STREET-SCALE BIORETENTION – PRACTICAL LESSONS LEARNT FROM APPLICATIONS IN CHRISTCHURCH

P. Christensen (CTN Consulting Ltd), Christchurch, New Zealand
M. Stone (Aurecon NZ Ltd), Christchurch, New Zealand
P. Wehrmann (Christchurch City Council), Christchurch, New Zealand

---

ABSTRACT

Improving water quality is a key issue for Christchurch. However, there are a number of challenges to meeting the desired outcome of healthy waterways. Bioretention offers a small footprint means to retrofit stormwater treatment into the urban area, and the rebuild following the Canterbury Earthquake Sequence offered an opportunity to install a number of rain gardens and stormwater tree pits (primarily a type termed 'passive irrigation tree pits'), and passively irrigated landscape areas. Bioretention devices such as these are relatively new to Christchurch, and Christchurch City Council developed design guidelines to assist in a consistent design approach.

Over the last few years a significant number of rain gardens and passive irrigation tree pits have been constructed or are currently under construction throughout the city both within the Council road reserve and private redevelopment projects as part of the earthquake recovery.

This paper provides a number of examples of rain gardens and passive irrigation tree pits installations across the city. These examples provide an opportunity to see what has worked well, what issues have been encountered, and potential changes to the current design guidelines that could be considered for future designs if required.

In general the Christchurch experience with bioretention devices has been positive, with many positive outcomes noted throughout the case studies. However, there is opportunity for further improvement throughout the entire design, construction and maintenance cycle.

Keywords

Bioretention, rain gardens, tree pits, construction, maintenance, stormwater treatment

PRESENTER PROFILE

Peter Christensen is a Surface Water Engineer with CTN Consulting Ltd and is based in Christchurch. He has a wide range of experience in surface drainage issues, including surface water modelling, stormwater treatment design and floodplain management.

1 INTRODUCTION

Improving water quality is a key issue for Christchurch. However, there are a number of challenges to meeting the desired outcome of healthy waterways. Bioretention offers a small footprint means to retrofit stormwater treatment into the urban area, and the rebuild following the Canterbury Earthquake Sequence (‘earthquakes’) offered an opportunity to install a number of rain gardens and stormwater tree pits (primarily a type termed ‘passive irrigation tree pits’). Bioretention devices such as these are relatively new to Christchurch, and Christchurch City Council (CCC) developed design guidelines to assist in a consistent design approach (CCC, 2015).

Over the last few years a significant number of rain gardens and passive irrigation tree pits have been constructed or are currently under construction throughout the city both within the Council road reserve and private redevelopment projects as part of the earthquake recovery.

In general the Christchurch experience with bioretention devices has been positive, with many positive outcomes noted throughout the case studies. However, there is opportunity for further improvement throughout the entire design, construction and maintenance cycle.

A number of design enhancements have been identified. These include things such as taking more care in identifying suitable sites (for instance due to groundwater constraints); improving inlets to ensure flows reach the device (particularly for passive irrigation tree pits); avoiding the use of resin bound aggregate; and media selection.

Although many aspects of the devices have been constructed well there are a number of areas identified which can be improved on, including items such as keeping runoff from the devices until the surrounding area is stabilised; adequate scarification of the sub-base; more attention to inlet detailing (e.g. ensuring design fall is included); and ensuring the device is not overfilled with mulch to allow for sufficient ponding volume.

Maintenance of bioretention devices is important, and as these devices are comparatively new in Christchurch some issues are arising. These include: inlets to passive irrigation tree pits have been blocking due to high sediment loads; litter not being removed; and no means to clean blinded resin bound aggregate.

This paper starts with some examples of where street-scale bioretention devices have been installed in Christchurch, highlighting the benefits offered. Following this design, construction and maintenance issues are each discussed using examples noticed around central Christchurch. The intention is to share knowledge about some of the practical issues encountered to ensure that future practice is improved.

2 A CHANGING STREETSCAPE

The impact of the earthquakes has resulted in significant rebuilding within Christchurch, and this extends to the streetscape as well. When the CCC asked people after the earthquakes to present their ideas about the central city recovery, there were more than 100,000 ideas shared. Advice also came from professional institutes, interest groups and community organisations. Out of all the ideas shared five key themes emerged, one of which was a ‘green city’.

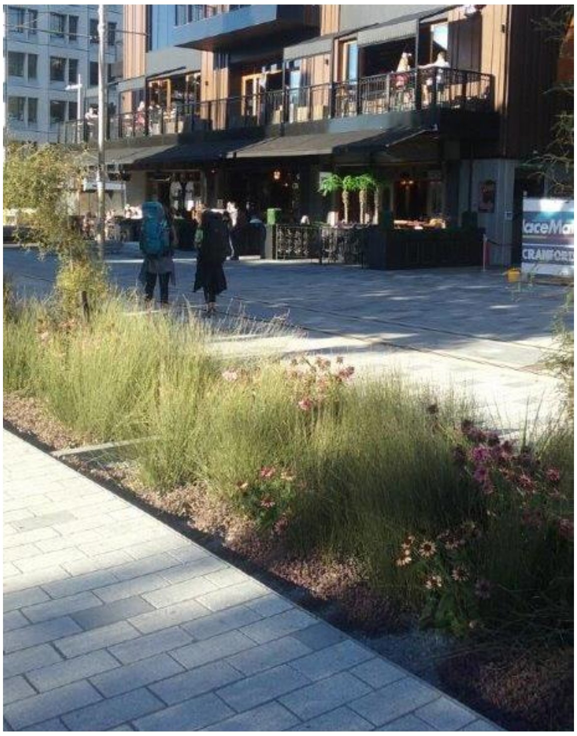
Two key aspirations noted under this theme were:

- New street trees, improved surface stormwater treatment and a new network of parks that encourage outdoor activities; and
- A greener, more attractive central Christchurch, which includes measures against climate change.

A number of projects throughout the city have sought to implement this vision resulting in bioretention devices being incorporated in a number of locations. This has had a positive impact on the streetscape through increased greenery while also providing treatment to previously untreated stormwater discharges. Some examples are shown below.

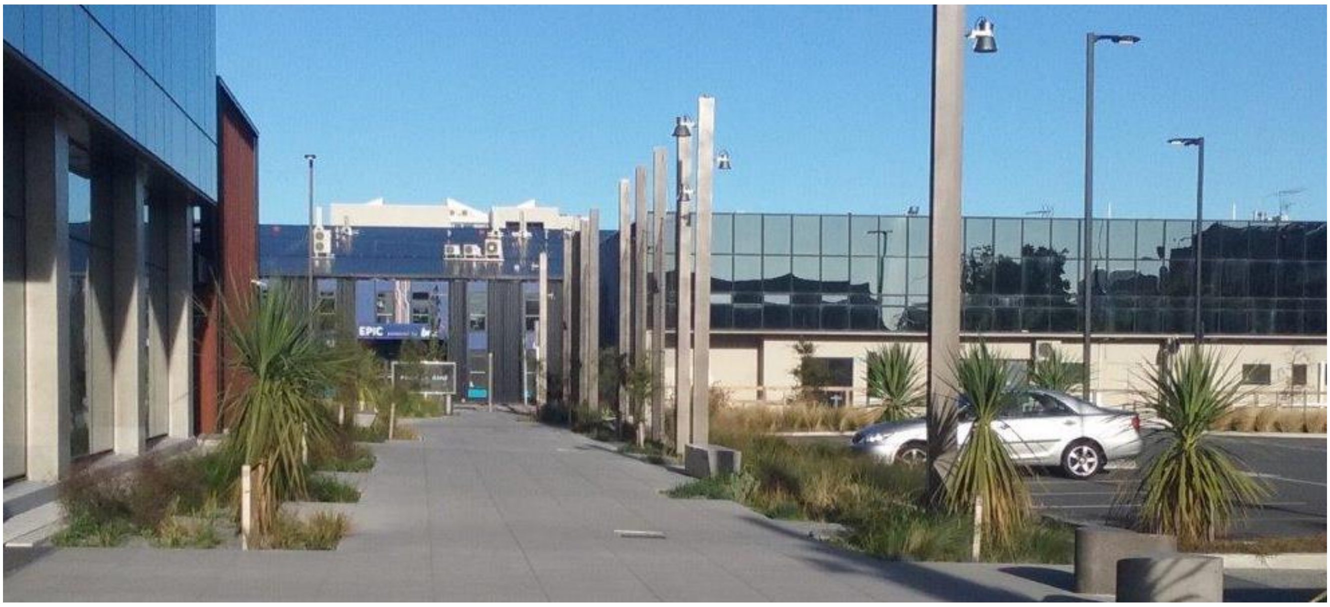
The Avon River Precinct (Figure 1) was one of the first projects to be completed with bioretention devices included. Located in a high traffic pedestrian mall environment, they were found to be less expensive than the surrounding pavement. They provide a linear strip of greenery while also providing treatment to the surrounding hardstand.

Figure 1: Avon River Precinct (Oxford Terrace, Christchurch)



The South Frame (partially completed) includes a Greenway (Figure 2) as a pedestrian and cycling corridor with distinctive gardens along the entire east-west length of the project. Bioretention devices will be included over the length of the greenway, along with other green infrastructure such as green walls.

Figure 2: South Frame Greenway (Between Tuam and St Asaph Streets, Christchurch)



The An Accessible City project comprises a number Central City transport projects where streets will be prioritised for different forms of transport to provide safer and more efficient ways for motorists, pedestrians, cyclists and public transport users to move around the city. The Durham Street / Cambridge Terrace (Figure 3) and Manchester Street (Figure 4) transport corridors are one of the first projects in Christchurch to retrofit street-scale bioretention devices into the public realm.

Figure 3: An Accessible City (Cambridge Terrace, Christchurch)

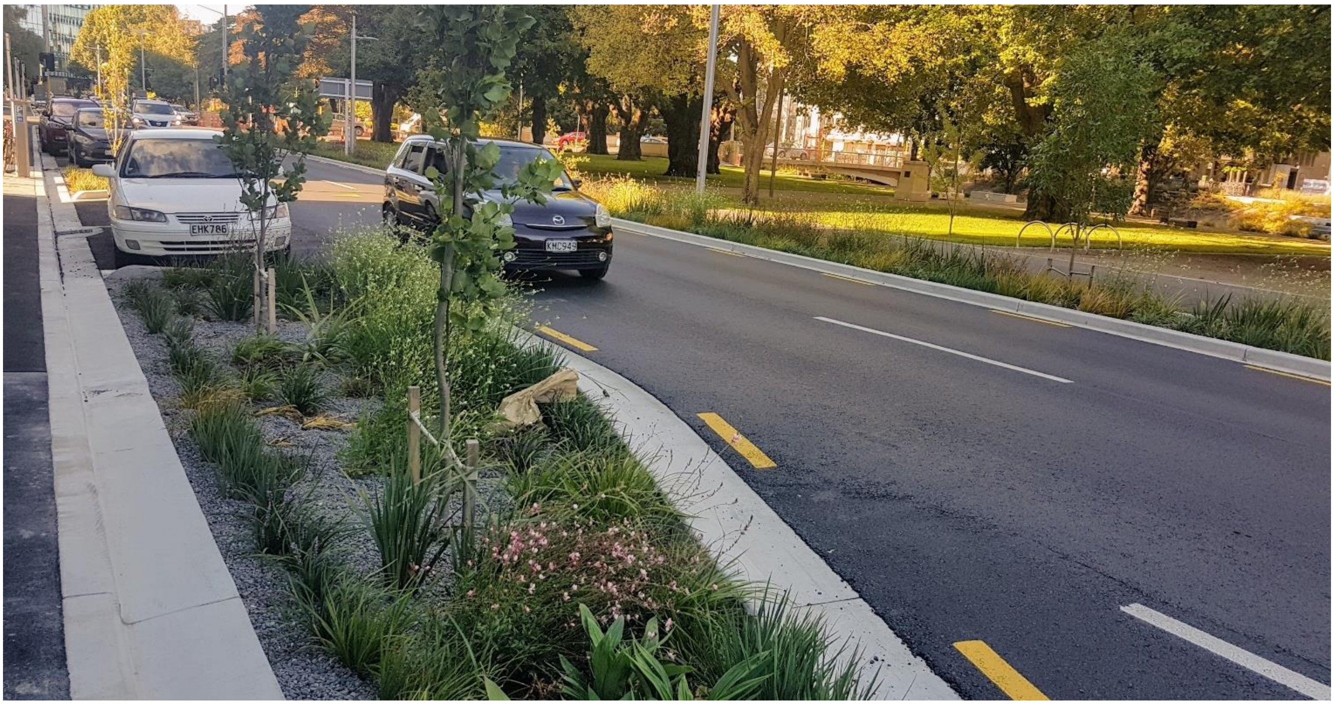


Figure 4: An Accessible City (Manchester Street, Christchurch)

The CCC Major Cycle Routes (MCR) programme will construct thirteen new cycleways in Christchurch to offer safe and direct routes around the city. A number of these projects will comprise new street-scale bioretention devices (Figure 5) to treat stormwater runoff.

Figure 5: Rain garden installed as part of cycle route development, Christchurch

3 LESSONS LEARNT: DESIGN

3.1 SITE INVESTIGATION

Site investigation is a key design element to ensure that the site is appropriate for a bioretention device, and that any device is designed to accommodate any site constraints. A lesson was learnt at a passive irrigation tree pit site where a thin layer of silt was missed in the site investigation which resulted in poor infiltration through the base of the tree pit and ponding that would potentially harm the tree. As the contractor was not aware of the requirement for a tree pit to freely drain, an inspection of the base was not carried out either. As a result the tree pit was isolated from runoff, effectively making it into a conventional tree pit. However, this issue may have been avoided through additional site investigation and through educating the contractor about the need for free infiltration through the base.

Other key site constraints that need to be identified through site investigation include groundwater level, contaminated soils, service clashes and legacy infrastructure (such as old tram tracks).

3.2 STORAGE OF PASSIVE IRRIGATION TREE PITS

The design intent for passive irrigation tree pits in the city was for the surface level to be about 50 mm lower than the kerb invert level to provide some stormwater treatment and passive irrigation of street trees. However, a number of early installations did not drain down quickly enough either due to low permeability soils or confining layers (such as that mentioned above).

While some installations performed well, there was a negative reaction from the asset owners toward the poorly draining devices as they were understandably concerned about tree health and mortality. Due to these early issues there was a risk of losing the support of asset owners. As a result it was considered prudent to adopt a conservative approach in the short to medium term by reducing the amount of storage within passive irrigation devices by raising the mulch level to the kerb invert level. While this reduces the amount of stormwater that can be treated it is at least maintaining the philosophy of connecting landscape features to the stormwater network.

In the longer term, where permeable soils allow, more storage in above the media is encouraged. This issue is still being worked through, but it illustrates how an initial problematic experience with a bioretention device can lead to preliminary conservatism in design practice.

3.3 INLET DETAILING

Inlets are a key part of a bioretention system as they contribute to plant health (through watering) and ensure that the water quality flows are captured and treated. Ideally street-scale devices will have a number of inlets from the kerb directly into the storage area, evenly distributing flow throughout the device. This is particularly important in dryer climates such as Christchurch which have fewer runoff generating rainfall events than some other climates.

In some instances, rather than cutting down the kerb locally, small openings were installed into the kerb. These have been noticed to be performing poorly and are mostly blocked after street sweeping (Figure 6, left). These inlet types are also sometimes constructed above the kerb invert level which results in low-flows bypassing the device. The thin section of concrete above these kerb inlets is typically cracked (Figure 4, right) and will require more frequent repair than a kerb opening. It is considered that wherever possible this type of inlet should be avoided. An alternative to this arrangement would be a combined tree grate and wide kerb inlet, although this is more costly and requires buy in from landscape designers.

Figure 6: Kerb inlets - blocked (left) and cracked (right)

Cast iron dome sump inlets and outlets have been incorporated in to a number of devices, particularly where the flows bubble up into the device. These have been found to be less prone to blockage than a standard flat sump inlet or a ‘scruffy’ dome, while also blending in to the planting more easily (Figure 7). ‘Scruffy’ domes also tend to let more litter pass through the system, and as most are galvanised also introduce additional zinc into the system. It is considered that this type of sump should be used for inlets and outlets to bioretention devices in the city, although appropriate locking mechanisms still need to be refined.

Figure 7: Dome sump inlet

3.4 MEDIA SELECTION

The Christchurch City Council manual (2015) provides some guideline specifications for the bioretention media mix. However, this is based on a mix (called 'ART3') that was developed for devices with introduced species that require more water than native species. A media mix for local native species could have a higher infiltration rate and less organic material. A media that can operate with a higher infiltration rate can have a smaller footprint resulting in a lower capital and operational cost. This is an area for development, and local media development is likely to be applicable to other regions around New Zealand with varying climatic conditions. However, the investment in this is considered worthwhile given the potential long-term cost savings provided by a correctly functioning media.

3.5 RESIN BOUND AGGREGATE

Resin bound aggregates were specified in some tree pits in reaction to maintenance concerns regarding ongoing weeding of planted areas. Resin bound aggregate was considered to provide a solution to this, although it was not favoured by the design engineers due to concerns over clogging. These concerns have been proved valid, with early clogging of the aggregated seen (Figure 8). It is considered that a mulch with planting will offer better long-term performance at a lower installation cost, and remove the need for specialised equipment to clean these areas.

Figure 8: Clogged resin bound aggregate

3.6 WEED MAT

There are varied opinions on the need for weed matting in rain gardens, and in Christchurch some have had weed mat installed while others do not have it. In some regions in Australia weed mat has been shown to be prone to blinding due to sediment build up at the base of the mulch (where the weed mat is typically installed). This prevents sediment being broken down on interaction with the media mix and results in the accumulation in one layer. This can result in a loss of infiltration capacity and remediation of the rain garden may be required earlier than expected.

Based on a visual comparison of rain gardens with and without weed mat, there does not appear to be any significant difference in the amount of weed present. The amount of weed present is considered to be more likely related to how well mulch has been installed, the density of plantings and the frequency of maintenance.

In some areas of Christchurch, because of the concurrent major rebuild work occurring with high sediment discharges into the street network there was a risk of early blinding of the media. To mitigate this, in some devices weedmat was considered a cheap temporary sacrificial investment to protect the rain garden media.

In light of the potential negatives (trapping sediment in a single layer, loss of infiltration capacity) and no observable difference with and without weed mat, it is considered that weed mat should be avoided, unless it is there as a sacrificial layer to prevent early blinding.

3.7 OTHER DESIGN ISSUES

There have been a number of design issues that have been encountered and the following provides a brief overview of the current approach to each of these.

3.7.1 STRUCTURAL SOIL

Structural soil is intended to provide a good environment for root development while protecting pavements. Two mixtures have been used with different permeabilities. However, neither has performed satisfactorily and further development is required. At present it is considered that using structural soil cells are likely a better solution despite the higher cost.

3.7.2 DEPTH OF CONCRETE SURROUND

Concrete surrounds have been used to protect surrounding pavement sub-base from becoming saturated or being damaged by roots. However, if the surrounds are too deep then there is a concern that roots will be confined. Based on experience to date it is recommended to have a concrete surround depth of 300 mm on the footpath side and 600 mm deep on the carriageway side.

3.7.3 INSPECTION PIPES

Inspection pipes currently protrude above the mulch up to approximately the design water level. However, these do not blend well into the rain garden. It is recommended that future designs have a lid flush with mulch and ensure that these are water tight up to the design water level (typically 200-300 mm).

3.7.4 DEPTH TO MULCH SURFACE FROM SURROUNDING PAVEMENT

The optimal design stored water depth in the CCC manual is 300 mm. With a typical kerb/pavement depth of 100 mm, this gives a total potential drop from the surrounding pavement of 400 mm. This was considered to be a safety hazard, and so in many cases the depth of storage was reduced to limit the fall height. However, having observed many rain gardens in-situ and comparing this fall to other hazards or drops nearby indicates that this is not as serious an issue as originally thought. In many cases street furniture can be placed as a barrier (e.g. cycle stands, seats) and in other cases planting provides a clear signal to avoid getting too close. It is considered better to maintain the maximum storage possible to reduce the total footprint, and to use alternative means of mitigating the potential hazard.

4 LESSONS LEARNT: CONSTRUCTION

4.1 MEDIA MIX

The media mix specified in guidelines, while still requiring development for each local situation, is mixed to meet a range of requirements relating to plant health, treatment ability and infiltration rate. The specifications need to be followed closely to ensure that these aims are met. It has been observed that some contractors have tried to create their own mix without fully understanding the specifications. It is important that the supervising engineer inspects media before it is installed and that anything not meeting the required specifications is rejected.

It is also important that infiltration testing is undertaken and observed by the engineer to be sure to falls within the lower and upper limit specified. Testing should be undertaken before the device is planted and mulch placed as it is difficult and expensive to remediate a rain garden at this point. Even a well-designed rain garden can fail to drain if not properly constructed.

A related issue if that some media has been found to contain contaminants which leach during the establishment period. This is a particular problem for media with a high organic material as the organic content may have been originated from material in contact with fertilisers, pesticides or herbicides. Media mix suppliers need to be able to prove that the media comprises a clean source of organic material and is free from contamination.

4.2 INLETS

Kerb openings are typically performing well. However, sometimes the cross fall of these are being constructed a bit flat, resulting in some sedimentation. Crossfalls should be greater than typical fender crossfall, but this requires close supervision during construction as it is not a familiar detail to construct. In Figure 9 it can be seen that when inlets in kerb fenders are not constructed to the required crossfall this can result in water not being able to easily enter the device.

Figure 9: Poorly performing kerb inlet with noticeable ponding

4.3 MULCH PLACEMENT AND DEPTH

In Christchurch the guidelines currently specify gravel mulch as this is a commonly available material. However, the observations made regarding mulch placement and depth relate to whatever mulch is selected.

Firstly, mulch has been observed being placed at or above the inlet level (Figure 10). This prevents water entering the devices, reduces the volume treated and traps sediment at the inlet causing water to bypass more frequently. This can be easily avoided through close supervision during construction. Ideally prior to mulch placement the height of the media will be checked to ensure there is sufficient depth allowed for the mulch.

A related problem is contractors throwing gravel mulch onto plants also resulting in damage to plants. This can be managed through supervision and a conveying to the contractor the need to protect plants during mulch placement.

Figure 10: Mulch placed at or above the inlet level

4.4 MISUNDERSTANDING FUNCTION

It is important that contractors and supervising engineers understand the purpose of bioretention devices. While the devices may seem simple (being seen as ‘just a garden’), they are highly engineered systems and each part needs to function well to ensure the best performance overall. This means that everyone involved in the project – from design through to construction through to maintenance – needs to understand the function of each element.

Where this is not conveyed this can lead to issues. An example of this is where the contractor did not understand that the device being constructed needed to infiltrate to ground. The contractor used it for a location to dispose of excess concrete (Figure 11) and this had to be removed. Issues like this require close supervision during construction to avoid, and an understanding by all parties of the intended function of the device.

Figure 11: Concrete disposed of in base of rain garden

4.5 SURFACE DETAILING

The surface of bioretention devices are required to have a flat (zero) grade to ensure that all areas are inundated by stormwater runoff. However, many instances have been observed where this is not occurring. An example of this is shown in Figure 12, although this was able to be rectified during construction.

Even compaction over the entire device is an important way of avoiding this, as is letting the media to settle for a while. An infiltration test provides an opportunity to wet the media and allow it to settle. The media can then be topped up and levelled prior to planting and adding the mulch. This avoids costly remediation once plants are established and mulch applied.

Figure 12: Depressions within a rain garden surface

4.6 CONCRETE DETAILING

Although it has no impact on performance, the rear face of exposed kerbs in many rain gardens do not have a smooth finish (Figure 13). This is because for a conventional kerb and channel these are typically hidden behind the kerb nib and contractors are not used to finishing that surface smoothly. However, if this is left rough it detracts from the overall aesthetic, and requires costly repair work. This can be avoided if designs specify a floated rear face for exposed kerbs, contractors are aware of this before constructing kerb, and it is inspected to ensure it is carried out correctly. The rear face of the kerb in Figure 13 should have been floated in accordance with the design.

Figure 13: Poorly finished rear kerb face

5 LESSONS LEARNT: MAINTENANCE

5.1 PROTECTION FROM CONSTRUCTION DISCHARGES

Sediment laden stormwater runoff must be prevented from entering bioretention devices during construction until surrounding surfaces have been fully stabilised. There have been some devices clog up with sediment during construction when proper erosion and sediment control requirements were not followed. Bioretention device are typically constructed and sometimes have media installed prior to stabilising the adjacent carriageway and footpath surfaces. This requires inlets to the devices to be blocked during the construction phase (Figure 14), and a procedure in place to remove these when contributing surfaces are stabilised. This needs to be covered in project specifications and closely managed during construction.

Figure 14: Temporary barrier to prevent construction sediment entering new rain garden

5.2 MULCH

The depth of mulch has an influenced on weed growth and plant growth. It has been observed in Christchurch that devices with approximately 50 mm thick mulch typically have less weeds and less stressed plants. A shallower mulch thickness than this increases weed issues. Thick mulch is also believed to be a contributor to stressed plants (Figure 15).

Figure 15: Plant stress observed in an area with thick mulch

There were also concerns raised about stone mulch being picked up and thrown, but the authors are unaware of this occurring. Another concern was that round aggregate was a slip risk if flicked by birds onto pathways. However, the size of the aggregate and the depth below the pavement means that this is minimised and has not been observed to be an issue.

5.3 LITTER REMOVAL

Any stormwater treatment device will trap litter. In a bioretention device, as the inlets are often relatively small, when litter is trapped then it can block the inlet (Figure 16). This can be prevented by ensuring the inlet area is lower than the surrounding device surface, increasing the number of inlets, and removing litter frequently. If litter is left to accumulate too much then there is the potential for bioretention devices to look like large ashtrays with the associated negative perception and likely lower uptake of these devices. Therefore it is important that appropriate maintenance allowance is made when proposing to install bioretention devices.

Figure 16: Litter partially blocking an inlet

One means of mitigating this is to use a submerged ('bubble up') entry. However this is more expensive.

5.4 PLANT DENSITY AND SPECIES DIVERSITY

It has been observed that rain gardens with a higher plant density are less prone to weed growth during the initial establishment period. This results in less initial maintenance for weed and litter removal. This experience suggests that it may be beneficial if devices are planted with a higher plant density than may be typical for garden bed establishment.

It is also noted that many devices are also being planted with a single species, Oi Oi, as this plant is well suited to rain gardens (Figure 17, right). However, this species takes some time to thicken up and spread throughout the device. During this time the device may be more susceptible to weed growth and litter is more visible requiring more frequent maintenance. Where rain gardens are planted with a variety of species (Figure 17, left), these may result in quicker coverage and helps to ensure that if one species fails then another species more suited to the conditions may grow instead.

Figure 17: Biodiverse rain garden (left) compared to a monoculture rain garden (right)

6 CONCLUSIONS

Bioretention stormwater treatment devices are becoming more common in urban centres in New Zealand. In Christchurch this has been aided by the large scale rebuild taking place in the city centre following the earthquakes. It has also been assisted by having design, construction and maintenance manual which gives confidence to designers and approvers that the devices are being built to locally relevant guidelines.

The large number of devices installed to date have provided the opportunity to identify several design, construction and maintenance issues. These range from significant issues (such as blocked inlets or blinded resin bound aggregate) to more aesthetic issues (such as poorly finished concrete). However, these issues are all easy to avoid and identifying these provides an opportunity for stormwater practitioners to continue to improve these devices and increase their uptake.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the inputs of the stormwater engineers and landscape architects who have contributed to the greener stormwater infrastructure which is becoming a feature of Christchurch streets.

REFERENCES

Christchurch City Council (2015) Rain Garden Design, Construction and Maintenance Manual.