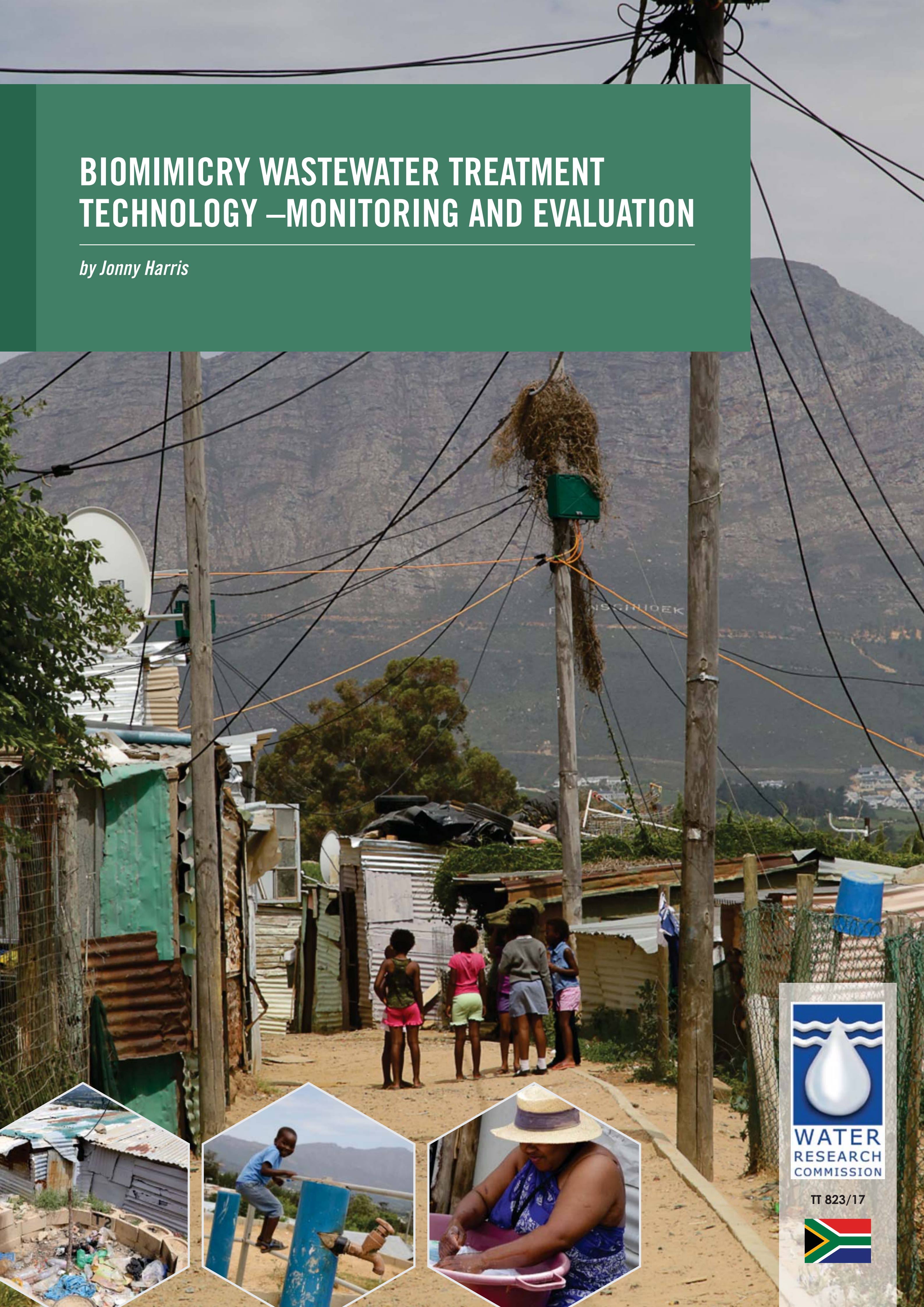

BIOMIMICRY WASTEWATER TREATMENT TECHNOLOGY –MONITORING AND EVALUATION

by Jonny Harris

WATER RESEARCH COMMISSION

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Biomimicry Wastewater Treatment Technology – Monitoring and Evaluation

Report to the

Water Research Commission

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Executive Summary

Biomimicry South Africa partnered with John Todd Ecological Design (JTED), Greenhouse Systems Development, Maluti GSM and Isidima Design and Development to work as a team in developing innovative ecological technologies to treat highly concentrated greywater that flows out of the Langrug informal settlement in Franschhoek. The resulting designs include source control, local and regional treatment systems based on biomimetic and ecological design principles. The downstream (regional) treatment system is based on the trademark Eco-machine concept developed by Dr John Todd. This design, together with all other components, has been developed through a transdisciplinary co-design process that included the community, government, and the project team.

The intricate nature of these systems involves the intersection of wastewater treatment science with ecology. The application of these systems in informal settlements as innovative prototypes for treating wastewater (and managing stormwater) required careful monitoring of the different components of the systems and how they evolve over time, as well as the water quality. The monitoring process enables the efficiency and efficacy of these treatment systems to be evaluated to determine the suitability of this technology in this context. In this regard, the objectives of the Biomimicry Wastewater Treatment Technology – Monitoring and Evaluation Project were as follows:

1. **Develop a research, monitoring and evaluation programme** for the Eco-machines implemented in an informal settlement in the Franschhoek area.
2. Generate **two Masters degrees** in the field of innovative, sustainable wastewater treatment technology.
3. Report on the findings to **inform the design of future Eco-machines**.
4. Improve understanding of the **operation and impacts of Eco-machines** in context.
5. Host **knowledge dissemination** workshops to present the results to key stakeholders.

The core component of this research study was to investigate and learn from the performance of the biomimicry-based wastewater treatment systems being constructed at Langrug informal settlement in Franschhoek. The implementation of this infrastructure is part of a separate project funded by the Western Cape Government. Unexpected delays encountered on this project meant the implementation of the Genius of SPACE project was not completed within the timeframe of this study. However, Phase 1 of the Genius of SPACE project was completed, which involved the collection, diversion and initial treatment of greywater. Since the Eco-machine component of the Genius of SPACE was not completed within the study, parallel research on the Plankenbrug Green filter was undertaken. The Green Filter installed on the Plankenbrug River, in the Stellenbosch area, was used to develop the research, monitoring and evaluation programme. The Plankenbrug River Green Filter system treats river water that is heavily polluted from local industry and from uncontrolled greywater discharge from the nearby settlements of Kayamandi and Enkanini, which closely simulates the Langrug settlement greywater discharge.

The greywater prototype source control pre-treatment step for the Eco-machine in Langrug has been implemented in Blocks S and T of the Langrug informal settlement, serving a total of 115 households. This system enables the separation of stormwater and greywater flows, filtering the greywater and diverting the flow into a series of tree gardens and micro-wetlands to promote greening. The excess greywater then discharges to the municipal sewer.

Masters Research

This study further incorporated field research and laboratory studies for three masters research projects focusing on:

(i) Developing a case study in transdisciplinarity based on the restoration of water systems using Eco-machines within the Langrug community.
(ii) The removal of anthropogenic xenobiotics from domestic wastewater by degradative biofilm communities.
(iii) Establishing the efficiency of the biomimicry-based Eco-machine for the removal of pharmaceutical and personal care products (PPCPs).

The findings of this research increased knowledge of the social and micro-biological processes required to achieve an effective community-based treatment technology, in particular, the need to align the project with the provision of local job opportunities. In terms of treatment performance, this research has laid the foundation for further research into the presence of biofilms within the system and the development of an evaluation procedure to enable the sampling of PPCPs in the waste stream. One of the key claims of the Eco-machine concept is improved performance in treating PPCPs compared to conventional wastewater treatment systems.

The Monitoring and Evaluation Programme

The greywater pilot system within the informal settlement was constructed using community labour and therefore require ongoing ***community-based*** monitoring and maintenance. The creation of employment and incremental steps towards security of land tenure aligns with the priority aims of the Langrug community. This contributes to community acceptance and ownership which are essential to the long-term success of these systems. A key finding of this project is that the social component is as important as the technical component for success of these systems. It is important to involve the local community in the monitoring, evaluation and maintenance of the systems, and to set up the monitoring programme in alignment with the skills of the community. Therefore, a simplified system for monitoring and maintenance has been developed as part of the monitoring and evaluation programme.

Five key components were incorporated into the monitoring and evaluation programme of the greywater pilot systems and the Eco-machines. The five components cover **operational**, **physical**, **chemical**, **micro-biological** and **ecological** parameters. Core elements of this monitoring programme can be undertaken by community operatives. This enables short feedback loops, effective maintenance and local design adaptation to support the long-term sustainability of the infrastructure. Ongoing research into this technology is required to verify the hydraulic retention time that is required to produce the required effluent water quality.

The study findings also generated valuable analytical methods useful for monitoring and evaluation of the effectiveness of Eco-machines in the treatment and management of greywater discharge from informal settlements.

Operation and Impacts of Eco-machines

The study findings have been incorporated, along with other micro-biological and chemical determinants, into a community-based monitoring programme which seeks to utilise the capacity that exists within Langrug settlement to assist with monitoring the performance of the system. This close interaction with the monitoring programme enables short feedback loops to activate maintenance activities and further development of the design of the system. The monitoring programme includes five categories, namely operational, physical, chemical, micro-biological, and ecological. An initial trial of this methodology confirmed the suitability of this approach as a useful tool for monitoring the performance of the biomimicry-based treatment systems.

Since the monitoring and maintenance of the systems in the Langrug informal settlement is done by community members, simple checklists and systems for monitoring by the community have been developed to enable effective monitoring of the maintenance requirements.

Initial observations and water quality analysis have confirmed that the greywater prototypes in Blocks S and T of the Langrug community are effectively separating the highly polluted greywater from stormwater flows and enabling the productive use of this water to contribute to the creation of green space within the informal settlement. The tree gardens do reduce the greywater flows discharging from the prototype into the sewer. The implementation of this prototype provides an incremental step in the upgrading and formalisation of the settlement.

As expected, the prototype only achieves minimal treatment performance, but does prevent the migration of solids which could lead to pipe blockages. The planned Eco-machine at the bottom of the settlement is required to provide effective treatment of this wastewater.

The water quality samples taken during periods of stable operation of the Plankenbrug Green Filter have confirmed a 99% reduction in E. *coli* from greater than 10 million E. *coli* per 100 millilitres to 4 700, with effluent concentrations reaching as low as 16 E. *coli* per 100 millilitres for lower flow rates. A comparable reduction in ammonia and chemical oxygen demand was also observed. These findings indicate that biomimicry wastewater treatment systems have the potential to treat polluted effluents to a quality that complies with the South African General Authorisation Limits for the discharge of treated effluent.

Inform the Design of Future Eco-Machines

The outcomes of this study will inform the future design of similar biomimicry-based wastewater treatment systems through an improved understanding of the biological treatment processes that establish within the system; the suitability of indigenous vegetation to handle the effluent quality and the treatment capacity for a given footprint. An increased understanding of the operation and maintenance burden of the systems will inform future design. For instance, future designs should ensure convenient access to those parts of the system which require the most frequent maintenance.

Based on this study, biomimetic constructed wetland systems show promising results in the treatment of wastewater, but, due to their lower throughput levels, do have limitations which may need to be addressed from a design point of view. These limitations can be addressed through the incorporation of a floating aquatic wetland system (such as the Eco-machine) which has increased porosity and increased water depth. This enables a reduced footprint to achieve the longer hydraulic retention time required by wetland systems. The increased surface area provided by the root matrix, compared with conventional filter media, enables increased surface area for biofilm growth which can lead to reduced retention times.

Further investigation into the benefits of a cellular design should be considered. This is particularly important when considering the scaling up of the floating aquatic wastewater treatment design where the use of individual tanks is unlikely to be as cost effective as a compartmentalised lagoon system.

Knowledge Dissemination

Two knowledge dissemination workshops were hosted to present the results to key stakeholders, including representatives from government, the private sector and research institutions. There was significant interest at these workshops in the application of biomimicry wastewater treatment systems and their maintenance by locally trained operatives.

Conclusion and Recommendations

The wastewater treatment technologies that were constructed at Langrug informal settlement and adjacent to the Plankenbrug River in Stellenbosch, utilise simple modular construction methods which incorporate standard materials and components. This infrastructure can be constructed using community-based labour who were then able to provide routine maintenance with relatively little external support.

Aside from the benefit of local job creation, the treatment technologies produced a visible improvement in the local environment through the separation of greywater and stormwater flows and the diversion of polluted greywater into a contained network of pipes, tree gardens and micro-wetlands. The preliminary analysis of this system indicates a reduction in the total discharge of greywater from the pilot site through the irrigation of tree gardens. Initial results also indicate that the COD, suspended solids and faecal coliform concentrations in the greywater effluent were significantly improved by the system.

The Eco-machine technology that is proposed for the downstream extent of Langrug informal settlement will enable effective treatment of the greywater flow. The initial performance of this technology was demonstrated by the Plankenbrug Green Filter which produced good quality effluent that was within the General Authorisation Limits for effluent discharge.

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Abbreviations

COD	Chemical oxygen demand
JTED	John Todd Ecological Design
PPCPs	Pharmaceutical and personal care products
SuDS	Sustainable drainage systems

CHAPTER 1

1 Biomimicry Wastewater Treatment Technologies

1.1 Background

Biomimicry South Africa partnered with John Todd Ecological Design (JTED), Informal South, Greenhouse and Maluti GSM to work as a team in developing innovative ecological technologies to treat the highly concentrated greywater that flows out of the Langrug informal settlement in Franschhoek. The resulting designs include source control, local and regional treatment systems based on biomimetic and ecological engineering design principles. The design includes a downstream (regional) treatment system based on the trademark Eco-machine concept developed by JTED. This design, together with all other components, has been developed through a co-design process with the community, government, and the project team.

A second design has been developed in partnership with JTED, Biomimicry SA and Isidima Design and Development to pilot the Eco-machine technology as a means of treating the Plankenbrug River in Stellenbosch. This river is heavily polluted from urban run-off arising from Enkanini informal settlement, Kayamandi, and adjacent industrial areas.

The nature of these systems is complex but not complicated, involving the intersection of wastewater treatment science with ecology. The application of these systems as innovative prototypes for treating wastewater (and managing stormwater) – particularly in informal settlements – requires careful monitoring of the different components of the systems, how they evolve over time, as well as the water quality. Through the monitoring process to date, the efficiency and efficacy of these treatment systems has been evaluated to inform the suitability of this technology in this context.

1.2 Project Aims

The design and development of innovative ecological technologies, based on the Eco-machine, for the treatment of wastewater has been piloted in both the Langrug informal settlements and the Plankenbrug Green Filter Eco-machine. This study focused on monitoring and evaluating the performance of these technologies, with the purpose of informing future design and implementation.

The aims of this project were:

1. Develop a research, monitoring and evaluation programme for the Eco-machines implemented in an informal settlement in the Franschhoek area
2. Generate two Masters degrees in the fields of innovative, sustainable wastewater treatment technology
3. Report on the findings to inform the design of future Eco-machines
4. Improve understanding of the operation and impacts of Eco-machines in context
5. Host knowledge dissemination workshops to present the results to key stakeholders.

The case studies for this project include the pilot projects located in Franschhoek within the Langrug community and the Plankenbrug River Green Filter pilot project which is located on the Plankenbrug

River in Stellenbosch. Both are in the Western Cape Province, South Africa. In addition, this study is informed by the research of three Masters' theses. Further background on each of these is included below.

1.3 The Langrug Informal Settlement Case Study

Langrug is an informal settlement community situated outside of Franschhoek, Western Cape, cascading down the side of a mountain. Highly concentrated greywater is discarded by residents into a matrix of constructed channels throughout the settlement. These greywater gutters are highly unsanitary, create a foul odour and deliver untreated wastewater to the bottom of the hill (and into the Berg River). Moreover, contact with this water is a danger to human health, a condition which is exacerbated by accumulation of solid waste within the gutter. A portion of this effluent is also dispersed onto the community sports field where it creates a stagnant bog condition. The effluent coming from the informal settlement has highly variable flows that fluctuate daily according to water usage and more drastically according to rainfall. The effluent has an extremely high bacterial count as well as high nitrogen levels.

Residents of the informal settlements do not usually have running water or formal plumbing in their homes. Community taps are located at various stations throughout the informal settlements and residents fill buckets of water and carry them back to their homes for drinking, cooking and washing. After use, this water may contain detergents, personal care products, food solids and human waste. Because this water has to be carried to the home, people are incredibly efficient with their water use, leading to a highly concentrated greywater which is more appropriately classified as wastewater. This wastewater is discarded outside the home, where, in the absence of a formal sewerage network, the wastewater combines with the stormwater drainage and discharges, untreated, into the river.

The wastewater described above discharges into the river systems, namely the Berg River and Eerste River, which are required to irrigate orchards and vineyards. The export of fruit and fruit products such as wine is an important aspect of the economy. Bacterial counts of the river water that do not meet regulatory standards have serious negative implications for the export of agricultural products. This economic factor, in combination with a growing awareness of the overall declining health of the rivers from eutrophication and contaminants, has galvanised the Western Cape region to seek solutions for their water crisis. Biomimicry-inspired wastewater treatment systems may present a sustainable and ecological solution that will support the health of the river and also bring forth a new approach of low-energy, decentralised wastewater treatment.

The Langrug informal settlement pilot project includes source control, local and regional treatment systems based on biomimetic and ecological engineering design principles. The monitoring and evaluation process for this study was based on the source control greywater prototypes. Since the (regional) Eco-machine is yet to be constructed, an additional case study was included to contribute to the aims of this project.

1.4 The Plankenbrug River Green Filter Case Study

The Plankenbrug River Green Filter case study was included in this research for two reasons – one is that the planned Eco-machine component of the Langrug informal settlement was delayed in construction – still to be done in mid-2017. Another reason is that the Plankenbrug River Green Filter is treating river pollution from sources such as informal settlements (amongst other sources) – so addresses another potential area for the application of Eco-machines.

The Green Filter is a modified version of the JTED Eco-machine. It was installed on the Plankenbrug River in Stellenbosch, where it treats river water that is heavily polluted from local industry and from uncontrolled greywater discharge from the nearby settlements of Kayamandi and Enkanini. This system is similar to the Eco-machine that is planned for the Langrug settlement. This system was therefore monitored in place of the Eco-machine planned for Langrug - to contribute to the aims of this project.

1.5 Masters Research Projects

This study is also informed by the results of three Masters degree research projects that focused on:

- The removal of anthropogenic xenobiotics from domestic wastewater by degradative biofilm communities
- Establishing the efficiency of the biomimicry-based Eco-machine for removal of pharmaceutical and personal care products (PPCPs)
- A case study in transdisciplinarity based on the restoration of water systems using Eco-machines within the Langrug community

Each of these add value to the aims of this project – informing the monitoring and evaluation programme, improving understanding of these systems and informing future design and implementation of similar systems.

CHAPTER 2

2 Literature Review

2.1 Introduction

More than half of the world's population lives in urban areas, where many do not have access to adequate water and sanitation services (Corcoran *et al*., 2010; UN, 2013). Globally, 827.6 million people live in informal settlements, which are densely populated areas on the peripheries of towns and cities experiencing inadequate water, inadequate sanitation and little-to-no waste removal system (UN, 2013; Kimoon, 2014). In developing countries such as South Africa, the contentious issues of tenure security within informal settlements mean that there is no formal piped water and wastewater infrastructure, resulting in poor drainage of blackwater, greywater and polluted stormwater (Murthy, 2010; Armitage 2011). Informal settlements in South Africa are characterised by 'shacks', which are unplanned, haphazardly constructed houses usually made of corrugated iron and any available materials. Domestic greywater and contaminated water from communal toilets and wash stations scattered all around the settlement make their way into nearby rivers (Armitage, 2011).

The Berg River in the Western Cape Province is a source of irrigation for commercial agriculture, mainly for vineyards, wheat fields and fruit. Over 50% of the Western Cape's rivers are polluted by effluent water from industries and urban settlements in some way (Fourie, 2005). With 75% of the fruit exported to the United Kingdom and the rest of the European Union (WCG, 2012), farmers must adhere to international export standards regarding the quality of irrigation water. The economic incentive and the threat of losing vital ecosystem services provided by the Berg River, have led to the development of an improvement plan by the Western Cape Government to recommend and implement water interventions for the Berg River (WCG, 2012). The Western Cape Department of Environmental Affairs and Development Planning found that informal settlements contribute significant amounts of effluent to the Berg River. In particular, Langrug is one such informal settlement in Franschhoek, where dwellers' health and well-being are compromised as a result of contaminated waste and stormwater, which ultimately makes its way into the Berg River. The informal settlement of Langrug is a high-density population area situated on a hill, where residents experience poor living conditions mostly due to poor water and sanitation access. In 2011, there were approximately 44.9 people allocated to one toilet and 91 people to one tap (Anon, 2011). Residents dispose of greywater into informal, unsanitary drains which also carry highly concentrated wastewater and solid waste (Anon, 2011).

2.2 Wastewater Quality and Drainage from Informal Settlements

The polluted waters draining informal settlements have deleterious impacts on the surrounding environments such as eutrophication, ecological degradation, erosion and river pollution (Taylor *et al*., 2004; Walsh *et al*., 2005). The pollution can either be point source (wastewater treatment works) and/or nonpoint source (domestic pollutants, wastewater) (Fourie, 2005). The amount of water used and rainfall rate changes the flow of the effluent coming from the informal settlement. The effluent often contains bacteria, faecal matter, PPCPs and other micro-pollutants which are health concerns.

2.3 The Physical, Chemical and Microbial Quality of the Water from Informal Settlements

Disease-causing pathogens can be bacterial or viral and often require testing to be identified (RSA, 1996; Ashbolt *et al*., 2001). Microbial indicators can be used to indicate how harmful water is to human health. The three types of microbial indicators are:

- index and model indicator organisms which indicate pathogens such as *E. Coli*;
- faecal coliforms which indicate sanitary conditions;
- heterotrophic indicators which are representative of the general quality of water (Ashbolt *et al*., 2001).

There are other kinds of non-microbial pollutants draining informal settlements. Technological and Industrial advancements have resulted in the production of synthetic compounds, usually originating from household products, such as detergents, toothpaste and medicines (Pillay, 1994). These pollutants include 'antibiotics, lipid regulators, anti-inflammatories, antiepileptics, tranquillisers, anti-depressants and X-ray contrast media' (Suárez *et al*., 2008: 126).

Micro-pollutants usually make their way from urban households into sewerage systems (Gros *et al*., 2007) where they are treated. The treatment of these micro-pollutants in sewerage treatment plants is a long process involving physical, chemical and biological processes (Suárez *et al*., 2008). However, there is concern that treatment technologies may not adequately remove the pollutants, as some pharmaceuticals have been detected after treatment. Some pharmaceuticals have been found in the organs of fish, while traces have also been found to impact the human endocrine system; meaning that their exact impact on human and animal health is not fully known (Ternes, 2001; Heberer, 2002; Fourie, 2005; Suárez *et al.*, 2008). This has resulted in rising research interests regarding nutrients, synthetic compounds and bacterial pollutants.

Some bacteria can attach to surfaces and combine in a matrix to form biofilms, forming resistant yet adaptive microbial societies (Costerton *et al*., 1999) that can degrade chemical pollutants and utilise synthetic compounds (Venail and Vives, 2013). Biofilms have been tested and manipulated in controlled environments (Wolfaardt, 1994) and interest in their use for bioremediation has increased (Venail and Vives, 2013).

Monthly monitoring, under the mandate of the National Water Act (No. 36 of 1998), has furthered our understanding of the anthropogenic influences of pollutants (Fourie, 2005). Regular monitoring and testing of PPCPs requires high expertise and is often expensive and time consuming because of the advanced analytical equipment required, such as gas or liquid chromatography and mass spectrometry (MS/MS) (Suárez *et al.*, 2008). In this case, the proposed monitoring and evaluation component of the project will contribute towards a database of readings regarding PPCPs. Under the auspices of the Department of Water and Sanitation, monitoring of chemical, microbial, eutrophication and aspects of the ecosystems of several river systems in the Western Cape has ensued together with the Berg River Improvement Plan (WCG, 2012); however, expertise in monitoring parameters concerning ecological and sustainable urban drainage systems is lacking (DWAF, 2002; Fourie, 2005).

2.4 Ecological Engineering and Sustainable Drainage Systems

New approaches to water management are required in order to sustainably manage water from informal settlements. Sustainable drainage systems (SuDS) are relatively new methods within the ecological engineering field, which seek to develop water management infrastructure that is holistic, people-centred and ecologically sensitive (Mitsch and Jørgensen, 2003). Unlike orthodox stormwater and wastewater systems that aim to remove water from the system and transport it elsewhere, SuDS treat effluent on-site, allowing for recycling and reusing of treated water (WSUD, 2015).

An ecological treatment system (Eco-machine) is designed to intercept stormwater and treat greywater through bioremediation. Bioremediation uses natural organisms to clean wastewater. Successful bioremediation processes have been implemented in different spheres. including bioengineering of soils and groundwater, bioremediation of surface and subsurface soils, bioremediation of freshwater and marine systems and hydrogeological information (Baker and Herson, 1994).

The first stage of SuDS for Langrug will be bioremediation within Langrug, upstream of the Berg River. The Langrug Eco-machine is made up of 87 cells, divided into three trains. Within each cell, the five taxonomic kingdoms of Monera, Fungi, Plantae, Animalia and Protista (Caprette, 2005) symbiotically degrade and sequester the microbial pathogens, organic compounds and heavy metal pollutants in the wastewater (JTED, 2015). A point source decentralised wastewater treatment utilising a 'living sewer' improves the informally constructed drainage pipes while improving robustness through 'collection, conveyance, treatment and disposal in a novel holistic system' (JTED, 2015). The branching drainage lines then converge into phototrophic soil makers (PSM), which are deep tree wells that clean greywater through decomposition, adsorption and micro-organisms. These are also known as constructed wetlands (Mitsch and Jørgensen, 2003). This will, over time, eliminate the odour that would be found in conventional sewer treatment as well as greening the community (JTED, 2015). Greywater and stormwater are then captured further downstream at a decentralised wastewater treatment centre that uses floating raft restorers (JTED, 2015).

2.5 Biomimicry

Biomimicry is learning from nature and emulating mechanisms found in the natural world, for the purpose of solving human challenges and creating sustainable designs, products, processes and policies (Benyus, 2002; Biomimicry Group, 2013). In order to design efficient and innovative solutions to challenges such as wastewater treatment, life's principles are considered. These principles or lessons from nature are based on the premise that life creates conditions conducive to life (Biomimicry Group, 2013: 13).

Table 2. 1: Life Principles Used in Biomimicry Design (Biomimicry Group, 2013)

Biomimicry Life Principle	**Subcategory**
Adapt to changing conditions	• Self-organise • Maintain integrity through self-renewal • Embody resilience through variation, redundancy and decentralisation
Be locally attuned and responsive	• Leverage cyclical processes • Use ready available materials and energy • Use feedback loops • Cultivate cooperation
Use life-friendly chemistry	• Break down products into benign constituents • Build selectively with a small subset of elements • Do chemistry in water
Be resource efficient (material and energy)	• Use low-energy processes • Use multi-functional design • Recycle all material • Fit form to function
Integrated development with growth	• Self-organise • Build from the bottom up • Combine modular and nested components
Evolve to survive	• Replicate strategies that work • Integrate the unexpected • Reshuffle information

According to biomimicry principles (Biomimicry Group, 2013), the Eco-machine implemented in Langrug should be reflexive and adaptive, yet robust enough to treat contaminated water. The principles listed in Table 1 are at the core of sound biomimicry design. In emulating nature, the Eco-machine should recycle waste and use it locally without having to out-source energy or resources elsewhere (Benyus, 2002; Biomimicry Group, 2013; JTED, 2015).

Biomimicry utilises similar principles to classic systems approaches to design. These approaches deal with the holistic suite of elements which interact both as separate parts and within their combined wholeness in an ecosystem (Richardson, 1986; Berkes and Folke, 1998). It has been argued that ecological engineering should consider whole ecosystems and utilise this systems approach to ensure that technologies are self-sustaining (Pahl-Wostl, 1995; Jiusto and Kenney, 2015). Ecosystems are the broader environments in which all living organisms thrive (MA, 2005). Biomimicry thus encourages resource management that is cognisant of the need for sustainability between humans and nature. Designing innovations based on biomimicry may result in only the function of a natural design being emulated, but not the structure, or vice versa. This is why it is important to fine tune types of design methods (Lakhtakia and Martin-Palma, 2013) to include inputs from different stakeholders. Interdisciplinarity has been observed in biomimicry design, which is bringing together individuals working in different disciplinary fields, such as designers and engineers, to work together to solve a challenge such as stormwater and wastewater management (Benyus, 2002).

2.6 Transdisciplinarity

Multidisciplinarity and interdisciplinarity means a combination of different disciplines collaborating in working together on one challenge (Max-Neef, 2005). There is a need for transdisciplinarity when a team is developing biomimicry-inspired technologies. Transdisciplinarity transcends disciplinary concepts and allows for joint learning and contribution towards fulfilling project outcomes (Max-Neef, 2005). Transdisciplinary research is able to tackle complex societal and scientific issues because it involves expertise from different backgrounds (Hadorn *et al*., 2008). Although transdisciplinarity is difficult to implement, it is able to identify how real world problems and science can merge, such as the designing of technologies to manage wastewater in urban areas (Hadorn *et al*., 2009). Therefore, when developing biomimicry designs, it is important to include researchers from different backgrounds and input from community members of informal settlements.

2.7 Sustainable Urban Water Management

There is a need to imagine better institutional and implementation frameworks for stormwater and wastewater management in informal settlements (Parkinson and Ole, 2005). The strategic inclusion of community members in design and education programmes regarding improper waste disposal have been recommended as a valuable aspect of integrated water resource management (Jiusto anad Kenney, 2015).

2.8 Summary

The sustainable treatment of stormwater and wastewater from informal settlements is imperative to the health of rivers and their ecosystems. The implementation and subsequent operation and monitoring of an effective ecological wastewater treatment system in Langrug informal settlement should consider three major activities, namely:

- Implementation of SuDS using biomimicry’s life principles
- monitoring microbial and physico-chemical properties
- fostering transdisciplinarity as well as inclusive ecological design.

CHAPTER 3

3 Biomimicry Wastewater Treatment Technologies

3.1 Summary of Technologies

The focus of this research study was to investigate and learn from the performance of the biomimicry-based wastewater treatment systems being constructed as part of the Western Cape Government project known as the Genius of SPACE in Langrug informal settlement in Franschhoek. Unexpected delays encountered with the implementation of this project meant that the Eco-machine component was not completed within the timeframe of this study. The study therefore focused on the Green Filter installed on the Plankenbrug River, in the area of Stellenbosch. The Green Filter is based on the same design principles as the Eco-machine planned for Langrug, and treats heavily polluted river water impacted by local industry and the nearby settlements of Kayamandi and Enkanini. The water quality closely simulates the Langrug settlement greywater discharge.

3.2 Design Solution 1: Point Source Decentralised Wastewater Treatment in Langrug

The point source ecological technology upgrade for Langrug improves on the settlement's ad hoc greywater sewer systems through the addition of living technologies and ecological treatment. The proposed system retains the flexibility of the ad hoc sewers while creating a system which is more robust, less prone to fouling, easier to maintain, increases the effectiveness of greywater treatment, recharges the groundwater table, and contributes to the overall greening of Langrug. The living sewer system combines collection, conveyance, treatment and disposal in a novel holistic system. Collection points and sediment traps are evenly spaced throughout the community and provide pre-filtration, removing fines and food-scraps that can cause the sewers to clog.

Along the path of conveyance, micro-wetlands provide biological filtration and maintain an aerobic condition. Above ground these micro-wetlands are small, well-irrigated gardens that enhance the community. Branching sewer lines converge at tree gardens. These are deep-pit tree wells where greywater is purified through the processes of adsorption, decomposition and root-associated micro-organisms and fungal communities. The tree garden removes nutrients and organic material from the greywater, converting them to humus and allowing purified effluent to infiltrate back into the ground.

As a disposal system the tree gardens contribute to a highly decentralised infiltration system. Compared to conventional infiltration systems, this mechanism of discharge creates steeper gradients of soil moisture and a more dynamic subterranean condition. Unlike a conventional foul sewer this living sewer is designed to utilise water and nutrients along its route to sustain a green corridor through the settlement. Over time, the system will leave behind a network of deep, planted tree wells with rich, high-carbon soils.

Figure 3. 1: Layout of the Block S& T Greywater Prototype

3.3 Design Solution 2: Bioremediation Eco-machine in Langrug

An additional downstream ecological treatment system (Eco-machine) will be located at the south of Langrug to intercept, collect and treat greywater and contaminated stormwater. The site is located at the school sports field where the treated effluent can be conveniently re-used for irrigation and other productive uses. It was communicated to the design team by the Langrug community that the Eco-machine design needs to be physically robust against vandalism and theft. As a result, the Eco-machine is designed to be housed within a secure shipping container. Effluent is conveyed through the system by gravity.

The Eco-machine consists of multiple cells divided into three trains. Within each of the cells of the Eco-machine, all five kingdoms of life are represented, from microbes, bacteria and fungi to higher life forms such as snails and fish. It is the combined actions of these numerous organisms that metabolise, degrade and sequester organics, pathogens and heavy metals from the wastewater.

From the surface, the aquatic cells appear to be beautiful, robust water gardens. Anaerobic digestion, aerobic digestion, nitrification and denitrification are all microbial processes that take place within the solar aquatic cells. These are a series of cells through which effluent is treated by mimicking natural water purification within wetland ecosystems. Microbial films grow on flocculants, which are a mass of suspended solids, as well as plant roots. Nitrification occurs in the biofilms which attach to the media. Phosphorus is removed through luxury uptake by bacteria. Pathogens are reduced due to predation by zooplankton and animals, and heavy metals are accumulated in the attached algal biomass that forms on the sides of the tanks.

3.4 Design Solution 3: The Plankenbrug River Restorer

The Plankenbrug River receives greywater, polluted stormwater and effluent overflow from the Kayamandi and Enkanini informal settlements of Stellenbosch. The recently formed Stellenbosch Rivers Collaborative is looking to improve the water quality in the town's rivers and, through funding raised by the Wildlands Conservation Trust, is supporting the piloting of an Eco-machine technology to divert and treat water from the Plankenbrug River. During the dry summer period, the river flows with highly concentrated effluent, comparable to the greywater discharge from Langrug community, but with additional pollution from the adjacent industrial areas.

A conventional Eco-machine design is proposed for this pilot which comprises multiple aquatic cells connected in series. Within the Eco-machine, all five kingdoms of life are represented, from microbes, bacteria and fungi to higher life forms such as snails. Fish and freshwater mussels can also be introduced into the system. It is the combined actions of these numerous organisms that metabolise, degrade and sequester organics, pathogens and heavy metals from the polluted water. The treatment process is similar to that described in Section 3.3.

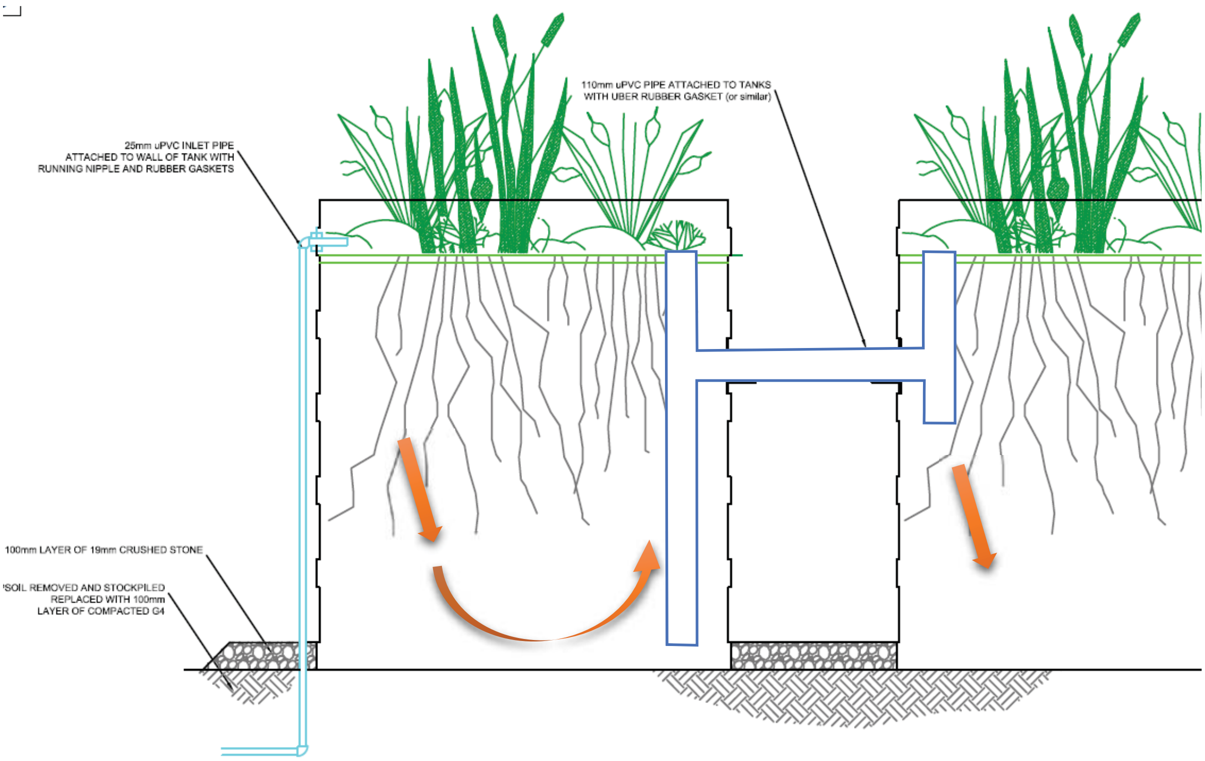

Figure 3. 2: Schematic of Plankenbrug Green Filter

CHAPTER 4

4 Research Requirements

4.1 Summary

The primary purpose of the research component of this study is to improve understanding of biomimetic ecological treatment systems (particularly in the context of the case studies), to develop a monitoring and evaluation programme, and to inform the future design and implementation of similar systems. To support these overarching goals, the research incorporated an evaluation of the following:

1) **The efficacy of the treatment systems**, in terms of how effective the technology is at treating the effluent. This included monitoring of influent and effluent to establish whether the treated effluent exhibits a measurable improvement in quality, with the final discharge meeting the General Authorisation Limits for effluent discharge. This also included monitoring the standard determinants of wastewater effluent (E. *coli*, chemical oxygen demand, biological oxygen demand, nitrates, phosphates, ammonia, etc.). In addition, the monitoring and evaluation programme investigates the effectiveness of the technology in removing PPCPs that are known to pass through conventional wastewater treatment systems. One of the expected benefits of ecological wastewater treatment systems is their ability to remove these products from the waste stream.

2) **The aquatic ecology and natural treatment processes** that occur in the treatment systems and consider their function in the treatment process. It was not possible within the scope of this research project to conduct detailed research on every aspect of this complex system. However, to deepen the learning and optimise the design of future systems, this research component focused on the performance of biofilms that are established throughout the ecological treatment system. A review of the aquatic ecology of the system enables a deeper understanding as to whether indigenous ecologies are suited to the required treatment function, and whether these ecologies could self-organise and respond to intermittent flow conditions and fluctuating pollutant loads.

3) **The impact of the community participatory process employed at Langrug**, and the impact of these processes on the effectiveness of the design, implementation and operation of the treatment systems. The project was developed in close collaboration with multiple stakeholders, including the municipality and the residents of Langrug. Central to the design is the community-level operation and maintenance, and, furthermore, the interdependence between the maintenance activities and the enterprise activities that will emerge from the maintenance processes (cut flowers, compost, tree nursery). The successful implementation of this approach has a significant impact on the long-term sustainability of this project, in terms of managing operations, financing and ownership.

4.2 Impact and Outcomes

This study contributes to determining the effectiveness of ecological water treatment technologies by developing a monitoring and evaluation programme for the systems. A key component is determining the response of flora and fauna in the technologies to the water treatment requirements. This research contributes significantly to the success of the design solutions by measuring results, providing feedback loops as to the functioning of the designs, and capturing lessons learned. This research contributes to the fields of ecological engineering and biomimicry as related to water treatment in South Africa. In addition, it supports the potential roll-out of similar designs for other communities and other applications in South Africa. In short, the research yields:

- Valuable scientific assessment of the technologies in place that can inform future designs
- Information dissemination on the water treatment impacts and the related Eco-machine development stages
- Capacity building through the involvement of three Masters students completing research in this innovative field of wastewater treatment.

This wastewater treatment approach is innovative and could, if monitored carefully to ensure success, revolutionise the wastewater treatment facilities in Langrug and similar areas of the Western Cape (and the rest of South Africa and Africa). What is most relevant is that these systems not only solve ecological challenges, but provide significant opportunities for job creation, thereby addressing the principles of the Green Economy. The desired impact of this study is to improve the quality and long-term sustainability of sustainable water treatment in South Africa, by monitoring and evaluating the impact of innovative, sustainable, living technologies. If these technologies can be fit for use in informal settlements (and other applications) there is potential to roll out their application in many other informal settlements.

CHAPTER 5

5 Research Sites

5.1 Langrug Informal Settlement (Genius of SPACE)

The Block S and T greywater prototype of the Genius of SPACE (Systems for People's Access to a Clean Environment) Project was completed at the end of September, 2016, and has since been operated and maintained by the community with support from the project design team.

The sports field greywater prototype (stormwater/greywater ecological treatment that was part of the Berg River bioremediation project) has been delayed subject to municipal approvals and finalisation of the solid waste component. The Plankenbrug River Green Filter Eco-machine was therefore added as an alternative for monitoring and evaluation to inform this study.

5.1.1 Implementation

The greywater pilot green filter in Block S and T in Langrug informal settlement was completed in September, 2016. The successful implementation of this programme was dependent on several building blocks, including social, institutional, economic, technical and ecological. The identification and development of these building blocks (shown in Figure 5.1) should inform the selection and implementation of future programmes to maximise the potential success of the project.

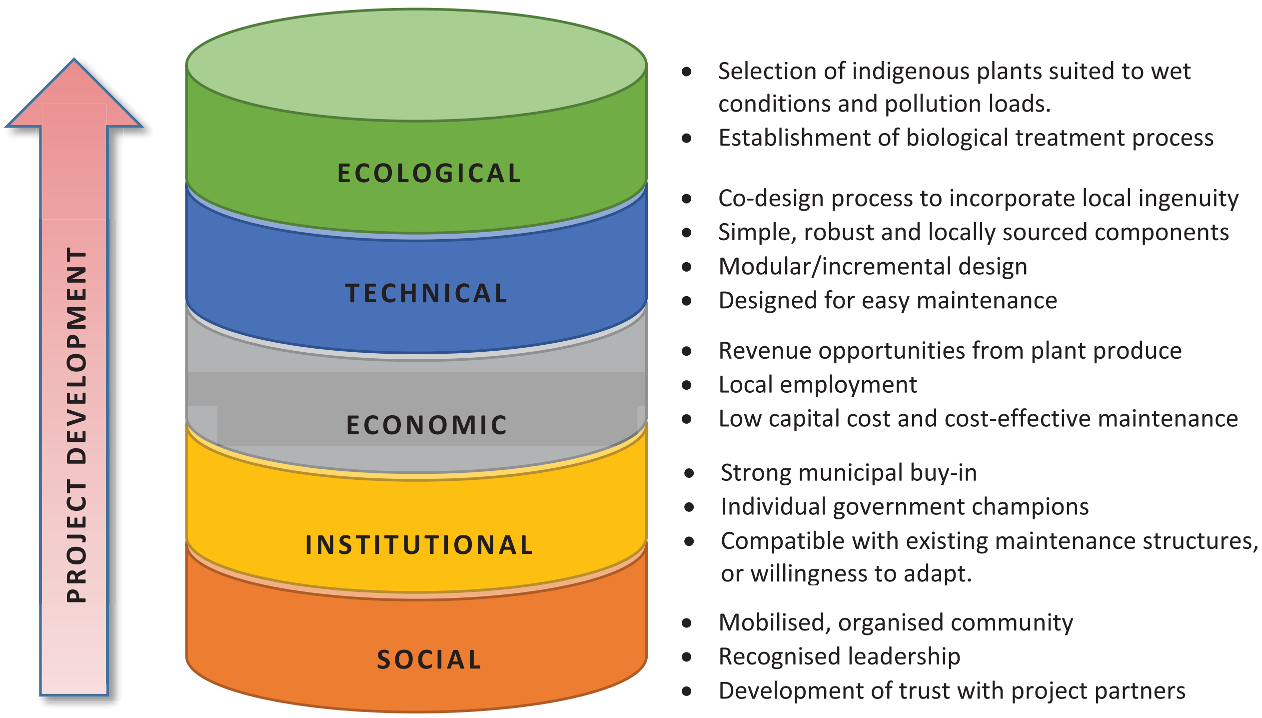

Figure 5. 1: Building Blocks for Project Implementation

The greywater pilot green filter in Block S and T in Langrug informal settlement was completed in September, 2016, as indicated in Figure 5.2.

Figure 5. 2: Completed GOS Components (Permeable Paving, Disposal Points, Tree Gardens)

5.1.2 Maintenance

The operation and maintenance programme of the Block S and T pilot is being managed by the Genius of SPACE project leader, Greenhouse Systems Development. A team of four community members has been appointed to maintain the solid waste and greywater prototypes within the pilot site. This team, called the FLOW agents, clean and maintain the systems.

5.1.3 Monitoring

The monitoring programme of the S&T pilot is managed by Greenhouse Systems Development in collaboration with the Langrug community. The monitoring comprises sensory reporting of the system's performance (visual problems, odour, etc.) and recording of the frequency of maintenance activities. This reporting uses a paper-based checklist (as shown in **Appendix A**).

Parallel to this, the project team decided to trial a phone-based system developed by SeeSaw. This system uses an automated missed call system whereby the operator phones a dedicated number to report a fault in a specific location. This will be complemented by a system called SeeCard, which is a smart phone reporting system. This reporting system provides the FLOW agents with a system for reporting the functionality or failure of a particular component of the system, addressing the questions below:

1. LIST OF ITEMS FOR MISSED CALL SYSTEM

Solid waste:

- Area contains rubbish
- Wheelie bins are overflowing
- Area is clean

Greywater:

- Disposal point is blocked
- Disposal point has been removed
- Disposal point looks clean

Tree gardens

- Tree garden is flooding/smelly
- Tree garden is dead/dying
- Rubbish inside tree garden
- Tree garden looks healthy/clean

Micro-wetland

- Wetland is flooding/smelly
- Wetland plants are dead/dying
- Rubbish inside micro-wetland
- Wetland looks healthy/clean

2. LIST OF QUESTIONS FOR MONITORING OF PROTOTYPES (e.g. with SeeCard)

Greywater disposal points and house connections:

- Are any disposal points or house connections broken or missing?
- Did you fix or find the broken or missing part/s?
- Do you need more maintenance equipment?
- Are any neighbours not following the rules?

Solid waste collections:

- Are any wheelie bins missing or broken?
- Did you find or fix the missing or broken wheelie bins?
- Do you need any more maintenance equipment?
- Are there any problem areas?
- Are any neighbours not following the rules?

Tree gardens and micro-wetland:

- Are any trees or plants dead?
- Have any trees or plants been cut or removed?
- Do you need more maintenance equipment?
- Are any neighbours not following the rules?

5.2 Plankenbrug River Green Filter

The initial general aims of the Plankenbrug Green Filter project included:

- Restore the river's water quality
- Demonstrate that the filter can improve relevant water quality parameters sufficiently to inform the design of future river remediation projects
- Provide an opportunity for education and outreach within the wider community
- Raise the profile of the polluted river and show a way forward toward restored and healthy waters.

5.2.1 Implementation

The Plankenbrug Green Filter was commissioned on 16 March, 2016, and is now well established, as indicated in Figure 5.3 below.

Figure 5. 3: Green Filter Established

5.2.2 Maintenance

The project was handed over to Wildlands in November, 2016, who took over responsibility for the day-to-day operation and maintenance of the system. This requires regular cleaning of the inlet screen and ensuring that the abstraction pump remains operational. In addition, meter and rainfall readings are observed. Isidima provides ongoing ad hoc maintenance support.

5.2.3 Monitoring

Ad hoc monitoring has been undertaken during the establishment phase of the Green Filter. Apart from the water quality analysis presented in Chapter 8, this has included regular monitoring of the flow and rainfall. The Green Filter is well established with good root penetration into the effluent as shown below.

Figure 5.4: Green Filter Handover and Root Growth

CHAPTER 6

6 Overview of the Masters Research Programme

6.1 Research Topics

This study to investigate the performance of biomimicry wastewater treatment technologies was complemented by related research undertaken by three Masters students. This research, in the fields of social science and microbiology, provided a combination of field and laboratory-based research into aspects of the study. The detail of this research is summarised in Table 6.1 below. A summary of the key findings pertinent to this study is described in the following section.

Table 6. 1: Masters Research Projects

Name	Thesis Title / Details	Degree	University
Gabriel Wolfaardt	A Case Study in Transdisciplinarity: The Restoration of Water Systems Using Eco-machines within the Langrug Community	MSc	Stellenbosch University
Kirsten Kenchenten	The Removal of Anthropogenic Xenobiotics from Domestic Wastewater by Degradative Biofilm Communities	MSc	Stellenbosch University
Niel Olivier	The Age-old Problem of Pollution, its Role in Endocrine Disruption and the Current Analytical Technologies that can be Employed to Monitor and Assess Wastewater Treatment Plants	MSc	Stellenbosch University

6.2 Monitoring and Evaluation

The project developed a monitoring and evaluation program for a new biomimetic water management approach, based on ecological systems. Water quality sampling was undertaken to develop this programme which continues to contribute to the long-term water quality monitoring of the project. This sampling was undertaken at different points along the treatment train, including influent and effluent, in order to determine the performance of the system. The performance of the technology, in terms of water quality, was determined by measuring physical-chemical and micro-biological parameters (further monitoring of the ecological parameters will be undertaken in a follow-on study). The ecological systems used for wastewater treatment use biomimicry design principles which emulate natural processes. The biomimicry approach has informed the research approach, which enables further development of these ecological systems. The overall functioning of the system was also analysed, including ecological, economic and social acceptability.

6.2.1 General sampling

Water quality sampling included analysis of microbial loads such as coliforms, nitrogen, ammonia, nitrate, phosphorus and chemical and biological oxygen demand. This data was compared to the General Authorisation Limits summarised in Table 6.2. This monitoring programme was complemented by research to assess biofilm formation and, more importantly, biofilm function, in terms of PPCP and xenobiotic removal. Samples were taken at identified points within the treatment system, including the influent and treated effluent. Samples were taken as the biological processes The sampling programme for ongoing research proposed frequent water quality sampling, including short periods of continuous sampling to observe water quality fluctuations on the influent water over a short time step. Climatic and process observations (temperature, rainfall, effluent flow, etc.) were observed alongside the sampling process so that the potential influence of these fluctuating conditions could be considered alongside the laboratory analysis.

6.2.2 Stabilisation phase

Monitoring of plant and root growth during the stabilisation phase enables monitoring of the adaptation of the local ecology within the different treatment components. This meant that the establishment of the biological processes could be measured and the system kinetics towards steady state described. This included laboratory analysis, but also included monitoring of the aquatic ecology and operation routine.

6.2.3 Operational phase

Observations of the various technologies were made and interviews were conducted with key stakeholders. During this process, the social-political climate was monitored in order to understand how changing perceptions in the community and other social-ecological factors impacted the implementation of the ecological technologies.

The proposed analysis of the biofilms included sampling from the walls of the cells, the non-woven geotextile and plant roots. Supplementing these results with those of general indicators (P, N, BOD) as well as PPCPs and xenobiotics, a larger picture will begin to emerge of how the ecological systems function with respect to wider environmental factors. In addition, analysis of biological material – plants, animals, organisms and aquatic ecosystems – should be undertaken in future research by incoming postgraduate ecology students. Of great concern is the implementation of these systems in the contexts of informal settlements, urban and industrial areas. With results from the transdisciplinary research, a picture will begin to emerge as to how to make the ecological systems most acceptable and beneficial to people and to the immediate environments where they dispose of greywater, wastewater and solid waste. This knowledge can be used as a platform for future community-based initiatives.

6.3 A Case Study in Transdisciplinarity: The Restoration Water Systems Using Eco-Machines Within the Langrug Community

6.3.1 Summary

Transdisciplinarity is an approach that transcends disciplinary concepts as it allows identification and merging of complex societal issues with expertise from differing disciplinary backgrounds (Max-Neef, 2005; Hadorn *et al*., 2009). This project focused on analysis of social and economic community dynamics related to the implementation of ecological systems in Langrug. Using transdisciplinarity, the project goes beyond biomimicry principles alone, in that different disciplines collaborated (interdisciplinarity), and social and ethical factors were included in implementation, and monitoring and evaluation of this process.

6.3.2 Key findings of relevance to this study

Stakeholder participation is a crucial component of the monitoring and evaluation programme, and of the efficacy of these systems in the context of informal settlements and river treatment. Community engagement is key to the success of any such project.

In terms of the efficacy of the systems, from a qualitative point of view, the Langrug greywater pilot project provides some initial infrastructure and healthier environments around some homes, while providing some temporary and permanent employment. The results of this research do not consider success or failure of these systems from a technical point of view.

A key finding from this research is that the greatest concerns for Langrug community members are **employment and land ownership**. Thus, any project with the hope of community engagement needs to involve those concerns in its design. Since the monitoring, evaluation and maintenance components of these systems have involved community members in the pilot project, this is an important consideration for the future success of these systems in similar contexts.

6.4 The Removal of Anthropogenic Xenobiotics from Domestic Wastewater by Degradative Biofilm Communities

6.4.1 Summary

Biofilms are groups of micro-organisms, which have combined to form a matrix. Biofilms can attach to surfaces, efficiently break down chemical pollutants and utilise compounds that are synthetic. This research project focused on the ability of biofilms to degrade endocrine-disrupting chemicals (xenobiotics), as well as the effect that another carbon source, Methylparaban, may have on the morphology, physiology and degradative abilities of the chosen biofilms. This research serves to inform future monitoring and evaluation of wastewater treatment systems, and will be particularly useful in determining the efficacy of ecological treatment systems (such as the Eco-machine) in their own right and in comparison to conventional wastewater treatment systems.

6.4.2 Key findings of relevance to this study

Microbial biofilms execute functions with flexibility, and adapt to conditions efficiently. Biomimicry shows promise as a framework for the design of wastewater treatments that replicate natural processes. Since mixed microbial biofilms appear to have the greater potential for flexibility, due to the large variety of microbes and associated genetic and metabolic functions, the focus should arguably be on these mixed consortia for remediation of polluted water. These biofilm consortia are found in natural water sources (rivers, lakes and dams), which is often an added advantage, since these microbes have already been exposed to the micro-pollutants in the water systems in which they reside.

An Eco-machine, like the one installed on the Plankenbrug River, and as planned at the bottom of Langrug, uses living organisms that work together, but these organisms are limited in the volumes which they can process. If larger volumes of water are required to be treated, then the wetland-mimic must be made physically larger to handle the larger volumes without a reduction in efficacy.

Wastewater treatment data from the literature shows that xenobiotic compounds are not being removed, to a degree considered adequate, from conventionally treated water and, in some cases, the levels of micro-pollutants actually increase in this treated water. The list of potential biologically-active micro-pollutants is long, and the two compounds studied are a drop in the ocean in comparison, but the fact that many compounds are still at detectable levels after treatment means that some of each of the compounds still evade removal. The more these compounds are used and are continuously added into water systems, while not being completely removed, the more these compounds will build up, albeit slowly, in our water systems. The implication is that these compounds, while perhaps not yet harmful, may eventually reach levels where they may elicit deleterious effects in higher organisms, if we don't develop a means to adequately remove them.

The second aim of this thesis was to determine the effects of the chosen micro-pollutants on biofilms. The effects are arguably significant, considering the very small concentrations they were tested at. The effects that these compounds appear to have on the growth and physical appearance of biofilms is also something of a concern because, if they do have an effect, it means that these compounds, even at nanogram levels, have a measurable effect on the structure – and perhaps even the metabolic activities – of micro-organisms. Microbes, especially those in biofilms, have shown the inherent ability to degrade some of these compounds, but excesses of these compounds may result in decreased functionality of the biofilms if the levels of pollutants change beyond the capabilities of these biofilms. The fact that these compounds have the capacity to alter the physical characteristics of biofilms also implies some level of possibly deleterious effect on the metabolism of the biofilms. This may, in turn, actually hinder the removal of the compound causing the effect, or even of other compounds present in the bulk flow of the exposed biofilms.

If wastewater is to be treated for reuse, then **the water needs to be sufficiently cleared of micro-pollutant contaminants**. **This research project indicates that conventional wastewater treatment is**

not sufficient to solve the imminent water crisis. The findings will inform the monitoring and evaluation programme for Eco-machine systems to determine whether these biomimicry systems may be more effective with regard to these pollutants. The effects of similar Eco-machine constructs were investigated in the literature section and, based on what was seen in literature, these constructed wetland systems show promising results in the treatment of wastewater but, due to their lower throughput capacity do have limitations which may need to be addressed. Other than biomimicry, **bio-utilisation or bio-assistance may be the best answer we have, by harnessing and augmenting the intricate metabolic abilities of microbes to remove the waste products that we cannot.**

6.5 Establishing the Efficiency of the Biomimicry-based Eco-Machine at Langrug for PPCP Removal

6.5.1 Summary

Toxic PPCPs and other micro pollutants in water draining urban areas often require long and intensive treatment processes (Suárez *et al*., 2008). This project focuses on monitoring and evaluating the Eco-machine at Langrug with regard to PPCPs.

6.5.2 Key findings of relevance to this study

The proposed solution, a natural wastewater treatment system called the Eco-machine, has been shown to be effective in a pilot-scale model. However, the actual system still needs to be evaluated at full-scale implementation.

The majority of the pollutants selected for monitoring have been shown to play some part in disrupting the endocrine system of mammals and therefore pose a great risk to the environment.

The methods developed on the three instruments were optimised and tested for their sensitivity and overall performance towards detecting these pollutants. Method validation showed that the UPC2-MS/MS had great potential to be the instrument of choice for detecting the selected commonly occurring pollutants. However, some of the data suggested that the method needed simplification and further optimisation before a final decision that it should be the analytical instrument of choice. In addition to developing analytical techniques for monitoring levels of pollution and ultimately their removal through treatment systems, studies were performed to show how some of the commonly occurring pollutants selected for monitoring can possibly influence signal transduction in mammals. This is particularly relevant as signal transduction plays a central role in regulating homeostasis.

This project fulfilled the overall aim of finding the most suitable chromatography method that could be used to evaluate the Eco-machine's ability to remove pollutants such as PPCPs. In addition, the project also fulfilled the aim of showing the possible consequences to humans and animals if exposed to contaminated water resources containing endocrine-disrupting compounds. Paul Viljoen will be using these for the future monitoring and evaluation of the Plankenbrug system.

CHAPTER 7

7 Langrug Community-Based Monitoring Programme

7.1 Summary

Our study has developed a monitoring and evaluation programme for the biomimicry systems, based on the context in which they are based. The Langrug informal settlement application has specific requirements for monitoring and evaluation – particularly with regard to involvement of the community. This section summarises this and provides an overview of the monitoring and evaluation program that has been developed as a key aim of this project.

The operational parameters inform the maintenance burden and cost of the system, and whether this can be effectively achieved at a community level with minimal external support, and, furthermore, whether this presents a more cost-effective maintenance model compared with conventional infrastructure.

The physical, chemical and micro-biological parameters enable the treatment performance of the system to be monitored and compared with wastewater treatment guidelines (See Table 7.1). Monitoring of the ecological condition of the system will inform future design and will enable an improved understanding of the role that these plants play in the treatment process, together with the ecological indicators of water quality.

Table 7.1: General Authorisation Limits

Determinant	Unit	General Limit	Special Limit
Faecal Coliforms	No./100mℓ	1000	0
Chemical Oxygen Demand*	mg/ℓ	75	30
pH		5.5–9.5	5.5–7.5
Ammonia (as Nitrogen)	mg/ℓ	6	2
Nitrate/Nitrite as Nitrogen	mg/ℓ	15	1.5
Chlorine as Free Chlorine	mg/ℓ	0.25	0
Suspended Solids	mg/ℓ	25	10
Electrical Conductivity	mS/m	(70mS/m above intake) max 150mS/m	(50mS/m above intake) max 100mS/m
Ortho-Phosphate as Phosphorous	mg/ℓ	10	1 (med.) 2.5 (max)
Soap, Oil & Grease	mg/ℓ	2.5	0

*after the removal of algae

Table 7.2: Monitoring Parameters

Category	Parameter	Units	Description / Interest
1. Operational	a. Effort	Person days	Intensity of maintenance
	b. Materials	Rands	Cost of maintenance materials
	c. Frequency	days	Cleaning interval
	d. Functionality	%	Proportion of system working
	e. Breakages/Faults	No.	Problems requiring repair
2. Physical	a. Water Flow	ℓ/s	Rate of water discharge
	b. Suspended Solids	mg/ℓ	Solids in greywater flow
	c. Water Depth	m	Depth of water inside system
	d. Turbidity	NTU	Clarity of water
	e. Rainfall	mm	Daily rainfall record
	f. Sediment Accumulation	Kg	Sludge build up
	g. Odour		Reported odour issues
	h. Solid Waste	Kg	Trash & organic waste collected
3. Chemical	a. Elec. Conductivity	mS/m	Measure of salts
	b. pH		Acidity of the water
	c. BOD	mg/ℓ	Biological oxygen demand
	d. COD	mg/ℓ	Chemical oxygen demand
	e. Ammonia	mg/ℓ	Indicator of urine
	f. Nitrite + Nitrate	mg/ℓ	Nitrate indicator of treatment
	g. Ortho-phosphate	mg/ℓ	Phosphates (in detergents)
	h. Alkalinity	mg/ℓ	Biological treatment capability
	i. PPCP	mg/ℓ	Pharmaceutical & personal care product removal
4.Micro-biological	a. E.*coli*	cfu /100mℓ	Indicator of faecal bacteria
	b. Biofilms		Presence biofilms and their contribution to treatment
5. Ecological	a. Plant Species		Record of species diversity and dominance
	b. Plant Health		Plant growth and health
	c. Micro-organisms	Score	Mini SAS assessment

In order to build on the transdisciplinary nature of the Langrug Genius of SPACE project, an effective community-based monitoring programme is required which enables residents to engage with the performance and functionality of the Block S and T greywater prototype. This should directly inform the FLOW agents' maintenance programme while enabling collection of the necessary data to inform external stakeholders about the performance of the system.

The monitoring programme considers five performance categories, as indicated in Table 7.2. The full monitoring programme is presented in Appendix B. The five categories were developed to enable a thorough understanding of the treatment performance and maintenance burden of the ecological treatment system.

7.2 Implementation of the Monitoring Programme

Initial training and testing of the monitoring programme was undertaken on 24 January, 2017. Several community members from the Project Steering Forum participated in the training session. The training presented the opportunity to discuss the physical observations and their possible cause and enabled refinement of the monitoring process in consultation with the residents.

Figure 7.1: FLOW Agents

Figure 7. 2: Measuring Tree Garden Water Depth

7.3 Preliminary Results

A test run of the monitoring system highlighted the need for effective monitoring of actual maintenance activities. The monitoring and maintenance team from within the community - the FLOW agents - did not have accurate records of their maintenance activities, and as such it was difficult to establish the duration over which the observed sludge had accumulated within the system. What was quickly apparent was that certain components required more frequent cleaning than had been undertaken. This led to revision of the maintenance checklists, as presented in Appendix A. These revised forms provide a simple check sheet for recording when components are cleaned and other specific maintenance activities.

Figure 7.3: Water Quality Samples

Figure 7.4: Project Steering Forum

Chemical and micro-biological analyses are presented in Table 7.3. This data highlights the high pollution concentrations in this waste stream. The Block S and T greywater prototype enables the separation of greywater and stormwater flows and promotes greening of the tree gardens to reduce the greywater flows discharging from the prototype into the sewer. As expected, the prototype only achieves minimal treatment performance, but does prevent the migration of solids which could lead to pipe blockages. The planned Eco-machine at the bottom of the settlement is required to provide effective treatment of this wastewater.

Table 7.3: Langrug Block S&T Water Quality Analysis

Parameter	29/02/2016	08/08/2016	24/01/2017
pH 25°C	7.45	7.22	8.80
Electrical Conductivity (mS/m)	232	566	136
Chemical Oxygen Demand (mg/ℓ)	3 748	3 910	1 292
Total Suspended Solids (mg/ℓ)	41 500	-	483
Ammonia (mg/ℓ)	90	185	24
Ortho-Phosphate as P (mg/ℓ)	25	30	4
Nitrate + Nitrite (mg/ℓ)	0.55	0.23	0.20
Alkalinity	789		308
Faecal Coliforms (no. per 100ml)	32 000 000	16 000 000	6 900 000

Preliminary flow data from the V Notch weir indicated that the peak greywater discharge aligns with the surveyed water demand of 49 litres per household per day, and a peak discharge of 0.5 litres per second for Block S&T combined. This indicates that the greywater prototype has minimal impact on the peak discharge rates from the system, when the tree gardens are saturated with greywater, although the total volume of greywater discharge will be reduced due to infiltration and evapotranspiration from the tree gardens.

Preliminary water quality data indicates that the S&T greywater pilot has produced a measurable reduction in both the E. *coli* concentration and the chemical oxygen demand (COD) of the greywater discharging from the pilot site (see Figures 7.5 and 7.6 below). Long-term monitoring of the greywater discharge is required to confirm these findings.

Continuous monitoring of the greywater discharge rate from the pilot site is required to confirm the flow pattern and to establish to what extent the pilot study is reducing the net volume of greywater through diversion into the tree gardens. Initial observations during rainfall events indicate that the flow is not influenced by rainfall; this suggests that the pilot is achieving one of the primary objectives of the prototype which was to separate greywater and stormwater flows.

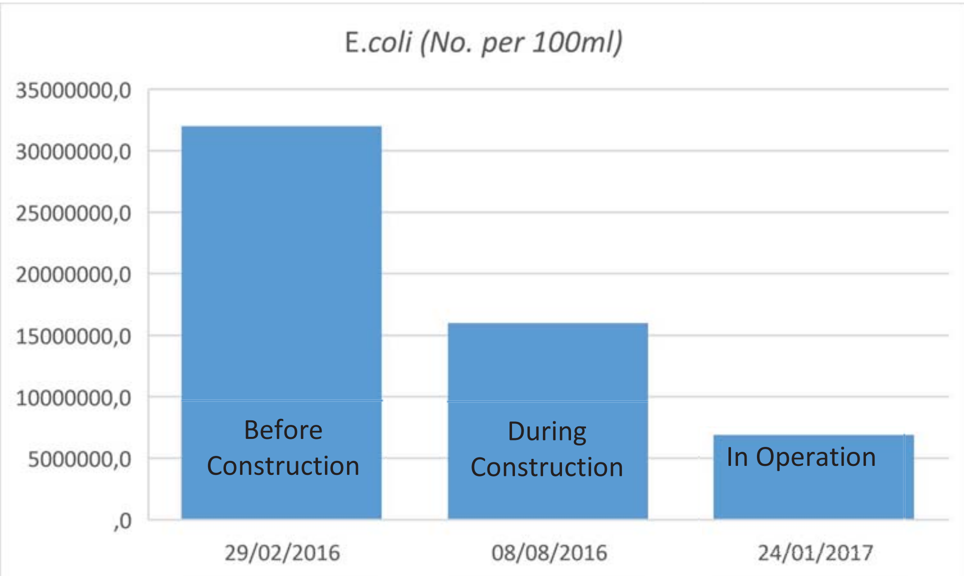

Figure 7. 5: E. *coli* of Greywater Discharge from Block S&T

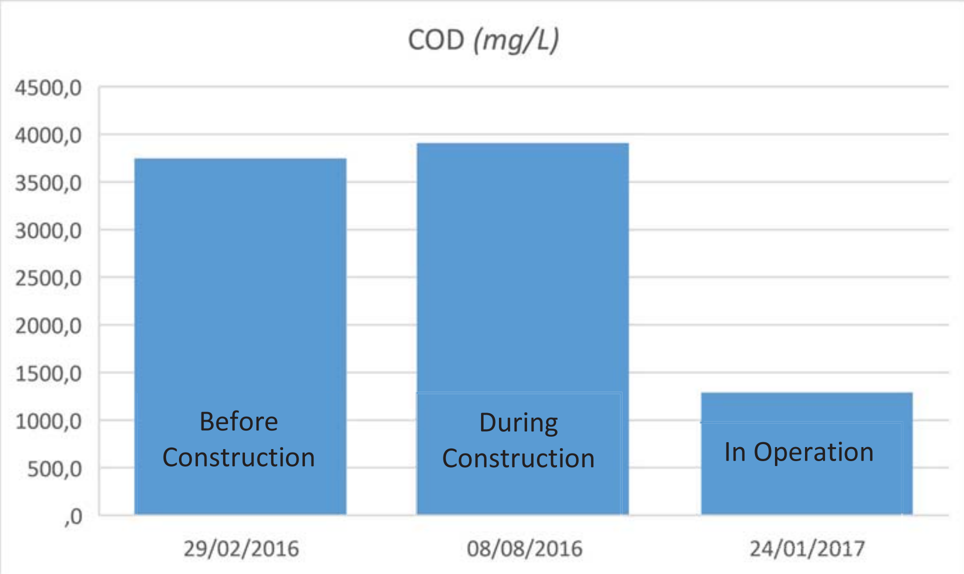

Figure 7. 6: COD of Greywater Discharge from Block S&T

CHAPTER 8

8 Plankenbrug Green Filter Monitoring Programme

8.1 Summary

The initial monitoring of the Green Filter has focused on sampling of chemical and microbial parameters, together with some physical and operational parameters. Ongoing monitoring will investigate the presence of biofilms within the different aquatic cells of the Eco-machine, and the efficacy of the system in removing micro-pollutants that conventional treatment systems are do not effectively remove from the waste stream.

8.2 Monitoring Results

Water quality sampling has been undertaken during the establishment phase of the system, as presented in Tables 8.1 to 8.3 below.

The filter is designed to have a retention time of 14 days, at a flow rate of 2.5 kl/day. The flow rate can be increased subject to treatment performance. The flow rate in Table 8.3 corresponds to the average flow rate for the preceding two weeks. This long retention time also means that influent fluctuations (high and low readings) will be buffered within the system. In addition to the pulse of point source pollution; rainfall events can lead to concentration or dilution of the pollutants in the sources water subject to the antecedent conditions. It is therefore important that the long-term monitoring programme should record weekly, daily and even hourly fluctuations of particular determinants in the Plankenbrug River in order to understand the characteristics of the influent water.

Table 8.1: Green Filter Inlet Water Quality

	Filter in			
Determinant	29/02/2016	26/05/2016	08/08/2016	24/01/2017
pH 25°C	6.38	7.12	7.56	6.30
Electrical Conductivity (mS/m)	75.0	80.6	75.8	68.3
Chemical Oxygen Demand (mg/ℓ)	150	56	28	607
Total Suspended Solids (mg/ℓ)	28	31		399
Ammonia (mg/ℓ)	8.00	8.20	0.52	19.00
Ortho-phosphate as P (mg/ℓ)	3.90	0.70	0.17	3.20
Nitrate + Nitrite (mg/ℓ)	0.10	1.20	0.23	0.05
Alkalinity	146.00	190.00		198.00
Faecal Coliforms (no. per 100ml)	12 000 000	496 000	6 800	4 820 000
E. *coli* (no. per 100ml)	12 000 000	404 000	3 000	2 620 000

Table 8.2: Green Filter Outlet Water Quality

	Filter out			
Determinant	29/02/2016	26/05/2016	08/08/2016	24/01/2017
pH 25°C	Filter not Commissioned	8.71	7.29	7.50
Electrical Conductivity (mS/m)		46.2	69.3	96.9
Chemical Oxygen Demand (mg/ℓ)		53	31	49
Total Suspended Solids (mg/ℓ)		5		5
Ammonia (mg/ℓ)		0.32	1.48	0.05
Ortho-phosphate as P (mg/ℓ)		0.80	0.35	0.60
Nitrate + Nitrite (mg/ℓ)		1.50	0.23	0.03
Alkalinity		83.20		209.00
Faecal Coliforms (no. per 100ml)		5 800	40	16
E. *coli* (no. per 100ml)		4 700	26	16

Table 8.3: Green Filter Micro-biological Treatment Performance

Sample Date	E. *coli*		% Reduction	Av. Flow m^3/day	Notes
	In	Out			
26/02/2016	12 000 000	-	-		Before installation of Eco-machine
26/05/2016	404 000	4 700	98.837%	2.13	Rainfall diluted influent concentrations
08/08/2016	3 000	26	99.133%	1.80	Winter river flow
24/01/2017	2 620 000	16	99.999%	1.43	Erratic pump flow

The following is a brief interpretation of the initial results presented in Tables 8.1 to 8.3 and Figures 8.1 to 8.3:

(Note that the results for August, 2016, are omitted from this assessment since heavy rainfall the day before sampling resulted in significant dilution of the influent water, giving a false impression of the influent water quality for the preceding two weeks that corresponds to the retention time of the filter).

a: There is a significant reduction in faecal coliforms and E. *coli*.

b: COD: low in and low out (see e below).

c: TSS out less than 5 mgl/ℓ . Water clarity is consistently improved.

d: Ammonia is high in and low. Nitrification is occurring efficiently. Also note the concurrent drop in alkalinity in the May 2016 results, indicating that nitrification is the dominant process driver.

e: Denitrification is occurring effectively. Most of the nitrate generated by the nitrification process is subsequently denitrified.

f: Ortho-P out is similar to, or less than, the incoming phosphates. More detailed and regular assessment of total phosphates will be useful to understand the real accumulation of phosphates within the system, aside from daily fluctuations of the inlet water.

The preliminary water quality results indicate promising performance of the system at low flow rates. Ongoing monitoring of these determinants is required at different points along the system to establish the ongoing treatment performance of the Green Filter and the hydraulic retention time required to meet the General Authorisation Limits.

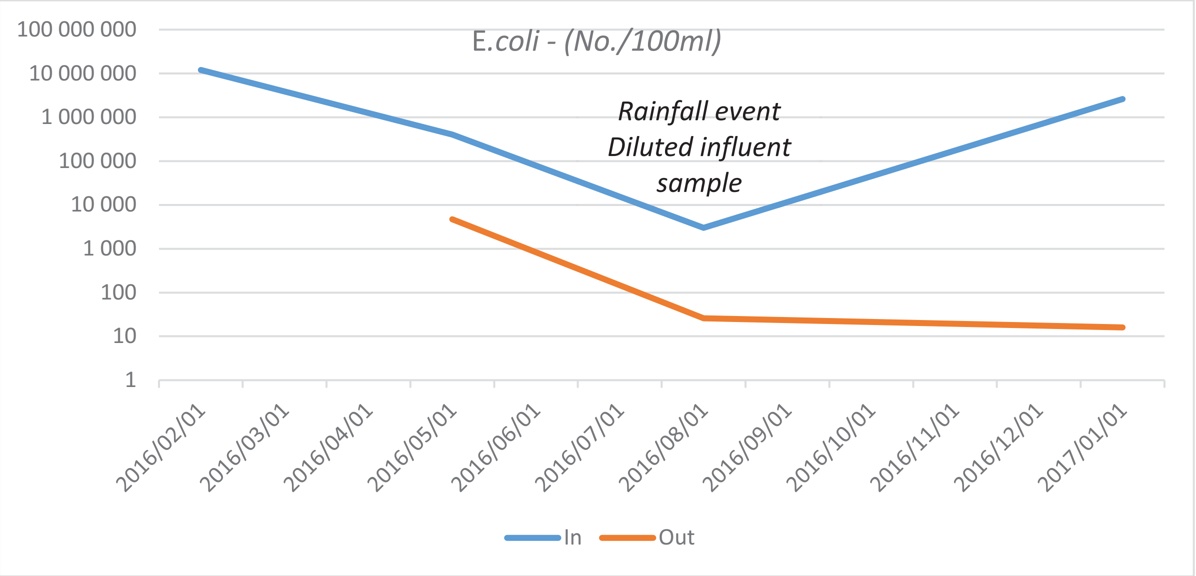

Figure 8.1: E. *coli* Reduction Through the Plankenbrug Green Filter

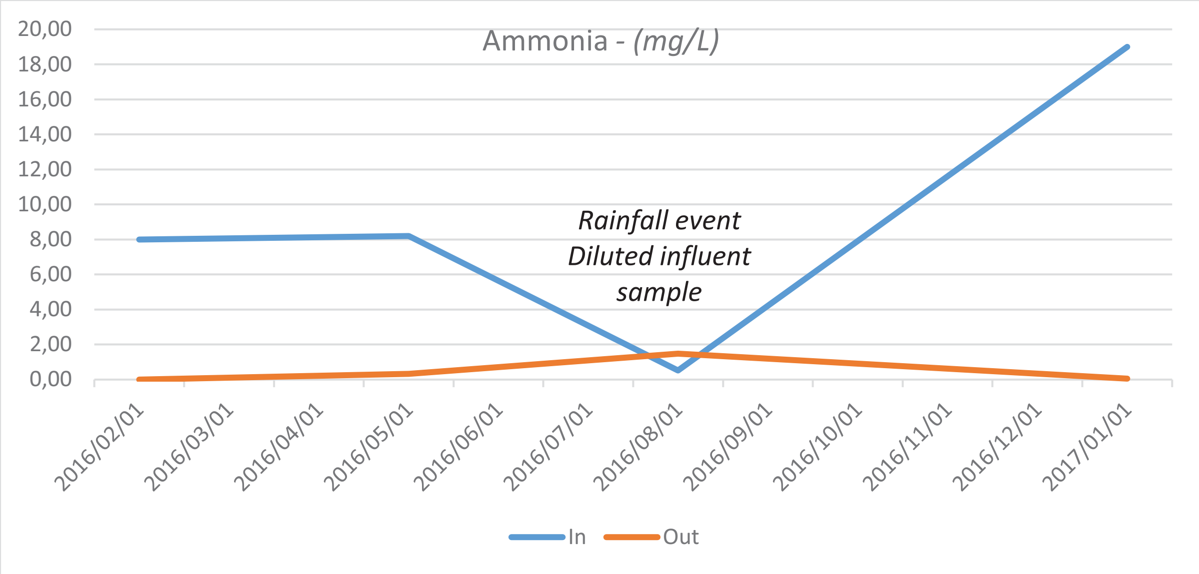

Figure 8. 2: Ammonia Reduction Through the Plankenbrug Green Filter

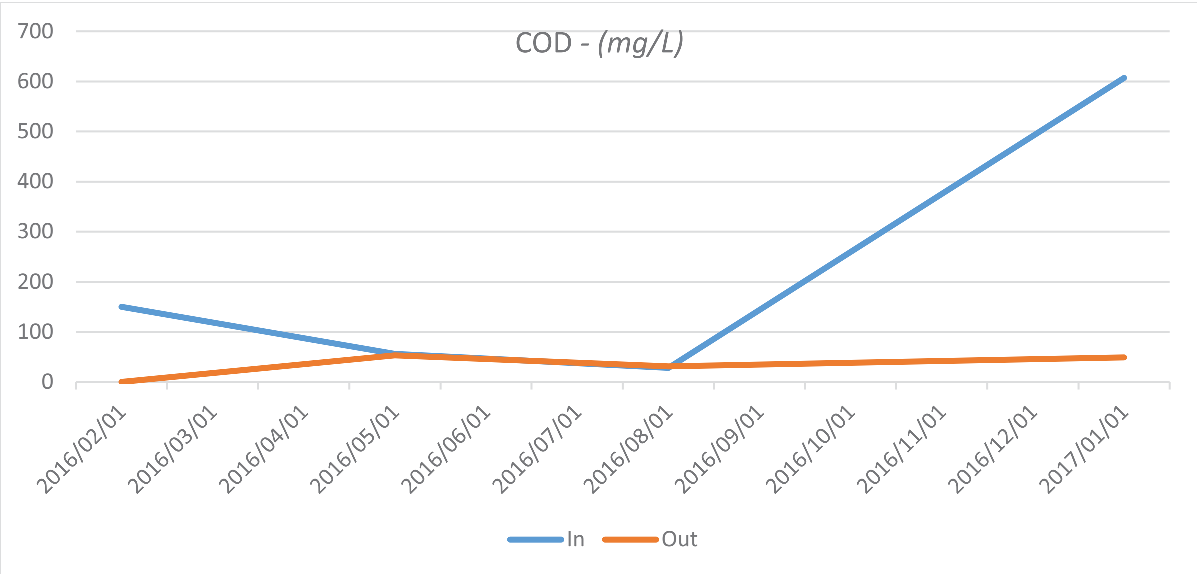

Figure 8. 3: COD Reduction Through the Plankenbrug Green Filter

CHAPTER 9

9 Conclusions

The design development of biomimicry-based wastewater treatment technologies in the context of Langrug informal settlement required the intentional placement of five key building blocks. Fundamental to the success of the project is a strong **social foundation** with a mobilised community and recognised leadership. With this in place, strong **municipal buy-in** was required with a demonstrated commitment to adapt existing maintenance structures to align with a new approach to infrastructure. With effective collaboration between the community, the municipality and the project team, a design was developed that maximised the impact on the **local economy** through creating local employment during the construction and maintenance phases. **Adaptive technical design** and the creation of suitable **ecological conditions** are the upper tiers of the essential building blocks for implementing the treatment technology as it is essential to create conditions suited to the selected indigenous vegetation or produce to be grown within the system.

The wastewater treatment technologies that were constructed at Langrug informal settlement and adjacent to the Plankenbrug River in Stellenbosch, utilise simple modular construction methods which incorporate standard materials and components. This infrastructure can be constructed using labour from members of the community who are then able to provide routine maintenance with relatively little external support.

Aside from the local job creation benefit, the treatment technologies produced a visible improvement in the local environment through the separation of greywater and stormwater flows and the diversion of polluted greywater into a contained network of pipes, tree gardens and micro-wetlands. The preliminary analysis of this system indicates a reduction in the total discharge of greywater from the pilot site through the irrigation of tree gardens. Initial results indicate that COD, suspended solids and faecal coliform concentrations in the greywater effluent were significantly improved by the system. Ongoing monitoring of these parameters will confirm the long-term performance of the system.

The Eco-machine technology that is proposed for the downstream extent of Langrug informal settlement will enable effective treatment of the greywater flow. The initial performance of this technology was demonstrated by the Plankenbrug Green Filter which treats heavily polluted water in the Plankenbrug River which has similar characteristics to the greywater flow in Langrug. Preliminary results from this biomimicry-based wastewater treatment technology indicated good quality effluent that was within the General Authorisation Limits for effluent discharge. Ongoing research into this technology is required to verify the hydraulic retention time that is required to produce the desired effluent water quality.

Five key components are considered necessary to monitor and evaluate biomimicry-based treatment systems. These include operational, physical, chemical, micro-biological and ecological parameters. Core elements of this monitoring programme can be undertaken by community operatives. This enables short feedback loops, effective maintenance and local design adaptations to support the long-term sustainability of the infrastructure.

The outcomes of this study will inform the future design of similar biomimicry-based wastewater treatment systems, through an improved understanding of the biological treatment processes that establish within the system, the suitability of indigenous vegetation to handle the effluent quality, and the treatment capacity for a given footprint. An increased understanding of the operation and maintenance burden of the systems will also inform future design. For instance, future designs should ensure convenient access to those parts of the system which require the most frequent maintenance.

Based on this study, biomimetic constructed wetland systems show promising results in the treatment of wastewater, but, due to their lower throughput levels, do have limitations which may need to be addressed from a design point of view. This can be addressed through the incorporation of a floating aquatic wetland system (such as the Eco-machine) which has increased porosity and increased water depth. This enables a reduced footprint to achieve the longer hydraulic retention time required by wetland systems. The increased surface area provided by the root matrix compared with conventional filter media enables increased surface area for biofilm growth which can lead to reduced retention times.

References:

Annon. (2011). Langrug Settlement Enumeration Report. Stellenbosch:

Armitage, N. (2011). The challenges of sustainable urban drainage in developing countries. Urban Water Management Group. UCT. (Online) Available: http://switchurbanwater.lboro.ac.uk/outputs/pdfs/W2-2_GEN_PAP_Challenges_of_sustainable_urban_drainage_in_developing_countries.pdf. [Accessed: 30/05/2015].

Ashbolt, N., Grabow, W., and Snozzi, M. (2001). Indicators of microbial water quality. In: Fewtrell, l., and Bartram, J. (eds). *Water quality: Guidelines, Standards and Health*. World Health Organisation.

Baker, K., and Herson D. (1994). *Bioremediation*. New York: McGraw-Hill.

Benyus, J. (2002). *Biomimicry: Innovation inspired by nature*. New York: Harper Perennial.

Berkes, F., and Folke, C. (1998). *Linking social and ecological systems: management practices and social mechanisms for building resilience.* Cambridge: Cambridge University Press.

Biomimicry Group. (2013). *Genius of Biome*. Missoula: Biomimicry 3.8. (Online). Available: http://biomimicry.net/. [Accessed: 28/05/2015].

Caprette, D.R. (2005). Five Kingdom Classification System. (Online) Accessed: https://www.ruf.rice.edu/~bioslabs/studies/invertebrates/kingdoms.html. [Accessed: 29/05/2015].

Corcoran, E., Nellemann, C., Baker, E., Bos, R., Osborn, D., and Savelli, H. (eds). (2010). *Sick Water? The central role of wastewater management in sustainable development. A Rapid Response Assessment*. United Nations Environment Programme, UN-HABITAT, GRID-Arendal.

Costerton, J., Stewart, P., and Greenberg, E. (1999). Bacterial biofilms: a common cause of persistent infections. *Science* **284**: 1318-1322.

DWAF (Department of Water Affairs and Forestry). (1996). Water quality guidelines for South Africa: first edition. (Online) Available: https://www.dwaf.gov.za/iwqs/wq_guide/index.asp. [Accessed: 27/05/15].

DWAF (Department of Water Affairs and Forestry). (2002). National Microbial Monitoring Programme for Surface Water. Implementation Manual. Department of Water Affairs and Forestry, Government Printers, Pretoria, South Africa.

Fourie, S. (2005). An assessment of water quality and endocrine disruption activities in the Eerste/Kuils River catchment system, Western Cape, South Africa. MSc Thesis. University of Stellenbosch.

Gersberg, R.M., Elkins, B.V., Lyon, S.R., Goldman, C.R. (1986). Role of aquatic plants in wastewater treatment by artificial wetlands. *Water Research* **20**(3): 363-368.

Gros, M., Petrovic, M., and Barceló, D. (2007). Wastewater treatment plants as a pathway for aquatic contamination by pharmaceuticals in the Ebro River basin (Northeast Spain). *Environmental Toxicology and Chemistry* **26**: 1553-1562.

Hadorn, G., Hoffmann-Riem, H., Biber-Klemm, S., Grossenbacher-Mansuy, W., Joye, D., Pohl, C., Wiesmann, U., Zemp, E. (2008). *Handbook of Transdisciplinary Research*. Springer. ISBN: 978-1-4020-6700-6 (pb).

Heberer, T. (2002). Occurrence, fate and removal of pharmaceutical residues in the aquatic environment: a review of recent research data. *Toxicology Letters* **131**: 5-17.

Jiusto, S., and Kenney, M. (2015). Hard rain gonna fall: strategies for sustainable urban drainage in informal settlements. *Urban Water Journal*: 1-17. URL: http://dx.doi.org/10.1080/1573062X.2014.991329.

JTED (John Todd Ecological Design). (2014). From missing infrastructure to ecological infrastructure: innovating in South Africa. JTED.

JTED (John Todd Ecological Design). (2015). Moskito Island Water Machine. (online) Available: http://www.toddecological.com/eco-machines/recent_work.php#moskito. [Accessed: 27/05/1025].

Kimoon, N. (2014). The Millenium Development Goals Report 2014, 14th edition. New York: United Nations (UN).

Lakhtakia, A. and Martin-Palma, R. (2013). *Engineered Biomimicry*. Waltham: Elsevier.

(MA) Millennium Ecosystem Assessment. (2005). *Ecosystems and Human Well-being: A framework for assessment*. Washington: Island Press.

Max-Neef, M. (2005). Foundations of transdisciplinarity. *Ecological Economics* **53**: 5-16.

Mitsch, W., and Jørgensen, S. (2003). Ecological Engineering; a field whose time has come. *Ecological Engineering* 20: 363-377.

Murthy, S. (2010). Land security and the challenges of recognizing the human right to water and sanitation in the slums of Mumbai, India.

Newing, H. (2011). *Conducting research in conservation: a social science perspective.* New York, Routledge.

Pahl-Wostl, C., (1995). *The Dynamic Nature of Ecosystems: Chaos and Order Entwined*. New York: Wiley.

Parkinson, J., and Ole, M. (2005). *Urban Stormwater Management in Developing Countries*. London: IWA Publishing.

Pillay, M. (1994). Detergent Phosphorus in South Africa: Impact on Eutrophication with Specific Reference to the Umgeni Catchment. M.Chem.Eng: University of Natal.

Richardson, G. (1986). Problems with causal loop diagrams. *System Dynamics Review* **2**: 158-170

RSA (Republic of South Africa). (1996). Department of Water Affairs and Forestry. 1993. Water quality guidelines: Domestic use. Volume 1. Pretoria: Government Printer.

Suárez, S., Carballa, M., Omil, F., and Lema, J.M. (2008). How are pharmaceutical and personal care products (PPCPs) removed from urban wastewater? *Reviews in Environmental Science and Biotechnology* **7**:125–138.

Taylor, S., Roberts, C., and Hatt, B.E. (2004). Catchment urbanization and increased benthic algal biomass in streams; linking mechanisms to management. *Freshwater Biology* **49**: 835-851.

Ternes, T.A. (2001). Pharmaceuticals and Metabolites as Contaminants of the Aquatic Environment. In: Daughton, C.G., and Jones-Lepp, T.L (eds.). *Pharmaceuticals and personal care products in the environment: scientific and regulatory issues*. Washington: American Chemical Society.

UN (2013). Water and Urbanization. United Nations (Online) Available: http://www.unwater.org/fileadmin/user_upload/unwater_new/docs/water_and_urbanization.pdf. [Accessed: 23/05/2015]. UNWater.

Venail, P.A., and Vives, M.J. (2013). Positive effects of bacterial diversity on ecosystem functioning driven by complementarity effects in a bioremediation context. *PLoS ONE* **8**: e72561.

Walsh, C., Roy, A., Feminella, J., Cottingham, P., Groffman, P., and Morgan, R. (2005). The Urban Syndrome: current knowledge and the search for a cure. *The North American Benthological Society* **24**(3): 706-723.

WCG (Western Cape Government) (2012). Berg River Improvement Plan. (Online). Available: http://capewinelandsbiosphere.co.za/images/latestnews/Berg_River_dam_2014_project.pdf. [Accessed: 25/05/15].

Wolfaardt, G.M. (1994). Multicellular organization in a degradative community. *Applied and Environmental Microbiology* **60**: 434-466.

WSUD. (2015). Water Sensitive Urban Design South Africa. (Online). Available: http://wsud.co.za/. [Accessed: 27/05/15].

APPENDICES

Appendix A: Maintenance Monitoring Forms

GENIUS OF SPACE 2017 DISPOSAL POINT & HOUSEHOLD CONNCTION MAINTENANCE CHECKLIST

BLOCK	DISPOSAL POINT	LID CLEANING					SOCK CLEANING DATE	LID CLEANING					SOCK CLEANING DATE	LID CLEANING					SOCK CLEANING DATE	LID CLEANING					SOCK CLEANING DATE	BASKET CLEANING DATE	COMMENTS
		Start date:						Start date:						Start date:						Start date:							
		Mon	Tue	Wed	Thu	Fri		Mon	Tue	Wed	Thu	Fri		Mon	Tue	Wed	Thu	Fri		Mon	Tue	Wed	Thu	Fri			
T	D1																										
T	D2																										
T	D3																										
T	D4																										
T	D5																										
T	D6																										
T	D7																										
T	D8																										
T	D9																										
T	D10																										
T	D11																										
T	D12																										
T	D13																										
T	D14																										
T	D15																										

BLOCK	HOUSE CONNECT	CHECKING & CLEANING DATE	COMMENTS
T	H1		
T	H2		
T	H3		
T	H4		

WRITE ADDIONAL COMMENTS HERE:

GENIUS OF SPACE 2017 DISPOSAL POINT & HOUSEHOLD CONNCTION MAINTENANCE CHECKLIST

BLOCK	DISPOSAL POINT	LID CLEANING Start date:					SOCK CLEANING DATE	LID CLEANING Start date:					SOCK CLEANING DATE	LID CLEANING Start date:					SOCK CLEANING DATE	LID CLEANING Start date:					SOCK CLEANING DATE	BASKET CLEANING DATE	COMMENTS
		Mon	Tue	Wed	Thu	Fri		Mon	Tue	Wed	Thu	Fri		Mon	Tue	Wed	Thu	Fri		Mon	Tue	Wed	Thu	Fri			
S	D17																										
S	D18																										
S	D19																										
S	D20																										
S	D21																										
S	D22																										
S	D23																										
S	D24																										
S	D25																										
S	D26																										
S	D27																										
S	D28																										

BLOCK	HOUSE CONNECT	CHECKING & CLEANING DATE	COMMENTS
S	H5		
S	H6		
S	H7		
S	H8		
S	H9		
S	H10		
S	H11		

WRITE ADDIONAL COMMENTS HERE:

GENIUS OF SPACE 2017 TREE GARDEN AND WETLAND MAINTENANCE CHECKLIST

TREEWELL	WEEKLY TASKS		SOCK CLEANING	WEEKLY TASKS		SOCK CLEANING	MONTHLY TASKS	COMMENTS
NUMBER	WEEK 1	WEEK 2	DATE	WEEK 3	WEEK 4	DATE		
T1								
T2								
T3								
T5								
T6								
T7								
T8								
T9								
T10								
T11								
T12								
T14								
T15								
Wetland (Inlet)								

WRITE ADDIONAL COMMENTS HERE

CLEANING ACTIVITIES:

ONCE A WEEK (or more if needed)
REMOVE RUBBISH TO MUNICIPAL COLLECTION AREA
WATER TREES AND SMALL PLANTS
REMOVE DEAD PLANTS - RECORD
REMOVE WEEDS
FIX FENCE IF NEEDED

ONCE EVERY TWO WEEKS (or more if needed)
OPEN DRUM AND CHECK
REMOVE RUBBISH FROM DRUM
REMOVE DIRTY TREE DRUM SOCK
PUT ON CLEAN TREE DRUM SOCK
WASH TREE DRUM SOCK
STORE SPARE CLEAN TREE DRUM SOCK
REPORT ANY DAMAGE TO SOCK

ONCE A MONTH (or more if needed)
CUT BRANCHES OF TREES IF TOO LARGE
CUT PLANTS SMALLER IF TOO LARGE

Appendix B: Monitoring Programme

Biomimicry Wastewater Treatment Systems - Monitoring Programme

Category	Parameter	Units	Description / Interest	Location	Frequency	Collection	Analysis
1. Operational	a. Effort	Person days	Intensity of maintenance	Pilot Projects	Monthly	Langrug Community	PSF / Greenhouse
	b. Materials	Rands	Cost of maintenance materials		Monthly		
	c. Frequency	days	Cleaning interval		-		SeeSaw
	d. Functionality	%	Proportion of system working		Daily		
	e. Breakages/Faults	No.	Problems requiring repair		Monthly		
2. Physical	a. Water Flow	l/s	Rate of water discharge	S&T Pilot	15 min	UCT	UCT
	b. Suspended Solids	mg/ℓ	Solids in greywater flow	S&T Pilot + Block P	Weekly	Langrug Community	UCT
	c. Water Depth	m	Depth of water inside system	Tree Gardens Micro-Wetland	Monthly		Langrug Community
	d. Turbidity	NTU	Clarity of water	Main Outlet	Monthly		
	e. Rainfall	mm	Daily rainfall record	Site Office	Daily		
	f. Sediment Accum.	Litres or Kg	Sludge build up	Disposal points Tree garden inlet Wetland inlet Eco-machine	Monthly		
	g. Odour		Reported odour issues	S&T Pilot	Monthly		
	h. Solid Waste	Bags or Kg	Trash & organic waste collected	S&T Pilot	Monthly		
3. Chemical	a. Elec. Conductivity	mS/m	Measure of salts	S&T Pilot outlet *with control at Block P discharge* *and* Eco-Machine	Monthly *with occasional batch sampling over 24 hour*	Langrug Community *and* Stellenbosch University	Stellenbosch University *and* Stellenbosch Municipality
	b. pH		Acidity of the water				
	c. BOD	mg/ℓ	Biological Oxygen Demand				
	d. COD	mg/ℓ	Chemical Oxygen Demand				
	e. Ammonia	mg/ℓ	Indicator or urine				
	f. Nitrite + Nitrate	mg/ℓ	Nitrate indicator of treatment				
	g. Ortho-Phosphate	mg/ℓ	Phosphates (in detergents)				
	h. Alkalinity	mg/ℓ	Biological treatment capability				
	i. PPCP	mg/ℓ	Pharmaceutical & Personal Care Product removal				Stellenbosch University
4. Micro-biological	a. E.*coli*	cfu / 100ml	Indicator or faecal bacteria	Outlet of S&T Pilot Eco-Machine Inlet / outlet	Monthly *and batch sampling*	Langrug Community	WALab
	b. Biofilms		Presence biofilms and their contribution to treatment	Various Esp. Eco-Machine	Quarterly	Stellenbosch University	Stellenbosch University
5. Ecological	a. Plant Species		Record of species diversity and dominance within the system	Tree Gardens, Micro-wetlands, Eco-Machine	Monthly	Langrug Community *and* Ecologist	Ecologist
	b. Plant Health		Plant growth and health				
	c. Micro-Organisms	Score	Mini SAS assessment to score eco system health	Eco-Machine	Monthly	Langrug Community	Langrug Community