Designing and Implementing Green Roofs for WSUD in Australasia

A Trans-Tasman Collaboration

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Abstract

Green roofs offer many potential benefits to water sensitive cities. However, it is important to understand that green roofs are a highly engineered best management practice and the purpose and the design greatly affect their performance. There are three key factors to designing a green roof. These are as follows:

1. Plant selection
2. The Soil (Substrate)
3. The Drainage.

Stormwater360 is a specialist stormwater solutions' provider based in Australia and New Zealand. Over the last 3 years Stormwater360 has been developing a pre-vegetated modular hybrid green roof system for use in Australasia. In March of 2012 Stormwater360 installed New Zealand's largest extensive green roof at Mount Difficulty wines in central Otago. The roof was designed to have many functions including the following:

1. Stormwater Reduction
2. Disposal of process water
3. Insulation
4. Energy reduction
5. Aesthetically pleasing

A section of this roof has been established at the University of Canterbury in Christchurch. This has allowed detailed and controlled monitoring of the system for its effect on water quantity and quality. This study has examined the effect of soil depth and various plant species and has monitored the performance over 18 months through various climatic conditions.

Stormwater360 has used these results of the Canterbury Study to develop a Stormwater360 green roof node for MUSIC (Model for Urban Stormwater Improvement Conceptualisation). The node allows the conceptualisation of the potential benefits and applications of green roofs in water sensitive site design.

The paper will discuss the development of the system, results of the monitoring and how these results were used to develop the MUSIC node. The paper will also give some examples (case studies) of different green roof designs installed over the last 3 years.

Introduction

A green roof or living roof is a roof of a building that is partially or completely covered with vegetation and a growing medium, planted over a waterproofing membrane. Green roofs serve several purposes for a building such as absorbing rainwater, providing insulation, creating a habitat for wildlife, and helping to lower urban air temperatures and to mitigate the heat island effect

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Green or living roofs is a technology that has been around for a long time. Since the Hanging Gardens of Babylon in the 6th century to the sod roofs from Scandinavia, green roofs have been used to improve aesthetics, waterproof and insulation for many.

Recently green roofs have being increasingly used in the USA for stormwater management and in Europe for habit restoration as well as carbon sequestration and energy conservation through passive reduction in heat gain.

Living Roofs Vs Green Roofs

A green roof is generally thought of as a roof with vegetation on it. However, not all vegetated roofs have green vegetation year round and not all green roofs are vegetated. The term green roof is also used for a cool roof, a roof with solar thermal collectors or photovoltaic panels or rooftop ponds. Therefore the term living roof has been adopted to more truly reflect what they are.

Benefits of Living Roofs

There are many benefits to living roofs:

- Reduce stormwater runoff
- Increase roof service life, reduce maintenance costs and replacement costs of waterproof membranes
- Reduce energy costs for heating in winter / cooling in summer
- Reduce noise transfer from outdoors
- Mitigate urban heat island effect
- Absorb air pollution, collect airborne particulates, store carbon
- Serve as living environments for birds and small animals, increased biodiversity and
- Aesthetics and Green Value

It is important to understand that water is an essential and natural element in plant growth, evapo-transpiration and photosynthesis and enables these benefits - so in turn these are examples of Water Sensitive Urban Design.

Living Roofs for Water Sensitive Urban Design

Water Sensitive Urban Design (WSUD) is a land planning and engineering design approach which integrates the urban water cycle, including stormwater, groundwater and wastewater management and water supply, into urban design to minimise environmental degradation and improve aesthetic and recreational appeal. (Wikipedia).

Living roofs are a manmade, engineered vegetated surface, that mimics the natural water balance promoting evapotranspiration and photosynthesis, which disposes of precipitation and other excess water. The vegetated surface also protects and insulates the building from the sun's energy reducing the virtual water elements such as building products' manufacture and power production. The combination of the absorption of the sun's energy, shading and evaporative cooling produced by a living roof greatly reduces the energy needs of a building especially in warmer climates. A living roof is a true example of WSUD as it minimises environmental degradation on many levels not only the minimisation of runoff.

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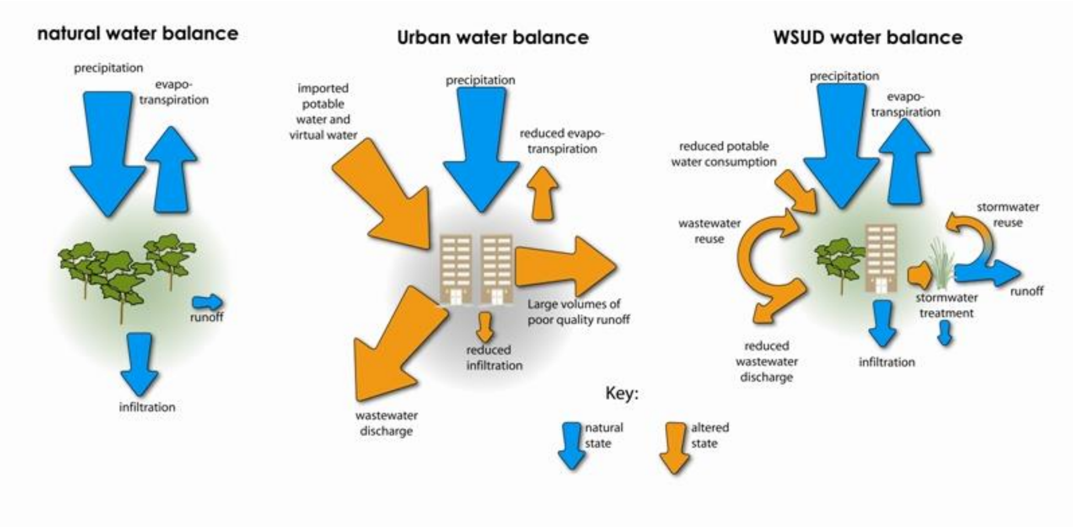

Figure 1 The Natural vs. urban water Cycle SOURCE: Water by Design

Design of living roofs

The two main design guides for designing living roofs are the German FLL guide lines and the ATSM. The FLL is a comprehensive manual for living roofs in a German context. The FLL is a How- to- guide drawing on the many years of experience that the Germans have in green roof technology.

The American Society of Testing Material (ASTM) had issued a number of living roof testing standards mainly focused on the substrate and drainage. Both give guidance on plant selection and maintenance, however the German guide is more comprehensive.

There are two types of living roofs- Intensive and Extensive. Intensive roofs are typically roofs with over 300mm soil depth. Intensive roofs enable the growth of larger vegetation, however they require a higher degree of maintenance and have an added dead load element which needs to be accounted for. The increased maintenance typically involves an increased water requirement, fertilisers and landscape maintenance. Extensive roofs are a modern phenomenon which includes a careful balance of plant selection, engineered growing media and drainage. Extensive living roofs have less maintenance and dead load component. Intensive living roofs typically have more scope for aesthetic design, while extensive living roofs are lower cost and typically a more functional design. This paper discusses the design of an extensive living roof system for WSUD.

Plant Selection

The most obvious place to start in a discussion of a living roof is the living component or the plants. The plants in a living roof are the engine or mechanism of the environmental machine that green roofs are. The process of transpiration and photosynthesis delivers most of the environmental benefits achieved by living roofs.

Roofs are a harsh environment for growing plants. A living roof is an exposed environment, with shallow and free draining soil profiles which have minimal available water. Careful consideration of the plants is required to create and sustain a living roof.

When considering the benefit to stormwater reduction, the amount by which a plant can transpire is critical. Different plants have different evapotranspiration capabilities. Sedums are a succulent ground cover and are often used for living roofs. Sedums have a less common method of photosynthesis called Crassulacean Acid Metabolism or CAM photosynthesis. CAM is an adaption by some plants to increase their efficiency. For CAM plants the stomata of the plant closes during the day to prevent water loss, Most plants have the stomata open during the day to allow CO2 to enter the cells of the plant so that it can quickly be converted by the energy from sunlight with the addition of water into carbohydrates i.e organic matter. The stomata of the plant is open during the night allowing CO2 to enter the plant where it is stored for conversion during the day.

As a result CAM plants like sedums are good for living roofs as they can tolerate the lack of water present in a living roof , they do not transpire as much as other plants and therefore offer less water retention properties.

Plants are also critical to the aesthetic the roof creates, the use of native and endemic species can blend the roof into the surrounding landscape and provides a native habitat of indigenous species of fauna and flora. Further, plants play a role in the stabilisation of the substrate, preventing erosion of sustaining soil.

One good method of identifying good living roof plants is to look for exposed soil and water restricted environments. Rocky out crops or mountain plants are a good example of this. Often native plants found in these areas can be sustained on a living roof.

Engineered Soils or substrate.

Plants need support, nutrients, protection from adverse temperatures, an even supply of moisture, and they need oxygen around the roots, which is usually supplied by soil. With an extensive living roofs the soil or substrate is generally an engineered media with 80 – 95% inorganic material and 5 – 20% organic material. The substrate needs to be free draining to limit the load of the roof and to ensure oxygen is available to the roots. It is preferable that inorganic material is light weight. The organic material provides nutrients to the plants, however this must be minimised and be stable because if this biomass breaks down over the life of the roof it can cause clogging in the substrate.

The water holding capacity of the substrate is critical for stormwater retention and plant health. This needs to be balanced against the weight. A precise specification and source material is critical and quality control on the substrate that is used to construct a roof is essential. Substrate water holding capacity is the most critical characteristic to promote stormwater retention and sustain plant life (Fassman and Simcock). Water holding capacity is a function of depth and enables greater plant selection and better transpiration. Deeper substrates provide more water storage and allow greater plant selection however increase structural considerations.

The FLL and ASTM guidelines provide testing procedures for quality assurance. These detail methods for determining maximum water holding capacity. There are three states of soil moisture content to consider:

1. Saturation- all pore spaces are filled with water,
2. Field capacity- pore spaces are filled with water and air. Large pores are air-filled and small to medium pores hold the water.
3. Permanent wilting point is where most of the pore space is air filled, however some water can be held tightly in minute pores. Below this point, water is not easily accessed by plants.

For stormwater retention ability, plant available water is the critical characteristic. This is different to field capacity and the permanent wilting point, which is roughly half the field capacity or water holding capacity according to ASTM or FLL guidelines.

For structural calculation, saturation weight should be used and further consideration of vegetation weights is critical for design.

Particle size and permeability influence stormwater control through attenuation as water travels through the drainage pathways in the media. Living roof substrate needs a specific particle size distribution to create these pathways and to ensure long term permeability. Failure to do this can see saturated conditions, excessive structural loading and poor plant heath. The FLL guide line specifies a particle size band as a guide. ASTM and FLL guidelines recommend minimum saturated permeability rates.

Nutrient content, cation exchange and Ph. of the substrate are all critical for plant health, however these attributes may effect water quality. It is important that the source of organic material does not leach other contaminants e.g. mushroom compost can be high in metals

Drainage

As previously discussed the particle size and drainage pathways in the substrate are critical in the weight of the roof and good plant heath. A secondary drainage system is essential in case of failure of the substrate or for larger rainfall events.

Most extensive green roof systems provide a synthetic drainage layer to allow water that travels through the substrate to quickly drain away. Some drainage layers use a filter fabric to prevent fine particles from entering the drainage pathway. Other designers of living roof systems use an aggregate layer or channels as a drainage layer. This can add weight to the structure but can offer detention properties. ASTM guidelines include protocols for testing synthetic drainage layer and the FLL guidelines details of drainage elements.

Developed design and system

Plants

Plant selection is often very regionally specific, and aesthetically driven. Stormwater360 has developed regional palates of NZ Native grasses and ground covers as well as a selection of exotics including sedums.

Substrate

Stormwater360 has developed a light weight substrate for stormwater retention for use in Australia and New Zealand. The substrate comprises of Pumice and mature compost. Also included in the substrate are soil amendments for cation exchange capacity for nutrient retention, chemical buffering and moisture storage and supply.

Dry Bulk Density (kg/m^3)	Porosity (%)	Water Holding Capacity (%w/w)	pH	Saturated Permeability (mm/sec)	Saturated bulk density (100 mm depth) (kg/m^2)
0.59	60	15	5.37	0.40 cm/s	130

Table 1: Properties of LiveRoof® Engineered Substrate

Modular system with integrated drainage

Stormwater360 uses the LiveRoof® modular system to grow and construct its roofs. The system utilises a horticultural designed nursery tray with removable sides. This enables vegetated tiles to be grown in local nurseries or on site at ground level while the building is being constructed. The vegetative tiles are transported to site by truck and placed on the roof.

University of Canterbury Monitoring.

In 2012 Stormwater360 worked with the University of Canterbury to establish 6 sub-roofs' modules on the roof of the engineering building at the University. They consisted of two different substrate depths viz 100mm and 150mm and three different vegetation options i.e. non vegetated, exotic sedum ground covers and native alpine grasses. The LiveRoof® modules used were grown as part of the Mt Difficulty barrel store project which is discussed later.

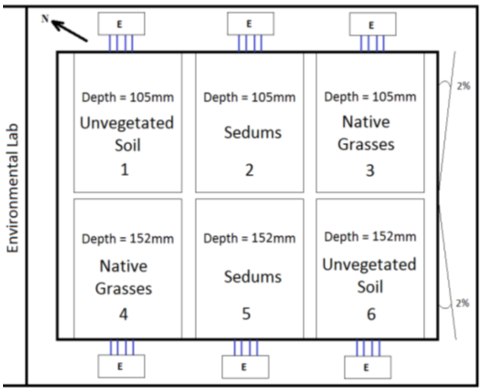

Figure 2: University of Canterbury LiveRoof® Monitoring

Metholodical Data was continously logged by a weather station adjacent to the systems. Soil temperature and moisture content was also montiored. Effluent water volume was measured after each event and are listed in the tables below.

Rainfall Depth Range (mm)	Rainfall Frequency (# of Events)	Proportion of All Rainfall Events (%)	Proportion Producing Effluent (%)	Average Rainfall Depth ± Variation (mm)	Average Effluent Depth ± Variation (mm)
<2	5	11.1%	0.0%	1.4 ± 0.3	0 ± 0
2 - 5	13	28.9%	53.8%	3.4 ± 0.7	1.5 ± 0.4
5 - 10	10	22.2%	70.0%	6.8 ± 1.6	2.2 ± 0.5
10 - 15	7	15.6%	85.7%	12.5 ± 2.9	3.3 ± 1.1
15 - 25	4	8.9%	100.0%	22 ± 2.8	7.3 ± 2.1
25 - 40	4	8.9%	100.0%	31.1 ± 5.4	7.2 ± 1.8
>40	2	4.4%	100.0%	57.2 ± 9.8	22.4 ± 6
Sum	45	100.0%			

Table 2: Hydrological Response Data

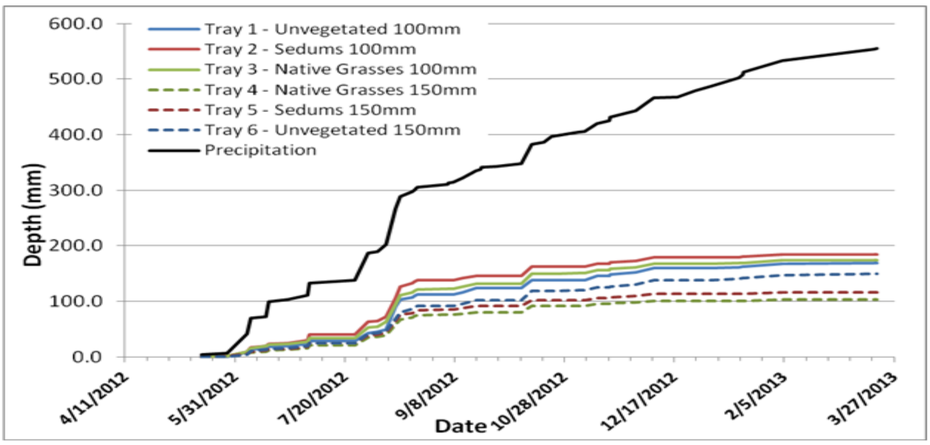

Figure 3: Total Effluent from each sub roof since installation

The results show that for rainfall events less than 15mm depth, the living roof systems maintained the majority of rainfall. For events larger than 15mm, a proportion of the rainfall was retained. The research (Voyde, Aishling) indicates that the antecedent rainfall conditions can greatly influence retention capability. This can be clearly seen in the figure below. As days pass without rainfall, the moisture content of the substrate falls. As it rains, the moisture content raises. Essentially the substrate is acting as a tank storing the water for the plants to dispose of through evapotranspiration over time.

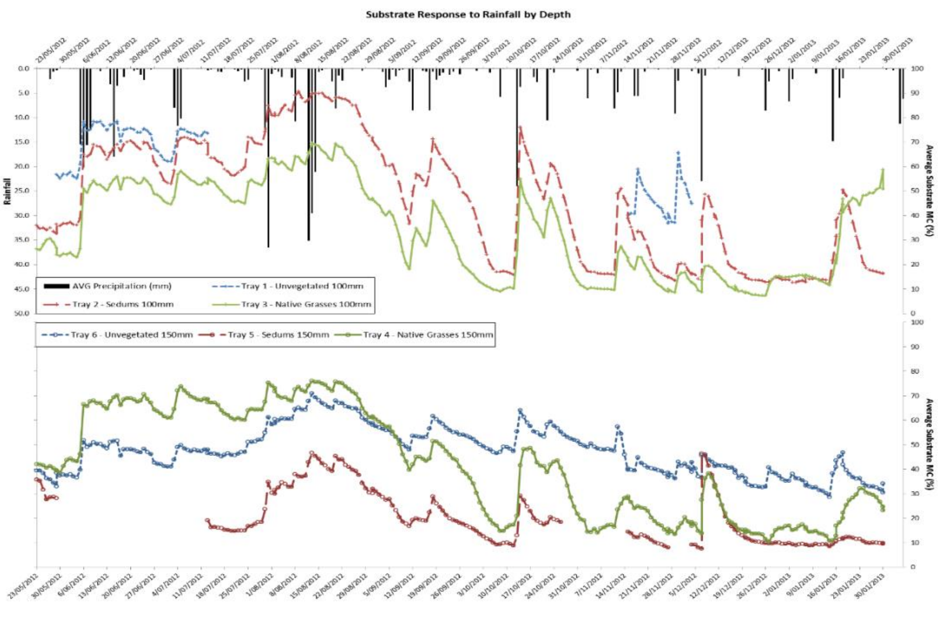

Figure 4: Rainfall (mm) and Soil Moisture Content (%)

Perodical rainwater and effluent samples were collected for water quality analysis.The figures present the results. The Sedums exhibited less effect on water quality than the native grasses. Nutrient concentrations tend to fall over time as organic material decomposes. As the roof is only one year old, these are preliminary results and further monitoring is required.

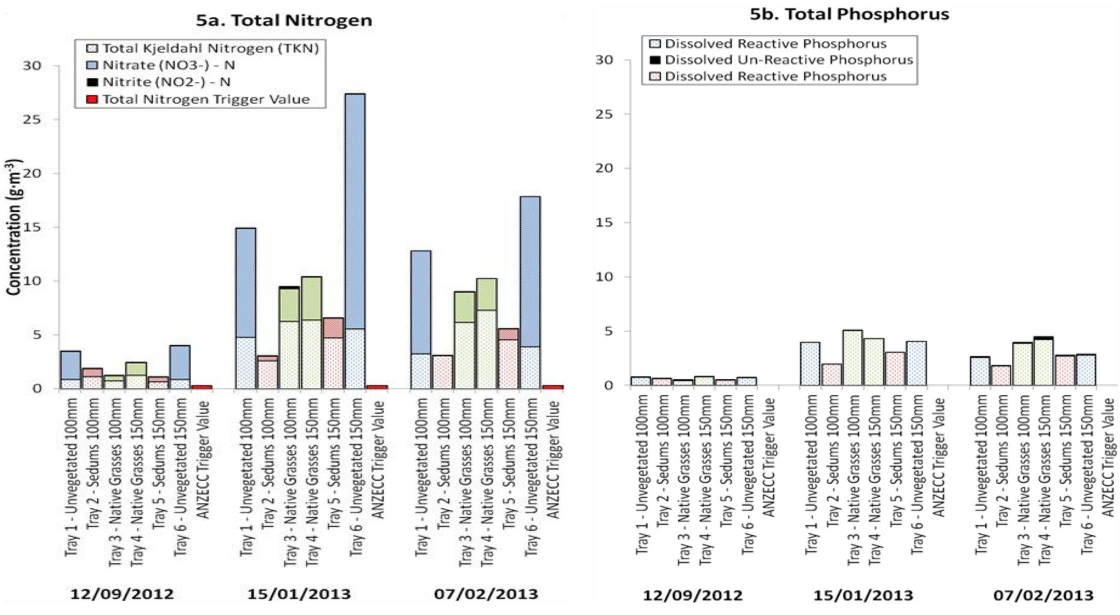

Figure 5: Effluent Nutrient Concentrations

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Case Study – Mt Difficulty Barrel Store.

The Modules used in the University of Canterbury study were grown as part of New Zealand's largest extensive green roof. The Mt Difficulty Winery commissioned the 900m2 green roof for their new wine barrel store. As well as looking like part of the natural Otago landscape, the roof is being credited for a marked saving in energy by regulating the temperature in the barrel store, reducing stormwater runoff and as a disposal area for the winery wastewater treatment plant. Traditionally in Europe, wine has been matured by keeping it in a cave to regulate temperatures. It was this vision that Mt Difficulty Wines wanted to create in Central Otago.

Figure 6: Mt Difficulty living Roof

By installing a living roof on the new barrel store, the temperature fluctuations between day and night and winter and summer are reduced, with the roof insulating the wine against the winter chill and evaporative cooling contributing to heat reduction in summer. The green roof naturally reduces the energy required to regulate the temperature of the barrel store.

The green roof addresses the issue of stormwater management with the engineered substrate of the living roof capturing and retaining stormwater runoff while the plants chosen for the roof, process the water back into the atmosphere through evaporation and transpiration processes. The Mt Difficulty LiveRoof® is the first time that a vegetated roof has been in use in New Zealand to dispose of excess process water (that would typically be sent to waste), while having the double benefit of reducing the summer temperatures through plant evapotranspiration . This has the effect of reduced energy being required to control the internal temperature of the barrel store building. Temperature is a critical element in the winemaking process and can be energy intensive if the building is not designed correctly.

The planting palette was designed to blend in with the surrounding environment, creating a natural and safe habitat. The roof is isolated from pests and the natural fauna can flourish free from threat.

The modular technology also means that plants are pre-grown in modules before being installed on the roof. The benefits of installing pre-grown plants are:

- Plant species can be tested to ensure they are right for the environment. This also allows for succession planting with the plants designed to evolve
- Plants are stronger and established when they are installed on the roof
- Greater surface coverage means less weeding and maintenance
- Protection against wind erosion and loss of substrate
- Pre-grown plants mean less time on site, leading to more efficient installation

Figure 7: Mt Difficulty living roof Installation

MUSIC Modelling

The Model for Urban Stormwater Improvement Conceptualisation (MUSIC) is a software tool that simulates the behaviour of stormwater in catchments. MUSIC is the preferred tool for demonstrating the performance of stormwater quality treatment systems within the urban areas by many Australian agencies.

MUSIC provides the simulation of stormwater runoff from catchments utilising conceptualised treatment systems, thereby providing output data for both stormwater quantity and quality. MUSIC considers the large number of variables that influence the effectiveness of any stormwater system in appraisal of its ability to meet nominated water quality objectives

The data collected from the LiveRoof® monitoring at the University of Canterbury was used to develop a LiveRoof® Treatment node for different substrate depths and planting depths. Effluent quality and rainfall to runoff reduction relationships were used to estimate the benefits the LiveRoof® would have over a standard roof.

To setup a model, general information has been used to predict the performance of the LiveRoof® technology. These are;

- MUSIC version 5.1
- Rainfall Station University of Canterbury, 6 minute time step for 14/05/2012 to 30/05/2013
- Water by Design Urban Commercial Roof Source Node properties
- 100% Impervious Area
- 290m2 Catchment Area (factored 10x)

Parameter	Flow (m3/s)	TSS (mg/L)	TP (mg/L)	TN (mg/L)	Gross Pollutants (ML/yr)
Input	10.0	1000	5.0	5.0	15
Output	3.8	20.0	0.5	1.1	0.0

Table 3: Treatment Characteristics of a LiveRoof® 152mm Deep Sedum Roof.

The roof source node for the model has been set at 100% impervious to ensure that all runoff from the rainfall simulation has been directed to the LiveRoof®. The treatable flow rate (high-flow bypass in MUSIC) of the LiveRoof® node has also been set at 100m3/sec. This is seldom the case when modeling treatment devices within MUSIC, as for example all gross pollutant traps have a predefined maximum flow rate that can be treated prior to bypass. The LiveRoof® system with LiteRoof media has demonstrated the ability to still reduce runoff in excess of 50% from rainfall depths over 40mm.

Treatment Train Effectiveness - Junction

	Sources	Residual Load	% Reduction
Flow (ML/yr)	0.142	54.0E-3	62.0
Peak Flow (m3/s)	4.83E-3	1.84E-3	62.0
Total Suspended Solids (kg/yr)	4.14	1.08	73.9
Total Phosphorus (kg/yr)	23.9E-3	27.0E-3	-12.9
Total Nitrogen (kg/yr)	0.456	59.4E-3	87.0
Gross Pollutants (kg/yr)	4.82	1.83	62.0

Table 4: Load Based Reductions for the LiveRoof® Sedum Roof in MUSIC

An initial examination of the model shows large percentage reductions in Nitrogen and suspended solids. It is also noted that the model shows a precentage release of phosphorus. It should be noted that roofs are a potential souurce of nitrogen because of atmospheric decomposition of the contaminant. The runoff from roofs typically has low concentration of phosphorus. Surface types such as landscaping and road pavement/car parks exhibit much higher mean influent storm flow concentrations. It needs to be noted that while the model shows a percentage addition of phosphorus, the overall effect of this on a sitewide analysis would be minimal.

To demonstrate this, a further example was set up detailing a typical site with 50% of a roof treated by the LiveRoof® system, 45% pavement and hardstand and 5% landscaped. The design has been augmented with a 1-cartridge EnviroPod™ StormFilter® treatment train. Due to the insignificant load of TP being exported from the roof with respective to the other surface types, the abovementioned model yields a 78% load reduction in TP.

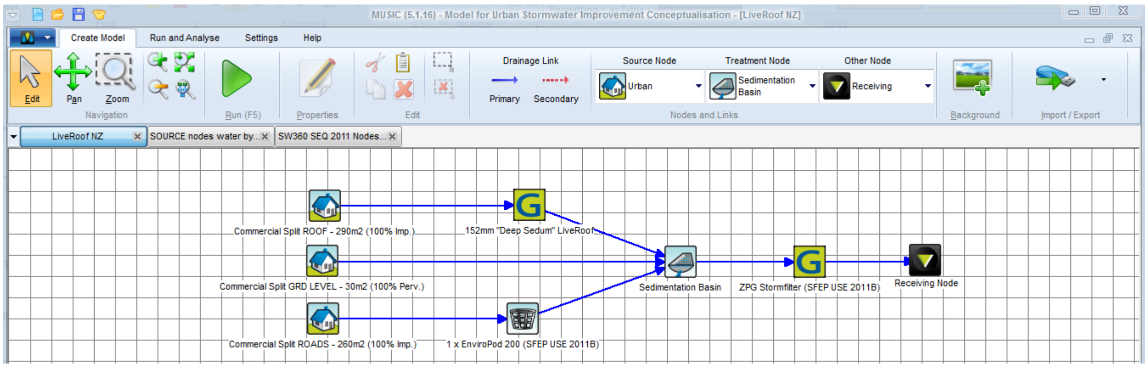

Figure 8: Site based MUSIC model

Given the approximations and accuracies within MUSIC, the parameters modelled determine that for a range of pollutants the LiveRoof® system can be modelled to show improved benefit of water quality from green roof structures. Further refinement of the model and treatment nodes are required. However, MUSIC can be used to demonstrate the potential benfits of the LiveRoof® system as part of a set of water sensitive design initiatives for a site.

Conclusions and Future Work

The work undertaken by Stormwater360 in New Zealand demonstrates the potential water sensitive benefits of their living roof system - the LiveRoof®. Having successfully undertaken a number of projects and scientific studies in New Zealand, the LiveRoof® system and engineered substrate LiteRoof is now available in Australia. Stormwater 360 is developing plant pallets for the different climates of NSW, Queensland and Victoria. Research carried out by the University of Canterbury is to be replicated with a study at the Sunshine Coast University. This will further refine the LiveRoof® treatment Node developed by Stormwater360 for the MUSIC modelling and Water Sensitive Urban Design in Australia.

References

ASTM. 2011a E2396-11 Standard Test method for Saturated Water permeability of Granular Drainage media (falling Head method) for vegetated Roof Systems. West Conchohocken, Pennsylvania: ASTM International.

ASTM. 2011c E2396-11 Standard Test method for Water Capture and Media Retention of geocomposite drain layers for Vegetated Roof Systems. West Conchohocken, Pennsylvania: ASTM International.

ASTM. 2011d E2396-11 Standard Test Method for Maximum media Density for Dead Load Analysis for Vegetative Roof Systems. West Conchohocken, Pennsylvania: ASTM International.

FLL 2008. Guidelines for planning, Construction and Maintenance of Green Roofing. Bonn Forschungsgessellschaft Landschaftsentwicklung landSchaftsbau e V

Fassman – Beck, E Simcock R, Voyde E & Hong Y 2013 4 Living roofs in 3 locations Does configuration affect runoff Mitigation? Journal of Hydrology, 490:11-20 (2013)

Fassman-Beck, E and Simcock R (2013). Living Roof Review and design recommendations for stormwater management. Auckland Council technical Report TR2013/045

Kohler M Schmidt M Grimme F, Laar M Paiva VL, Tavares S (2001) green roofs in temperate climates and in Hot humid tropics – far beyond

O'Sullivan A, De Vries T, Hannah M, Design Stormwater budgets and water quality of Christchurch Green Roof Systems. Proceedings of the 8th South Pacific Stormwater Conference, New Zealand Water Association, Auckland, New Zealand, May 8-11 2013, 16 pp