CREATING SPACE FOR BIODIVERSITY IN DURBAN:

GUIDELINE FOR DESIGNING GREEN ROOF HABITATS

ENVIRONMENTAL PLANNING & CLIMATE PROTECTION DEPARTMENT

BIODIVERSITY | CLIMATE | PEOPLE

ETHEKWINI MUNICIPALITY

GREENING DURBAN 2010

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This guideline has been prepared as part of the Green Roof Pilot Project (GRPP), an initiative of eThekwini Municipality's Environmental Planning and Climate Protection Department. The GRPP was initiated in 2008 as part of the adaptation work stream of the eThekwini Municipal Climate Protection Programme (MCPP). The aim of the GRPP is to assess the effectiveness of green roof habitats in Durban in reducing temperatures and stormwater runoff, both of which are projected to increase as a result of climate change. The co-benefits of the GRPP in terms of its role in promoting urban biodiversity are also being assessed.

This guideline forms part of the Green Guideline Series, an initiative of the Greening Durban 2010 Programme. The aim of the Greening Durban 2010 Programme was to ensure that the 2010 FIFA World Cup™ was hosted in an environmentally sustainable way, and that a positive environmental legacy was achieved from hosting the event in Durban. As part of that legacy, the series is now being extended in the post-World Cup™ phase with this new green roof habitat guideline.

The content of this guideline is intended for information purposes only and does not constitute legal advice. While every effort has been made to ensure the comprehensive nature of the information, the suggestions and technologies contained herein should not be considered exhaustive. Any liability that arises from the use of the guideline is excluded.

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Contents:

Abbreviations:

BTU	British Thermal Unit
CBD	Convention on Biological Diversity
CH_4	Methane
CO_2	Carbon Dioxide
CO	Carbon Monoxide
DIY	Do-It-Yourself
GHG	Green House Gases
GRPP	Green Roof Pilot Project
dB	Decibel
EPCPD	Environmental Planning and Climate Protection Department
EMA	EThekwini Municipal Area
EPA	U.S. Environmental Protection Agency
KwH	Kilowatt-hour
LECA	Light Expanded Clay Aggregate
MCPP	Municipal Climate Protection Programme
NO_x	Nitrous Oxides
O_2	Oxygen
PM	Particulate Matter
SO_x	Sulphur Oxides
TEEB	The Economics of Ecosystems and Biodiversity
UNFCCC	United Nations Framework Convention on Climate Change
VOC	Volatile Organic Compound

Quick Definitions Guide:

Adaptation
In the context of climate change, an adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities [1].

Biodiversity
The variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part: this includes diversity within species, between species and of ecosystems [2].

Carbon Footprint
Measures the total amount of green house gases (GHG) caused by an activity or a person's day-to-day life through the burning of fossil fuels for electricity, cooling, transportation etc., and is generally measured in units of tonnes (or kilograms) of carbon dioxide equivalent.

Climate change
Change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods[3].

Direct Green Roof System
Is a system where the vegetation is not planted in containers or modules, but onto specially designed layers that are placed on top of the existing roof.

Ecosystem Services
The direct and indirect contributions of ecosystems to human well-being[4].

Extensive Green Roof System
Is a roof system which is generally shallower than an intensive green roof system (i.e. soil depth of less than 20cm) and not intended for recreational use.

Evapo-transpiration
Evapo-transpiration occurs when water from the leaves, stems, flowers and roots of plants have sufficient heat or energy to turn to vapour.

Food Security
Food security refers to the availability of basic foods and how accessible they are.

Green Infrastructure
Green infrastructure refers to the array of products, technologies, and practices, such as green roof habitats, that use naturals systems to enhance overall environmental quality and provide ecosystem services, such as filtering air pollution, carbon sequestration, and stormwater attenuation[5].

Green Roof
Is the roof of a building which has been intentionally partially or completely covered with vegetation.

Intensive Green Roof System
Is a roof system which is generally deeper than an extensive green roof system (i.e. soil depth of 20cm-1m) and is generally intended for recreational use.

Mitigation
In the context of climate change, a human intervention to reduce the sources or enhance the sinks of greenhouse gases[6].

Modular Green Roof System
Is a green roof system where the plants are planted in portable containers or modules which together make up the green roof.

Urban Heat Island Effect
This is a phenomenon whereby urban areas experience higher temperatures than the surrounding countryside. This is caused primarily by the change in landcover from green open spaces to buildings, roads and other infrastructure which absorb solar radiation during the day and releases it as latent heat during the night.

[1] Based on United Nations Framework Convention on Climate Change (UNFCCC) definition.
[2] Based on United Nations Convention on Biological Diversity (CBD) definition.
[3] Based on United Nations Framework Convention on Climate Change (UNFCCC) definition.
[4] Based on The Economics of Ecosystems and Biodiversity (TEEB) definition.
[5] Based on U.S. Environmental Protection Agency (EPA) definition
[6] Based on United Nations Framework Convention on Climate Change (UNFCCC) definition.

1 Introduction

Durban, like many other cities around the world, is being challenged by the impacts of global climate change. It is projected that climate change will result in:

- Increased temperatures.
- Rising sea levels.
- Increased numbers of extreme weather events.
- Altered rainfall patterns and seasons.

These changes are already being experienced in Durban and have and will continue to result in a number of negative impacts for the city's residents, such as:

- Increased health problems (e.g. heat exhaustion).
- Decreased water availability (due to irregular rainfall).
- Decreased agricultural productivity.
- Increased flooding and soil erosion.
- Loss of biodiversity.
- Damage to infrastructure.

It is projected that Durban will experience an increase in the frequency of severe weather events in the future. Storms, such as the one depicted in the image below, result in extensive damage to houses, businesses, and municipal infrastructure.

What most people don't realise is that the building sector is responsible for over a third of global GHG emissions[7]. This is mostly due to the large amount of energy that is required to run buildings e.g. lighting, cooling, electrical appliances etc.

The building sector, however also has the greatest potential for reducing its contribution to climate change through sustainable building design and improved building management.

What is Climate Change?

Climate change is the increase in the average temperature of the earth's atmosphere, which produces changes in local weather patterns, and increases sea levels worldwide.

These increased temperatures are the result of Green House Gases (GHG) being emitted into the atmosphere, as a result of human activities, such as burning fossil fuels, waste production, and land-use change.

Flooding of the main promenade along Durban's "Golden Mile" (left) as a result of the large coastal storm in March 2007

(Source: EPCPD (2007), *Climate Change: What Does it Mean for eThekwini Municipality?*)

[7] Milford R. (2009), *Green House Gas Emission Baselines and Reduction Potentials from Buildings in South Africa*, Discussion Document for United Nations Environment Programme, South Africa.

What is a Carbon Footprint?

A carbon footprint is used to measure the impact of an activity or a person's day-to-day life on the environment, and in particular, on climate change. It measures the total amount of GHGs caused by an activity or a person's day-to-day activities through the burning of fossil fuels for electricity, cooling, transportation etc., and is generally measured in units of tonnes (or kilograms) of Carbon Dioxide (CO_2) equivalent.

One of the ways in which a building can reduce its carbon footprint is through the creation of a green roof habitat.

In addition, green roof habitats can also play an important role in providing "green infrastructure"[8] in the urban environment.

The aim of this guideline is to provide a step-by-step guide for creating a green roof habitat on your building, thereby transforming Durban's empty rooftops to green roof habitats. This would contribute positively to the creation of a healthier, more sustainable, and resilient urban area.

What is a Green Roof?

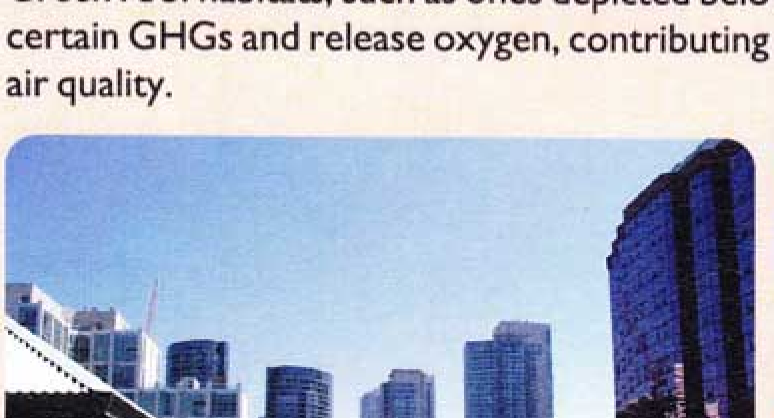
A green roof is the roof of a building which has been intentionally partially or completely covered with vegetation. Green roofs are also referred to as vegetated roofs, roof gardens, eco-roofs or living roofs.

This guideline will refer to green roofs as green roof habitats, as these vegetated roof tops can create space or habitats for birds, butterflies, and other insects, within urban areas.

An example of traditional buildings with green roofs in the Faroe Islands, Denmark (source: Erik Christensen).

It is estimated that ecosystems, such as oceans, forests, and grasslands, absorb 40% of CO_2 emissions from fossil fuels. However, changes in land-use and deforestation decrease the extent and functionality of these ecosystems, decreasing the amount of CO_2 that can be absorbed and increasing the amount of CO_2 emitted to the atmosphere. In addition, it is estimated that the processes of land-use change and deforestation are responsible for 20% of global GHG emissions.

Green roof habitats, such as ones depicted below, create natural ecosystems which can capture certain GHGs and release oxygen, contributing positively to global climate protection and local air quality.



The Mountain Co-op in Toronto shown on the left (source: www.mnn.com) and city hall in Chicago shown on the right (source: www.re-nest.com) are two of the best known green roofs in the world.

[8] Refer to quick definitions guide.

2 Green Roof Pilot Project

2.1 Background and introduction

The green roof pilot project (GRPP) is part of the eThekwini Municipality's Municipal Climate Protection Programme (MCPP). This programme was initiated in 2004 by eThekwini Municipality's Environmental Planning and Climate Protection Department (EPCPD) to better understand the vulnerability of the city to the impacts of climate change and to identify appropriate climate change adaptation and mitigation interventions.

The overall aim of the programme is to make Durban more resilient to existing and future climate challenges. Projections suggest that climate change will exacerbate the already high temperatures experienced in the city as a result of the 'urban heat island effect'[9] and increase levels of surface run-off and flooding that result from the hardening of permeable surfaces in the city[10].

The aim of the GRPP is to explore the potential benefits of green roof habitats in reducing temperatures and stormwater run-off, thereby enhancing the city's adaptive capacity. However, in comparison to cities around the world, such as Stuttgart, Singapore, Chicago, Toronto, Tokyo, Linz, and Montréal, where the use of green roofs is well developed, experience in the creation of green roof habitats in South Africa, and in Durban, is limited.

In addition, little or no primary research is currently being undertaken in South Africa on the benefits and complexities of green roof applications. One of the objectives of the GRPP is therefore to better understand how to create these green roof top habitats in Durban using local resources.

In order to achieve the goals of the GRPP, the following research questions are in the process of being investigated:

- The structural considerations and implications of green roof habitats.
- The advantages and disadvantages of different green roof systems.
- The types of growth media available and their characteristics.

- The suitability of a range of indigenous plants for green roof habitats.
- The extent to which green roof habitats can reduce stormwater run-off.
- The extent to which green roof habitats can reduce the temperature of buildings and the 'heat island effect'.
- The extent to which green roof habitats can contribute to food security.
- And most importantly, the extent to which green roof habitats promote biodiversity in the inner city.

The project was initiated in 2008 by eThekwini Municipality's Environmental Planning and Climate Protection Department (EPCPD) and is still on-going.

[9] See section 2.3.6 for more information on the 'urban heat island effect'.

[10] See EPCPD (2007), *Climate Change: What Does it Mean for eThekwini Municipality?* for more information.

2.2 Location and Design

The GRPP is situated on the roof of a building in the City Engineers Complex at 166 KE Masinga Road (Old Fort Road), Durban. As shown in the figures below, this roof was selected for the GRPP for the following reasons:

- It is a flat roof with easy access.
- The roof is highly visible to those that visit the City Engineers Complex.

The carrying capacity of the roof was assessed by a structural engineer and found to be suitable for the project. The entire area of the green roof habitat is approximately 550m².

The roof used for the GRPP consists of two flat slabs on either side of a raised arch.

The GRPP was divided into three areas, as shown in the image (below):

- Areas where a direct green roof system[11] was used (see section 4.2.1 for more information).
- Areas where a modular green roof system[12] was used (see section 4.2.2 for more information).
- And control areas[13].

Aerial view of the GRPP in 2009 showing location of areas where direct green roof systems were used (dark green), areas where modular green roof systems were used (light green), and control areas (red). The layout of the GRPP was amended in 2011 to allow for the testing of different edging for direct green roof applications.

2.3 Results

2.3.1 Structural Considerations

A structural engineer determined the carrying capacity of the roof selected for the GRPP prior to start of construction. The loading capacity of the roof was estimated to be between 100-150kg per m².

Modules to be used in the GRPP were weighed when fully planted and saturated with water in order to determine the load which would be placed on the roof structure.

The following weights were recorded, depending on the plants used:

Module depth (cm)	Weight (kg)	Weight per m² (kg)
7.5	15-25	80
10	30-40	85
20	40-50	90

[11] Is a roof system where the vegetation is not planted in containers or modules, but onto specially designed layers that are placed on top of the existing roof.

[12] Is a roof system where the plants are planted in portable containers or modules which together make up the green roof.

[13] Control areas were included in the GRPP so that the results of the project could be verified. These areas allow for the comparison of measurements from treated or green roof habitats and untreated or blank roofs.

It was not necessary to measure the loading weight of the direct green roof system as this was deemed to be similar to that of the modular green roof system, as the growing medium and growing medium depth would be the same for both systems.

Based on these results, the roof was determined to have adequate loading capacity for the GRPP.

For more information on structural considerations when creating your green roof habitat see Section 4.1.2.

Planted modules being weighed at the eThekwini Municipality's soil laboratory.

2.3.2 Growing Media

A number of locally available organic and inorganic growing media were investigated as part of the GRPP. These included vermiculite, perlite, potting mix, compost, Berea red sand, ash, crushed brick, and Light Expanded Clay Aggregate (LECA).

These media were weighed when dry and saturated to determine the resulting loading capacity. As shown in the table below, vermiculite and perlite were the lightest media, while crushed brick and Berea red sand were the heaviest.

Medium	Dry Weight per Litre (g)	Saturated Weight per Litre (g)
Perlite	174	461
Vermiculite	178	596
Potting mix	337	749
Compost	264	760
Ash	786	878
LECA	784	930
Brick crushed	1,200	1,400
Berea red sand	1,500	1,800

Saturated growing media being weighed at the eThekwini Municipality's soil laboratory (left) and saturated samples to be weighed (right).

Due to the loading capacity restrictions of the roof selected for the GRPP, specialised growing media were developed. Three combinations were tested at the start of the project:

1. A mixture of 60% compost, 20% vermiculite, and 20% perlite. With the exception of two areas, this medium was used on all green roof habitat areas.
2. A mixture of 50% Berea red soil, 20% compost, 15% vermiculite, and 15% perlite. This mixture was only used in one area.
3. Only potting mix. This mixture was only used in one area.

It was found that both mixtures 1 and 2 were successful in supporting plant growth. However, the mixture containing the Berea red sand was much heavier than the other media tested and as a result a shallower soil depth of between 5cm and 7cm had to be used. This is significant because soil depth is one of the most important factors effecting plant growth. Plants generally tend to do better in deeper soils. In comparison, the growing medium which contained only potting mix was found to be less successful in supporting plant growth. This is likely due to its high organic content.

For more information on choosing the correct growing media for your green roof habitat see Section 4.2.

2.3.3 Plants

As part of the GRPP, a broad spectrum of indigenous plant species were planted to determine which species are suitable for creating green roof habitats. The majority of these plants were sourced from within 50km of the project site, and are therefore considered to be locally indigenous.

In total, 81 indigenous plant species were tested. Of these,

- 37 were found to be suitable for creating green roof habitats.
- 44 were found to not be suitable for creating green roof habitats.

In general, most of the plant species which did not survive required more watering or space than could be provided on the roof. Water and space will be the key limiting factors for many green roof habitats. Some of the plant species which did not survive were also found to be more prone to pest infestations than others.

For more information on choosing the correct plants for your green roof habitat see Section 4.3.

2.3.4 Increasing Biodiversity

A key objective of the GRPP was to determine the extent to which green roof habitats can promote biodiversity in urban areas, and in particular the Durban city centre.

In order to determine what insects were being attracted to the GRPP, eight pan trays were placed at regular intervals on the green roof. These were half filled with water containing a small amount of dishwashing liquid[14]. The trays were left out for between three and seven days at a time, depending on the weather. Two pans were also set out at a parking area in the Durban Natural Science Museum grounds to act as controls. The pans were then drained through a strainer to separate the insects from the water. The collected insects were placed in collection bottles containing 70% ethanol to preserve them.

An entomologist from the Durban Science Museum identified the insects to their morpho-species (insects with different morphologies are considered to be different species).

The most recent survey period started on 26 October 2010 and ended on 07 February 2011. During this period, a large number of insects (2,898 in total) from several different species (nine orders of insects) were caught. Of this, only 24 insects were caught in the control trays.

For more detailed results on the biodiversity of the GRPP see Section 3.1.

2.3.5 Reducing Stormwater Run-off

Urban areas are dominated by hard and impermeable surfaces, from which there is substantial stormwater run-off. This increases the burden on existing stormwater management infrastructure, particularly during heavy rainfall events. A key objective of the GRPP was to determine the extent to which a green roof habitat can contribute to reducing stormwater run-off.

In the initial stages of the GRPP, a simple system was set up to collect and measure stormwater run-off. The system comprised rain gauges (placed on the north and south side of the GRPP) and two 250 litre barrels placed below each of the three rainwater outlets from the GRPP (six barrels in total). A dial stick was then used to measure the amount of rainwater collected in the drums. While this system could measure the effectiveness of the different areas of the GRPP in reducing the amount of stormwater run-off, it could not measure the effectiveness of the different areas of the GRPP in reducing the velocity of the stormwater run-off. EThekwini Municipality's Coastal, Stormwater, and Catchment Management Department then installed a more sophisticated system consisting of electronic tipping rain gauges (placed on the north and south side of the GRPP), water usage meters (placed on the north and south side of the GRPP), four water run-off loggers (three

Gaudy Commodore (*Precis octavia*) larvae feed on the *Crassula sarmentosa* planted on the GRPP (left). Mature butterfly (right).

[14] The dishwashing liquid breaks the surface tension of the water, preventing insects from escaping.

have been placed underneath different areas of the direct green roof system and one under the blank roof), and data loggers (situated on each of the water run-off loggers). This system was able to measure not only the amount of stormwater run-off from the different areas of the GRPP, but also the velocity of the stormwater run-off.

It was found that run-off from both the direct and modular green roof systems was significantly lower than the run-off from the blank roof. For more detailed results on the reduction of stormwater run-off from the GRPP see Section 3.2.

250 litre drums initially used to collect and measure stormwater run-off from GRPP (left). The barrels were later replaced with water run-off loggers to measure the amount and velocity of stormwater run-off from the GRPP (right).

2.3.6 Reduce 'Urban Heat Island Effect'

Another key objective of the GRPP was to determine the extent to which a green roof habitat can contribute to reducing the 'urban heat island effect' in Durban. The 'urban heat island effect' is a product of the hard concrete, brick, stone, and blacktop surfaces, which occur in cities and absorb and retain heat. These surfaces trap and store the sun's heat during the day, and release it back into the surrounding environment (see Section 3.3 for more information).

A number of temperature probes were installed in the following areas of the GRPP to measure air temperature fluctuations. Probes were placed:

- In a Stephenson screen above the GRPP to measure the ambient air temperature (see image on the right).
- Under the modules to measure the air temperature below the modular green roof system.
- Under the direct green roof system to measure the air temperature below the direct green roof system.
- In the roof membrane of the control area to measure the air temperature of a blank roof.
- On the surface of the direct green roof system to measure the air temperature above the direct green roof system.

It was found that air temperatures were significantly higher on the blank roof than temperatures below both the modular and direct green roof systems. Air temperatures below the two green roof systems were very similar to the ambient air temperature above the GRPP. It was also found that the air temperature above the direct green roof system was higher than the temperatures below both the modular and direct green roof systems, but not as high as the air temperature on the blank roof.

For more information on the cooling benefits of green roof habitats, as well as more detailed results from the GRPP, see Sections 3.3 and 3.4.

Temperature probe within a Stephenson screen to measure ambient air temperature above the GRPP.

2.3.7 Food Security

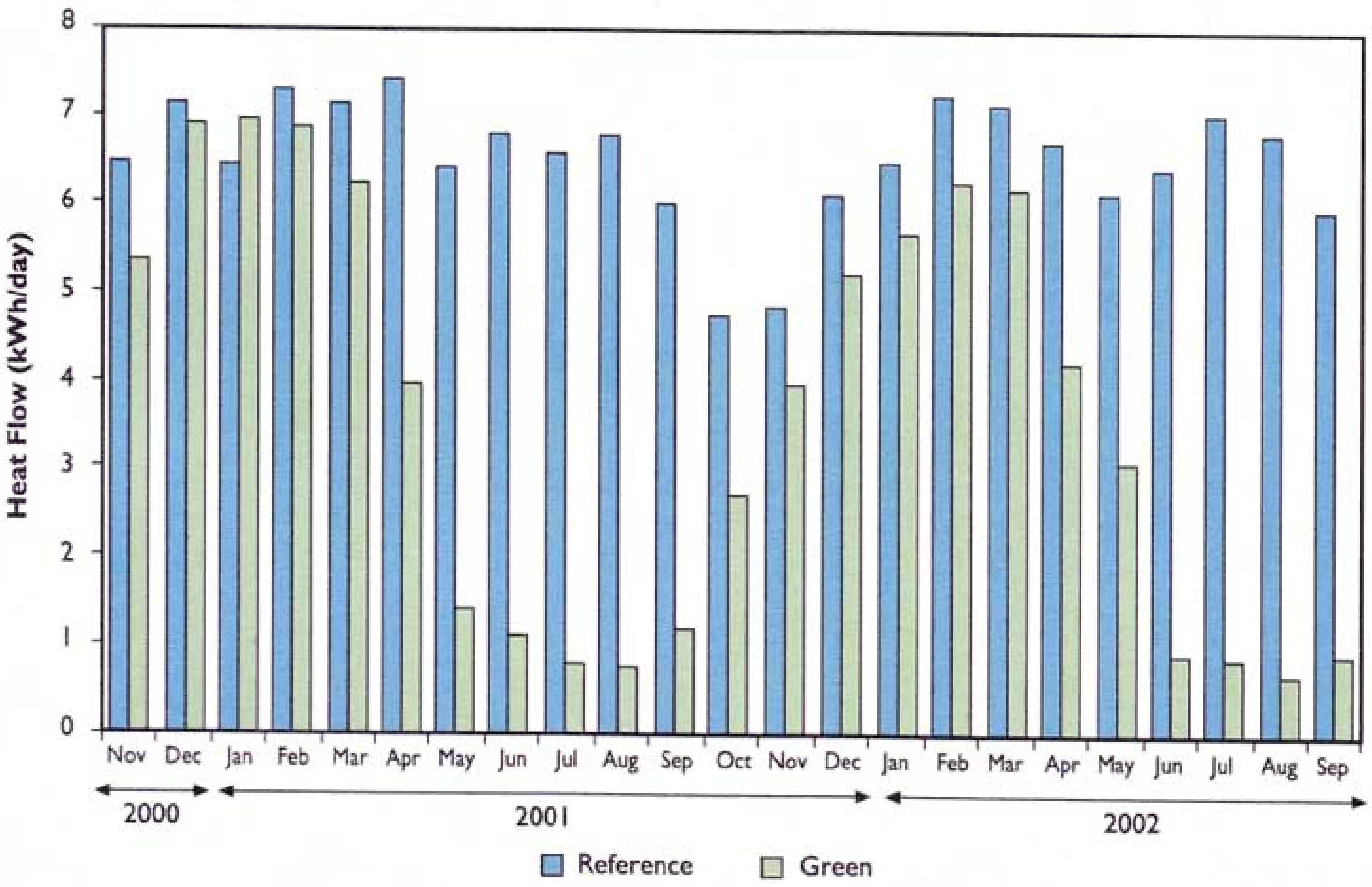
A key objective of the GRPP was to determine the extent to which vegetables can be grown on a rooftop, and thereby contribute to local food security.

A broad spectrum of vegetables were grown to test their suitability. This included eggplant, cabbage, tomato, cauliflower, lettuce, basil, spinach, nasturtium, green peppers, spring onion, chillies, and celery. With the exception of cabbage, cauliflower, lettuce, basil, nasturtium, and celery, all the other vegetables were grown successfully.

Vegetables were planted in 20cm deep modules in a growing medium containing only potting mix.

A study undertaken by Canadian researchers found that green roof habitats were very effective in reducing a building's energy demands[23].

The results show that a conventional roof (shown in blue in the figure below) absorbs solar radiation during the day, creating a high daily energy demand for cooling internal air spaces. In contrast, the growing medium and plants of a green roof habitat reduce the heat flow through the roof by providing shading, insulation, and evaporative cooling (shown in green below). It was found that the green roof habitat reduced the daily energy demand for cooling by 95% from 19.3 kWh or 7,080 British Thermal Unit (BTU) per m^2 for a building under a conventional roof to 0.9 kWh or 324 BTU per m^2 for a building under a green roof habitat.



Average daily heat flow through roof systems from 22 November 2000 to 30 September 2002

In addition, the study also found that a green roof habitat can reduce heat loss from a building by approximately 26% during the winter months, reducing the energy demand for heating from 44.1 kWh or 16,200 BTU per m^2 to 32.8 kWh or 12,120 BTU per m^2.

Studies in Germany have shown that a green roof habitat can decrease the ambient temperature in underlying rooms by 3-4°C [24].

3.4 Reducing the 'Urban Heat Island Effect'

As mentioned earlier, Durban experiences high temperatures and high levels of humidity in the summer months. This situation is exacerbated in the city centre where there is a higher surface area of heat absorbing materials, such as concrete, asphalt, and steel, than the surrounding countryside. These materials act as a heat sink, resulting in higher temperatures than would otherwise be the case. This is known as the 'urban heat island effect'.

Green roof habitats can significantly reduce the temperature of a rooftop by providing shade, insulation and evaporative cooling, thereby contributing to the reduction of the 'urban heat island effect' in the inner city.

[23] Liu K. and Baskaran B. (2003), *Thermal Performance of Green Roofs Through Field Evaluation*, NRCC-46412, National Research Council, Ottawa.

[24] Porsche U. and Köhler M. (2003), *Life Cycle Costs of Green Roofs: A Comparison of Germany, USA, and Brazil*, Paper presented at the World Climate & Energy Event, Rio de Janeiro.

The study also showed that if the following benefits of a green roof habitat are factored in, the additional costs of establishing a green roof are significantly offset:

- More than doubles the lifespan of the roof.
- Reduces heating and cooling costs in the building.
- No loss of space for detention pond or disruption during construction period.
- Potential to increase rental due to more aesthetically pleasing work environment.
- Social benefits, such as greater worker productivity.

Germany has started introducing tariffs for stormwater run-off which accumulates on impervious surfaces, such as roof tops. Studies have shown that a green roof habitat with a soil depth of 10cm can reduce annual stormwater run-off by as much as 50%, thereby effectively halving the amount of run-off, which would be subject to annual fees, from the roof [21].

3.3 Reducing Temperature Inside Buildings

Durban experiences a sub-tropical climate with high temperatures and high levels of humidity, particularly in summer. Buildings in Durban are generally energy intensive, requiring high volumes of electricity for cooling. This is often the result of poor building design, that is, architectural design has not allowed for the free movement of air or ventilation through the building. Projections suggest that climate change will exacerbate the already high temperatures in Durban, increasing the need for and use of energy intensive cooling systems, such as air conditioning.

Green roof habitats can reduce the demand for energy intensive cooling of the inside of buildings, and hence GHG emissions[22], through direct shading of the building, through evapo-transpiration, and improved insulation.

How does evapo-transpiration cool the inside of a building?

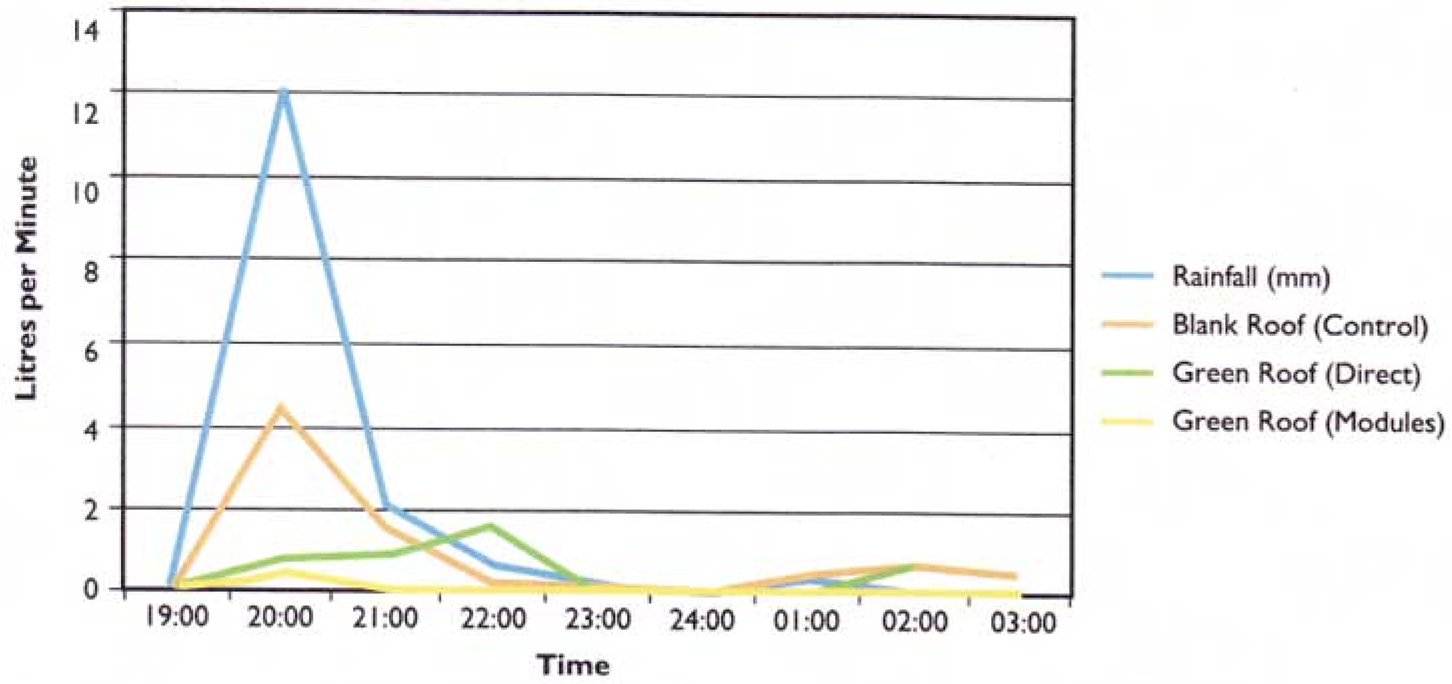
Evapo-transpiration occurs when water from the leaves, stems, flowers and roots of plants have sufficient heat or energy to turn to vapour. As the faster moving water molecules break free and rise up into the atmosphere, the slower moving molecules remain behind. This process results in a cooling of plants, and thus the surrounding environment.

Green roof habitats, such as the one on the building of the Master Builders Association (left) and the GRPP (right), have the potential to significantly reduce the temperature inside the buildings.

[21] Porsche U. and Köhler M. (2003), *Life Cycle Costs of Green Roofs: A Comparison of Germany, USA, and Brazil,* Paper presented at the World Climate & Energy Event, Rio de Janeiro.

[22] The majority of South Africa's electricity is generated by coal-powered fire stations which release large amounts of CO_2 into the atmosphere. Reducing the use of electricity reduces the amount of electricity which must be generated and therefore the pollution of the atmosphere.

Results from the GRPP indicate that green roof habitats can significantly reduce stormwater run-off from a roof top. As shown in the below graph, the peak flow from a green roof habitat (green and yellow) is far lower than that of a blank roof (orange) during a rainfall event.



Comparison of rainfall run-off from the green roof and blank roof from 19:00 on 13 February 2010 to 03:00 on 14 February 2010

This significantly decreases the amount of stormwater that discharges into the stormwater system, and therefore the rivers at any one time, reducing the risk of flooding, damage to property, and possible loss of life.

It is important to note that the green roof habitat also substantially delays the peak run-off. It holds back the stormwater and releases it slowly over a longer period of time. This reduces the pressure on stormwater infrastructure during heavy rainfall events.

The ability of green roof habitats to attenuate stormwater can also provide a cost saving for new developments. The eThekwini Municipality's Coastal, Stormwater and Catchment Management Department require that all new developments attenuate stormwater run-off on site to ensure that post-development stormwater run-off levels do not exceed pre-development stormwater run-off levels. Green roof habitats can potentially offset the cost of constructing expensive on site stormwater attenuation features, such as concrete attenuation tanks or attenuation dams, by reducing the amount and rate of run-off.

American researchers compared the costs of constructing a green roof habitat, such as the one shown below on the left, to attenuate stormwater run-off, as an alternative to an underground stormwater attenuation tank, such as the one shown below on the right[19].

Examples of a green roof habitat (source: www.glasscityjungle.com) and underground stormwater attenuation tank (source: www.hamilton-co.org).

The study showed that the initial cost of constructing a green roof habitat is 45% more than the detention vault (R125 per square foot vs. R85 per square foot)[20]. The annual maintenance costs of a green roof habitat are however 25% lower than that of a detention vault (R60,000 vs. R80,000).

[19] Source: www.epa.gov/region8/greenroof.

[20] Cost estimations have been converted to rand values based on exchange rate of R8 to $1.

Creating habitat or refuges for biodiversity is only one of a suite of very important ecosystem services which green roof habitats can provide us with.

What are Ecosystem Services?

Ecosystems services refer to the direct and indirect contributions of ecosystems to human well-being. The suite of services provided by ecosystems can be grouped into four broad categories:

- Provisioning services e.g. food, water, wood and fibre etc.
- Regulating services e.g. climate regulation, flood regulation, disease control etc.
- Cultural services e.g. aesthetics, spiritual, educational etc.
- Supporting services e.g. nutrient cycling, soil formation etc.

Green roof habitats can for example provide the following services:

Provisioning Services (Products obtained from ecosystems)

- Food e.g. vegetables
- Natural medicines
- Ornamental resources
- Maintenance of genetic diversity

Regulating Services (Benefits obtained from regulation of ecosystem services)

- Improve air quality e.g. pollution
- Global and local climate regulation e.g. reduce 'heat island effect'
- Water regulation e.g. attenuate stormwater run-off
- Pollination

Cultural Services (Non-material benefits obtained from ecosystems)

- Aesthetic values
- Inspiration
- Social relations
- Sense of place
- Educational
- Cultural heritage values

Supporting Services (Processes which support provisioning, regulatory and cultural services)

- Provision of habitat e.g. birds, butterflies, etc.
- Production of atmospheric oxygen
- Primary production e.g. photosynthesis
- Water cycling

Ecosystem services that green roof habitats could potentially supply (adapted from Millennium Ecosystems Assessment 2005)

Some of these ecosystem services are discussed further in more detail.

3.2 Reducing Stormwater Run-off

Cities generate a substantial amount of accelerated stormwater run-off as a result of large areas of impervious surfaces, such as roof tops and roads. This is channeled into the city's stormwater drainage system, from which it is discharged into rivers or the sea. In the case of Durban, this can result in the capacity of the city's stormwater drainage systems being exceeded, resulting in the flooding of rivers and streams, and possible destruction of property and loss of life.

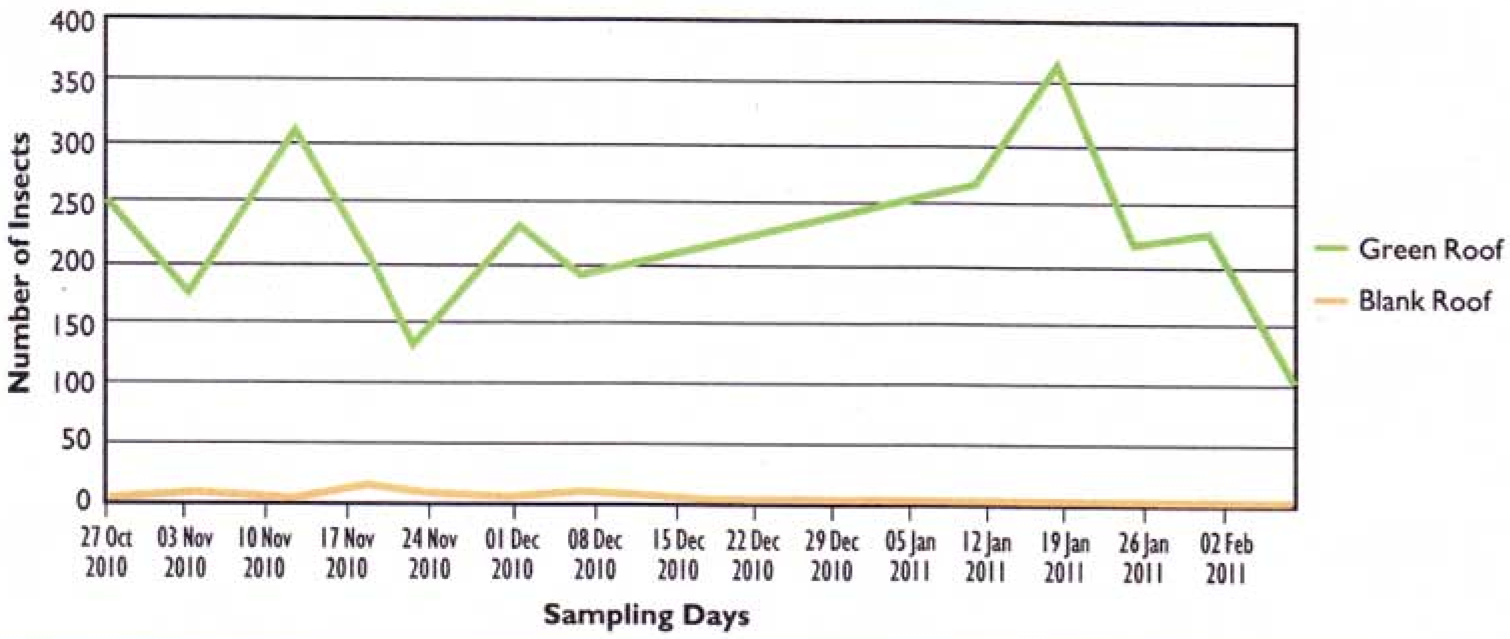
Projections suggest that climate change will exacerbate this situation by increasing the frequency and intensity of rainfall events. This can result in extensive flooding and possible damage to houses, businesses, and municipal infrastructure, as depicted below.

Green roof habitats can capture and absorb rainwater, thereby reducing, and delaying stormwater run-off from roof tops.

Several small towns on the KwaZulu-Natal south coast were flooded in June 2008 when heavy rainfall resulted in a number of rivers overflowing (source: John Gore).

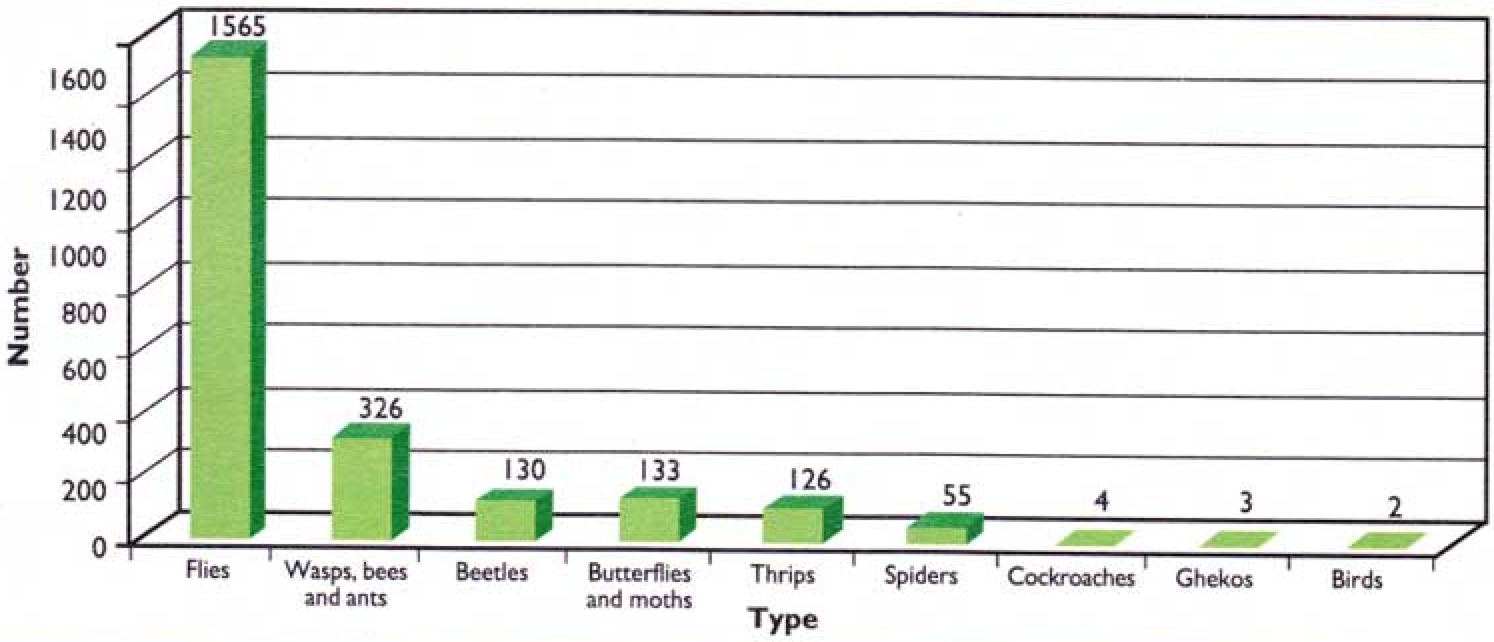
The GRPP found that green roof habitats have significant potential to bring biodiversity back into urban areas, and in particular, the city centre.

In the GRPP, a total of 2,898 insects were caught during the survey period. Of these, 2,874 were caught on the green roof and 24 were caught in the control area. The average catch on the green roof for each of the sample periods was 221 insects, with the highest catch on a single day being 365 insects (18 January 2011 below). In contrast, the average catch on the blank roof (control area) was 2 insects, with the highest catch on single day being 11 insects (16 November 2010 below).



Total number of insects caught on the green roof and on the control area between 27 October 2010 and 02 February 2011.

As shown in the figure below, a total of 66 different insect species were caught on the green roof. This included flies, wasps, beetles, ants, butterflies, moths, true bugs and thrips. It is interesting to note that the presence of true bugs and butterflies indicates that a relatively healthy ecosystem is starting to develop on the green roof.



Types and numbers of individuals caught on the green roof during survey period.

This does not mean that only insects will be attracted to your green roof habitat. A number of birds, such as those shown below, have been recently seen on the green roof. Many of these birds, such as the Paradise fly-catcher, are attracted by the insects, their main source of food.

Paradise fly-catcher (left), White-Breasted Sunbird (centre), and Black-eyed Bulbul (right) (source: www.birdforum.net).

This project has shown that it is important to use a diverse choice of plants as this will attract a greater variety of insects and birds.

3 Why Create Green Roof Habitats?

3.1 Creating Habitats for Biodiversity

Durban is situated in the middle of a biodiversity "hotspot". This is a term that is used to describe areas that have the richest, but also the most threatened collection of plant and animal life on earth. In Durban alone, there are over 2,000 plant species[15], 82 terrestrial mammal species, and 380 species of birds. There are also 69 species of reptiles, 25 endemic invertebrates, and 37 frog species[16].

Biological biodiversity is under threat from a range of factors, including habitat loss, exploitation of species, climate change, and the spread of invasive alien species. In 2007, it was estimated that more than 60% of the 2,000km^2 eThekwini Municipal Area (EMA) had been transformed by urban development and agriculture and that a number of ecosystems were, and still are, under serious threat[18].

One way of bringing biodiversity back into the urban areas, and in particular the city centre, is through the use of empty rooftops to create green roof habitats. There are a number of large, flat and empty rooftops throughout Durban which could be developed into a network of green spaces, providing important natural habitats for birds, reptiles and insects. It is not only large buildings in the city centre, however, which could be used to create green roof habitats. The roofs of most houses and outbuildings in the suburban areas could also potentially be used to create habitats that will attract interesting and unusual wildlife.

Green roof habitats create open spaces or areas of natural habitat within the city centre which can attract interesting creatures, such as butterflies, millipedes, frogs, lizards, and birds. These habitats can also play an important role in providing green "stepping stones" between fragmented open spaces in urban areas. The figure on the right shows how these stepping stones could help create green corridors between large open spaces, encouraging the movement of mobile species, such as birds and insects. Also shown is the extent to which green roof habitats can potentially increase the net coverage of open spaces within the city centre.

What is Biodiversity?

Biodiversity, or biological diversity, refers to variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part. This includes diversity within species, between species and of ecosystems[17].

Biodiversity can be used to measure the health of a region where greater biodiversity implies greater health.

Biodiversity could be seen as the engine which drives the provision of ecosystem services, such as food, safe drinking water, and clean air - which contribute to human well-being. Losses in biodiversity and changes in ecosystem services can thus result in declining human well-being, and even exacerbate poverty.

(Source: Myles Mander)

Aerial view of the Durban city centre near South Beach with potential green roof habitats superimposed (adapted image from www.skyimaging.co.za).

[15] According to PRECIS (2007).

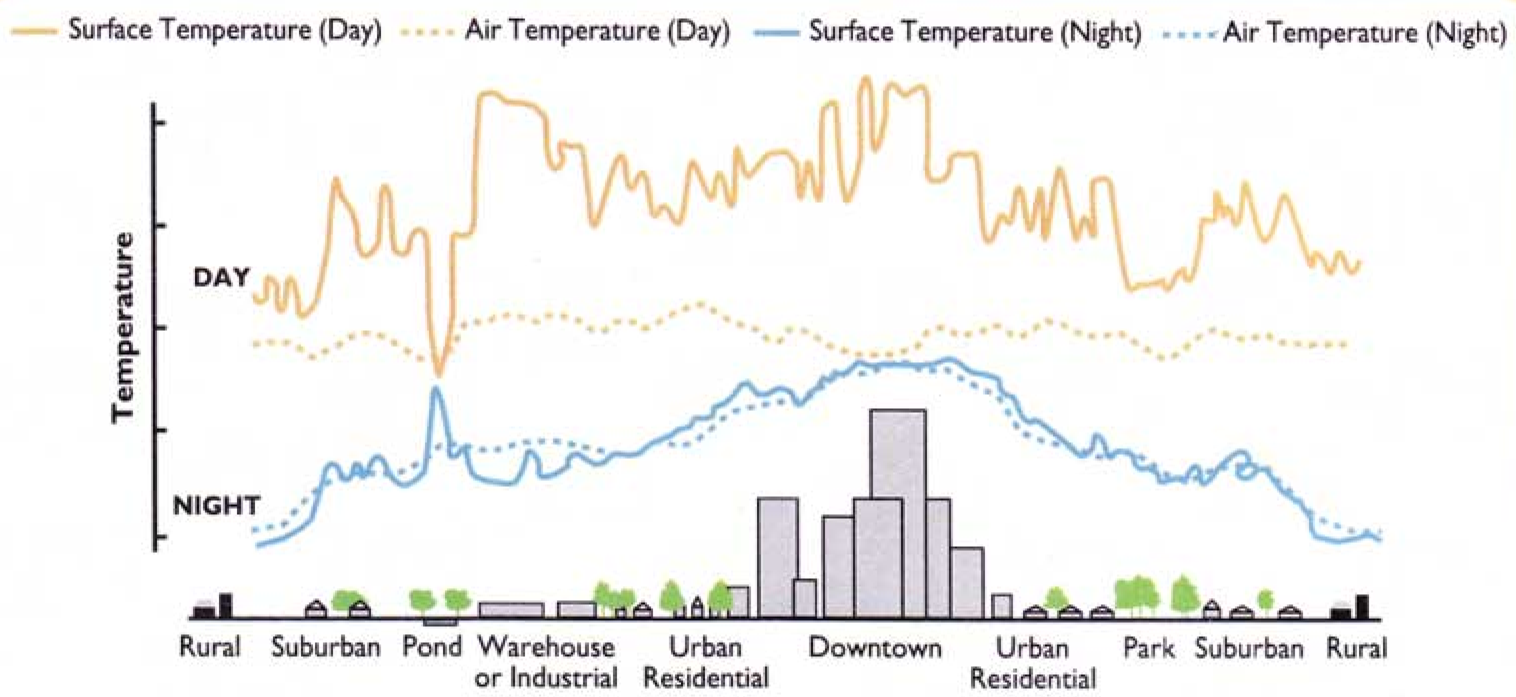
[16] EThekwini Municipality (2007), *Biodiversity Report 2007*. Local Action for Biodiversity.

[17] See United Nations Convention on Biological Diversity (CBD) at www.cbd.int for more information.

[18] EThekwini Municipality (2007), *Biodiversity Report 2007*. Local Action for Biodiversity.

What is the 'Urban Heat Island Effect'?

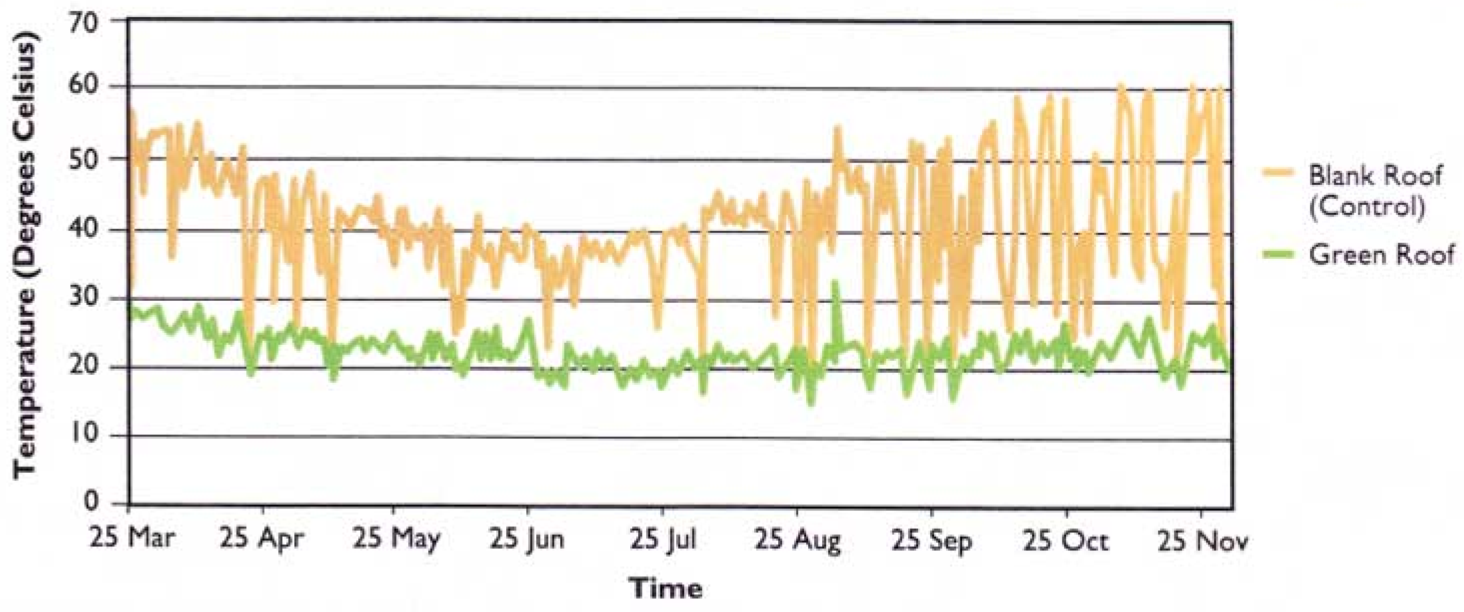
This is a phenomenon where urban areas experience higher temperatures than the surrounding countryside. On average, temperatures can be between 5°C and 15°C higher in urban areas than in rural areas. This effect is caused primarily by the change in landcover from green open spaces to buildings, roads and other infrastructure which absorb solar radiation during the day and release it as latent heat during the night (see figure below).



Increase in day and night time air and surface temperatures as you move from the rural areas to the urban areas (source: www.epa.gov.za).

Projections suggest that climate change will exacerbate the already high temperatures in Durban, contributing significantly to the city's existing 'urban heat island effect'.

Results from the GRPP show that green roof habitats can significantly reduce ambient air temperatures. Temperature readings taken above the green roof (shown in green below) were found to be considerably lower than temperatures taken above the blank roof (shown in orange below). The average ambient air temperature above the green roof and blank roof was 22°C and 41°C respectively from 24 March 2009 to 24 November 2009.



Average temperature readings taken on blank and green roofs from 24 March 2009 to 24 November 2009. All temperature readings were taken at 13:00.

On average, there was an 18°C temperature difference between the green roof habitat and blank roof from March to November 2010. However, on 28 November 2010, the difference in ambient temperature above the green roof (24.2°C) and the blank roof (60.4°C) was 36.2°C.

It was also found that the green roof habitat reduced or moderated daily temperature fluctuations. On average, there was a 2.7°C fluctuation in ambient temperatures above the green roof habitat with a maximum difference in temperature between the lowest and highest reading of 17.6°C. In contrast, the average fluctuation in ambient temperatures above the blank roof was 9.8°C, with a maximum difference in temperature between the lowest and highest reading of 45.6°C.

Thus, there exists a significant opportunity to reduce the 'urban heat island effect' in Durban by creating green roof habitats on empty roof tops. This refers not only to empty roof tops in the city centre, but also densely developed suburban areas.

3.5 Extending the Life of Roofs

Conventional roofs, such as those covered by bitumen, asphalt, or gravel, deteriorate over time due to extreme temperature fluctuations (see Section 3.4), the negative impact of ultraviolet light, and exposure to wind, rain and hail. In general, roof replacement is required every 20 years.

European studies show that green roof habitats can easily double the life span of a conventional roof by reducing temperature fluctuations and exposure of the roof surface to ultraviolet light, wind, rain, and hail. This results in reduced maintenance costs. It also decreases the disruption to building users during maintenance work and the amount of waste material that needs to be disposed of at a landfill site [25].

A study by German researchers compared the life cycle costs of different roof types[26].

Comparison of the lifecycle costs of bitumen, gravel, and extensive green roof systems

Type of Roof	Construction (R/m²)	Repair intervals (yrs)	Renovation intervals (yrs)	Renovation cost during life span (R/m²)	Disposal (R/m²)	Total (R/m²)
Bitumen	320 [27]	10	15	(6 x 320) 1920	160	2,560
Gravel	400	15	15-20	(5 x 400) 2000	200	2,360
Extensive green roof habitat	680	-	Occasional	320	160	1,480

As shown in the table above, over a 90 year period, the total cost of an extensive green roof habitat is the lowest at R1,480 per m². In comparison, gravel roofs, such as the one shown below on the left, cost 60% more than a green roof habitat. Bitumen roofs, such as the one shown below on the right, cost 70% more than a green roof habitat.

Example of a typical gravel roof (source: www.johnwaderoofing.com) and a typical bitumen roof (source: www.patentroofing.com).

It is important to note that while the construction costs of gravel and bitumen roofs are substantially lower than that of a green roof habitat (70% - 225)%, the renovation costs over the lifecycle of the roof are significantly higher (500% - 600%).

[25] Peck S. and Kuhn M. *Design Guidelines for Green Roofs*, http://www.cmhc-schl.gc.ca/en/inpr/bude/himu/coedar/upload/Design-Guidelines-for-Green-Roofs.pdf

[26] Porsche U. and Köhler M. (2003), *Life Cycle Costs of Green Roofs: A Comparison of Germany, USA, and Brazil*, Paper presented at the World Climate & Energy Event, Rio de Janeiro.

[27] Cost estimations have been converted to rand values based on exchange rate of R8 to $1.

3.6 Reducing Air Pollution

Air pollution is generally concentrated in densely populated urban areas, particularly where there is heavy industry or large numbers of motor vehicles (see images below). These anthropogenic sources of pollution introduce pollutants, such as Sulphur Oxides (SO_X), Nitrogen Oxides (NO_X), Carbon Monoxide (CO), Carbon Dioxide (CO_2), Volatile Organic Compounds (VOC), and Particulate Matter (PM) into the air, which can be harmful to human health and the environment. Poor air quality can result in a number of health effects, including difficulty in breathing, coughing, and aggravation of existing respiratory and cardiovascular conditions.

Vehicle exhaust fumes (source: www.sciencedaily.com) and industrial emissions (source: Michael van Niekerk) are two of the main sources of air pollution in many cities.

Some types of pollutants, such as Carbon Dioxide (CO_2), Nitrous Oxide (NO_X), and Methane (CH_4) also contribute to global warming and climate change.

Studies, such as the ones presented below, have shown that vegetation is relatively effective in removing pollutants and GHGs from the air. It does this by trapping the fine, airborne particles on the moist surfaces of the leaves. Rain then washes the trapped particles into the soil. Plants also absorb gases, such as CO_2, during photosynthesis, while at the same time releasing oxygen (O_2). Green roof habitats can therefore play an important role in improving air quality.

Canadian researchers estimate that each square metre of green roof habitat can remove ± 200g of PM from the air each year[28]. Based on this research, a green roof habitat of 6m^2 can absorb roughly the amount of PM that one passenger vehicle will emit in a year[29].

Similarly, a modeling exercise undertaken in Washington DC, examined the air quality benefits of establishing green roof habitats on 20% of the total roof surface of buildings with a roof surface of greater than 930m^2. It was estimated that green roof habitats would cover about 2 million m^2 and remove 6 tonnes of Ozone (O_3) and almost 6 tonnes of PM annually. This is equivalent to what could be absorbed by about 25,000 to 33,000 street trees.

A study was recently undertaken by American researchers to determine the carbon storage potential of an extensive green roof habitat (i.e. shallow green roof)[30]. Several plots were established with substrate depths ranging from 2.5 - 12.7cm. All the plots were planted with *Sedum* species, which is typically used for green roof habitat applications in the USA. The results from the two year study showed that on average, the extensive roof system sequestered 0.38kg of carbon per m^2 in the above and belowground plant material, and substrate organic material.

If the above findings were applied to the GRPP, the 550m^2 green roof habitat would:

- Remove annually, approximately 100kg of PM, which is roughly equivalent to that emitted by 92 passenger vehicles in a year.
- Sequester approximately 209kg of carbon over a two year period[31]. This is equivalent to the carbon that one passenger vehicle will emit in approximately four months[32].

[28] Wong E. (2008), *Reducing Urban Heat Islands: Compendium of Strategies*, U.S. Environmental Protection Agency, Washington.

[29] This estimate is based on a passenger car that travels an average of 20,000km p.a. and emits on average 0.1g of PM per km.

[30] Getter K.L., Rowe D.B., Robertson P., Cregg B.M. and Andersen J.A. (2009), Carbon Sequestration Potential of Extensive Green Roofs, *Environmental Science & Technology*, 43 (19), pg 7564–7570.

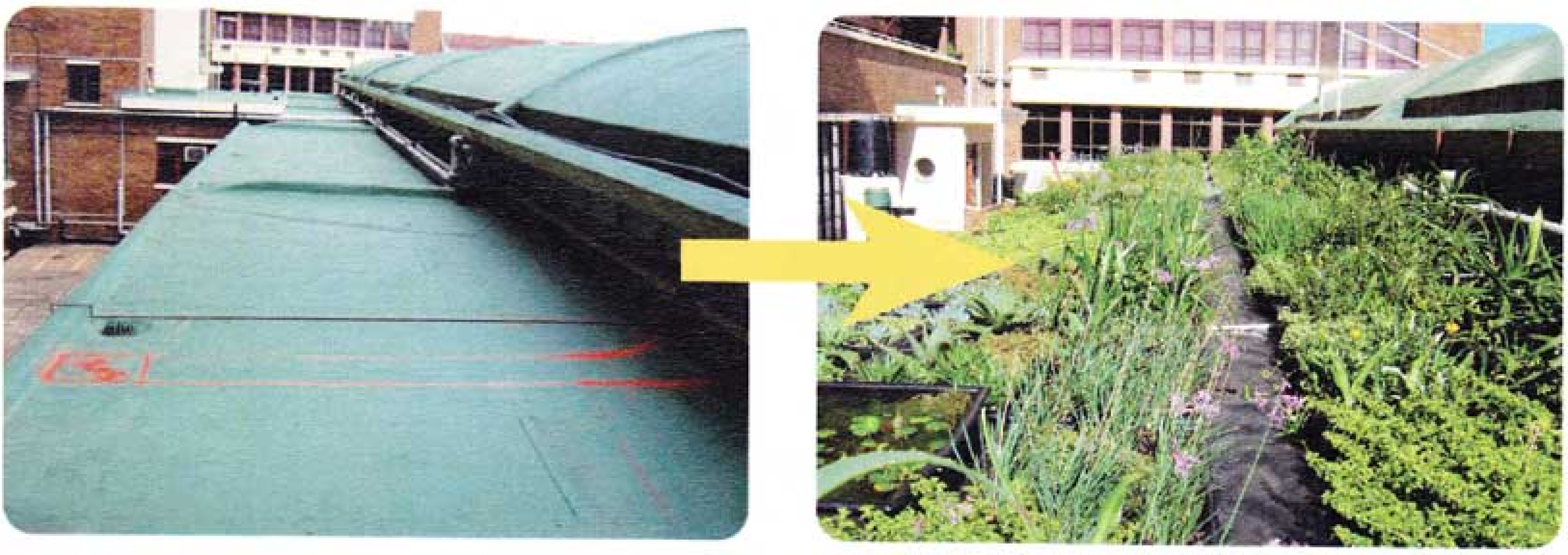
[31] Note that these are estimations used for illustrative purposes. The potential of a green roof to sequester carbon is dependent on a number of factors, such as climate, soils, condition, and plant species, and therefore varies widely.

[32] This estimate is based on a passenger car that travels an average of 20,000km per year or 1,666km per month, and emits on average 120g of CO_2 or 33g of carbon per km.

3.7 Improve Working and Living Environment

Green roof habitats can greatly improve the working and living environment in the inner city by bringing back nature and breaking the monotony of concrete buildings, asphalt roads, and empty roof tops.

Several studies have shown that green spaces, in the inner city such as green roof habitats, can play an important role in reducing stress, anxiety, and depression of the people living and working in the city.



The GRPP can be used to illustrate the positive effect that a green roof habitat can have on the aesthetics of a building, where the bare roof on the left has been converted to an attractive green roof habitat as depicted on the right.

Dutch researchers looked at the health records of 350,000 people across the Netherlands to determine the effect of green spaces on the annual rates of 24 major physical diseases[33].

The study found that people living closer to green spaces (less than 1 kilometre) had lower rates of 15 of 24 diseases, and in particular, anxiety disorders and depression. Researchers think green spaces have contributed to this by helping people recover from stress and by providing an important space for social interaction.

Studies have also shown that introducing plants into the work place can improve the aesthetics of the working environment and also worker productivity.

This is because employees feel happier, more relaxed, and more motivated with plants around them, improving their productivity.

Norwegian researchers looked at the effect of indoor plants on well-being and health of workers[34].

The study found that levels of complaints were significantly lower among workers that had plants on their office tables. The researchers attributed these results to a combination of the improved air quality in the office and to the positive psychological effects of bringing people in contact with nature.

In another study, an American researcher looked at the effect that the view from a window has on well-being and health[35]. The study found that patients with a view of nature from their window generally had shorter post-operative hospital stays, required fewer injections of strong pain reducing drugs, and tended to have fewer minor post-surgical complications, such as persistent headaches or dizziness, than those that looked out onto a brick wall.

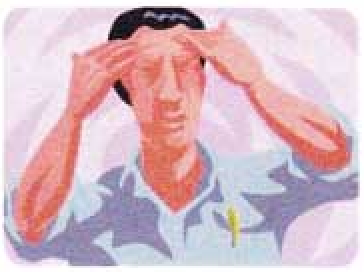
These results indicate that the presence of a green roof habitat could play a role in improving the health of workers.

[33] Maas J (2009), *Vitamine G: Effecten van Groene Ruimte op Gezondheid,* Welbevinden en Sociale Veiligheid.

[34] Fjeld T. and Bonnevie C. (2002), *The Effect of Plants and Artificial Day-Light on the Well-Being and Health of Office Workers, School Children, and Health Care Personnel.*

[35] Ulrich R. (1984), View Through a Window May Influence Recovery from Surgery, *Science*, 224: 420-421.

3.8 Reducing Noise Pollution



Ambient noise levels in the inner city are generally very high due to a concentration of industry, business, traffic and people. In this context, noise can be defined as any unwanted sound, such as hooting, sirens, or shouting. Combined, these make the inner city a very noisy working and living environment, both indoors and outdoors.

Plants can act as noise buffers, reflecting and absorbing part of the sound. For example, dense vegetation can reduce noise levels by up to 5 dB for every 30m of vegetation, up to a maximum reduction of 10 dB.

Green roof habitats could therefore play an important role in absorbing and dampening the ambient noise levels in the city centre, as well as, in office complexes, dense housing developments, and industrial zones.

Researchers from Germany have tested the noise insulation properties of green roof habitats[36].

The study found that insulation of the building from airborne sound improves as the thickness of the green roof habitat increases. The study also found that green roof habitats can reduce noise levels by 2 -3 dB compared to a gravel roof. A green roof habitat with a substrate depth of 20cm can, for example, improve sound absorption by up to about 46 dB.

Green roof habitats therefore provide an excellent opportunity to insulate buildings located in noisy areas, such as near airports.

3.9 Providing Food Security

Food security refers to the availability of basic foods and how accessible they are. For many of the residents of Durban, this is one of their greatest challenges - it is estimated that 15% of households in Durban do not earn enough money to pay for food[37].

Projections suggest that climate change will exacerbate this situation as agriculture is very sensitive to changes in temperature, rainfall patterns, and extreme weather events. It is likely that changes in agriculture will result in food shortages in some areas, increasing the cost of foods, which need to be imported from other areas. This decreases the accessibility of basic foods for poorer communities, threatening their food security.

The response of Durban, and many other cities, has been to promote urban agriculture as a means of ensuring local food security. This allows people to grow their own food, making them less susceptible to changes in commercial food availability. The problem is that there is very little open space for agriculture in the city centre and surrounding suburban areas. This is where empty rooftops can be used, not only for creating a network of green open spaces, but also for urban agriculture, thereby contributing to local food security.

The green roof or roof top garden depicted in the images above was created on the roof of a home in the suburb of Glenwood, in Durban. A number of fruits, vegetables, and herbs have been successfully grown for several years, including tomatoes, cabbage, spinach, lettuce, green peppers, spring onion, eggplants, cowpeas, amadumbe, and chillies.

[36] Porsche U. and Köhler M. (2003), *Life Cycle Costs of Green Roofs: A Comparison of Germany, USA, and Brazil*, Paper presented at the World Climate & Energy Event, Rio de Janeiro.

[37] EThekwini Municipality (2011), *eThekwini Quality of Life Household Survey 2009-2010.*

One of the objectives of the GRPP is to assess the feasibility of establishing urban agriculture on Durban's roof tops. In total, 10m² of the GRPP was planted with vegetables and herbs. A number of different vegetables and herbs were tested, including:

Eggplant	Cabbage	Tomato
Cauliflower	Lettuce	Basil
Spinach	Nasturtium	Green peppers
Spring onion	Chillies	Celery

Spinach and spring onion were found to be relatively successful green roof plants.

With the exception of cabbage, cauliflower, lettuce, basil, nasturtium, and celery, all the other plants were relatively successful as high yield, low maintenance crops.

The cabbages, for example, did not do well because they were attacked by cabbage worm (see image on right). While an insecticide could have been used to remove these pests, the decision was taken at the start of the GRPP to avoid where possible the use of chemicals.

Cabbage was found to be prone to pest infestations which makes them relatively unsuitable as a green roof plant.

The following table presents the amount of vegetables harvested from the 10m² of the GRPP planted with vegetables between June 2010 and January 2011, as well as, the approximate retail value.

Vegetable	Weight (Kg)	Retail cost (R/Kg)	Total savings (R)
Spinach	14.6	10	146
Tomato	22.2	11	244
Green pepper	2	17	35
Chillies	1	25	25
Eggplant	2.2	20	44
Spring onion	1.4	50	70
Total:			R564.00

In total, approximately R564 worth of vegetables was harvested from the GRPP. This represents potential savings or a source of income for the household.

4 How to Create a Green Roof Habitat

4.1 Getting Started

4.1.1 Structural Considerations

The very first step towards creating a green roof habitat is to determine whether or not your existing roof can accommodate the additional weight. People tend to underestimate the weight of the linings, substrate, and the plants needed to create a green roof habitat, including the weight of the green roof habitat when water-logged.

It is therefore highly recommended that a structural engineer is consulted to determine the load bearing or carrying capacity of the existing roof as this will determine the type, size and design of the green roof habitat. If, however, your building is yet to be built, ensure that the engineers/architects have accommodated the need for extra weight loading in their design.

The loading capacity of the roof for the GRPP was determined by a structural engineer to be between 100 and 150kg per m^2. The roof was therefore able to safely accommodate the estimated weight of 80 - 90kg per m^2 for the proposed green roof habitat with a depth of 10 - 20cm.

4.1.2 Safety Considerations

It is important that strict safety considerations are taken into account during the planning and construction of the green roof habitat, to protect against damage to property, human injury, or possible loss of life. This includes the following:

Fire:

Green roof habitats can potentially be a fire hazard if they have not been constructed properly or if they are not being adequately maintained. For example, a green roof habitat planted with succulents is less flammable than a green roof habitat planted with grasses which die back in winter. Fires can also be prevented by removing potential sources of ignition. For example, smoking should not be permitted near or on the green roof habitat.

It is also recommended that fire fighting equipment be situated near your green roof habitat. This will help to minimise the spread and intensity of the fire within the building and spread of fire to other buildings. It is important to allow a 50cm to 1m walkway around your green roof habitat to act as a fire-break and to allow access for fire fighting. This pathway can then also be used for future maintenance.

Access and Fencing:

If the green roof habitat has been designed for public use, then safe and easy access to the roof must be provided, as per relevant safety regulations. For example, it is a requirement of the National Building Regulations that the stairways or ladders up to your green roof permit the safe movement of people. The regulations also require the edge of a flat roof be designed to prevent people from falling off. A fence should therefore be erected along the perimeter of the rooftop as a preventative measure.

There should also be adequate warning signs and a liability disclaimer on the rooftop. It is also recommended that you notify your insurance company of your intention to allow staff or visitors onto the roof top.

4.1.3 Roof Slope

The pitch (or angle) of the roof is an important consideration. If it is too great (i.e. more than 10°) the substrate materials tend to slip/slump, and water tends to run-off too quickly. While it is possible to construct green roof habitats on steep roofs with a pitch of up to 70°, or on vertical walls, specifically designed systems have to be used. If, however, the roof is too flat, water tends to pool, leading to root rot and damage to plants.

The ideal roof for a green roof habitat should therefore have a slight angle of between 3° and 10°. The roof used for the GRPP was relatively flat (approximately 3°), which meant that the drainage system needed to be effective in preventing rainwater from pooling.

4.1.4 Location

Any roof, whether it is only a few square metres or several hundred square metres in area, will have a range of micro-climates on it. The choice of which plants to place where on the roof needs to respond to these different micro-climate zones in order to achieve optimal plant growth rates, minimise watering and maintenance, and curtail plant death rates. The location of the roof will therefore influence both the design and selection of plants.

As shown in the images above, the green roof habitat at the Master Builders Association building in Westville (a suburb of Durban) is situated adjacent to a large glass wall, which reflects sunlight onto the green roof habitat, creating very hot conditions. As a result of the high temperatures, only plants resistant to drought and high temperatures, such as succulents, can be used.

The table below lists elements which must be considered when identifying micro-climatic zones on a roof top:

Element	Description
Regional climate	• The general climate of the region must be considered when choosing plants for a green roof habitat. For example, coastal versus inland.
Aspect	• Sloped roofs which face south or west experience less direct sunlight and are therefore cooler and wetter. • Sloped roofs which face north or east experience more direct sunlight and are therefore warmer and drier.
Wind	• Plants in exposed areas of a rooftop experience higher wind influence. Wind stresses plants by increasing evaporation off their leaves, and damaging foliage and branches.
Shading	• Some areas of the rooftop may be permanently or periodically shaded by surrounding buildings.

The table below presents the elements which were considered in setting up the GRPP:

Element	Description
Regional	• The climate in Durban is generally hot and humid, particularly on the roof top, which is under direct sun. Plants, which are drought, temperature and wind resistant, were therefore selected for the GRPP.
Aspect	• Aspect has no real influence on the GRPP as the roof is not sloped. The roof is, however, orientated in a east-west direction and experiences morning sun with shading in the afternoon from the surrounding buildings.
Wind	• As shown in the images below, the roof is generally shielded from the prevailing winds by the surrounding buildings (i.e. NW and SE winds). However, when the wind does get between the buildings, it tends to swirl, creating wind eddies around and above the GRPP.
Shading	• The south-west areas of the GRPP are permanently shaded by surrounding buildings. This provided the opportunity to plant shade-loving plants, such as *Sanserveria hyacinthiodes* (Iguana Tail) and *Chlorophytum comosum* (Vittatum or Spider Plant).

The surrounding tall buildings shield the GRPP from the prevailing winds and shade parts of the roof at certain times of the day.

4.2 Types of Green Roof Systems

The second step in creating a green roof habitat is to select the type of green roof system. In order to simplify the information, this guideline will only discuss extensive green roof systems, in which there are two forms; direct and modular green roof systems.

Which green roof system is best for you? The table below provides a useful comparison of the two green roof systems with regards to weight considerations, installation, cost, maintenance, alterations or additions, and plant selection.

What is the difference between Direct and Modular green roof systems?

In a direct green roof system, the plants are not planted in containers or modules, but onto specially designed layers on top of the existing roof membrane. In a modular green roof system, the plants are planted within specially designed containers or modules.

Options	Direct	Modular
Weight	Direct systems are often heavier than modular systems, and may require additional roof surface replacement or support.	Modules can be installed on any existing roof surface in good condition and with sufficient structural capacity. Modules are able to be installed on corrugated roofs with a pitch up to 15 degrees.
Installation	Various layers need to be installed prior to planting.	Modules can be pre-planted, thus offering quick installation. The modular system components can quickly be put in place on the roof in accordance with design. It is also a Do-It-Yourself (DIY) user-friendly technique.
Costs	Cheaper as no modules are required.	Slightly more expensive owing to the costs of the modules.
Repair and maintenance	Layers need to be lifted, rolled until problem found. This may disturb plants.	Modules can be moved easily without disturbing plants and growing medium.
Alterations and additions	Often difficult to change and requires longer periods of time for installation.	The modular application allows for the installation of green roof habitats in sections. This offers opportunities for future add-ons and alterations.
Plants	Plant roots have more space to move and network.	Some plants may struggle as the containers or modules constrain root growth, particularly for plant roots which need space to roam.

The green roof systems discussed in this guideline refer only to extensive green roof systems which are generally shallow (i.e. soil depth of less than 20cm) and not meant for use as a recreational area. Preference is given to these systems for the following reasons:

- More suitable for retro-fit installations on existing buildings – lower load bearing demands.
- Lower costs - systems are lighter and require less structural support.
- Lower maintenance – shallow growing medium limits plant selection to less demanding and low-growing plants.

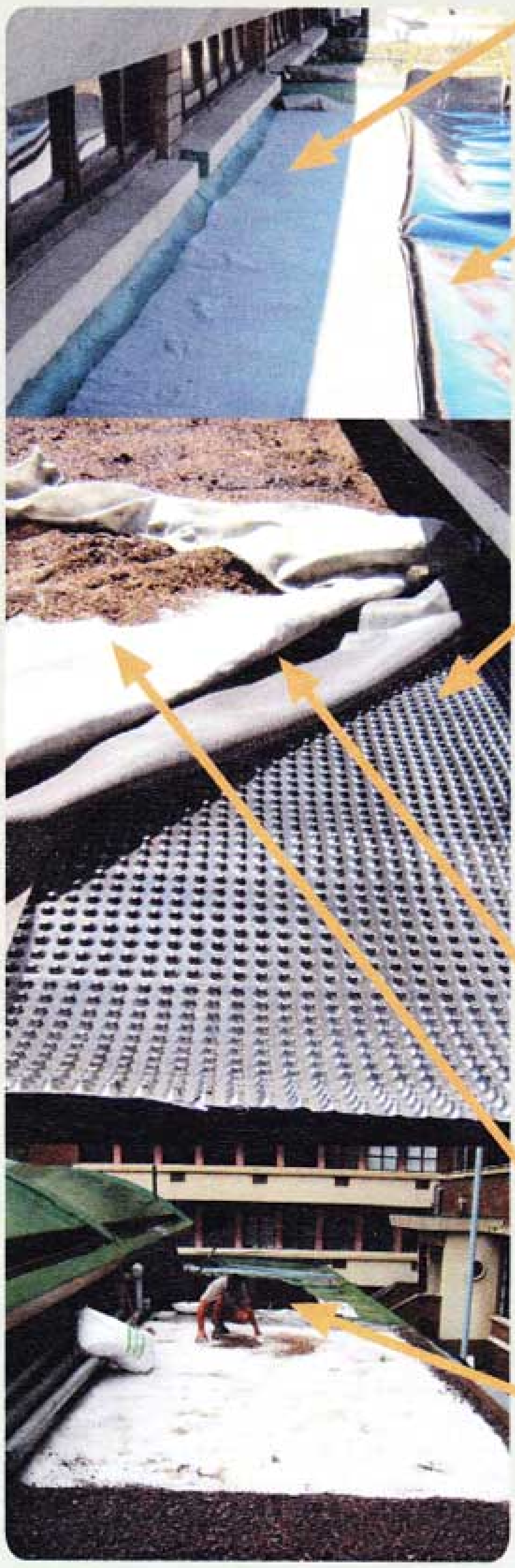
In contrast, intensive green roof systems tend to be a lot deeper (i.e. soil depth of between 20cm and 1m) and used primarily for recreational purposes. Intensive roof systems, however, add considerably more weight to roof structures and additional cost for the required structural support or construction.

4.2.1 Direct Green Roof System

This is a system where the vegetation is not planted in containers or modules, but onto specially designed layers that are on top of the existing roof.

The above images of the GRPP depict what a direct green roof system could look like once the plants have established themselves.

The construction method adopted for the GRPP will be used to illustrate a suggested method for installing a direct green roof system. This system consisted of the following seven layers:



LAYER 1: PROTECTION LAYER

- Purpose of this layer to protect the root barrier (i.e. layer 2) from being damaged or punctured by the existing roof.
- Recommended: Bidum A2 Geotextile Fabric.

LAYER 2: ROOT BARRIER

- Purpose of this layer to is to protect the existing roof from wandering roots which can cause structural damage.
- Recommended: 1000μm polyethelene sheeting.

LAYER 3: DRAINAGE LAYER

- Purpose of this layer is to prevent oversaturation, ensure roots are well ventilated, and provide roots with extra space to grow.
- There are two options:
  - Granular materials, such as crushed bricks or stones. These store water more effectively than synthetic drainage mats, but are much heavier.
  - Geotextile/synthetic materials which are usually made of strong, lightweight plastic and come in a range of sizes and shapes.
- Recommended: 7.5 mm PRO 600 GSM, LDPE Zip core.

LAYER 4: SEPARATION LAYER

- Purpose of this layer to prevent the growing medium from entering and blocking the drainage layer.
- Recommended - Geomesh BSP.

LAYER 5: ADDITIONAL ROOT BARRIER

- Purpose of this layer is further protect the roof from wandering roots.
- Recommended - Bidum A2 Geotextile Fabric.

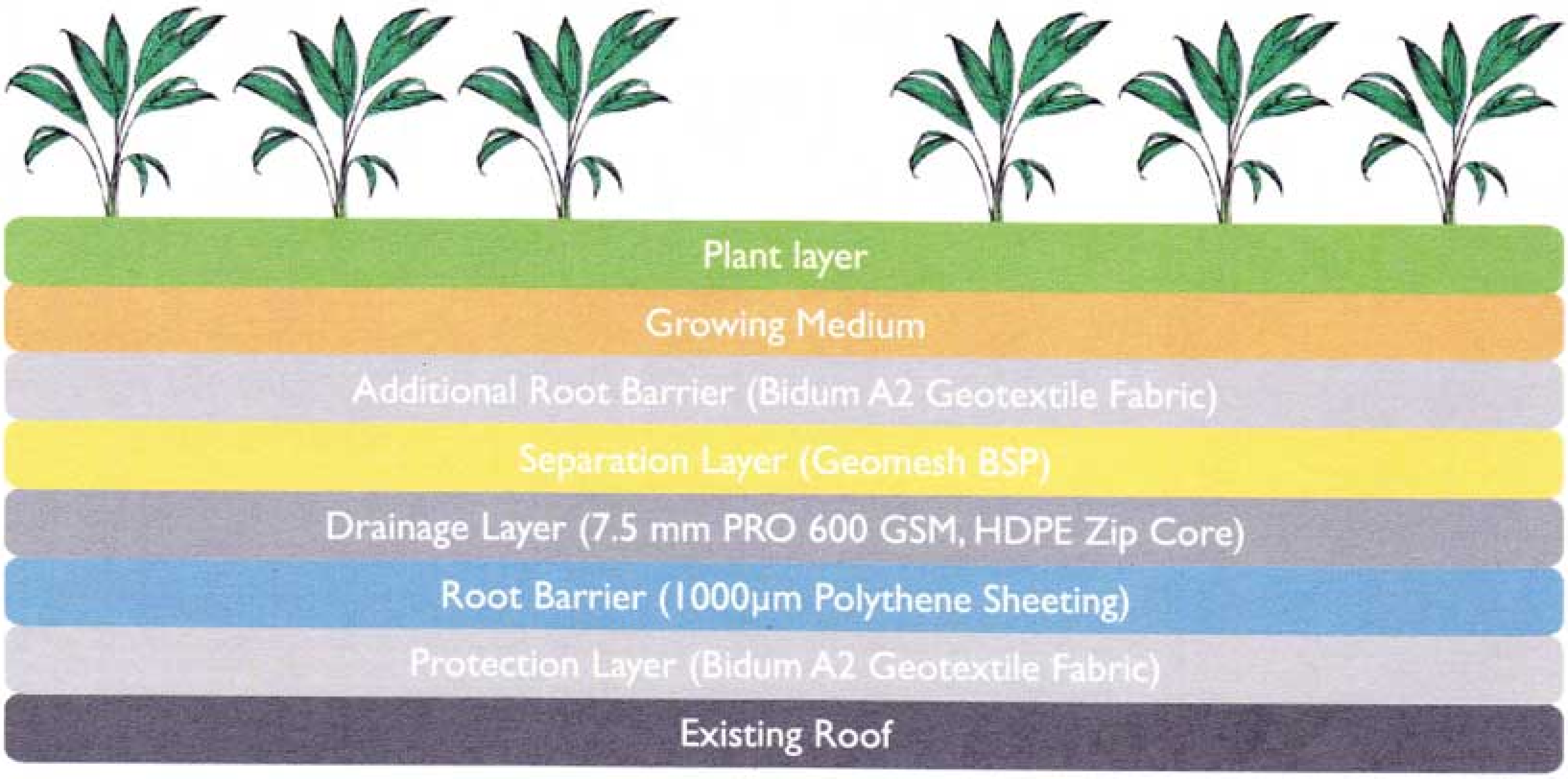
LAYER 6: GROWING MEDIUM

- Discussed in more detail in Section 4.3

LAYER 7: PLANTS

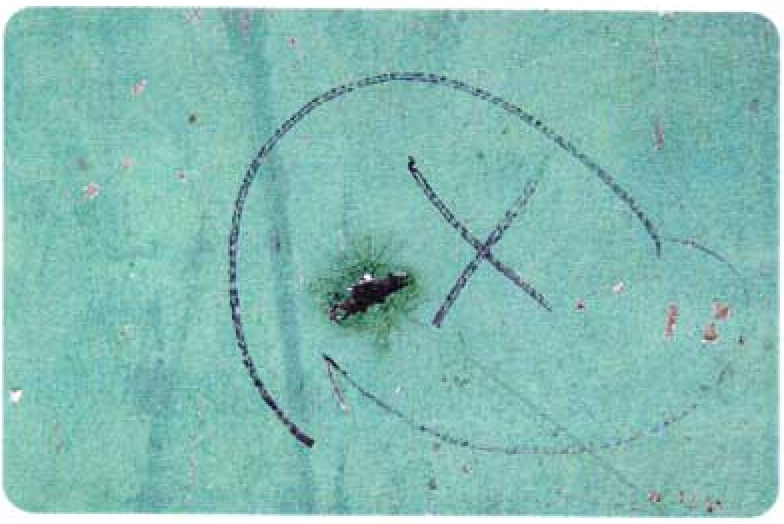
- Discussed in more detail in Section 4.4

Researchers working on the GRPP noticed that many of the plants which were planted had aggressive penetrating roots. As shown in the images above, in the absence of a root barrier layer, these roots could potentially damage the roof structure. The root barrier layer is therefore very important.



The above figure shows the seven layers used to construct the direct green roof system for the GRPP. The GRPP adopted a best practice approach to the construction of the direct green roof system. Of these layers, the most important are the root barrier layers, drainage layer, growing medium, and plants. These layers should be included in all direct green roof habitat applications.

Please note that before starting construction of both the direct and modular green roof systems, it is very important for a structural engineer to check the integrity of the existing roof, and also for any existing holes in the roof to be repaired or patched.



In the GRPP, a structural engineer checked the integrity of the roof and identified a number of holes in the existing membrane (as shown in the images above). An acrylic-based sealer and geofabric membrane was then used to seal the various holes or defects in the membrane.

4.2.2 Modular Green Roof System

The modular green roof system is is a roof system where the plants are planted in portable containers or modules which together make up the green roof cover.

The above images of the GRPP depict what a modular green roof system could look like once the plants have established themselves.

The construction method adopted for the GRPP will be used to illustrate the installation of a modular green roof system. This system consisted of the following four layers:

LAYER 1: PROTECTION LAYER

- Purpose of this layer to protect the root barrier (i.e. layer 2) from being damaged or punctured by existing roof.
- Recommended: Bidum A2 Geotextile Fabric

LAYER 2: ROOT BARRIER

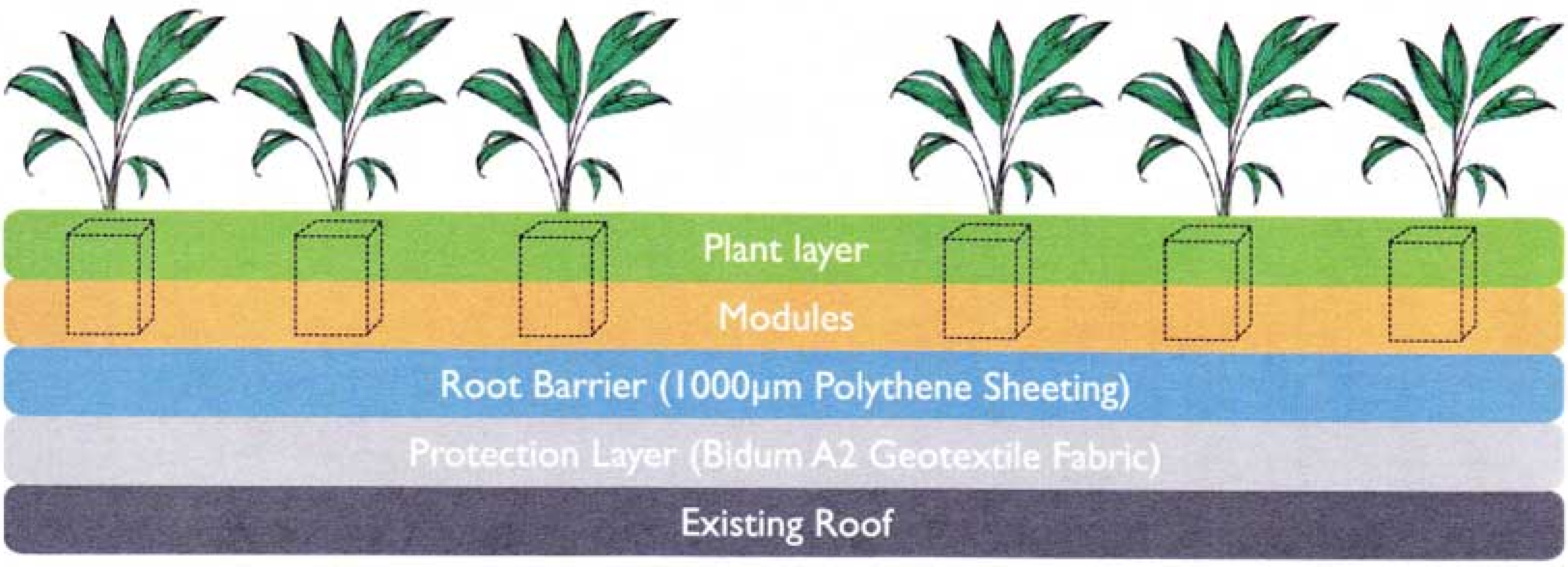
- Purpose of this layer to is to protect the existing roof from wandering roots which can cause structural damage.
- It is however also the most expensive layer on the roof.
- Recommended: 1000µm polythene sheeting.

LAYER 3: MODULES

- Discussed in more detail below.

LAYER 4: PLANTS

- Discussed in more detail in Section 4.4.



The above figure shows the four layers used to construct the modular green roof system for the GRPP. Initially 250µm polythene sheeting was used for the root barrier in the GRPP. Experience, however, showed that this was too thin and likely to result in either tearing from the expansion and contraction of the green roof materials, or provide little or no protection against wandering roots. A 1000µm sheet was used in order to eliminate these problems.

Scientific Name	Common Name	Form	Height (m)	Sun needs	Flower colour and season	Comments	Image
Crassula expansa	Dainty Crassula	GC	0.2		All year	• Groundcover that has a variety of forms – good ornamental plant. • Easily planted from cuttings. • Uncommon nursery availability.	
Crassula multicava	Fairy Crassula	GC	0.4		May-Nov	• Easily planted from cuttings. • Miniature groundcover. • Successful green roof habitat plant when grown with other plants which provide shade. • Common nursery availability.	
Crassula ovata	Kerky -Bush	S	2		Jul-Aug	• Great succulent feature plant. • Attracts a wide variety of insects. • Easily planted from cuttings. • Common nursery availability.	
Crassula pellucida	Carpet Crassula	GC	0.15		Dec-Apr	• Semi-succulent ground cover. • Attracts a wide variety of insects. • Easily planted from cuttings. • Uncommon nursery availability.	
Crassula perfoliata	Pointed Leaf Crassula	S	0.4		May-Oct	• Great succulent feature plant. • Successful green roof habitat plant, especially in shallow soils. • Attracts a wide range of insects. • Prone to being overcrowded by other plants. • Uncommon nursery availability.	
Crassula sarmentosa	Bushy Crassula	GC	0.5		Jun-Aug	• Successful green roof habitat plant. • Attracts a wide variety of insects. • Easily planted from cuttings. • Available at nurseries.	
Crassula setulosa	Furry Crassula	GC	0.2		Jan-May	• Good ground cover to small shrub. • Easily planted from cuttings. • Plant must be kept dry – too much moisture can lead to plant rot.	
Crinum macowanii	River Crinum	B	0.9		Oct-Feb	• Medicinal properties – used to treat urinary infections and itchy rashes. • Prone to damage from Lilly borer/Amaryllis worm. • Common nursery availability.	
Cyanotis speciosa (rupestris var.)	Dolls Powder-puff	GC	0.35		All year	• Hardy trailing plant. • Easily planted from cuttings. • Medicinal properties – used to treat infertility. • Available at nurseries.	

Scientific Name	Common Name	Form	Height (m)	Sun needs	Flower colour and season	Comments	Image
Albuca setosa	Climbing Albuca	B	0.3		Aug-Jan	• A hardy green roof habitat plant. • Attracts insects when in flower. • Available at nurseries.	
Aloe arboresecens	Krantz Aloe	SH	1-3.5		May-Jul	• Large feature plant. • Very successful green roof habitat plant – may require pruning if it gets too big. • Flowers attract bees and birds. • Common nursery availability.	
Aloe maculata	Common Soap Aloe	S	1		May-Oct	• Good feature plant. • Flowers attract bees and birds. • Common nursery availability.	
Asparagus densiflorus	Emerald Asparagus	GC	0.5		Nov-Apr	• Good hanging or trailing green roof habitat plant. • Produces red berries which are eaten by birds. • Looks scruffy in dry periods. • Common nursery availability.	
Bulbine abyssinica	Bushy Bulbine	GC	0.4		Aug-Mar	• Hardy succulent. • Attracts insects when in flower. • Average success as green roof habitat plant. • Common nursery availability.	
Bulbine natalensis	Broad-Leaved Bulbine	GC	0.5		All year	• Hardy succulent. • Attracts insects when in flower. • Medicinal properties - used for certain skin ailments. • Common nursery availability.	
Cissus quadrangularis	Cactus Vine	CL	10		Dec-Jun	• Vigorous climbing plant - must be monitored and pruned when necessary. • Easily planted from cuttings. • Uncommon nursery availability.	
Cotyledon orbiculata	Narrow Pig's Ears	S	1		All year	• Easily planted from cuttings. • Attracts birds, butterflies and a wide variety of insects. • Prone to being fed on excessively by butterfly larvae – can effect plant growth. • Medicinal – sap heals warts. • Available at nurseries.	
Crassula alba	Common Crassula	S	0.2		All year	• Attracts a wide variety of insects. • Uncommon nursery availability.	

When selecting plants for a green roof habitat, it is important to remember that they will be exposed to high temperatures, periods of little or no water, and high levels of saturation during rainfall events (due to shallow growing medium), and must therefore display the following characteristics:

- Drought, flooding, temperature and wind resistant.
- Small and low growing.
- Reproduce easily from seed or vegetatively in the event that the parent plants die-off during times of extreme heat or drought. For example, *Kleinia fulgens* and *Kalanchoe rotundifolio* grow well from the leaves of parent plants.
- Have a mildly creeping habit so that they are easily able to fill gaps left by die back during times of moisture stress. Plants with a very vigorous creeping habit are mostly unsuitable.

As green roof habitats provide space for biodiversity in the city and create biodiversity corridors in urban and suburban areas, there are additional biodiversity considerations when selecting possible plants:

- Plants must be indigenous and endemic where possible, as this helps to increase the presence of naturally occurring species which will attract local populations of birds, butterflies, and other insects.
- Plants must be grown from seeds collected locally (i.e. within 50km radius of the green roof habitat site), as plants more suited to local conditions are likely to require less maintenance (watering, pest control etc.), and have a greater chance of survival. This also reduces the carbon footprint of the plants used, and maintains the genetic composition of the local species populations.
- Variety of plants – the greater the variety of plants, the greater the variety of birds and insects attracted to the roof. Plant diversity also increases the chance of year round plant cover as some species may die off seasonally or under certain conditions, while others survive. For example, if only bulbous plants, such as Clivias, are planted, there is the potential that all the plants could be lost with an outbreak of a pest, such as Amaryllis Worm or Lily Borer.

One of the main objectives of the GRPP was to determine which plants are suitable for creating a green roof habitat. Due to the harsh conditions, many of the plants tested did not do well. The following table lists plants which were found to be suitable for green roof habitat applications.

Form:	GC: Ground Cover	B: Bulb	SH: Shrub	S: Succulent	CL: Climber		
Sun needs:	Full Sun	Semi-shade	Shade				
Flower colour:	Pink	Blue	Purple	White	Orange	Yellow	Red

Scientific Name	Common Name	Form	Height (m)	Sun needs	Flower colour and season	Comments	Image
Aeollanthus parvifolius	Rocksheet Spar Bush	GC	0.4	Full Sun, Semi-shade	Pink, Nov-Apr	• A hardy green roof habitat plant. • Attracts insects when in flower. • Uncommon nursery availability.	
Agapanthus praecox	Large Agapanthus	B	0.8	Full Sun, Semi-shade	Purple, Dec-Feb	• A hardy green roof habitat plant. • Attracts insects when in flower. • Medicinal properties – ensure easy child birth and for healthy children. • Susceptible to attack from Lily Borer. • Common nursery availability.	
Albuca nelsonii	Candelabrum Lily	B	1	Full Sun	White, Sep-Dec	• Medium size feature plant. • Uncommon nursery availability.	

The concept of green roof habitats is still relatively new in South Africa and as a result, many of the internationally recommended materials and substrates are not yet locally available. The following tables present potential growing media which are readily available[39].

Potential Inorganic Media [40]

Medium	Saturated weight per litre	Comment
Vermiculite	178 grams	• Extremely light weight. • Readily available at a reasonable cost. • May break down over a long period of time.
Perlite	174 grams	• Extremely light weight. • Readily available, but most expensive of inorganic materials. • May break down over a long period of time.
Berea Red Sand	2kg	• Very heavy (when saturated). • Readily available.
Dark Building Sand	2kg	• Very heavy (when saturated). • Readily available at a reasonable cost.
Decomposed Granite	2kg	• Very heavy. • Readily available. • As granite decomposes, it releases both macro and micro nutrients, which are essential for plant growth. • Affordable.
Crushed Brick	2kg	• Very heavy. • Difficult to crush unless one has relevant machinery.

Potential Organic Media [41]

Medium	Saturated weight per litre	Comment
Compost	760 grams	• Readily available at low cost - ensure that it is good quality compost before purchasing (i.e. plant derived and contains bark/woodchips).
Potting mix	749 grams	• Readily available at low cost - ensure that it is good quality potting mix before purchasing.

It is highly recommended that you first test your growing medium with a selection of the plants you intend growing. This will ensure that the composition of your growing medium is appropriate for your chosen planting theme.

4.4 Choosing Your Plants

4.4.1 Plant Selection

The next step in constructing a green roof habitat is the selection of suitable plants[42]. It is important to note that conditions on a roof top are relatively unique and differ from those on the ground.

Roof top conditions in Durban are very similar to the dry granite and sandstone outcrops and cliffs found in the Valley of 1000 Hills. In areas such as the ones depicted to the left, the soils are relatively shallow and temperatures relatively high (source: Michael van Niekerk).

[39] See Section 7.4 for local suppliers of green roof materials.

[40] In this context, inorganic media are something that was either mined or human-made. This includes vermiculite, perlite, tyre chunks, pea gravel and sand.

[41] In this context, organic media are something that is or was alive. This includes compost, sphagnum peat, wood chips, grass clippings, straw, compost, manure, bio-solids, sawdust and wood ash.

[42] See Section 7.5 for a list of nurseries which stock indigenous plants in Durban.

4.3 Choosing a Planting Medium

The third step in creating a green roof habitat is choosing the planting medium. While the depth of the growing medium is probably the most important factor, the type of growing medium is also important as this provides plants with a nutrient base and space to grow. In most cases, a specialised growing medium will need to be developed because of weight considerations.

As part of the GRPP, the dry and saturated weight of a number of potential growing media was measured. The results showed that soil-based materials, such as Berea red sand, were 8.5 times heavier than vermiculite and perlite, 5.6 times heavier than compost, and 4.5 times heavier than potting mix. It is therefore impractical to only use a soil-based material.

The above image depicts some of the growing materials tested. This includes, from left to right, vermiculite, potting mix, Berea red sand, compost, and perlite.

The ideal planting medium should be lightweight, well-drained, and be able to retain a high degree of water, without becoming waterlogged. International studies show that planting media made up of lightweight materials, such as expanded clay, perlite, vermiculite and volcanic rock, are most suitable.

A number of commercial media are available. These are, however, generally expensive and have to be imported. The considerable distance that the media have to be transported means that they also have a high carbon footprint.

In order to reduce costs, you can produce your own planting medium.

A good starting point for producing your own substrate is to aim for a blend of 60-80% inorganic materials with 20-40% organic materials.

One of the lessons learned from the GRPP is that the organic material content, such as potting mix shown in the image on the right, should not be too high for the following reasons:

- The high rate of decomposition and loss of substrate through weathering – therefore medium requires constant replenishment.
- The high concentration of salts, such as magnesium and potassium, in potting soil makes it difficult for plants to abstract water from the substrate – i.e. salts retain water in soil.
- The high animal manure content of compost results in numerous young plants/plant cuttings not surviving as conditions are too acidic.
- Some succulent species, such as *Crassula spp.*, do not grow well in organic materials and eventually rot.

(Source: www.nitrate.com)

The creation of green roof habitats is relatively new to South Africa and as a result, there are very few options for modules or trays. The greatest challenge is finding suitable modules or trays which can withstand the harsh conditions on a roof top, particularly from UV rays. For example, geyser trays perish within months on a rooftop. While car tyres and wooden crates are more durable options, they are relatively heavy, and can be unsightly.

Modules

The containers or modules used in modular green roof systems are available in a range of sizes[38]. The size of the module is generally determined by the depth of the soil that the container can hold. As depicted in the below image, 20cm (left) 10cm (centre) and 7.5cm (right) deep modules are available.

The modules used in the GRPP are patent-pending custom-made trays. These trays were chosen for the following reasons:

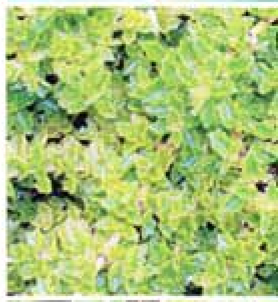
- Made of recyclable HDPE (High Density Polyethylene);
- UV resistant;
- Made in varying depths of 7.5cm (shallow), 10cm (medium) and 20cm (deep) - allowing for greater variety of plants;
- Each module has a built-in drainage system and water reservoirs that aid in both storing water for plant usage, as well as slowing down rainfall run-off;
- Modules are raised 30 mm off the roof by custom designed reservoirs on the underside of the modules. This allows for free movement of air, which aids in cooling and insulating the rooftop, as well as allowing the unhindered movement of excess run-off water; and
- Modules are portable allowing for easy maintenance of the existing roof, and changes in design.

Another advantage of the modular green roof system is that the modules can be used as ponds (see below images). This creates small aquatic habitats which attract water-loving insects, such as dragonflies.

As part of the GRPP, five modules were used as ponds to test the suitability of aquatic plants, such as *Nymphoides thunbergia*, for green roof habitats. In general, these plants survived if the ponds did not dry up.

[38] See Section 7.4 for local suppliers of green roof materials.

Scientific Name	Common Name	Form	Height (m)	Sun needs	Flower colour and season	Comments	Image
Cyrtanthus sanguineus	Inanda Lily	B	0.35		Dec-Jan	• Colourful feature plant - large red flowers. • Medicinal properties – used to ensure easy child birth. • Uncommon nursery availability.	
Delosperma lineare	N/A	GC	0.2		May-Sep	• Good ground cover. • Easily planted from cuttings.	
Delosperma tradescanthiodes	Trailing Delosperma	GC	0.15		All year	• Good trailing plant. • Easily planted from cuttings. • It was noted that plants sourced locally grow less vigorously than plants from other areas. • Available at nurseries.	
Drimiopsis maculata	Spotted-Leaf Drimiopsis	GC	0.25		Sep-Apr	• Suitable for shady areas on a green roof habitat, but can tolerate some sun. • Needs to be planted with other plants which provide additional shade • Common nursery availability.	
Gladiolus dalenii	African/Parrot Gladiolus	B	2		Feb-Jun	• Colourful feature plant. • Attracts birds. • Prefers deeper soils – from 7.5cm. • Available at nurseries.	
Gloriosa superba	Flame Lilly	B	2		Nov-Mar	• Colourful feature plant. • Poisonous. • Prefers deeper soils – from 7.5cm. • Available at nurseries.	
Huernia hyterix	Porcupine huernia	S	0.2		All year	• Hardy green roof habitat plant. • Attracts African Monarch butterflies. • Easily planted from cuttings. • Available at nurseries.	
Kalanchoe rotundifolia	Common Kalachoe	GC	0.6		Mar-Dec	• Successful green roof habitat plant. • Easily planted from cuttings. • Available at nurseries.	
Kalanchoe thyrsiflora	White Lady	S	1.5		Feb-Sep	• Successful green roof habitat plant – good feature plant. • Easily planted from cuttings. • Available at nurseries.	
Kleinia fulgens	Coral Senecio	S	0.6		Jan-Aug	• Successful green roof habitat plant. • Available at nurseries.	

Scientific Name	Common Name	Form	Height (m)	Sun needs	Flower colour and season	Comments	Image
Ornithogalum longiscapum		B	0.9		Dec-Apr	• Good feature plant. • Attracts a wide variety of insects when in flower.	
Plectranthus spicatus	Long-Spiked Spur Flower	SH	0.15		Mar-Oct	• Hardy feature plant. • Attracts Gaudy Commodore Butterflies. • Easily planted from cuttings. • Grows vigorously and may need to be pruned.	
Plectranthus madagascariensis	Swedish Ivy	SH	0.5		Apr-May	• Spreading ground cover for semi shady areas.	
Portulacaria afra	Porkbush/ Spekboom	SH	2		Sep-Nov	• Attracts certain moth species. • When in flower it attracts a wide variety of insects. • Easily planted from cuttings.	
Sarcostemma viminale	Caustic Vine	CL	5-10		Nov-May	• Successful green roof habitat plant. • Creeping stems can grow up to 7m - must be monitored for vigorous growth and pruned when necessary. • Easily planted from cuttings.	
Senecio barbetonicus	Succulent Bush Senecio	SH	2		Aug-Sep	• Low maintenance - does not require pruning. • Available at nurseries.	
Senecio brachypodus	Climbing-Forest Senecio	CL	4-6		Apr-Jul	• Scrambling type of shrub. • Vigorous growth- needs pruning. • Attracts butterflies. • Available at nurseries.	
Senecio Pleistocephalus	Honey Scenecio	CL	2-4		Nov-Jun	• Attracts butterflies. • Uncommon nursery availability.	
Stapelia gigantea	Carrion flower	S	0.3		Mar-May	• Very hardy succulent. • Attracts butterflies. • Medicinal properties – used to treat hysteria and pain. • Easily planted from cuttings. • Available at nurseries.	
Tetradenia riparia	Iboza/Ginger bush	SH	3		May-Aug	• Can get quite big - may need pruning. • Attracts birds/butterflies and other insects. • Easily planted from cuttings. • Common nursery availability.	

4.4.2 Plant Themes, Combinations and Communities

A planting theme is a combination of plant types selected with the aim of producing a particular effect. A green roof habitat can be based on one or a combination of the following themes:

Attracting Birds, Butterflies and other Insects

The aim of this theme is to attract a variety of birds, butterflies, and other insects to your green roof habitat. This is done by using plants which provide food and a refuge or nursery for the insects or organisms that you are trying to attract. It is important to choose species that are either larval host plants (e.g. caterpillars) or needed for the breeding cycle of your target species (e.g. butterflies). The key is to create a variety of microhabits using a variety of plant species and features, such as logs, rocks, and gravel. It is also beneficial to choose a variety of species that flower and die-back at different times of the year so that there is always food and a breeding place on your green roof habitat.

This planting theme may, however, become unattractive at certain times of the year when the insects utilise the vegetation or certain plants naturally die back. It is also important to remember that pesticides or herbicides should not be used to control these pests as these chemicals will kill or chase away species that would otherwise be attracted to your green roof habitat.

For example, plants such as the Porcupine Huernia (*Huernia hysterix*), depicted above on the left, can be planted to attract African Monarch Butterflies, depicted above in the centre (Source: Viren Vaz). These plants are a favourite food source of the butterfly larvae, as depicted above on the right. These plants also attract flies which are an important food source for lizards, birds, and dragonflies.

Based on experience from the GRPP, the following indigenous plants were found to be successful in attracting birds, butterflies, and other insects to the green roof habitat:

- *Heurnia hysterix*
- *Cotyledon orbiculata*
- *Bulbine abyssinica*
- *Plectranthus spicatus*
- *Aloe arborescens*
- *Cyanotis speciosa*
- *Tetradenia riparia*
- *Aloe maculata*
- *Portulacaria afra*
- *Crassula species*
- *Bulbine natalensis*
- *Senecio species*

Aesthetics

The aim of this theme is to create a green roof habitat which is attractive to the eye. As shown in the images below, this is done by using variations of plant mass, texture, and colours. These plants are selected primarily for the way they look and not necessarily for what birds, butterflies, or other insects they attract. It is important to remember to plant a variety of plants that flower at different times of the year. In this way, the green roof habitat can remain attractive all year round.

Images from the GRPP showing how variations of plant species can be used to create a roof top which is attractive to the eye.

Based on experience from the GRPP, the following indigenous plants were found to be suitable for creating an attractive green roof habitat:

- *Portulacaria afra*
- *Delosperma tradescanthoides*
- *Plectranthus species*
- *Crassula sarmentosa*
- *Aloe maculata*
- *Senecio barbetonicus*
- *Aloe arborescens*

Water-wise

The aim of this theme is to minimise watering your green roof habitat. This theme is particularly useful for roof tops which are not easily accessible. This is done by planting species, such as succulents, which tolerate low-water conditions.

A number of succulents were planted in the GRPP. Most of these were found to be very successful green roof habitat plants.

Based on experience from the GRPP, the following indigenous plants were found to be suitable for creating a water-wise green roof habitat:

- *Aloe maculate*
- *Heurnia hysterix*
- *Crassula species*
- *Aloe arborescens*
- *Tetradenia riparia*
- *Kalanchoe rotundifolia*
- *Portulucaria afra*
- *Senecio barbetonicus*
- *Cotyledon orbiculata*
- *Stapelia gigantea*
- *Delosperma species*

It was also noted that the growing medium for succulents should not have a high organic content (i.e. less than 40%) as this results in root rot.

Carbon sequestration

The aim of this theme is to maximise the sequestration or trapping of carbon, thereby reducing the amount of GHGs, which contribute to climate change. Very little research has however been done on the carbon sequestration potential of indigenous plant species in South Africa. One species which has shown some potential is *Portulacaria afra* (Spekboom) from the Thicket regions of the Eastern Cape [43].

Spekboom has become a popular plant for carbon sequestration projects because it requires very little water and has great carbon sequestration potential, estimated to be similar to that of tropical forests.

Food

The aim of this theme is to maximise the use of your roof top for growing fruit, vegetables, and herbs. For more detail on the suitability of a roof top for this purpose, see Section 3.9.

The GRPP found that the following improved the success of the vegetables and herbs planted:

- A growing medium with a high organic content. The vegetables tested in the GRPP were planted in 100% organic growing medium comprising only potting mix.
- More regular watering than for areas planted with indigenous plants.
- Some form of fertilisation. Organic fertilisers should preferably be used. The directions for use on the product must also be followed.
- Although vegetables and crops can generally be planted all year round in Durban, the best time for planting is from April to May.

[43] Mills, A.J. & Cowling, R.M. 2006. Rate of Carbon Sequestration at Two Thicket Restoration Sites in the Eastern Cape, South Africa. *Restoration Ecology* 14: 38-49.

4.5 Edging

The next step in creating a green roof habitat is to select the type of edging. Edging is necessary to prevent the spread of fires and to prevent the loss of growing medium to wind or rain erosion.

The following table summarises the advantages and disadvantages of common types of edging that can be used for green roof habitat applications.

Material	Advantages	Disadvantages
Wood	• Readily available. • Average cost. • Easy to work with. • Light in weight. • Is a carbon sink.	• Needs to periodically be treated to protect wood. • Needs to be replaced in long-term.
Aluminium	• Readily available. • Provides clean finish. • Can be custom-made to fit any roof. • Light in weight.	• Relatively expensive. • Needs to be firmly secured to prevent it blowing away with strong winds. • Large carbon footprint – mining and smelting aluminium is energy intensive.
Fibre Cement	• Readily available e.g. fascia boards. • Fairly light in weight.	• Can be cumbersome to install. • Can crack and break. • Can have a large carbon footprint.
Concrete	• Readily available. • Can be custom-made to fit any roof.	• Very heavy. • Can be cumbersome to install due to weight. • Can have a large carbon footprint – cement manufacturing process produces large amount of CO_2.






In the GRPP, three types of edging were tested. This includes aluminium edging (top), fibre cement edging (middle), and wooden edging (bottom).

5 Maintenance

Maintenance is necessary to maintain and enhance the condition of your green roof habitat. If the green roof habitat is not properly maintained, it can become an eyesore, and detract from the experience of bringing nature back into the city. A poorly maintained habitat is also less functional in terms of providing food and shelter for birds, butterflies, and other insects, and performing other ecosystem services, such as stormwater attenuation, temperature reduction, noise insulation, and improving air quality.

The following section discusses important points which need to be considered when preparing your green roof habitat maintenance programme.

5.1 Irrigation

In general, indigenous plants require less watering than exotic plants. Due to the harsh conditions on a roof top, the plants recommended for a green roof habitat are also more water-wise or drought-resistant than other indigenous plants. By choosing indigenous plants which are drought-resistant you can also minimise the need for watering.

For the GRPP, new plants were watered two to three times a week for the first 3 months until the plants had become established. Thereafter, the plants were watered on an *ad-hoc* basis when there had been no rain for several weeks and plants were starting to die-back.

The following tips should also be considered to further reduce the need for watering:

- Purchase and plant young plants or shrubs, as these require less water before they are established than larger more mature plants.
- Planting should ideally take place between August and November when Durban's climate is relatively mild. This will reduce the frequency of watering required and increase the plant's chances of survival.
- Include water absorbing materials, such as vermiculite, in your growing medium to hold water in the soil for longer.
- Plant larger plants or species along the edges of the green roof habitat to act as a windbreak, reducing the drying effect of the wind.
- Group plants with similar water requirements together (i.e. low, medium, and high).
- Reduce water loss through evaporation by watering early in the morning or late in the afternoon. Afternoon is preferable as the plants have more time to use the water provided.
- Remove weeds as these compete with indigenous plants for water.
- Check the weather forecast to avoid watering before rain.
- Instead of removing leaves or cuttings from the green roof habitat, spread them across the surface of the growing medium, as mulch. This will help to reduce water loss from the soil. Weeds must, however, not be used as a mulch as they will drop their seeds in the soil. Bark chips, cut grass, or sawdust can also be used as mulch.

The sustainability of a green roof habitat can be further improved by installing a water harvesting system. With the rising price of water and the likely reduction in the availability of water in the future, it is becoming necessary to reduce the consumption of potable water, especially for watering plants. For a green roof habitat there are two feasible options, described in the following table:

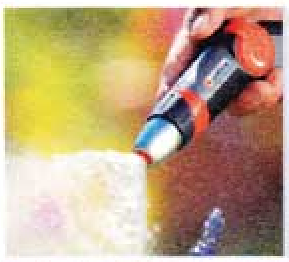
System	Description
RAINWATER HARVESTING 	• Provides high quality water. • Can be collected from roofs using gutters, which feed into a container, and pumped up to green roof habitat. • Containers should be mounted on a secure, level platform, and include an overflow pipe for heavy rainfall. • Ensure roof and drainage system (gutters etc.) are in good condition – clean and free of holes. • Run-off from the green roof habitat can also be captured using this system.
REUSING GREYWATER 	• Refers to waste water from basins, showers, air-conditioners and baths. • Can be collected in a container and pumped up to the green roof habitat or collected by hand. • Unlike rainwater, greywater is not seasonal. • Considered safe for use in green roof habitats as long as organic detergents are used. • Avoid watering edible crops or fruits with greywater.

For the GRPP, a greywater harvesting system was installed. This system collects waste water from the building's air conditioners and stores it in two 5,000 litre rainwater tanks (see below images). The water from the tanks is then pumped up to the GRPP were it is used for watering the plants. It is interesting to note that during hot periods when the air-conditioners are running continuously, it only takes four days to fill these two 5,000 litre tanks using waste water from the air conditioners.

In general, 4.3 litres of water was used for watering a square metre of the GRPP, with a soil depth of 10cm. Based on this figure, the 550m² GRPP uses approximately 2,365 litres when it is watered. If the GRPP is watered twice a month, the total amount of water used is approximately 4,739 litres per month[44].

Thus, there is sufficient capacity in the greywater tanks to water the GRPP for two months without ongoing replenishment.

There are two options for watering your green roof habitat; hand watering or installing an automated system. The table below presents a summary of the advantages and disadvantages of common irrigation systems which can be used for watering your green roof habitat.

System	Advantages	Disadvantages	
Hand-Watering	• Simplest system. • Easily avoid over-watering. • Control flow using nozzle on hose.	• Time consuming. • Easy to use excessive flow – wash away soil and mulch. • Requires easy access to green roof habitat.	
Micro-Sprayer System	• Most common automated system. • Effective for flowering plants/vegetables. • Flexible spray options e.g. 360°, 180°, 90° and fine mist to jet spray.	• High water losses through drift and evaporation (up to 70%). • Not effective for large areas. • Not effective for penetrating soil beyond mulch layer. • Relatively costly to install.	
Sprinkler System	• Cover large areas. • Flexible spray options e.g. 360°, 180°, 90° and soft to hard spray.	• High water losses through drift and evaporation. • Not effective for sensitive plants – excessive force. • Relatively costly to install.	

(Source of images: www.gardena.uk)

It is difficult to give guidelines on how much to water a green roof habitat as this is largely dependent on the type of plants and characteristics of the growing medium.

In the GRPP, the plants were watered by hand. It would take on average 20 minutes to water 45m², and four hours to water the entire 550m² GRPP. The general rule was to water an area until the top 2 to 3 cm of the planting medium was saturated. A fine spray was also used to avoid pooling of water on the surface.

[44] By choosing hardy indigenous plant species it is possible to limit irrigation to the establishment phase.

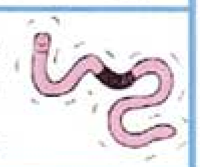
5.2 Composting and Garden Waste Management

A sustainable waste management programme should form part of the maintenance programme of your green roof habitat. Waste is defined as anything that is no longer useful for it's present purpose and needs to be disposed of. Sustainable waste management aims to move away from disposing of wastes (e.g. to landfill sites) to the avoidance or re-use of wastes. The golden rules of responsible waste management are to reduce, reuse, and recycle:

1. **Reduce** the amount of waste produced. For example, choose products which do not have excessive packaging.
2. **Re-use** garden materials again and again. For example, use durable refuse bags which can be used over again instead of thin plastic bags which can only be used once.
3. **Recycle** or convert garden materials into a new or different form (e.g. composting).

Composting is an easy way to reduce the amount of organic waste which needs to be disposed of. This process breaks down organic materials, such as fallen leaves or leftover food, releasing and making available nutrients essential for plant growth. This compost can then be used to enhance the quality of the growing medium by returning vital nutrients.

The following table lists useful tips for setting up a composting site for your green roof habitat[45]:

1	The compost site or heap should be placed in a sunny area to ensure that there is always warmth.	
2	The compost site or heap should be contained using a cage made of wooden slats. There should be sufficient space between the slats to allow circulation of air. A commercial compost bin, which is generally less of an eyesore, can be used.	
3	Compost heaps must be situated on bare soil to allow insects and bacteria to move up from the soil into the compost heap. As this is not possible on a rooftop, a "starter pack" of manure or commercial bacteria activator must be used to start the process.	
4	Organic materials, such as kitchen scraps, left-over food, dry leaves[46], and weeds should be added to the compost heap.	
5	It is important to ensure that there is sufficient water to keep contents moist (not wet).	
6	The compost heap should be turned regularly to increase oxygen levels and to kill the seeds of weeds and fly larvae. In general, the heap should be turned when it gets cool inside.	

Both organic and inorganic fertilisers can also be used to replace essential nutrients in the growing medium instead of compost.

The amount of fertiliser and the frequency of application are dependent on a number of factors, such as plant type, soil composition, soil depth, and amount of watering. The manufacturer's application rate recommendations should be used as a guide when calculating the application rate for your green roof habitat. Careful observation of the plant growth and health is therefore the only reliable indicator of the frequency and amount of fertiliser to be applied.

Based on experience, it is be best to give 3 to 4 light dressings of fertiliser per year rather than one or two large doses as this greatly reduces the run-off of fertiliser and loss of nitrogen to the atmosphere. In general, more applications need to be made in summer than in winter.

It is important to water your green roof habitat within an hour of fertilising to ensure that the fertiliser does not burn the plants.

It is important to note that in the GRPP, inorganic fertilisers were only used twice in the first year to assist the newly planted plants in becoming established. Ideally, however, the use of fertilisers should be minimised where possible, and if fertilisers are to be used, organic fertilisers are preferable to inorganic fertilisers.

[45] See eThekwini Municipality (2010), *Green Landscaping Guideline*, for more information.

[46] Please note that succulents are generally not suitable for composting. If they are to be used, they need to be air dried before being added to the compost heap.

5.3 Controlling Weeds

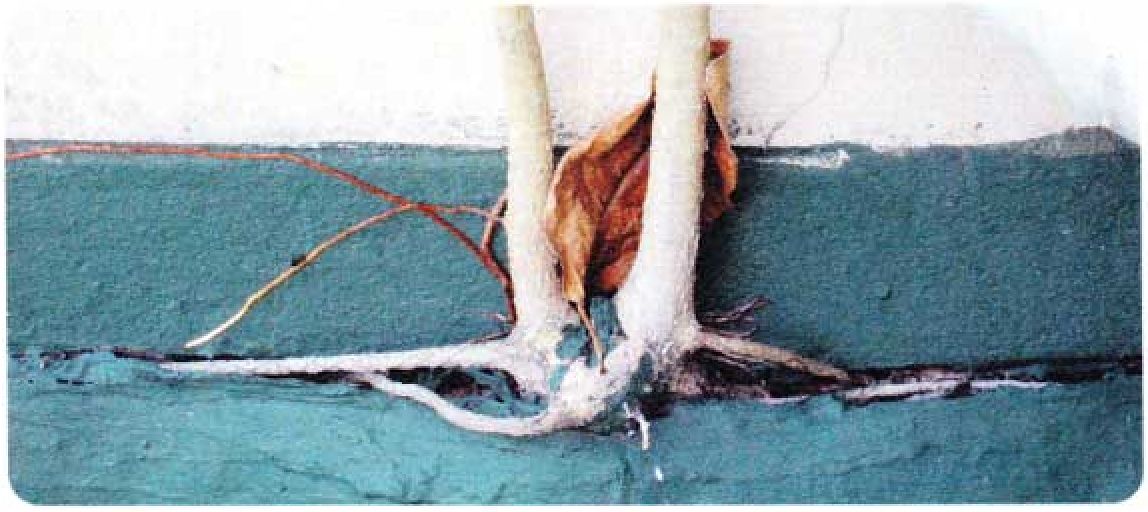
Weeds refer to plants which grow where people do not want them. In many cases, weeds are actually indigenous. In a green roof habitat, the primary source of weeds will be the organic growing media, such as compost and potting mix, and the soils that the plants come in.

Some weeds must, however, be controlled by law. These are referred to as invasive alien plants as they do not occur naturally in an area and have the potential to invade an area, pushing out indigenous plants.

These plants are classified as either Category 1, 2 or 3, depending on the extent to which they colonise an area, displace indigenous plants, or their commercial value (e.g. timber plantations).

There are generally two methods for controlling weeds and invasive alien plants; physical removal or treatment with a herbicide or weed killer. In most cases, physical methods, such as hand pulling, are the most effective for a green roof habitat. Weeds should ideally be removed as soon as possible before they are able to seed.

The use of herbicides is only recommended as a last resort because these chemicals can impact negatively on the birds, butterflies, and other insects, attracted to the green roof habitat, as well as potentially killing the plants within the green roof habitat.

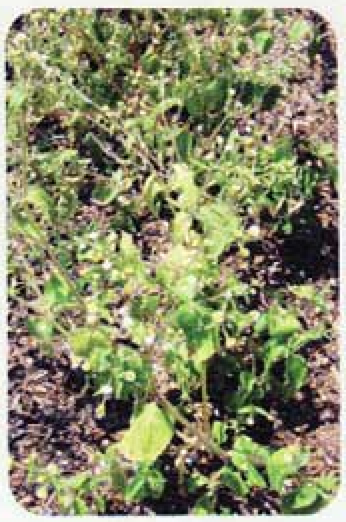



For example, in the GRPP, there were several plants which started to grow, that were never planted. While most of these were left alone, trees such as the Swazi Fig (*Ficus bubu*), were removed, because their root system can cause structural damage to the roof (see above).

In the early stages of the GRPP, weeding was done weekly. This was because the plant cover was limited, leaving large, exposed areas of growing medium where weeds could become established without any competition. During these early stages, a 15 litre container could be filled with weeds after 45 minutes of weeding. The frequency of weeding, however, decreased as the plant cover increased.

The following are images of weeds that commonly occur on the GRPP:




From left to right: *Talinum paniculatum, Lactusa spp., Euphorbia maculate, Bidens pilosa* and *Portulacca alaracea*

As with the use of herbicides, the use of chemical insecticides or pesticides is only recommended as a last resort. This is because these chemicals also affect non-target species. In addition, many of these chemicals are potentially dangerous to people.

The need or use of insecticides can be greatly reduced by the following:

- Select pest resistant plants which are suited to local conditions. Most of the plants listed in Section 4.4.1 were found to be relatively resistant to pests.
- Ensure that planting areas have been sufficiently prepared (e.g. good drainage, compost etc.) – healthy plants are less susceptible to pests and diseases.
- Attempt physical pest/disease control methods first (e.g. remove by hand or wash with water from hosepipe).
- Set traps for particular pests e.g. snails and slugs are attracted to liquids containing yeasts. Set the trap by placing stale beer in a shallow plate or container. The snails and slugs will crawl into the liquid and drown.
- Use either a plant-based insecticide, using, for example chilli or garlic, or an organic insecticide, using wood ash or bicarbonate of soda.
- Check plants regularly for early detection of pests and diseases. Remove infected parts of plant or whole plant in severe cases. This reduces the spread of pests and diseases.

As part of the GRPP, one of the plants tested for its suitability in a green roof habitat, was *Clivia miniata*. *Clivia spp.*, like most bulbous plants, are generally known to be susceptible to the Amaryllis Worm or Lily Borer (*Brithys crini*).

Within weeks of being planted on the GRPP, the Clivias were infested with Amaryllis Worm. As no insecticides were used on the GRPP, the Clivias soon died. The Amaryllis Worms then spread to several of the other bulbous plants, such as the *Crinum spp. Albuca spp.* and *Agapanthus spp.*, killing some of them too.

This highlights the importance of selecting pest resistant plants for your green roof habitat.

Crinum macowanii infested with Amaryllis worm.

Fungal or bacterial infections can also be a problem in a green roof habitat. Infected parts of the plant should be removed and tools sterilised to prevent the spread of infection. As a last resort, fungicides, such as Copper Sulphate, can be used to treat infections.

6 Summary and Conclusion

The aim of this guideline was to provide a guide for designing green roof habitats in Durban. It forms part of the Green Roof Pilot Project (GRPP), an initiative of the eThekwini Municipal Climate Change Programme (MCCP), and the Green Guideline Series, an initiative of the Greening Durban 2010 Programme.

The guideline started by providing the reasons for designing a green roof habitat. In this context, green roof habitats have the potential to decrease the carbon footprint of a building (by reducing energy use) and therefore its contribution to climate change. Perhaps more significantly, they also facilitate climate change adaptation through a range of positive impacts. These include reducing the temperature of the building (and potentially the city if established on enough city roofs) thereby reducing heat stress and its associated negative health impacts. A very significant adaptation advantage is the reduction in stormwater run-off which reduces the chance of flooding and infrastructural damage. Green roof habitats also enhance biodiversity in the urban environment, and offer an opportunity to improve inner city food security.

Section 2 introduced the GRPP. It presented the background to the project, its aim and objectives, the location and design, and a summary of the key findings.

Section 3 unpacked the benefits of green roof habitats in more detail. It was found, based on experience from the GRPP and evidence from international studies that green roof habitats can:

- contribute positively to the creation of habitats for biodiversity,
- reduce stormwater run-off,
- reduce the temperature inside buildings,
- reduce the 'urban heat island effect',
- extend the life of roofs,
- reduce air pollution,
- improve the living and working environment,
- reduce noise pollution,
- and enhance food security.

Section 4 presented a step-by-step guide to creating a green roof habitat. This included structural considerations, safety considerations, the slope of the roof, the roof location, the types of green roof systems available, the types of planting media available, suitable plants and plant themes, and types of edging. The information presented in this section was based primarily on experience gained through the GRPP.

Section 5 presented a brief guide to maintaining a green roof habitat. This included irrigation, composting and sustainable waste management, controlling weeds, and controlling pests and diseases. The information presented in this section was again based primarily on experience gained through the GRPP.

In summary, the following table presents key recommendations obtained from this guideline and the GRPP:

Issue	Recommendations
Roof slope	• Ideally between 3 - 10°
Type of green roof system	• Modular or direct.
Planting medium	• 60% inorganic (containing mixture of decomposed granite, crushed brick, Berea red sand, and vermiculite). • 40% organic (containing only compost).
Most successful green roof plants	• *Aloe arborescens* • *Crassula sarmentosa* • *Kalanchoe rotundifolia* • *Aloe maculate* • *Heurnia hysterix* • *Stapelia gigantea*
Recommended edging	• Treated wooden edging.
Irrigation	• Hand watering – until top 2-3cm of growing medium saturated.
Fertilisation	• Compost or mulch.
Controlling weeds	• Hand-pulling.
Controlling pests	• Selecting pest-resistant plants. • Physical removal of pests or infected plants.

7 Existing Green Roof Habitats in Durban

Project name	eThekwini Municipality Green Roof Pilot Project
Year established	2008
Owner	eThekwini Municipality
Building type	Municipal - Offices
Purpose	Pilot / research
Type	Extensive. Direct and modular
System	Single source provider
Size	550m²
Roof Slope	1-3%
Access	Accessible (not to general public). Visible from balconies and windows of surrounding buildings.
Project Managers and Designers	Green Roof Designs cc. Ecosystems Management & Green Roof Designs. Geoff Nichols Horticultural Services.

Project name	Beachfront Promenade
Year established	2010
Owner	eThekwini Municipality
Building type	Municipal - Retail
Purpose	Part of Greening Durban 2010
Type	Extensive to Semi-intensive Direct
System	Single source provider
Size	240m²
Roof Slope	1-5%
Access	Accessible (not to general public). Visible from sidewalks.
Project Managers and Designers	Mike Tod Arhitects.

Project name	Master Builders' Association
Year established	2010
Owner	Master Builders' Association
Building type	Offices
Purpose	Pilot /research
Type	Direct Modular
System	Single source provider
Size	80m²
Roof Slope	1-5%
Access	Accessible (not to general public). Visible from inside building and adjacent sidewalks.
Project Managers and Designers	Green Roof Designs cc.

8 Useful Resources

8.1 Publications and Articles

Bergs J. (2009), *The Effect of Healthy Workplaces on the Well-being and Productivity of Office Workers*, Amersfoort, The Netherlands

Brenneisen S. (2006), Space for Urban Wildlife: Designing Green Roofs as Habitats in Switzerland, *Urban Habitats*, (4:1)

EThekwini Municipality (2007), *Biodiversity Report 2007*, eThekwini Municipality: Environmental Management Department, Durban

EThekwini Municipality (2006), *Climate Change: What Does it Mean for eThekwini Municipality?*, eThekwini Municipality: Environmental Management Department, Durban

EThekwini Municipality (2010), *Green Landscaping Guideline*, eThekwini Municipality: Environmental Planning and Climate Protection Department, Durban

EThekwini Municipality (2010), *Energy Efficiency Guideline*, eThekwini Municipality: Environmental Planning and Climate Protection Department, Durban

EThekwini Municipality (2011), *eThekwini Quality of Life Household Survey 2009-2010*, eThekwini Municipality, Durban

Fjeld I.T. and Bonnevie C. (2002), *The Effect of Plants and Artificial Daylight on the Well-Being and Health of Office Workers, School Children and Health Care Personnel*, Floriade, Norway

Gedge D., Dunnet N., Grant G., and Jones R. (2007), *Living Roofs*, Research Report, Natural England

Getter K.L., Rowe D.B., Robertson P., Cregg B.M. and Andersen J.A. (2009), Carbon Sequestration Potential of Extensive Green Roofs, *Environmental Science & Technology*, 43 (19), pg 7564–7570

Grant G. (2006), Extensive Green Roofs in London, *Urban Habitats*, (4: 1)

Grant G., Engleback L. and Nicholson B. (2003), *Green Roofs: Their Existing Status and Potential for Conserving Biodiversity in Urban Areas*, Report No. 498, English Nature Research Project, Peterborough

Kadas G. (2006), Rare Invertebrates Colonising Green Roofs in London, *Urban Habitats*, (4: 1)

Kö'9ahler M. (2006), Long-Term Vegetation Research on Two Extensive Green Roofs in Berlin, *Urban Habitats*,(4:1)

Liu K. and Baskaran B. (2003), *Thermal Performance of Green Roofs Through Field Evaluation*, NRCC-46412, National Research Council, Ottawa

Lundholm J.T. (2006), Green Roofs and Facades: A Habitat Template Approach, *Urban Habitats*, (4: 1)

Milford R. (2009), *Green House Gas Emission Baselines and Reduction Potentials from Buildings in South Africa*, Discussion Document for United Nations Environment Programme, South Africa.

Peck S. and Kuhn M. *Design Guidelines for Green Roofs*, www.cmhc-schl.gc.ca

Porsche U. and Köler M. (2003), *Life Cycle Costs of Green Roofs: A Comparison of Germany, USA, and Brazil*, Paper presented at the World Climate & Energy Event, Rio de Janeiro

Rosenzweig C. (Ed.) (2006), *Mitigating New York's Heat Island with Urban Forestry, Living Roofs, and Light Surfaces*, Research Report 06-06, New York State Energy Research and Development Authority

Rosenzweig C. Gafflin S. and Parshall L. (Ed.) (2006), *Green Roofs in the New York Metropolitan Region*, Research Report, Columbia University Centre for Climate Systems Research, New York.

Ulrich RS. (1984), View Through a Window May Influence Recovery from Surgery, *Science*, (224), pg. 420-421

Williams N.S.G., Rayner J.P. and Raynor K.J. (2010), Green Roofs for a Wide Brownland: Opportunities and Barriers for Rooftop Greening in Australia, *Urban Forestry and Urban Greening*, Article in Press.

Wong E. (2008), *Reducing Urban Heat Islands: Compendium of Strategies*, U.S. Environmental Protection Agency, Washington

8.2 Websites

Centre for Green Roof Research	www.web.me.com/rdberghage/Centerforgreenroof/Home.html
CSU Green Roofs	www.greenroof.agsci.colostate.edu/
Ecosystems Management & Green Roof Designs	www.ecosystem-management.com
eThekwini Municipality: Bylaws	www.durban.gov.za/durban/government/bylaws
eThekwini Municipality: Environmental Planning and Climate Protection Department	www.durban.gov.za/durban/services/epcpd
Sika	www.sika.com
Greenroofs Australia	www.greenroofs.wordpress.com
Greenroof Centre, Neubrandenburg, Germany	www.gruendach-mv.de/en/index.htm
Greenroofs.com	www.greenroofs.com
Greenroofs for Healthy Cities	www.greenroofs.org
Greenroof Research Programme	www.hrt.msu.edu/greenroof/
Livingroofs.org	www.livingroofs.org
U.S. EPA - Heat Island Effect	www.epa.gov/heatisld/index.htm
Urban Habitats – An electronic Journal on the Biology of Urban Areas Around the World	www.urbanhabitats.org

8.3 Relevant Legislation

Legislation	Relevant Sections
Conservation of Agricultural Resources Act (43 of 1983)	• Classifies weeds and invader plants as either Category 1, 2 or 3 plants based on extent to which they colonise an area and displace indigenous plants. • Requires landowners to control Category 1, 2 and 3 plants.

Constitution of South Africa (108 of 1996)	• First legislation to introduce an "environmental right" into South African law.
	• Requires protection of the environment, for the benefit of present and future generations, through reasonable legislative and other measures that:
	  ◦ Prevent pollution and ecological degradation.
	  ◦ Promote conservation.
	  ◦ Secure ecologically sustainable development and use of natural resources.

Environmental Conservation Act (73 of 1989)	• Regulates waste, noise, and activities which may have a detrimental impact on the environment. • However, the regulation of activities which may have a detrimental impact on the environment were repealed when the National Environmental Management Act (107 of 1998) came into effect.
eThekwini Municipality: Building Bylaws	• Regulates roof coverage, loading of buildings, and management of stormwater. • Most of these bylaws were repealed when the National Building Regulations and Buildings Standards Act (103 of 1977) came into effect.
eThekwini Municipality: Water Supply Bylaws.	• Regulates the installation of water systems, storage tanks, wasting of water, prevention of the pollution of water, and use of water from other sources other than the municipal supply.

Natal Nature Conservation Ordinance (15 of 1974)	• List plants which are specially protected and protected.
	• In terms of the Ordinance:
	  ◦ It is an offence, punishable with a fine and/or imprisonment, to gather, export, import, purchase, sell, relocate, or translocate a specially protected species without a permit.
	  ◦ It is an offence to gather, export, import, or sell a protected species without a permit. You may however buy a protected species from someone that has valid license to sell the plant.
	• No permit is required for collecting seeds or cuttings from unprotected species.

National Building Regulations and Buildings Standards Act (103 of 1977)	• Regulates construction of new buildings and alteration of existing buildings. • Sets minimum standards for buildings in terms of public safety, fire installations, and management of stormwater.
National Environmental Management Act (107 of 1998)	• Gives effect to the environmental rights contained in Constitution. • Sets out several environmental management principles which apply to all actions which effect the environment. • Regulates activities which may have a detrimental impact on the environment and for which prior Environmental Authorisation is required.
National Environmental Management: Biodiversity Act (10 of 2004)	• Was enacted to meet South Africa's obligations in terms of the 1992 Convention on Biological Diversity. • Represents a shift in the approach to species protection, acknowledging that in order to protect a particular species, such as Black-Head Dwarf Chameleon, its habitat and the ecosystem of which it is a part must also be protected. • Empowers the Minister of Environmental Affairs to publish a list of ecosystems that are threatened and in need of protection. The draft national list of Threatened Ecosystems was published in GNR 1477 (of 2009). • Also empowers the Minister of Environmental Affairs to publish a list of species which are considered to be critically endangered, endangered, vulnerable, or in need of protection. This list was published in GNR 150 (of 2007). • In terms of the Act, a permit is required for the collection, transport, and possession of any of the above listed species.

8.4 Green Roof Materials Suppliers

The following table presents list local suppliers of green roof habitat materials[47].

Product	Company	Specifications	Contact
Waterproof Membrane	a.b.e. Construction Chemicals Limited	Index Unigum Torch on	031-913 5400
	Derbigum	Derbigum CG4	031-700 2195
Root barrier	a.b.e. Construction Chemicals Limited	Index Defend H	031-913 5400
	Derbigum	Derbigum CG3 and Derbigum CG4H (horticultural) waterproofing membrane	031-700 2195
	Gundle Pastall	1000 micron dam liner LDPE	031-263 0777
	Sika	MTC Green. MTC Ballast	031-792 6500
Drainage layer	a.b.e. Construction Chemicals Limited	Abe drain G	031-913 5400
	Maccaferi	Macdrain 1L or 2L	031-705 0522
	Derbigum	Delta MS20P (perforated)	031-700 2195
Modules	Green Roof Designs cc	UV Resistant, Recyclable HDPE	083 398 6902

8.5 Green Roof Plant Suppliers

The following table presents a list of nurseries in the Durban area that supply indigenous plants[48].

Name	Area	Telephone	Name	Area	Telephone
Assagay Nursery	Assagay	031-768 1333	Indigro	Waterfall	031-763 3045
Bloomingdales Garden Centre	Glen Hills	031-564 5859	Jenny Dean Wildflowers	Assagay	031-768 1209
Burgess Garden	Westville	031-266 4366	Jungle Garden Nursery	Sherwood	031-207 7642
Dieters Nursery	Hillcrest	031-768 2173	Palms and Tropicals	Westville	031-267 1111
Dunrobin Nursery	Botha's Hill	031-777 1855	Plant Collectors Nursery	Queensburgh	031-464 9909
Garden Hub Nursery & Garden Centre	Kloof	031-764 6329	Plant Nursery	Bluff	031-466 5599
Geoff's Jungle	Pinetown	031-702 0836	Plants-a-plenty	Westville	031-266 7455
Greenman Nursery	Kloof	031-764 3944	Queensburgh Garden & Hobby Centre	Queensburgh	031-464 9938
Halls Garden Pavilion	Amanzimtoti	031-903 6737	Silverglen Nursery	Chatsworth	031-404 5628
Havenside Nurseries	Chatsworth	031-400 3355	Tropical Nursery	Sherwood	031-208 4925
Illovo Nursery	Amanzimtoti	031-916 2491	Ridgemont Nursery	Waterfall	031-766 3794

8.6 Green Roof Specialists Involved in the GRPP

Green Roof Designs
We put nature back on top

Green Roof Designs cc:

Cell: 083 398 6902

Email: cgreenstone@mweb.co.za

Ecoman

Ecoman:

Cell: 082 061 2593

Email: info@ecosystems-management.com

[47] While care was taken to be as comprehensive as possible in compiling this list of local suppliers at the time of writing, some suppliers may have been omitted.

[48] While care was taken to be as comprehensive as possible in compiling this list of local suppliers at the time of writing, some suppliers may have been omitted.

Download this document for free:

http://www.imaginedurban.org/
http://fifaworldcup.durban.gov.za/Pages/GreeningDurban2010

For more information on the GRPP contact:

Meggan Spires
Tel: 031 311 7920
Email: LewisM@durban.gov.za

Contact details:

Environmental Planning and
Climate Protection Department
eThekwini Municipality

PO Box 680
Durban 4000
Tel: +27 31 311 7875
Fax: +27 31 311 7134

www.durban.gov.za