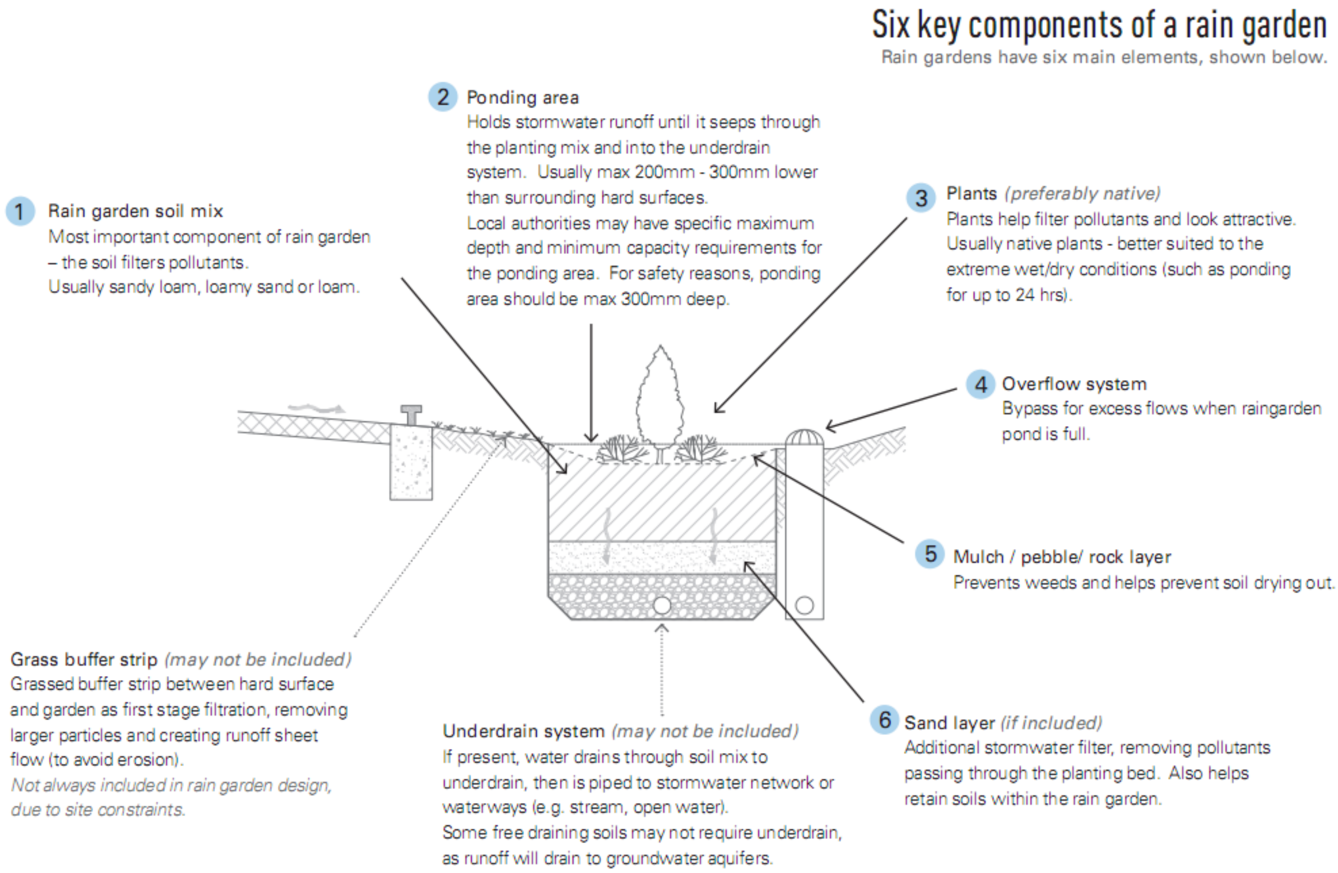

Figure 1: Key components of a bioretention cell (Auckland Council 2011)

2 BIORETENTION MEDIA

The filter media (or fill media) used in bioretention has a major influence on bioretention performance. The current design advice in Auckland for a fill media is to use a "sandy loam, loamy sand, loam, or a loam/sand mix (35–60% sand), with a maximum of 25% clay content" (Auckland Regional Council 2003). Defining the media using a soil textural classification is consistent with other older design guidelines in the United States and United Kingdom (Table 1; Fassman et al. 2013; Carpenter and Hallam 2010).

Auckland, however, has few natural, sandy-textured soils. The creation of sandy-textured bioretention media by adding 30% to over 50% sand to local clay- and silt-textured soils has inconsistent outcomes, as such mixes are vulnerable to compaction and slumping, usually associated with inadequate permeability, inadequate aeration, and poor plant growth, particularly if plants adapted to free-draining media are selected. Some amended local soil mixes have also developed cracks upon drying, increasing the risk of stormwater bypassing this core filtering layer. Newer international guidelines recommend ranges of aggregate particle size distribution (PSD) to use as a screening process to achieve desired hydraulic conductivity, K_s (e.g., FAWB 2009; Seattle Public Utilities 2008) (Table 1). This has increased the use of engineered media, which have some advantages over natural soils. If the individual components of engineered media have high uniformity and known properties, a product with consistent performance can be created.

*Table 1. Recommended Bioretention Media Mixes, worldwide (*Fassman et al. 2013)[1]

Guideline	Aggregate	Organic	Note
TP10 Auckland Regional Council (2003), Waitakere City Council (2004)	Sandy loam, loamy sand, loam, loam/sand mix (35–60% v/v sand)	Not specified	Clay content < 25% v/v
Prince George's County, Maryland (2007)	50–60% v/v sand	20–30% v/v well aged leaf compost, 20–30% v/v topsoil[2]	Clay content < 5% v/v
The SUDS manual (Woods-Ballard et al. 2007)	35–60% v/v sand, 30–50% v/v silt	0–4% v/v organic matter	10–25% v/v clay content
Facility for Advanced Water Biofiltration (FAWB 2009)	Washed, well graded sand with specified PSD band	3% w/w organic material	Clay content < 3% w/w, top 100 mm to be ameliorated with organic matter and fertilizer
Seattle Public Utilities (2008)	60–65% v/v mineral aggregate, PSD limit ("clean sand" with 2–5% passing #200 sieve), U[3] ≥ 4	35–40% v/v fine compost which has > 40% w/w organic matter content	
North Carolina Cooperative Extension Service (Hunt & Lord 2006)	85–88% v/v washed medium sand[4]	3–5% v/v organic matter	8–12% v/v silt and clay
City of Austin (2011)	70–80% v/v concrete sand[5]	20–30% v/v screened bulk topsoil[2]	70–90% sand content, 3–10% clay content, silt and clay content < 27% w/w. Sandy loam ("red death") is not permitted[6]

1. % v/v is percent by volume; % w/w is percent by weight (mass).
2. "Topsoil" is a non-technical term for the upper or outmost layer of soil, however there is no technical standard for topsoil.
3. U, Coefficient of Uniformity = D_{60}/D_{10}, where D_{60} is particle diameter at 60% passing and D_{10} is particle diameter at 10% passing.
4. A specific definition for "medium sand" was not identified. ASTM (2011a) D2487-10 classifies coarse-grained sands as those with $\geq$50% retained on a (USA) No. 200 sieve (75 um) and $\geq$ 50% of coarse fraction passing a No.4 sieve (4.76 mm). Clean sands contain <5% fines. Fine-grained soils are silts and clays whereby > 50% passes a No.200 sieve.
5. Concrete sand is described by ASTMD2487-10 as coarse sand that is retained by a (USA) No. 10 sieve (2.00 mm)
6. "Red death" is a commercially available fill material in Austin marketed as sandy loam.

The following characteristics were assessed when developing an engineered bioretention media or determining the suitability of a natural soil. Fit-for-purpose bioretention media has:

- infiltration rate and permeability that allows water to pond for short periods, but avoids ponding for more than a defined extended period (i.e. minimum permeability)

- permeability that minimizes untreated overflow from water quality volume events and allows adequate contact time with stormwater to achieve pollutant removal (i.e. a maximum permeability). This varies with the target contaminants with contact time for nitrogen removal longer than for phosphorus or zinc

- uniform flow (no preferential flow). This is usually a characteristic of single grained, non-cohesive media displaying no cracking and minimal shrink/swell characteristics

- attenuation of contaminants of concern through favourable chemical characteristics and low baseline concentrations of potential contaminants (i.e. not 'pre-loaded')

- adequate nutrient storage and supply, aeration, moisture storage, and physical support for the selected plants and media depth. Allows plant root extension throughout the media

- structurally stable over the relatively long term without excessive shrinking or structural collapse

- resistant to compaction under a range of moisture conditions (unless physically protected from compaction). Specifically able to achieve the specified permeability under the level of compaction applied at construction.

International guidelines since 2003 give a target range for *long-term* K_s of 12.5 – 150 mm hr^{-1}, corresponding to a 2–24-hr drawdown from ponding depth of 300 mm. The minimum drawdown period must allow plant survival as under saturated conditions air diffusion is slowed and the rate at which the soil becomes anoxic increases. Guidelines for ponding depths are commonly 150–300 mm depth. Ponding depths may be shallower and/or ponding durations shorter in intensely urban areas. The short-term (as installed) saturated K_s may be higher than the long-term range to take account of settling, particulate particle capture, and to maintain adequate conductivity through the period while plants are establishing.

The research assessed combinations of materials readily available in the Auckland region that have consistent physical and chemical properties to satisfy hydraulic and water quality objectives for stormwater management. The investigation process included:

- establishing physical characteristics and performance criteria
- investigating available materials
- PSD testing and identification of individual materials and potential mixes
- compaction assessment
- K_s testing
- chemical analysis

- water quality testing
- plant growth trials.

Multiple, commercially available sands and composts were assessed individually, and then in combinations. The materials and/or products tested were largely selected on the basis of availability at the time of the research. The information presented in the report is not intended to endorse any particular product or company.

The core part of research assessed how candidate bioretention filter materials reacted to different mixing and compaction treatments, and how their performance compared to criteria established from literature review. Two key K_s and compaction methods used in the physical testing of potential media are described below. These methods are recommended for future development and screening of rain garden media, followed by monitoring of field-scale bioretention installations.

K_s testing did not use ASTM (standard) K_s test methods as they use miniature permeameters that measure K_s from small-scale sample cores. Instead, the research used a larger set-up with 600 mm media depth (for most treatments), 140 mm internal diameter, and 220 mm ponding depth (the height - over which falling head was measured). This was chosen to mimic more closely a field bioretention system, including the construction and compaction phase. The test set-up isolated the filter media; mulch layer, transition layer and drainage layer were not included.

Compaction was achieved either by wetting each layer or by light tamping. Wetting compaction used water to promote settling. For each 300 mm lift, water was applied from the top of the column to a condition when ponding occurred and effluent flow was visually relatively constant. No mechanical action was imposed. Light tamping aimed to replicate field compaction practices using a repeatable method. Light tamping is the recommended method used to install rain garden media in Auckland (Healy et al. 2010, TR2010/052). The compacted density of a local bioretention cell with known medium was measured (Torbati 2010). This density was achieved for the same media by 15 blows of a modified proctor hammer (2700 kN-m/m^3 force or 4.5 kg falling through 457 mm) on each 300 mm lift.

Five candidate media from the PSD and K_s tests were selected for water quality testing. Water-quality tests were indicative of the relative pollutant removal ability of media (rather than considered representative of field performance), and also helped understand how pollutants were attenuated (or not). The selected media were two commercial mixes with light tamping compaction and three 90% v/v sand-based mixes (East Coast Sand [all passing 0.425 mm], Woodhill Sand [all passing 0.425 mm], and Pumice Sand [all passing 2 mm]). Each sand was individually blended with 10% v/v bark-based compost and compacted using wetting. The two different compaction methods were applied to achieve approximately the K_s identified as providing adequate contact (or retention) time.

Water-quality testing combined simulated water-quality storms with concentrated dosing to accelerate media aging in laboratory columns. Plants were absent. Filter media performance was quantified after 0, 5, 10, and 15 'years' of stormwater loading. Testing focused on dissolved Zn, Cu, and phosphorus (P). Dissolved contaminants are more difficult to remove in many treatment devices, and are also often the bioavailable fraction of the total contaminant (thus driving impacts on aquatic organisms).

2.1 MEDIA PERFORMANCE RESULTS

The 12.5 to 150 mm/hr K_s target range could not be achieved in the *short term* (i.e. post-mixing and compaction) using internationally recommended PSD guidelines and available aggregates. The sand that best satisfied PSD criteria had permeability that was likely too high to provide adequate contact time for broad pollutant removal. Three finer sands showed the greatest potential to satisfy the K_s criteria despite being >150 mm/hr: East Coast Sand, Woodhill Sand, and Pumice Sand. Relatively high Ks values were considered acceptable as K_s has been shown to decline by a factor of 2 to 4 times in both medium-term (>6 months) laboratory trials and field installations (Le Coustumer et al. 2009, 2012; Hatt et al. 2009). East Coast Sand and Woodhill Sand did not fit within PSD guidelines. Two commercially available bioretention media achieved target hydraulic conductivities with light tamping compaction of 300-mm deep-lifts.

Compaction testing showed water content is an important property to consider when installing filter media with appreciable volumes of compost. Different water contents produced significantly different densities of media under the same compactive effort. Compacted densities for media with a high proportion of compost changed by up to 26% under the same compactive effort as water content increased. This elevated density reduced infiltration rates by a factor of four. The density–infiltration rate relationship is unique to individual media. East Coast Sand and Woodhill Sand without organic content were insensitive to changes in water content; and mixes with c. 10% v/v of compost were less sensitive than those with higher proportions of compost. Testing also showed the K_s of mixes with c. 10% v/v organic matter were similar, whether compacted by light tamping or wetting and settling.

Chemical analyses of the commercial media, composts, and sands were used to indicate the potential for pollutant removal and support for plant growth. Both commercial bioretention mixes had very high levels of P, including plant-available and organic P. Four out of five media reduced P when exposed to high P concentrations; however, when exposed to low P concentrations, they instead leached P. High P concentrations may cause other ions to be displaced from media anion sites, making anion sites available for P ion adsorption. This displacement may not occur with low concentrations of P. All tested media contained at least 10% v/v organic matter as compost, and all media demonstrated some potential for P leaching. P leaching should be further investigated, preferably including field studies with plant cover, before media are considered for implementation in P-sensitive receiving environments.

Results indicate the three sand-based mixes are capable of removing dissolved Cu and Zn in synthetic stormwater to less than 5 µg/L and 10 µg/L. Mass loads were estimated to be reduced by approximately 60% and 70% respectively over a simulated 15 years. Commercial Mixes similarly reduced mass loads of Zn by about 50%. One commercial mix displayed initial Cu leaching and an estimated overall contribution of Cu. However, results from the 15-year simulations are only indicative. Under field conditions metals are present in both dissolved and solid form, and at lower concentrations. Cu mobility in particular is influenced by wetting and drying cycles, and biological activity exerted through plant uptake, biofilms, and fungal activity.

The addition of compost in 90% sand: 10% compost mixes was important to increase cation exchange capacity (CEC), given the near-absence of a clay and silt component (while attempting to adhere to PSD criteria). CEC provides cation storage (positively charged nutrients and metals). This buffers sudden changes in pore water chemistry, as can occur with spills, alkaline detergents or fertilisation. Sand physically stabilizes the system, providing resilience to compaction and a stable hydraulic performance that maintains an adequate water retention time for the organic component to attenuate chemical pollutants. The sands maintain uniform flow, providing a non-degrading physical filtration of contaminants attached to sediment. They also provide adequate aeration to support plant growth. In addition, two of the sands had mineralogies that promoted metal attenuation: the East Coast sand contained a significant shell fraction (calcium), while the pumice had some inherent Anion Removal Capacity provided by low levels of carbon (naturally in the deposit). Volcanic materials such as scoria, and pumice from sources with significant iron and aluminium oxides have potential for naturally enhanced Anion attenuation.

Two plant species were each planted in two of the sand-based media and one commercial mix for replicated plant growth trials. Biomass accumulation and vigour *Carex secta* (wet tolerant sedge) and *Austrofestuca littoralis* (drought tolerant tussock) were measured after 6 months of growth in three bioretention mixes: East Coast Sand + 10% v/v bark-based compost, Pumice Sand + 10% bark-based compost and a commercial mix. Under an as-needed watering regime, plant species grew satisfactorily in all bioretention mixes. Grasses and herbs germinated on all bioretention mixes.

The Pumice Sand mix (containing low compost) and both commercial mixes (containing a high proportion of compost) stored similar volumes of plant-available water as measured at 10–1500 kPa tension. This was more than double the plant-available water of the (non-vesicular) East Coast sand, which (like most sands) does not have significant internal porosity that can store water. At an installed media depth of 600 mm, approximately 120–144 mm of water per bioretention cell unit surface area could be stored by the media tested, whereas at 1000 mm media depth, 200–240 mm per unit surface area could be stored.

2.2 MEDIA STUDY RECOMMENDATIONS

None of the media mixes tested completely satisfied the initial objectives; however, sand-based, low organic-matter bioretention mixes appeared to provide substantial attenuation of heavy metal while enabling plant establishment. Of the 90% sand, 10% v/v sand mixes had low levels of nitrogen likely to lead to slow plant growth in the short term if mulches that remove nitrogen are used. Nitrogen stress could occur in the medium term where stormwater has very low nitrogen loads or high demand for nitrogen from vegetation (trees). Sand-based bioretention mixes should be tested in the field in combination with different mulches, to quantify N and P behaviour and establish medium-term K_s (i.e. after the establishment period). Further laboratory work (also followed by field testing), likely including investigation of amendments, should address phosphorus retention and release. Rain gardens in droughty areas or shallow rain gardens may benefit from the additional plant-available water provided by pumice sand and higher organic matter levels.

The media used for bioretention has an important role in water-quality treatment, water attenuation, and supporting associated vegetation. The draft Auckland Council Bioretention Design Guide requires rain garden media to conform to the requirements given in Table 2, and discusses how these values were selected.

Table 2. Rain garden media specifications

Item	**Requirement**
K_s	Between 50 mm hr^{-1} and 300 mm hr^{-1}

Item	Requirement
PSD	100% < 25 mm, 90–100% < 10 mm, < 5% < 0.05 mm
Plant available water[1]	>100 mm
Moisture	30–50%
Organic matter	10–30%
pH range	5.5 – 7.5
Electrical Conductivity	< 2.5 dS m^{-1}
Total Nitrogen	< 1,000 mg kg^{-1}
Orthophosphate (PO43-)	< 80 mg kg^{-1}
Total phosphorus	Leachate testing required if > 100 mg kg^{-1}
Total Copper	≤ 80 mg kg^{-1}
Total Zinc	≤ 200 mg kg^{-1}

[1] Plant available water is a measure of water held in soil between matric potentials of -10 kPa (nominal field capacity) and -1500 kPa (nominal wilting point), representing the water a soil can store for plant growth (McLaren and Cameron 1996). It is not discussed further in this paper.

Examples of media that have been tested to comply with this specification include 90% v/v East Coast sand or Pumice sand with 10% v/v bark-based compost mix. This specification has achieved target K_s regardless of moisture content at installation, under either light tamping or water settling compaction levels. Note that other media can be used, including commercial products, provided that they have been tested to comply with the specifications in Table 2.

Photograph 1: Auckland bioretention devices, from left to right: Waitakere Civic Centre rain gardens; Albany Town Centre tree pits; East Auckland bioswale.

3 BIORETENTION MULCH

Many rain garden and bioretention construction guides specify the placement of a mulch layer over the surface of bioretention devices for three reasons: to supress weed growth; to enhance plant moisture supply and; to reduce the risk of short-term sealing, crusting or clogging of the media. Suppression of weed establishment reduces the maintenance required to control weed competition with selected plants and retain desirable aesthetics. Enhancing the water available for rain garden plants is particularly important during establishment when plants have small root systems, and when rain gardens are planted in summer. Sealing and crusting slows the rate of infiltration into rain garden substrate. Sealing may be caused by breakdown of rain garden substrate, and/or deposition of fine sediments. Mulches used in rain gardens must not float, as this can expose or erode the underlying media, block overflows, and contaminate receiving waters.

Some mulches also contribute to removal or buffering chemical contaminants. The absorption, microbial processing, and filtration processes depicted by Brix (1993) (Figure 2) as occurring in rain garden media, also occur to some extent in the mulch layers. Hence mulches may extend the life of a rain garden. Mulches may also influence attenuation of nitrogen and phosphorus. Organic mulches with low N contents and slow decay rates tend to immobilise N in the short to medium term. In contrast, mulches with high N or P contents and rapid decomposition rates such as lawn clippings should not be used in bioretention (Hinman 2007; Woods-Ballard et al. 2007). Some mulches cushion the rain garden surface from compaction. Elastic mulches, i.e. those that bounce back from compactive forces, are most effective. Many organic mulches are elastic, particularly stringy organic mulches. Elasticity is important if rain gardens are planted when the media are wet and hence highly vulnerable to compaction.

A report has been prepared for Auckland Council on non-floating mulches (Simcock and Dando 2013). This report reviewed bioretention mulches used in New Zealand and overseas. The potential of mulches to float was measured, and characteristics of organic mulches that confer a low potential to float were identified. The chemistry of a limited range of mulches was quantified. Based on this report, three types of mulches are recommended for use in rain gardens, and methods of minimising the risk of floating mulches were identified.

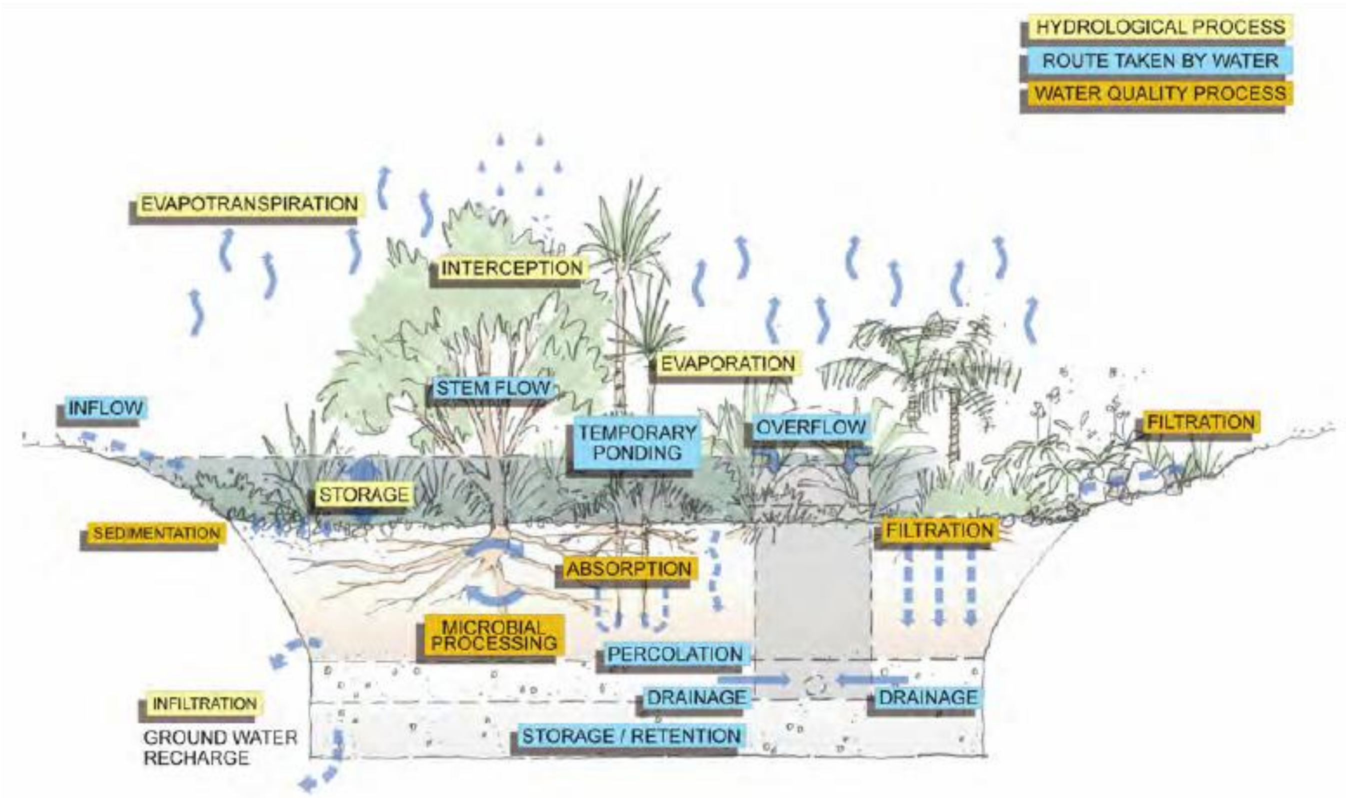

Figure 2: The processes attenuating stormwater volume and quality that occur in a rain garden (Brix 1993).

3.1 MULCHES INVESTIGATED

A wide range of organic and inorganic mulches are available in Auckland. Organic mulches are based on radiata pine bark, fresh green waste or wood waste. Radiata pine bark is a by-product from the plantation forestry industry. It is salvaged from timber processing plants and log marshalling areas. Pine bark is used composted, shredded, ground or sieved to various sizes, shapes, and grades to create high-quality composts for growing media. It may either be ground and sieved to create even-sized decorative bark 'nuggets' for landscaping, or minimally processed and used to supress weeds over large areas of landscape (so-called 'cambium bark'). Green waste can be divided into soil, weed, and contaminant-free, arborist (tree) prunings, and 'yard' waste. Both arborist mulch and yard waste are converted into a range of products using composting and sieving. Wood chip, known as 'Reharvest', is manufactured from recycled, untreated wood waste such as packing cases. Arborist mulches with low leaf contents can have properties similar to Reharvest wood chip. Two organic mulches have been commercially produced as non-floating mulches for rain gardens. One is based on Reharvest, the other on composted, shredded arborist mulch. Non-floating, shredded, bark-based mulch was identified in Palmerston North but an equivalent product could not be sourced in Auckland. The fine, stringy organic mulches based on fibrous tree barks (e.g. redwood) or long pine needles used in USA rain gardens are not currently available in Auckland.

Table 3: Potential mulches for use in rain gardens and rationale for including in, or excluding from, testing

Mulch	Rationale for testing
Arborist Mulch (fresh)	Widely available, low cost, and the base of many composts. Floats without pre-soaking. Highly variable when produced in small volumes, depending on leaf: wood ratio and plant species. When made from garden waste it can contain soil, plastic, and noxious plants. Tree mulch may include weed seeds (e.g. privet and acacia).
Arborist mulch (part-composted)	The degree of composting is variable. Resistance to floating increases with composting as material becomes denser and absorbs water.
Arborist mulch & compost	Not commercially available at small-scale retail. Retains the potential to introduce weeds depending on source material.
Bark nugget 20 mm	Not suitable for rain gardens. Included because this product is widely used (by mistake), and because it provides an upper boundary for float tests.
Double-shredded Bark	This is the closest to United States triple-shredded mulch[1]. Triple-shredded mulch has been made in Auckland in the past. Small piece size and thin shape is influenced by the moisture content of the bark or wood and method of shredding (Ted Yates, pers. comm.)
Double-Shredded Bark & Compost	Not commercially available in Auckland. Tested as potential non-floating mulch using 20% v/v compost.
Shredded Bark & Compost	Product similar to non-floating, shredded, arborist mulch processed in Vertical Composting Units (VCU) successfully used on rain gardens at Paul Matthews Road and Waitakere Civic Centre in 2006 and 2007. This product was sourced from Palmerston North (the Henderson plant is closed).
Reharvest (Black)	Variable particle-size and shape depending on producer and location in stockpile (for bagged product). A variety of dyes are used with a range of colourfastness. Iron oxides have previously been used to colour the mulch, but not in Auckland; some are vegetable dyes (Ted Yates, pers. comm.).
Reharvest (Black) & Compost	Commercial product identified as being non-floating and suitable for rain gardens.
Crushed Shell	Shell probably has lower thermal mass and higher reflectivity (where white) than dark-coloured stone so may be a more favourable option where heat may damage near-surface roots and inorganic mulch is wanted.
Crushed Waste Shell	Crushed, processed, waste mussel shell. Trials have shown crushed mussel shells from processing plants increase pH and decrease soluble metals in stormwater; Product chemically tested but not included in float testing because it smelt 'rotten' so could not be used on a rain garden surface.
Limestone chip	Limestone has been shown to have a beneficial impact on acidic stormwater by raising pH until a rind forms on the limestone.
Other inorganic mulches, Not tested	Non-reactive or weakly reactive mulches include all the main pebble and stone mulches used in rain gardens and bioretention devices, and recycled glass.

[1] triple-shredded mulch is the dominant mulch specified for raingarden in the United States. This is a fine, fibrous mulch manufactured from specific tree species that forms interlocking fibres.

3.2 MEASURING THE POTENTIAL FOR MULCHES TO FLOAT

A representative range of organic and inorganic mulches were tested for floating. Floating was quantified at moisture contents ranging from air dry to 'maximum moisture content'. Maximum moisture content was achieved by three cycles of saturation and drainage over 3 consecutive days. It was designed to simulate rain garden ponding and drainage. Two factors control the potential of mulch to float. The most important of these is moist bulk density. The second is the extent to which particles bind or knit. Inorganic mulches such as shell and limestone chip do not float as they have dry bulk densities of around 1000 kgm^{-3}. Particle shape does not impact their floating performance. In contrast, all organic mulches had oven-dry bulk densities less than 260 gm^{-3} and had a high propensity to float when at air-dry moisture contents. Air-dry bulk densities varied from 210 to 320 kgm^{-3}. When organic materials were wetted, the proportion of floating material dropped to between 0.3 and 8% v/v, which made them suitable for use in rain gardens. When most organic mulches were at maximum moisture content, bulk densities increased to over 520 kgm^{-3}, a 'tipping point' (Figure 3). The exception was 20 mm decorative bark nuggets. About 20% v/v of decorative bark nuggets floated at the maximum moisture content. These nuggets absorb water slowly and their round shape means they bind poorly. Bark nuggets are therefore unsuitable for use in rain gardens.

Two organic products did not appreciably float at lower moisture contents. Shredded-composted bark product with added compost was the only organic product that did not appreciably float (0.4% v/v floating) at an 'as delivered' moisture content, giving a wet bulk density of 510 kgm^{-3}. Commercially available Reharvest wood chip with 25% v/v added compost was also highly resistant to floating after minimal wetting (wet bulk density 520 kgm^{-3}) achieved by 3 hours of irrigation (Figure 3). A lower rate of irrigation was not trialled.

The ability of organic mulch to absorb water is linked to the extent of decomposition or composting, and the type and particle size. Absorbance varies with the organic source. Arborist mulch and wood chip absorb water more readily than coarse pine barks. More decomposed mulches, or those containing a significant proportion (20–25%v/v) of decomposed material (such as compost) are less prone to floating when moist because they are heavier. Composted materials take longer to dry than uncomposted materials. This means they stay within a 'non-floating bulk density' in the field for longer. Field observations indicate the risk of an organic mulch floating is greatest in the first few storms after spreading. This is consistent with a relatively rapid increase in mulch bulk density due to both an increase in moisture content and, for finer materials with lower C: N ratios (such as arborist mulch), to decomposition. The rate at which organic mulches dry should be slower when pore spaces are smaller and less continuous. Finer mulch and mulch with an even spread of particle sizes (allowing packing or compression) are therefore likely to be more resilient to floating than coarse or uniformly sized mulches.

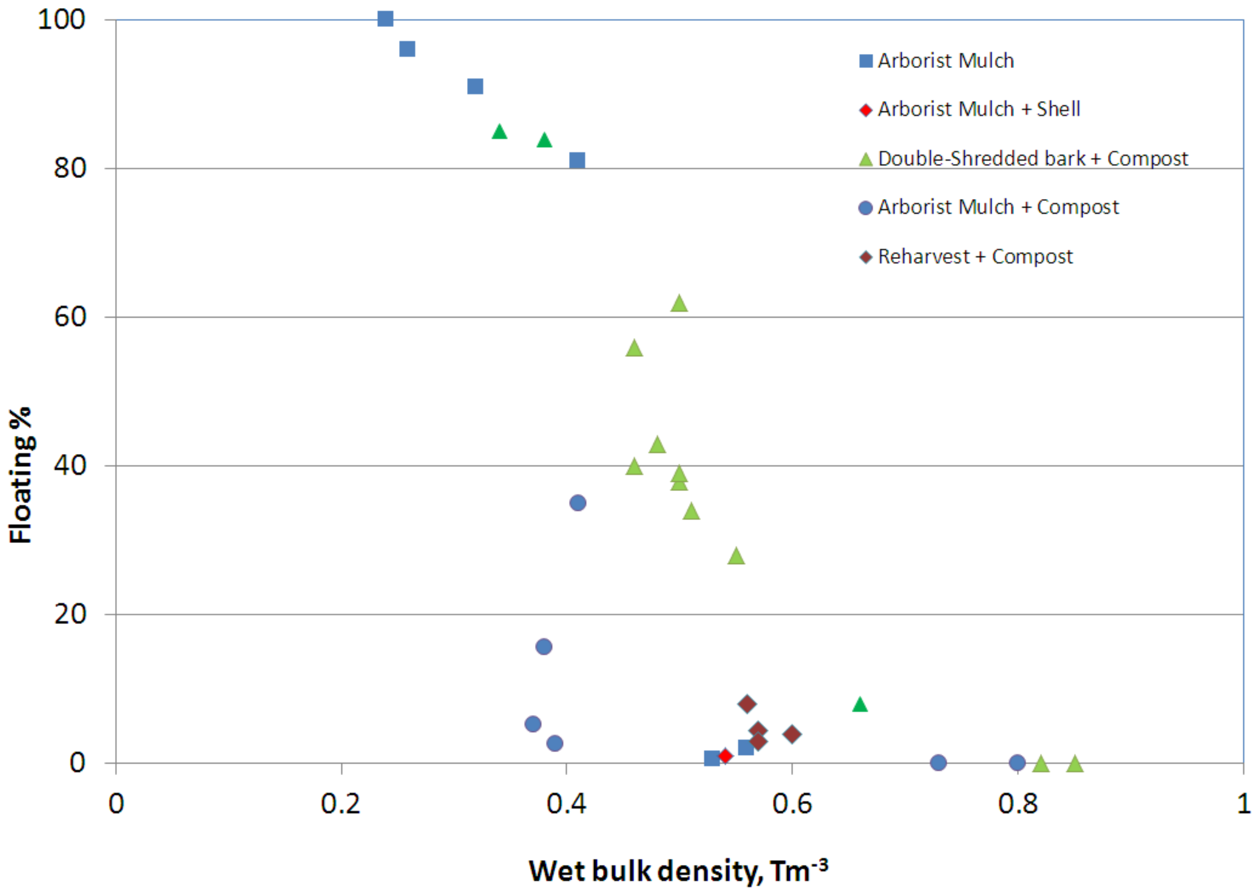

Figure 3: Wet bulk density and flotation (%) of potential 'non-floating' bioretention mulches and un-amended arborist mulch (Simcock and Dando 2013).

3.3 MULCH RECOMMENDATIONS: METHODS TO SUPRESS ORGANIC MULCH FLOATING

Three methods can be used to supress floating of organic mulches.

First, 25%v/v crushed shell or compost can be added. Adding 25% crushed shell to arborist mulch prevented floating. However, evenly mixing shell through the organic mulch by hand took time. Also, over time the shell appeared to settle to a greater degree than the arborist mulch. This may increase the risk of floating material in the short term if the arborist mulch is slow to wet to an adequate bulk density. It may be as cost-effective to spread a thin sheet of shell (or other heavy inorganic material) over organic mulch rather than blend the products. Adding shell to organic mulch, particularly the more acidic bark mulches, is also likely to enhance the mitigation of contaminants such as metals. Many composts, particularly less-mature composts manufactured from greenwaste, contain substantial available N and P. Where a 70 mm depth of mulch is applied to a sand-based mulch, this is unlikely to leach beyond the root zone; however, if the raingarden media already has high levels of N or P leaching will be exacerbated.

Adding 25% v/v compost to either Reharvest wood chip or Arborist mulch and irrigating for six hours reduced the proportion of floating mulch to between 4 and 9% v/v. The primary mechanism that reduces floating is increased wet bulk density. The rate at which the compost component wetted also appeared to increase. Adding compost to double shredded bark was not consistently effective at significantly reducing floating.

Both 3 and 6 hours wetting of both bark/compost mixes was not long enough to prevent an unacceptable 50% v/v of the material floating. This appeared to be because the architecture of the bark creates large gaps into which compost is washed away from the surface. It is therefore likely that much finer shredded barks would be a more suitable base material. Part-composted bark mulches are also likely to be more effective, as they have higher initial moisture content, wet up more quickly and achieve a higher wet density.

Second, mulches can be composted to a level that increases the wet bulk density and speed of wetting. The impact of a higher proportion of fines, from either adding compost or breakdown during composting process on the effectiveness of weed suppression was not quantified. However, adding compost or using part composted material enhances the N and P levels. In moderate amounts this helps avoid plant N stress, which can temporarily impact plant growth as organic mulches with low N concentrations decompose. N stress is most likely if rain garden media has low organic matter content. High levels of N or P, or added P should be avoided, as it will increase risk of N leaching.

Table 4: Summary of properties of six mulches suitable for bioretention cells, F = organic fines (compost) (Simcock and Dando 2013)

Mulch Property **+ = positive outcome** **o = neutral outcome** **-- = negative outcome**	**Shredded Bark + Fines** note 6	**Wood chip, Reharvest + Fines** note 6	**Arborist Mulch + Fines** note 6	**Crush Shell**	**Lime, scoria**	**Inert gravel, glass**
Do not contribute floating material Result depends on moisture content and % fines for organic materials (+ when wet, - when dry)	-- to +	-- to +	-- to +	+	+	+
Supress weed growth to decrease maintenance and enhance aesthetics	Dependant largely on depth & piece size of mulch, and weeds present – 30–80 mm adequate					
Maintain infiltration rate into soil by reducing crusting, avoiding surface degradation or blocking by sediment	+	+	+	+	+	+
reducing runoff by absorbing rain note 1	+	+	++	o	o	o
cushioning against soil compaction	++	++	+	o to +	o	o
Feed plants – short /long term	-	-	+ note 2	o to +	-	-
Conserve moisture and reduce soil surface temperatures	++	++	++	+	+	- to +
Absorb, immobilise or buffer contaminants: (filter, pH-precipitate, chemically bind)	++	++	++	+ to ++	+	-

Do not contribute excess/bioavailable chemical or biological contaminants Cu, Zn, pathogens	+	+ Colour?	+	- to +	+	+
Ease of spreading	+ to – note 3	++	++	+	+	+
Longevity (>12 months) influenced by piece size for organic mulches	++/+	+ note 4	-	++	++	++
Consistency of product note 5	+	+	-	++	++	++

[1] absorbing water allows higher infiltration, surface evaporation and plant-available water

[2] variable P and Cu (P can act as a chemical binder); N depends on C: N and activity of microorganisms

[3] depending on the piece size; coarse bark with long pieces is very hard to spread finely

[4] Long-life Reharvest products may be available

[5] Arborist mulch may be consistent within a specific location or source, but is highly variable across different sources, and may vary seasonally where deciduous vegetation is dominant

[6]+F = plus organic fines, achieved by back-blending composted (weed free, stabilised) material

Third, create mulch particles that physically bind together. Physical interlocking appeared to improve resistance to floating when organic mulches were at marginal bulk densities. Thinner, stringy, particle shapes bind more effectively than short, rounded, particle shapes, so the bulk density of the overall mulch, rather than individual pieces, determines the extent of floating. Stringy mulches can be achieved by managing the shredding process with expert knowledge of existing mulch feedstock moisture, density, and shredder characteristics. As the rain garden market grows, industry may explore feedstocks from timber mills that process redwoods and suitable eucalyptus species that have intrinsic ‘stringy’ qualities used successfully by overseas agencies.

If the binding of light mulches is disrupted, for example, around high-energy rain garden inflows, sections of mulch may be broken away and float. Thinner, smaller shapes are also more likely to compress or compact over time, increasing resistance to scouring and floating. However mulches must maintain a higher permeability than the underlying rain garden media. Physical locking is important for rain gardens and bioswales in which significant horizontal water flows (energy) occur. In these situations an inorganic mulch or erosion fabric would be specified. Mulches bind best to a rough underlying surface. Crimping, in which long-fibred mulches are pressed into the surface in a herringbone pattern, is another method of binding mulches to an underlying surface.

Results were presented and discussed at a meeting with three mulch manufacturers. Manufacturers commented on limitations imposed by the small volumes of mulches currently used by the bioretention industry. Small volumes minimise product investment and availability. Given the relatively small volumes of organic mulches currently used in rain gardens, this research indicates the most cost-effective way to achieve consistent, non-floating mulches is to add either 20–25% v/v compost or crushed shell to Reharvest, to weed-free arborist mulch or to suitable fine bark, and ensure the mulches are wetted after installation. Adding fines or compost to consistent-quality mulch is more likely to achieve a consistent outcome than attempting to compost to a specified density. Manufacturers indicated that specification based on the existing NZ4454 (Compost New Zealand 2005) or AS4454 (Australian Standard 2012) standard for mulches would be more practical than a specific standard for rain gardens. This may prevent use of suitable but non-composted materials such as arborist mulch.

All tested mulches conformed to the NZ4454 Compost standards for Cu and Zn; however, the lower Cu standard of 100 mg/kg for Grade A Biosolids is probably more suitable, given rain gardens receive more than background levels of Cu and Zn (when receiving runoff from roads or copper roofing material) and are designed to reduce the concentration of contaminants in discharged stormwater.

In addition to specifying non-floating mulches, this survey identified three additional practices or guidelines to reduce the risk of floating mulches:

- Thoroughly wet organic mulches at installation. As plant establishment is improved by an initial irrigation, this should be a routine procedure
- Design rain gardens to receive sheet flow, or provide energy dissipation for areas of concentrated flow to avoid separation and disaggregation of mulches
- Ensure a dense cover of plants is achieved within 24 months so re-mulching is unnecessary. This reduces the risk of decorative bark being used to fill gaps between plants and of over-mulching, which reduced rain garden ponding depth.

Photograph 2: Non-floating organic mulch placed over the bulk of a rain garden and stone mulch used in areas around stormwater inflow points, North Shore

3.4 MULCH STUDY CONCLUSIONS

Rain garden mulches can achieve a variety of functions that enhance the performance and aesthetics of rain gardens, and are vital to minimise both the risk of surface sealing (inadequate infiltration rates) and the maintenance costs associated with weeding. Use of mulches increases the moisture available to plants, aiding establishment in dry areas and seasons, if the media are thoroughly wetted. Inorganic and organic mulches are available that will achieve these functions with nil to minimal floating. This reduces the associated risk of overflow blockage or surface water contamination. Mulches can also be chosen to enhance resilience to compaction and attenuation of contaminants. Refer to the non-floating mulches report for more details on mulches suitable for use in rain gardens (Simcock and Dando 2013).

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