# IDEAS TOWARDS WATER SENSITIVE SETTLEMENTS

Report to the
**WATER RESEARCH COMMISSION**

by

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# EXECUTIVE SUMMARY

Rapid urbanisation brings complex challenges for urban systems to be able to meet the diverse needs of its populations while adapting to uncertain global changes. In South Africa, these challenges are coupled with redressing inequities inherited from the racial segregation of the colonial & Apartheid eras. Despite significant efforts, informal settlements have continued to grow as the formal city do not have the capacity to absorb new citizens and people resort to find their own informal ways to establish themselves.

South Africa is also facing a water crisis that calls for major transformations in its water governance. The concept of 'water sensitive design' (WSD) has emerged in recent years for urban water systems to be managed in a more coherent framework where water supply, wastewater and stormwater systems can complement each other in ways that can benefit the whole city as well as its larger catchment. While this framework provides clear guidelines towards end goals, there is less certainty about what the transition towards these goals might mean in practice, especially how such approach in informal contexts could simultaneously increase social equity and protect the environment.

Whilst technical solutions are recommended where passive treatment technologies are the main focus in the literature, in the absence of adequate social and institutional planning and support, sustainable success is low. Solutions are often implemented without due regard to consequences, as evident in this study. The success of solutions in the developed countries, where institutional support, skilled personal capable of managing the full implementation of technologies cannot simply be translated into the informal settlements environment.

Water quality modelling is complex and furthermore so for informal settlements, where data is difficult to find. The lack of data is indicative of the challenges, such as no formal planning and dynamic within the settlements. To date these dynamics have been studied in some detail, however there is still no real solutions provided in the literature, particularly with regard to formal infrastructure to manage and mitigate pollution. Currently, the literature recommends treatment solutions which are aligned towards passive treatment technologies.

It is often preferable to begin with simple models when a decision, in terms of which passive treatment technology is suitable. Is it possible that the bias in the model, may be consistently bias in the solutions it provides, however still point one in the right direction? If this approach proves to be true then building up from a simple model over time, by adding additional complexity as justified by the collection and analysis of additional data. The approach is considered in this study. This strategy aims to make efficient use of resources. It targets the effort toward information and models that will reduce the uncertainty as the analysis proceeds.

Models should be selected (simple versus complex) in part on the basis of the data available to support their use. This study sets out an approach that could be considered for a detailed model design and the requirements for undertaken such a study. A very important question that is to be examined out of this study is 'what is water knowledge and subsequently what determines water related knowledge' particularly in the context of that community. Therefore can the idea of water sensitive settlements be achieved and what would these be in the context of the informal settlement. A community-based inquiry was conducted with a group of residents from Stjwetla informal settlement in Alexandra, Johannesburg. As many other

informal settlements, Stjwetla's context is characterised by poor access to services, the absence of health and education facilities and unsuitable environments as the area gets regularly flooded by the adjacent Jukskei River. This social learning approach was adopted to reconnect water issues with its societal context and to be able to take into account the complexity and uncertainties associated with human, natural and built environments.

Over the course of 6 months, tools were used as facilitator of dialogue and as a way to make alternative realities visible. The participants of the workshops discussed their stories, perceptions of their environment, acted out improvisations and dramatized scenes of some situations that had been brought up. Drama allowed for participants to make apparent a number of intricacies in the interaction between water risks, lack of rights, migratory pressures, and poverty among others which are often dismissed in water studies. Residents were often acutely aware of both some of the social and environmental risk and some potential solutions. However they also expressed that they are often compelled to make a choice in the dilemma between economic survival and environmental quality. This vicious circle intensify the risks of social and ecological harm both to their communities and to the wider area while exacerbating poverty and vulnerability.

New concepts such a WSUD must allow the opportunity to re-think the above. Can the opportunity with these 'fresh ideas' allow us to think of new ways to do things, since the concepts challenge researchers. Principles of WSUD is not completely new, but it affords the previously disadvantaged to be recognized and push for change and representation. Although there are just a few examples of the research related to informal settlements in South Africa, initiatives undertaken internationally recognize the need for more representation from the communities.

Through this case study, the paper points to some of the critical re-skilling and capacity-building areas that are needed before local government can roll out water sensitive design within informal settlement upgrading programmes at scale.

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# 1 INTRODUCTION

It has become evident that the old forms of managing water in South Africa, both the public and private sectors need to become more relevant due the rapidly changing conditions at the national, municipal and community level. These changes are due to a variety of factors which include, but not limited to, deeper and accelerated understanding of self-worth, move towards a growing demographic diversity within country, incessant pressures exerted by economic, social and political dynamism, higher levels of education, rapid scientific and technological developments, information and communication technological developments, institutional innovations, changing societal perceptions, institutional values and structure and variability of the climate (Biswas *et al.*, 2010). One of the biggest drivers for the changing paradigm shifts related to water management must surely be associated to the changing political landscape. Siebrits and Winter (2013) demonstrate the shifts in water management paradigms for South African over the years, where it is evident that the context of urban topics have moved towards that of community related research becoming more prevalent. It can be expected that water management in South Africa will evolve more during the coming years than it has in past 25 years if societal, economic needs for water related activities, including environmental requirements, are to be met successfully in a timely, equitable and cost-effective manner. The water research community must recognize the needs for new ways of tackling problems in South Africa as a result of highlighting these facts above.

One of the legacies of apartheid is the informal settlement, which are not peculiar within South Africa. The Housing Development Agency (HDA, 2012) reported in 2011 that approximately 13% of the households classify as 'informal settlements'. Stormwater management is generally been excluded from the basic conditions, where the Upgrading Informal Settlements Programme (UISP) was incorporated into policy (Chapter 13 of the National Housing Code) (2004) is yet to consider this an issue to focus. The lack of stormwater management for informal settlements have over the years resulted in flooding and related health risks to communities. Informal high-density settlements have become associated with an increase in polluted stormwater runoff, resulting in the degradation of the receiving rivers (Campbell, 2001; Ashton and Bhagwan, 2001; Schoeman *et al.,* 2001; Simpson, 1993, Owusu-Asante and Stephenson, 2006; Wimberley and Coleman, 2003). The Water Research Commission (WRC), through its interactions with key stakeholders over a long period and the overall needs analyses conducted for the KSA: "Water Use and Waste Management", has identified the need to determine and prioritise stormwater research needs, particularly in the field of stormwater control and management (Burke and Mayer, 2009).

The City of Johannesburg Municipality, Gauteng Province has experienced serious water quality problems in the rivers due to inflows of contaminated drainage from informal settlements. Basnath *et al.,* 2015 state that the Jukskei River is highly polluted and degraded and under a lot of pressure due to the presence of the informal settlements like Stjwetla. Stjwetla forms part of the Alexandra Township located on the banks of the Jukskei River. As early as the 1990s reports that 'the Jukskei River was arguably one of the most polluted rivers in the country, specifically severe at Alexandra Township (van Veelen and van Zyl, 1995). Therefore, it can be seen the state of the Jukskei River has not improved, if not worse and is directly linked to the living conditions (such as access to basic services) and social challenges experienced by this community. Armitage, 2011 argues that a general weakness, is the failure to see the problem of urban water management in a holistic manner. This study follows on from the WRC findings above, specifically on the technical and social aspects towards water management of the informal settlements. New concepts such as Water Sensitive Urban Design (WSUD) has gained increased acceptance (see www.wsud.co.za) by the implementation of Sustainable Urban Drainage Systems (SuDS) to manage and improve runoff in urban settings (Kirby, 2005). Can these WSUD concepts be translated into 'Ideas towards water sensitive settlements,' ultimately improving the water quality before entering the Jukskei River.

The vision of a 'water sensitive city' have established goals that water systems, the urban environment and governance arrangements are designed to provide multi-functional benefits. Informal settlements are often associated with a lack of urban socioeconomic integration and their growth are increasingly recognised as a major planning and design challenge. With regard to water planning, the connectedness and diversity of issues faced within informal settlements together with the illegal nature of these settlements has prevented traditional technology-driven approach to be successfully implemented.

## 1.1 STUDY OBJECTIVES

This study program was designed within a "traditional" academic approach that would have focused on "what" water sensitive design are appropriate to an informal context through academic literature review and modelling. The aim of this approach was to aid in 'optimal' selection of water sensitive designs that would be adapted to informal settlements settings and to propose "ideas towards water sensitive settlements". These objectives would build on the research required identified from project K8/606, specifically toward "Water Use and Waste Management". A broad overview of the proposed scope included;

- Options for the treatment of stormwater prior to discharge to receiving waters (control and removal of various pollutants from stormwater conduits and streams, in particular excessive nutrient loads and the implications of not treating stormwater prior to discharge. This study proposal outlined the following:
  - The strategy will outline a strategic approach to deal with existing flooding, hotspots in the settlement by addressing legacy issues and capacity constraints. The costs of implementing this strategy will form the basis of a stormwater offset scheme for feasible scenario development options. A key and immediate drainage strategy is to isolate the site drainage from the existing drainage infrastructure so that the scenarios reduce identified flooding hotspots. The stormwater management scenarios will establish achievable design principles to the settlement.
  - Harness water servicing infrastructure and landscape elements in a single integrated design.
  - Maximise on-site uses of fit-for-purpose water to reduce volumes discharged off site. To give effect to this principle, all water within the site will be managed firstly as a resource before any residual is planned for as a waste.
  - Research toward storm water bio-filters and associated filter technologies present the greatest potential for delivering reliable and safe water fit-for-purpose, e.g. irrigation. Is it possible to develop cost effective filtration materials for inactivation

of pollutants. Can materials be incorporated into the bio-filters and filters to improve the quality of treated water to non-portable standards. These may incorporate novel material for delivering safe treated storm water for unrestricted irrigation without any post-treatment.

- Is there potential to rethink the water quality issues within the settlement design platform. Within the actual settlement can measures be developed such as filter storage beds. Can these areas be furthermore managed with vegetation beds and the filter beds will to an extent act as a detention bed and a passive treatment. The analysis will further aim to validate the potential for passive stormwater treatment system which could be developed and tested fully.
- Determining the target pollutants, their required reduction levels and identify the key treatment mechanisms that should be presented in a well-functioning system. Challenging operation conditions also need to be determined for the pollutants.
- It was proposed that the water quality would be modelled using MUSIC software. MUSIC lets you conceptually choose appropriate sizes for stormwater infrastructure options such wetlands, etc. until design meets or exceeds appropriate standards for storm water volume and pollutants. The model allows for a wide range of treatment devices to identify the best way to capture and reuse stormwater runoff and remove its contaminants and reduce runoff frequency, therefore evaluate these treatment options to achieve the required goals.
- Monitoring will be about testing the system performance under challenging operational conditions, thereby providing evidence that the system can cope with extreme situations. The study will aim to be a driver for further input from other researchers and organizations. This will ultimately present to local municipalities/government information and drive innovations required to better understand water management within the informal settlements.

The team member that was involved over the course of this research:

- Mr Gary Morgan, a hydrologist and water quality specialist with a strong interest in water sensitive design.

Preliminary visits and interactions with residents of Stjwetla together with research into a heterogeneous range of academic literature on informal settlements in South Africa, challenged our perception of the fundamental issues and the selected methodology. In particular, the formal modelling approach to design failed to meet the needs to understandings the complex dynamics of informal settlements. While the objective to propose “ideas towards water sensitive settlements” remained the same throughout the study, the focus rapidly moved from the “what” designs are adapted to informal contexts to the “how” the informal context can contribute to what design. Through this case study, the study considers some of the critical re-skilling and capacity-building areas that are needed before local government can roll out water sensitive design within informal settlement upgrading programmes at scale. Armitage *et al.*, 2010 argue this as ‘the effort to combine science with local and traditional knowledge to solve problems in which neither science nor local knowledge is sufficient by itself’.

If water sensitive planning in informal settlements is defined as a mostly technical discipline which plans and builds infrastructure, it will not be able to respond fully to the needs of already marginalized communities. If it is focused more on non-structural and regulatory tools, it may also fail by not providing the infrastructure needed to serve people and protect the environment. If it fails to respond to the urgent needs of other sectors such as food, health, and urban development it will also be inadequate. In short, the idea of water sensitivity for informal settlement will be demanding, but must be comprehensive and integrated with parallel management activities in other sectors and at multiple scales. In this part, the study further aimed to assess the Stjwetla resident's water-related knowledge and examine the individual and contextual challenges/factors that influence this knowledge, ultimately their water-related attitudes which can then subsequently influence their water sensitive behaviours.

This part further aimed to demonstrate to the community that they themselves may to some extent worse some of the issues they are experiencing, instead of blaming the government or infrastructure and be able to challenge their own misuse and water neglect. The study focuses on the feasibility of applying alternative approaches to water sensitive design and planning within South African informal settlements. The diversity and multi-faceted issues faced within informal settlements requires a wider perspective to designs and deeper involvement of communities for better use and applicability in the future. One of the tools used to engage Stjwetla was for them to 'Take Part in Drama and Theatre' which gave individuals softer tools to challenge their lack of power and knowledge that perpetuates recklessness around the water issues. The nature of drama is a dynamic and a personal way of learning that better enabled communities to understand themselves. Drama workshops create a safe space for discussion and challenging stereotypes. The researchers involved in this study strongly believe that in trying to improve living conditions within informal settlements, an effective start is at the community level. By enabling the community to build resilience towards the issues and helping them see that these issues such as the contamination of the Jukskei, affects us all. Together with this community, through facilitated dialogue, we aimed to bring about behaviour and social change. The composition of the team involved to meet the challenges of interconnected water and social issues which span disciplines and value systems, included:

- Mr Simon Chambert, a water resources engineer with a specific interest in understanding transdisciplinary between specialisations;
- Miss Thokozani Ndaba, an applied educational and theatre practitioner specialized in community engagement and social justice; and
- Mr Kyle Haselsteiner, a student at Wits interested in politics and philosophy.

## 2 INFORMAL SETTLEMENTS – A REALITY

The naming of informal settlements vary across countries and organisations from the term 'slum' used in Kenya to the term 'squatter camps' which was also previously used in South Africa. Squatter camp is now deemed inappropriate. 'Informal settlement' have different definitions (see Table 1) and characteristics but it generally defines "housing that has been created in an urban or peri-urban location without official approval". The term does carry some ambiguity as it both refers to the type of housing and the type of land it is built on. A very wide range of situations may be included, like spontaneous occupation of the territory, absence of property titles, self-building of houses, and illegal inhabiting in contexts with rapid urbanisation, temporary uses of space. Informal dwellings are normally developed in undeveloped land and accessible land and are often characterised by one or several of the following: inadequate infrastructure, poor access to basic services, unsuitable environments, uncontrolled and unhealthy population densities, inadequate dwellings, poor access to health and education facilities and lack of effective administration by the municipality (Huchzermeyer & Karam, 2006).

**Table 1: Definitions of informal settlements Source (HDA 2013)**

| Data Source | Definition of informal settlement |
|---|---|
| Statistics South Africa | "An unplanned settlement on land which has not been surveyed or proclaimed as residential, consisting mainly of informal dwellings (shacks)." Definition of an informal dwelling :"A makeshift structure not approved by a local authority and not intended as a permanent dwelling" |
| National Department of Human Settlements | The 2009 National Housing Code's Informal Settlement Upgrading Programme identifies informal settlements on the basis of the following characteristics:<br>• Illegality and informality;<br>• Inappropriate locations;<br>• Restricted public and private sector investment;<br>• Poverty and vulnerability; and<br>• Social stress |
| City of Johannesburg Metropolitan Municipality | No formal definition, however the following working definition is used: An informal settlement comprises "An impoverished group of households who have illegally or without authority taken occupation of a parcel of land (with the land owned by the Council in the majority of cases) and who have created a shanty town of impoverished illegal residential structures built mostly from scrap material without provision made for essential services and which may or may not have a layout that is more or less formal in nature." |
| City of Tshwane Metropolitan Municipality | "Informal settlement means one shack or more |

| | |
|---|---|
| | constructed on land, with or without the consent of the owner of the land or the person in charge of the land." "Shack means any temporary shelter, building, hut, tent, dwelling or similar structure which does not comply with the provisions of the National Building Regulations and Building Standards Act, 1977 (Act 103 of 1977), the regulations promulgated under that Act and the Municipality's Building Control By-laws and which is primarily used for residential purposes." |
| Ekurhuleni Metropolitan Municipality | "As a basic characteristic, the occupation of the land is unauthorised. In addition, the use of the land may be unauthorised, and in most cases the construction standards do not comply with building regulations." |

The spatiality and urban structure of South African cities have been inherited from both colonial times and the racial segregation of the Apartheid era where non-white citizens were systematically relocated on the outskirts of the city (Robinson, 1997). During this era, government policies systematically segregated people based on race from housing, education and job opportunities which has significantly affected the spatiality of South African cities. Since the end of Apartheid and despite significant investment in affordable or low-income housing, the need for housing remains high in South Africa (DHS, 2009). This is a direct response to low housing access as the formal city does not have the capacity to absorb its new citizens, newcomers find their own informal ways to establish themselves, resulting in the spreading informal settlements. It reveals discernibly the human geographical fault lines of an inherited inequality in land and housing, and conditions that reproduce exclusion.

The quantitative dimension of this challenge, coupled with the delivery of basic and social services, is however only part of the bigger reality. Historical spatial investment patterns in infrastructure and housing resulted in specific settlement and daily use-patterns that create a dysfunctional, inefficient and inequitable space economy. The main spatial challenges in South Africa centre on the continued spatial exclusion of the poor from the main socio-economic fabric of cities and regions. "Informal settlement areas are the results of various inadequate spatial planning, outdated and complex legislation, housing policies that do not ensure the provision of affordable housing policies and outdated public administration structures. Illegal constructions practices in urban areas, often due to the lack of a clear system of property rights and urban poverty, have created significant challenges in many townships." (REF)

## 2.1 TOWARDS UPGRADING OF INFORMAL SETTLEMENTS

Over the past two decades, housing delivery has shifted from an emphasis on building houses to recognising the importance of providing access to resources and opportunities, which would facilitate active participation in the social and economic fabric of South Africa. This shift is illustrated by the introduction of the Comprehensive Plan for Sustainable Human Settlements (commonly referred to as BNG – Breaking New Ground) in 2004 and the renaming of the Department of Housing to the Department of Human Settlements (DHS) in 2009. Moving from this narrow conceptualisation ('housing') to a more holistic framing ('human settlements') requires considerable conceptual, political, and practical adjustment.

Some of the concerns raised included the measurement of housing delivery performance (which continued to be based on the number of houses built), the lack of public participation, the location of housing (on the periphery of cities) and the alignment of funding for human settlements across different functions.

In response, new grant instruments were introduced: the Upgrading Informal Settlements Programme (UISP) (Chapter 13 of the National Housing Code) and the Social Housing Programme (SHP). The UISP promotes an incremental (or phased), holistic and developmental approach to upgrading human settlements. The Upgrading of Informal Settlement Programme is a significant policy shift, which is more flexible, participative, and integrated. The UISP has been a cornerstone of the housing and human settlements delivery programme. This grant comes in the form of a capital subsidy for housing. The only way they can access tenure is if and when they are incorporated into the government subsidy programme. A significant proportion of those living informally will be relocated far from the city, services and job opportunities because of land affordability. The government's Upgrading of Informal Settlement Programme (UISP), contained in the National Housing Code of 2009 now prioritises in situ upgrading and provides funding for incremental, participative upgrading projects.

The government has been trying to address the fact that large numbers of people live in sub-standard environments with no running water, electricity and sanitation. These often do not adhere to official planning guidelines, building regulations and construction standards and, as they are not officially recognised by local authorities, are rarely provided with adequate infrastructure and services. Whereas there is a clear case for improving the living conditions of people in slums, there is still much debate and uncertainty about what exactly constitutes upgrading, the most appropriate methods and approaches to upgrading, and what the objectives and desired outcomes of upgrading interventions ought to be.

# 3 INTRODUCTION TO STJWETLA

The informal settlement of Stjwetla was established in the late 1980s (comms. Stjwetla leader) is located on the northern boundary of Alexandra Township, Johannesburg. Alexandra, referred to often as 'Alex' was established in or around 1912 (Bonner and Nieftagodien, 2008). The land was bought by a wealthy farmer who later divided the land and sold the plots off to black families Alexandra Township offered affordable accommodation for poor migrants, but more importantly was conveniently located when seeking employment in surrounding areas (Bonner and Nieftagodien, 2008). The community of Stjwetla (also sometimes written as "Setswetla") is one of the poorly neglected informal settlements in this country.

## 3.1 LOCALITY OF STJWETLA

Stjwetla currently has an approximate area of 13 ha confined between the Jukskei River and the Alexandra West Bank cemetery. Stjwetla is located at the northern boundary of Alexandra Township lies on a floodplain of the Jukskei River (see Figure 1). The Jukskei River is dominated by urban and residential areas, and is as a result, greatly impacted upon by human activities. Based on the studies carried out by the City of Johannesburg, the key problems highlighted in the Water Management Unit include pollution due to sewage leakages, solid waste (Basnath *et al.*, 2015). Also owing to the Water Management Unit's urban locality, the river systems receive excessive runoff from the surrounding impermeable urban and residential settlements, subjecting the rivers to flooding and in turn, flood hazards for settlements like Stjwetla which are located on the banks. The rivers experience excessive water pollution through polluted runoff from the urban surfaces and combined sewer overflows from leaking sewer pipes. The Jukskei River is highly polluted and degraded, and under a lot of pressure due to the presence of high density informal settlements like Stjwetla along its banks. The river is classified as a Class E river (being intensely modified and far from its natural state), and is highly unsuitable for natural and aquatic life. The river's Present Ecological State is classified as a Class E (Extensively Modified) (Basnath *et al.*, 2015).


**Figure 1: Top: Location of Stjwetla (red area) at the northern boundary of Alexandra Township (purple area). Bottom: Zoom into Stjwetla informal settlement.**

The Jukskei flows into Hartbeespoort Dam, the major source of drinking and irrigation water for the eastern part of the North West province and Pretoria. The Jukskei River in the North flows into the Crocodile River to the Limpopo River and discharges its waters into the Indian Ocean (Figure 2). It is important to understand how the water systems have been built and operate in South Africa. For example, the contaminated water ultimately is adding pressure on the systems of the drinking water, since the water used for drinking is extracted from these same sources. Therefore, if there is a way to reduce the level of contaminants in the water entering the source, the added pressures can somewhat be reduced on the operational infrastructure that clean these same waters for drinking.

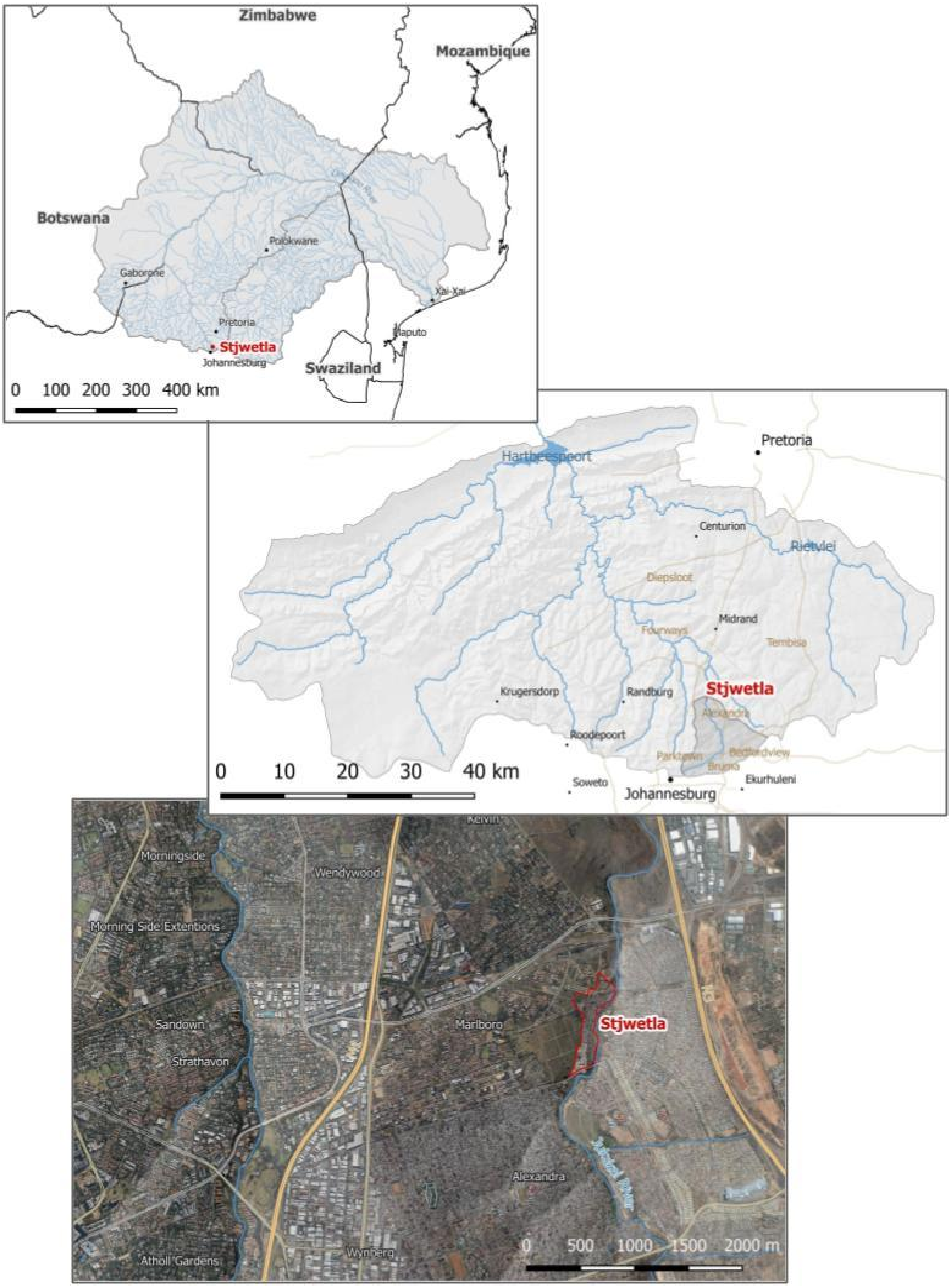


**Figure 2: Stjwetla and its localities at different scales**

## 3.2 SOCIO ECONOMIC CONTEXT

Stjwetla is characterized by its high population densities with a population estimated to be 5130 inhabitants in 2011 (StatsSA, 2012). This is equivalent to a density of 40670 inhabitants per square kilometre. The first language of its inhabitants is primarily Xitsonga (55.5%) and Sepedi (20.5%). A major portion of the residents live in informal housing structures made of makeshift material (as shown in Figure 3). The settlement lacks a number basic infrastructure and services like water, sanitation services, solid waste management, roads, and electricity. Other problems that characterize Stjwetla include the haphazard layout of the infrastructure. There is a very low sense of security since there is no NGOs or policing currently based in Stjwetla (comms. Stjwetla leader). The level of poverty has crippled and paralyzed this community. The issue of housing and health has been ignored by the government, no matter how they try to voice out their issues or frustration are deliberately silenced and marginalized. This community is driven by poverty and social exclusion. This has made this community vulnerable to all forms of crime, drugs, violence and diseases such as cholera, malnutrition, tuberculosis and HIV/AIDS.

**Figure 3: View of Stjwetla informal settlement from Jukskei River bank**

# 4 CONDITIONS IN STJWETLA INFORMAL SETTLEMENT

The Macroscopia team engaged the Stjwetla community and involved them in various group activities, where the overall layout of the issues were mapped and these tools could then be used to demonstrate and bring perspective of their challenges. These locations were visited by the Macroscopia team where they could also then understand the extent of the issues and challenges of the community.

**Figure 4: Community members involved in activities developed by Macroscopia Team**

**Figure 5: Macroscopia team learning about the condition and setting of Stjwetla**

**Figure 6: Macroscopia Team engaging Stjwetla community members**

## 4.1 SANITATION

Stjwetla is not served by the formal sewerage system and a number of plastic bucket toilets have been provided by the municipality (see Figure 7). A private company is in charge of emptying and maintaining the toilet system. A census conducted during this study estimated a total of 236 of these toilets in the settlement. This would average to approximately 1 toilet per 25 inhabitants. For access and maintenance reasons, the majority of the toilets are located on the periphery of the settlement as shown in Figure 8. The map shows that a majority of the toilets are located on the upper section of Stjwetla while distance to sanitation can be as much as 150 m for people staying closer to the Jukskei River.

Different mechanisms have been developed by the residents to cope with the limited access to sanitation. While some of the toilets are poorly maintained due to the high number of users, some residents have organised collective systems to be able to maintain the toilets in their own area. In this system, the toilets are privatised by a number of resident from the area and a padlock is put onto the toilet door. Keys are shared across the various users who are then in charge of maintaining the toilets in a roll out system. Other residents have built their own bricked toilets which is either pit or bucket latrines outside of their dwelling. Others defecate in plastic bags and then wrap and throw them like other solid wastes. Some residents because of lack of access, combined with the threat of crime, residents cannot venture out in the night to use the facilities. Hence overnight containerization of waste is required which is disposed of next day. For a larger number of the residents, inadequate sanitation compels to dispose themselves of their own of faeces either directly with solid waste into the nearby Jukskei River.

**Figure 7: Dry type toilet in Stjwetla**

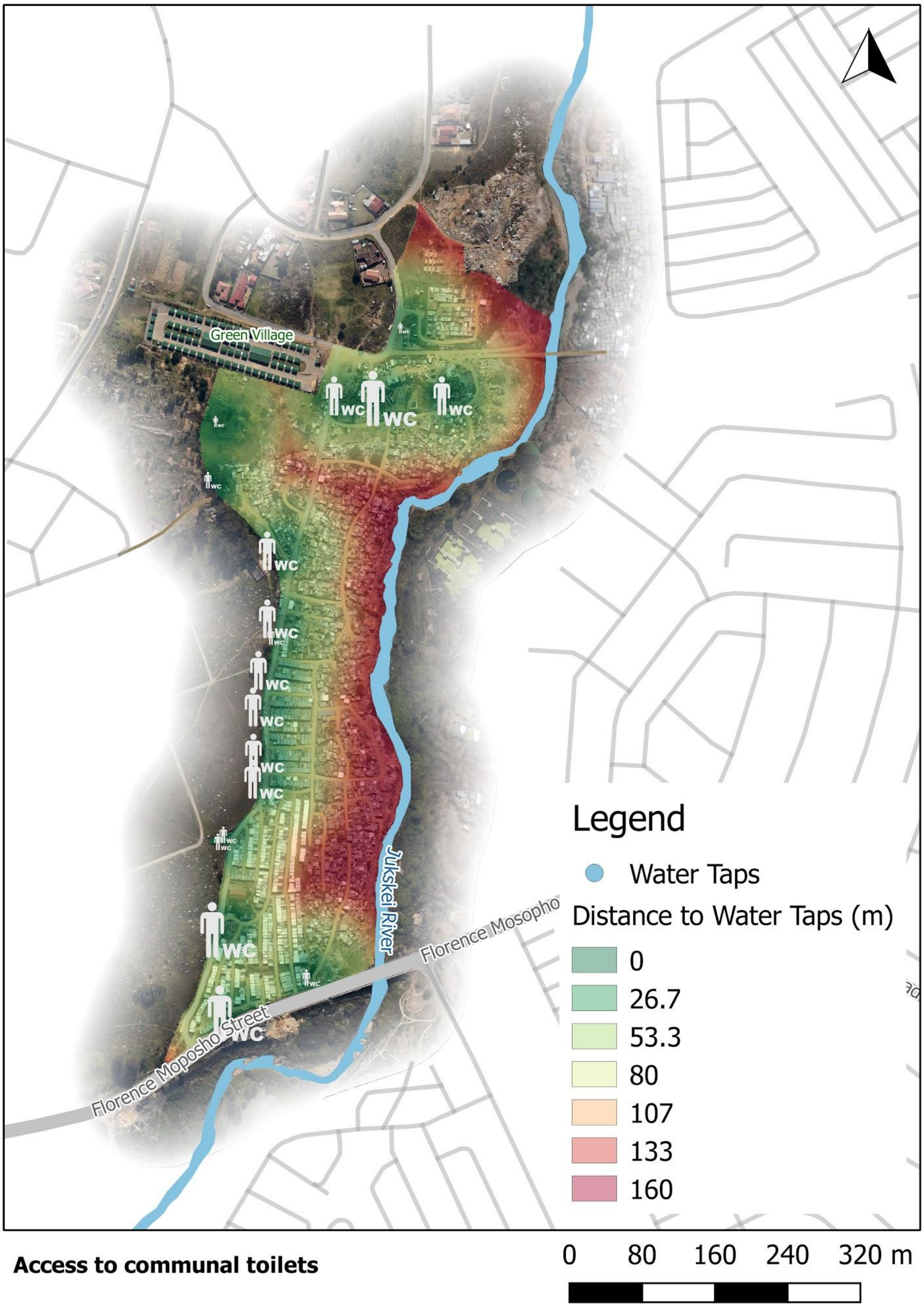


**Figure 8: Localities of the communal toilets and the indicative distances (m) to closest toilet**

## 4.2 COMMUNAL TAPS

The community in Stjwetla share communal taps, however due to the high population which results in high demand the system design cannot meet supply capacity. This results in low pressures at peak times. The significant, unplanned population has overloaded the infrastructure such that water pressures are low. Maintenance of such systems is very difficult because the high densities and congested nature of the shack development which makes access for maintenance very difficult or impossible in places. The surrounding areas of the communal taps are always characterised with ponding water as there is no removal mechanisms or drainage infrastructure to move water away from these areas.

**Figure 9: Communal Tap**

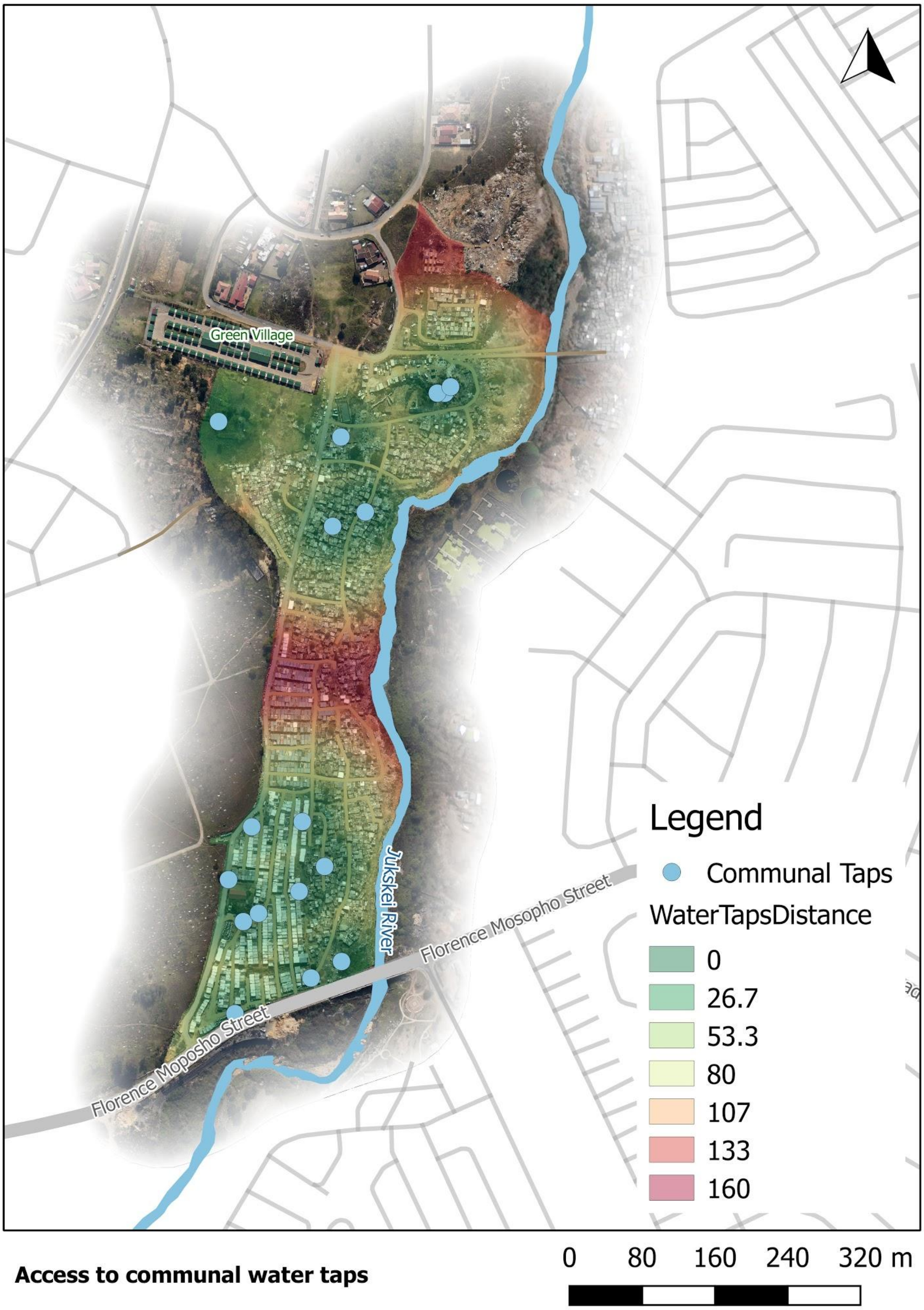


**Figure 10: Localities of the communal taps and indicative distance (m) to closest tap**

## 4.3 SOLID WASTE

Residence of Stjwetla indicate that they needed government to provide them with dust bins and refuse bags in order to keep their area clean. Stjwetla has solid waste, like plastic and waste material scattered throughout, which is characteristic of most informal settlements. They say if government provide them with dustbins, their neighbourhood would look and smell clean. Overcrowding makes the removal of wastes (garbage collection) difficult and residents end up creating their own waste dumps (as depicted in Figure 11). The drainage paths toward the Jukskei present evident of all kinds of waste, including faeces and solid waste.

**Figure 11: Solid waste dumping site in Stjwetla**

In the absence of services, Stjwetla residents say they have no choice but to dump their waste. Overtime this resulted in the development of a huge illegal dump site at the bottom of Stjwetla (see Figure 12), which had significant consequences on the morphology of the Jukskei River.


**Figure 12: Illegal dumping site (yellow arrows) and subsequent areas impacted (blue circles) by flooding dynamics**

The shift of the Jukskei River channel into the decommissioned wastewater treatment works clarifier has a significant impact on the hydrology (Figure 13). The impact resulting from this illegal dumping then results on the extent of flooding of the Jukskei, ultimately affecting the residents of Stjwetla.


**Figure 13: Jukskei River morphology changes due to illegal dumping which have shifted the River channel into a clarifier**

### 4.3.1 Flooding of Stjwetla

The floodline analysis was undertaken by EnviroSource with the study aims to establish the extent of flooding that is experienced in Stjwetla. The hydrological and hydraulic conditions were made available by SRK Consulting and data for analysis was extracted from Mahlangu and Mathole (2014).

The Jukskei River which drains past Stjwetla is approximately 100 $km^2$, where the catchment is completely urban and comprises of residential, commercial and industrial. The catchment area is illustrated in the Figure 14.

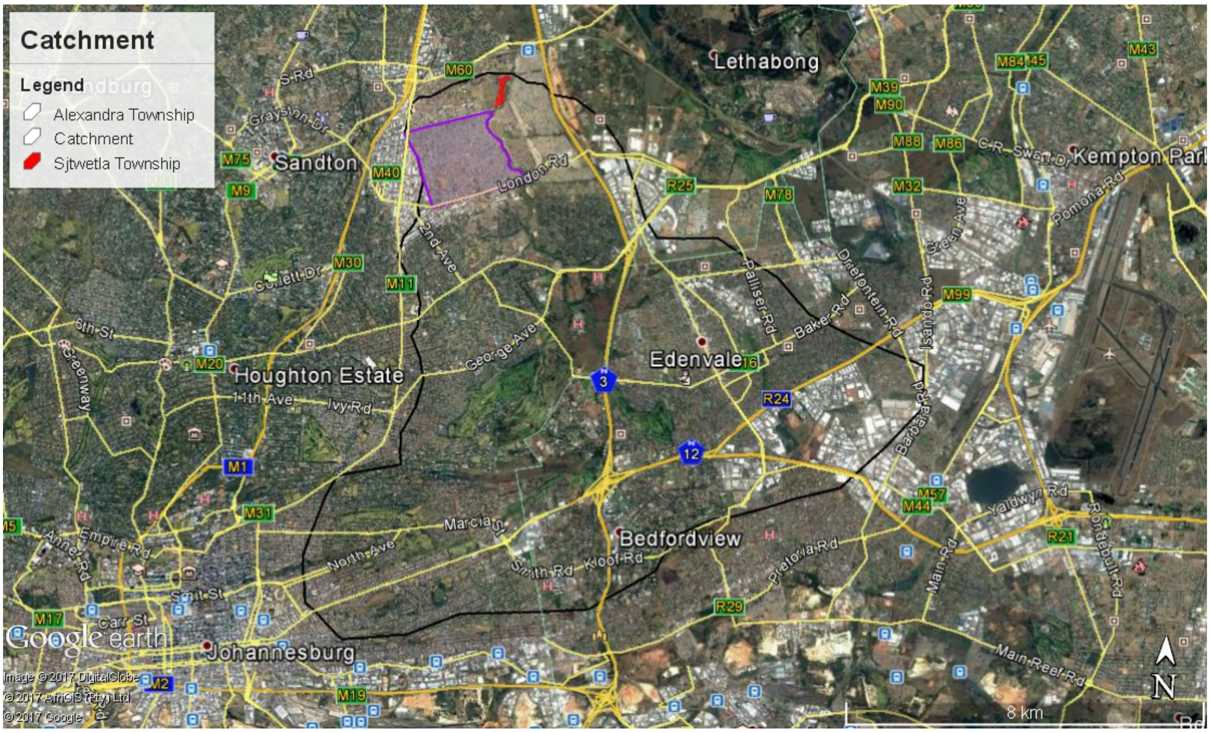


**Figure 14: Stjwetla catchment contributing runoff to the catchment**

The general topography was established using 1m contour data, which was surveyed in 2015. Therefore it must be understood that this floodline analysis will not have the most up-to-date topography developments/changes at Stjwetla, such as the illegal dumping. This flooding assessment should still achieve the objective of illustrating the extent of flooding (reasonably) within Stjwetla.

Mahlangu and Mathole (2014) made the Hec-Ras data available which already considered all the hydraulic structures for example the bridge above Stjwetla. The Hec-Ras Model (Version 4.0) was used to perform the floodline analysis. The program uses the detailed channel morphology derived from the 2015 contour data together with the hydrological data (see Table 2) to perform one dimensional hydraulic calculations for the Jukskei River.

**Table 2: Rainfall depth and peak flow estimates for the Stjwetla catchment (Mahlangu and Mathole, 2014)**

| Return Period (yr) | 2 | 5 | 10 | 20 | 50 | 100 |
|---|---|---|---|---|---|---|
| Rainfall depth (mm) | 62 | 86 | 104 | 123 | 151 | 175 |
| Peak Flow ($m^3/s$) | 164 | 227 | 275 | 327 | 552 | 813 |

The 100 year flooding simulations are illustrated in the Figure 15, it is evident that flooding in Stjwetla is significant. Flooding information illustrated in this report should only be considered for the purpose of illustration as conditions current conditions on the ground (bank topology) and the Jukskei River (morphology) are not accounted for in the contour data set used in this analysis.

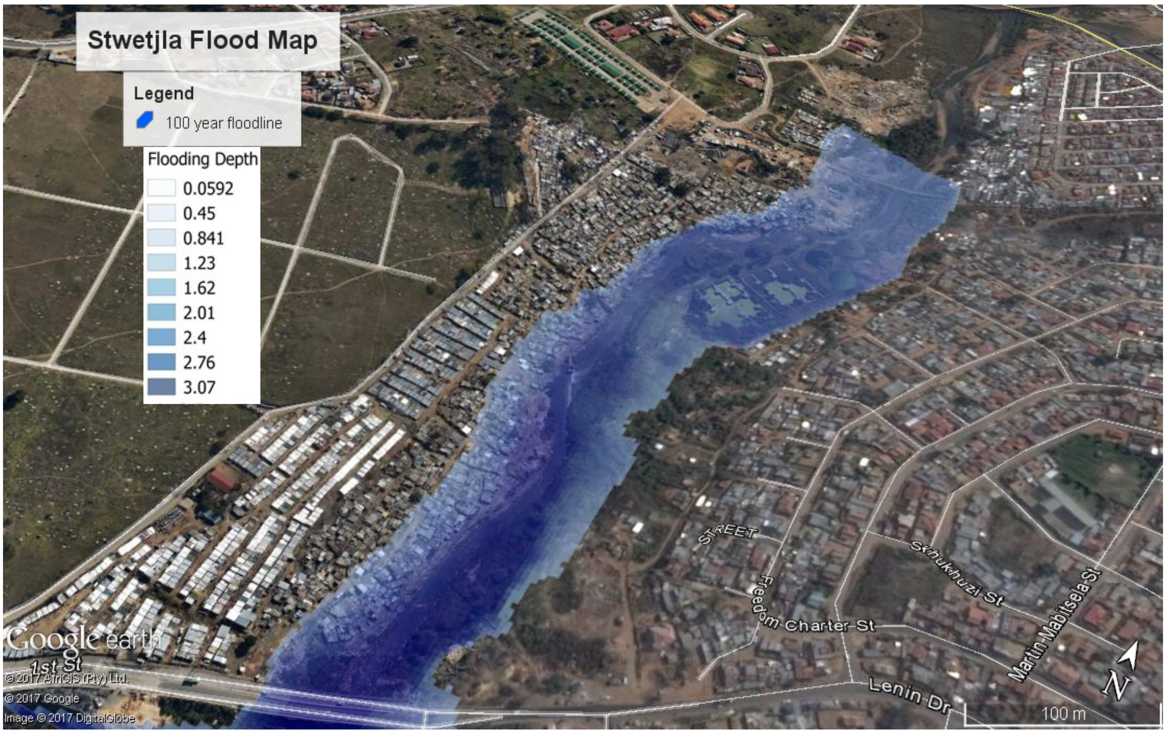


**Figure 15: Jukskei River simulation for the 100 year peak flow**

The flooding levels experienced on 09 November 2016 were devastating for the Stjwetla community. According to the South African Weather Services approximately 90 mm of was recorded in parts of Johannesburg for a 3 hour period. Johannesburg would normally receive around 117 mm of rain for the whole of November.

On the evening of the 9$^{th}$, a 3-year-old girl, Everite Chauke, was swept away by the strong waters of the Jukskei River while trying to escape from the rising waters with her family. The family's dwelling was located on the embankment of the river in Stjwetla informal settlement. Forty two (42) households from this settlement were swept away during this event and many more lives were directly or indirectly affected.

**Figure 16: The aftermath of November 2016 floods at Stjwetla**


**Figure 17: Stjwetla community leaders indicating the water level during the November 2016 flood**

This was further confirmed by a preliminary review of the storm undertaken by Fourth Element (2017). Fourth Elements comparisons of the maximum values extracted from the time series with design rainfall by Smithers & Schulze (2002) suggests the event falls not only in the extreme category, but also in the “devastating” category (>100 years) and approaching the “catastrophic” category (~500 year). These rainfall depths are well above normal design standards where a summary of the storm depths and estimated equivalent return period is presented in Table 3.

**Table 3: Summary of maximum storm depths at estimated return period (Fourth Element, 2017)**

| Rainfall data for weather station 0476399 OR Tambo International Airport 09 November 2017 (approx. 10 km from Stjwetla) | | Approximate Return Period |
|---|---|---|
| Max 5 min | 17.2 mm | 21 year |
| Max 10 min | 26.6 mm | 27 year |
| Max 15 min | 37.4 mm | 50 year |
| Max 30 min | 57.4 mm | 140 year |
| Max 45 min | 75.2 mm | >200 year |
| Max 60 min | 83.4 mm | > 200 year |

A visit to the affected site can rapidly identify some of the causes of the flooding additional to the severity of the rainfall event.

- Urbanisation within the catchment has rapidly increased which has decreased the buffer capacity of the catchment to attenuate the runoff volumes.
- At a local level a new road and bridge were built in 2012 just downstream of the Stjwetla. This new development has allowed for the ability for the illegal dumping of construction material and had encroach into the river bed. This catchment is characterised by dispersive soils, which results in high rates of bank and bed erosion, particularly at locations associated by these anthropogenic impacts.

All these factors contribute to increasing the risk of the flooding in Stjwetla. Despite the flooding which has become a regular occurrence, this has not stopped the development of new informal housing along the banks. In 2008 and 2013, homes were destroyed by heavy storms and then, where the government promised to act. Relocation plans have been established over the years however, the implementation have been painstakingly slow. Even though community members realise their problem and their desperation for better housing, they usually associate the idea of being relocated with harsh processes. Informal settlements have been historically viewed as problematic, and where brutal methods were applied to do away with informal settlements in urban areas, relocations are not always seen positively. Part of these methods involved forced relocation which was normally carried out through bulldozing (Huchzermeyer & Karam, 2006). As a consequence informal settlers have associated relocation with oppression and have learned to defend their informal settlements from projects that involve relocation.

At one point in time an allocation of 800 homes made from corrugated iron sheets to sections of Stjwetla, but residents complained the one-roomed houses made from flimsy material would not be able to withstand a turbulent storm. Stronger housing units made from prefabricated materials were given to 70 households affected by floods in 2014 by Gift of the Givers.

The residents know living on the banks of the river is dangerous, but they see no alternative.

# 5 WATER QUALITY AND INFORMAL SETTLEMENTS

The literature review is not exhaustive and only includes review of literature aligned to the specific objectives of this study above. The study reviewed literature available from the WRC, journals, and the internet. The aim is to give the reader reference to the research that has been undertaken and subsequent outcomes of water management specifically from the informal settlements. These are related to water quality, modelling and social aspects developed specifically to Stjwetla are described in section 10 of the report.

For the purpose of this study water management will include stormwater that encompasses all runoff out of the settlement, which includes greywater and sewage water. Carden *et al.*, 2007 presented the following definitions, where;

- greywater is the wastewater that is produced from household processes (e.g. washing dishes, laundry and bathing) without input from toilets, and
- non-sewered areas are those areas without on-site waterborne sanitation. Waterborne sanitation has been taken to include all methods of sewage treatment from flush toilets, including septic tanks. Communities with dysfunctional or inadequate sewerage systems (particularly communal toilet facilities) were included in the definition of non-sewered areas. Stjwetla falls into this category

Water management within the informal settlement has become an increasing topic of concern over the last decade in South Africa. This can be seen from the increase in this topic on the content of urban water management in recent years. The Water Research Commission (WRC) understands the importance for water management through the KSA: "Water Use and Waste Management", and has identified the need to determine and prioritise informal settlement research needs, this through interactions with key stakeholders. Based on the findings from previous water management related research toward urban settlements, it became clear that most research related water in informal settlements have been funded by the WRC (WRC, 2014).

An analysis by Siebrits and Winter (2013) demonstrates the shifts in water research paradigms throughout the years. Essentially, their analysis comprised of keywords and five year time-slices from 1977 to 2011. The searches which become relevant for this study begin to show up at time-slice from 2002 to 2006. Emerging research fields relate to the increase in overall publications in which the word 'management' becomes more pronounced and more social science orientated terms such as community, impact and application show up. Their final time-slice from 2007 to 2011 shows management as the current dominant research area of prominence. While engineering sciences such as treatment systems are present, they are dominated by assessment research, modelling and community related research.

As part of the process towards finding solutions to urban water management problems, the WRC commissioned a specific needs analysis study in 2005 for identifying research needs in urban stormwater drainage and sanitation (Armitage and Hendricks, 2005). The study K8/606 established the research needs toward informal settlements as a major gap through;

- a series of seven multi-stakeholder workshops held around the country;

- consideration of recommendations for further research contained in relevant WRC research reports over the last ten years; and
- information from the websites of a number of high-profile international research organisations in the field and selected conference proceedings: these two information sources were accessed specifically to indicate international trends.

The findings of the study were categorised as follows:

- knowledge/information management and advocacy (improving access to relevant information for those responsible for policy making and implementing projects on the ground);
- institutional and management aspects of infrastructure delivery (service delivery must be sustained beyond the implementation of infrastructure projects);
- health and hygiene improvement (the goal is improved health and quality of life for all);
- technical and financial sustainability (the services provided must meet the needs of users and the environment and must be affordable to operate and maintain);
- social development aspects (infrastructure must be accepted and owned by the communities and people should be empowered through job creation and skills development); and
- service provision for public institutions (delivery, operation and maintenance of services to these facilities, including school curricula that provide learners with the necessary tools for understanding the various services).

The country wide two year investigation undertaken by Carden *et al. (*2007), assessed greywater in informal settlements and their impact to human and environmental health. This study provided a general overview of conditions in non-sewered settlements in South Africa, and highlighted the implications for greywater management in non-sewered, informal settlements. Settlement density was found to be one of the most challenging obstacles in dealing with greywater management. Of the many findings, Winter *et al*. (2011) summarized four which are pertinent to Stjwetla:

- no attention was given to the resultant longer-term impacts on environmental health in non-sewered areas once increasing volumes of water were supplied to these settlements;
- social dynamics and behavioural patterns have a significant impact on the way that communities deal with water supply and wastewater management issues, including greywater disposal;
- the quality of greywater in non-sewered areas varies significantly, and when most concentrated, should be considered hazardous and therefore should be managed as a sanitation issue rather than a drainage one; and
- people living in non-sewered settlements are generally not prepared to use greywater for growing vegetables. This factor is particularly important for this study, as one of the ideas was to assess the feasibility of re-use options of the greywater.

Recommendation from the Carden *et al. (*2007), specifically relevant to Stjwetla include;

- A need to conduct a longer-term study in which communities without on-site waterborne sanitation could consider various options for managing greywater including re-use and disposal.
- High-density, non-sewered settlements in close proximity to water bodies have significant impacts on the biophysical environment. These sites must be clearly identified and some form of technological and strategic intervention must be implemented as a matter of urgency

It is increasingly evident amongst practitioners and academics alike that the water management approaches of the past have failed to deal adequately with the challenges posed by complex and rapidly changing dynamics of informal settlements. These systems are characterised by complexity in which an understanding of linkages, multiple drivers and unpredictable outcomes is critical (see Appendix A). Armitage (2011) argues a major factor to sustainable urban drainage in developing countries has to do with the inability of local government to provide appropriately serviced sites for the multitudes steaming into the towns and cities. Subsequent "crisis management" fails to address the needs of the new residents who are then all too often forced through circumstances to fend for themselves. A major factor in developing countries is the lack of adequate numbers of skilled personnel who are able to plan and implement urban drainage in a timeous and holistic manner.

## 5.1 STORMWATER QUALITY – INFORMAL SETTLEMENTS

Impacts related to urbanisation on stormwater runoff, where the focus was on informal settlements have been studied by a number of researchers in South Africa. The overall conclusion of all research is the runoff emanating out of high density informal settlements has a negative impact on water quality. The main focus of these studies was low income, high density urban areas, which have grown enormously in recent years.

Wimberley and Colman (2003) showed the pollution concentration levels in the stormwater runoff emanating out of Alexandra (informal high-density settlement) and Sunninghill Park (formal development) catchments respectively. The comparison was for a period of 1 month (October and November 1991) and based on 14 respective rainfall events. 'The results of the monitoring period have shown that the stormflow off Alexandra is similar to raw sewage, for a number of pollutant concentrations, and dry weather flow is comparable to settled sewage. The concentration in the storm-and dry-weather flow off Sunninghill Park are considerably lower. Pollutant loads are greater from Alexandra catchment by factor of between 20 and 130.'

Novotny and Olem (1994) describe stormwater quality as multifaceted, a limited number of factors may not adequately explain the complexity of the stormwater quality response to a rainfall event or site-to-site differences in stormwater quality. This is one of the main factors that lead to inadequate design of stormwater treatment systems as accurate modelling results are a key requirement. Therefore, the stormwater quality emanating from the informal settlement will be dependent on the activities that are taking place in the informal settlement and the rainfall characteristics.

## 5.2 MODELLING WATER QUALITY

Mourad *et al. (*2005) argue the main disadvantage of many models is the lack of calibration data. This was certainly a challenge during the literature review process of Stjwetla and more importantly defining the appropriate range of concentration values which are so large between respective informal settlements. Mourad *et al. (*2005) states that reliability of the models did not increase with increasing model complexity. However, increased complexity demands increased data complexity which is not available for the informal settlements. Although predictions are typically made with the aid of mathematical models, there are certainly situations where expert judgement can be just as good. Reliance on professional judgement and simpler models is often acceptable, especially when data are limited. Therefore, it can be assumed that this complexity will translate into the modelling of remediation options.

A summary of important factors in the literature related to water quality and modelling includes;

- Highly detailed models require more time and are more expensive to develop and apply. In some cases this may result in unnecessarily costly analyses.
- Complex modelling studies should be undertaken only if necessary by the complexity of the management problem. More complex modelling will not necessarily ensure that uncertainty is reduced, and in fact added complexity can compound problems of uncertainty analyses.
- Effective and efficient modelling for water quality management may dictate the use of simpler models. Placing a priority on process description usually leads to the development and use of complex deterministic models rather than simpler deterministic or empirical models. In addition, physical, chemical and biological processes that occur terrestrial and aquatic environments are far too complex to be fully represented in even the most complicated models. The inability to describe all relevant processes completely contributes to the uncertainty in the model predictions.
- Data availability and accuracy are sources of concern in the development and use of models for water quality management. The complexity of models used for water quality management should be compatible with the quantity and quality of available data.
- The use of complex deterministic models for water quality prediction in situations with little useful water quality data does not compensate for that lack of data. Model complexity can give the impression of credibility, but this is usually misleading.

Some water quality modelling targeting informal settlements (specifically Alexandre) are out-dated, but demonstrate the complexities in modelling these environments. The following water quality modelling studies relating to informal settlement include;

- Campbell, L., A. (1996) A Study on the Fate of Urban Stormwater Runoff from Alexandra Township in the Jukskei River. A water quality model developed by Systems Research Group of the University of the Witwatersrand.
- Owusu-Asante, Y. and Stephenson (2006) did a comparison of simple regression equations to estimate event pollutant load using a case study in Alexandra, Johannesburg. The study found that event loads were best estimated using power functions and relating the loads to rainfall. The verified model was then used to develop load-duration-intensity curves as predictive tools for load.

# 6 THE IDEA OF WATER SENSITIVITY

'Water Sensitive' is a concept that was first proposed by Wong and Brown (2008) and Brown *et al.* (2008) at the 11th International Conference on Urban Drainage. The term 'Water Sensitive City (WSC), is used where water is given prominence in the design of urban areas. Brown *et al.* (2009) put forward a conceptual framework for visualising and 'benchmarking' the evolution towards a WSC through the adoption of Water Sensitive Urban Design (WSUD).

A Water Sensitive City is based on holistic management of the integrated water cycle to protect and enhance the health of receiving waterways, reduce flood risk, and create public spaces that harvest, clean, and recycle water. It recognises that a water sensitive approach to urban development and regeneration processes can help deliver on a range of objectives critical to the liveability of a city, including: biodiversity, public green space, healthy waterways, connected communities, and cultural significance. Ultimately, a water sensitive approach is underpinned by a recognition that water can contribute to the creation of connected, vibrant, and liveable communities.

The goals of the water sensitive city are broad, centred on the philosophy that water systems, the urban environment and governance arrangements are designed to provide multi-functional benefits:

- Recognising all values in the integrated water cycle
- Holistic management of water systems
- Water conservation
- Fit-for-purpose water use
- Flood risk reduction
- Pollution minimisation
- Urban landscape improvement
- Shared governance processes
- Knowledgeable and engaged citizens

WSUD was first considered the context of RSA through the WRC by Armitage *et al.* (2014) where they provide a framework of WSUD that can be translated into RSA and subsequently further the idea towards water sensitive settlement. The well-recognised 'Brown framework' by Brown *et al.* (2009) for visualising transitions within the urban water management sector details the critical stages through which towns and cities progress as they become more sustainable. The 'Brown framework' does not take into account the impact on the urban water cycle of a number of factors unique to South Africa, such as informal settlement. The WRC research by Armitage *et al.* (2014) therefore, adapted the framework for our context, as shown in Figure 18 – where the legacy of Apartheid has resulted in significant backlogs in infrastructure. Typical of these backlogs are the large numbers of poorly serviced informal settlements like Stjwetla.

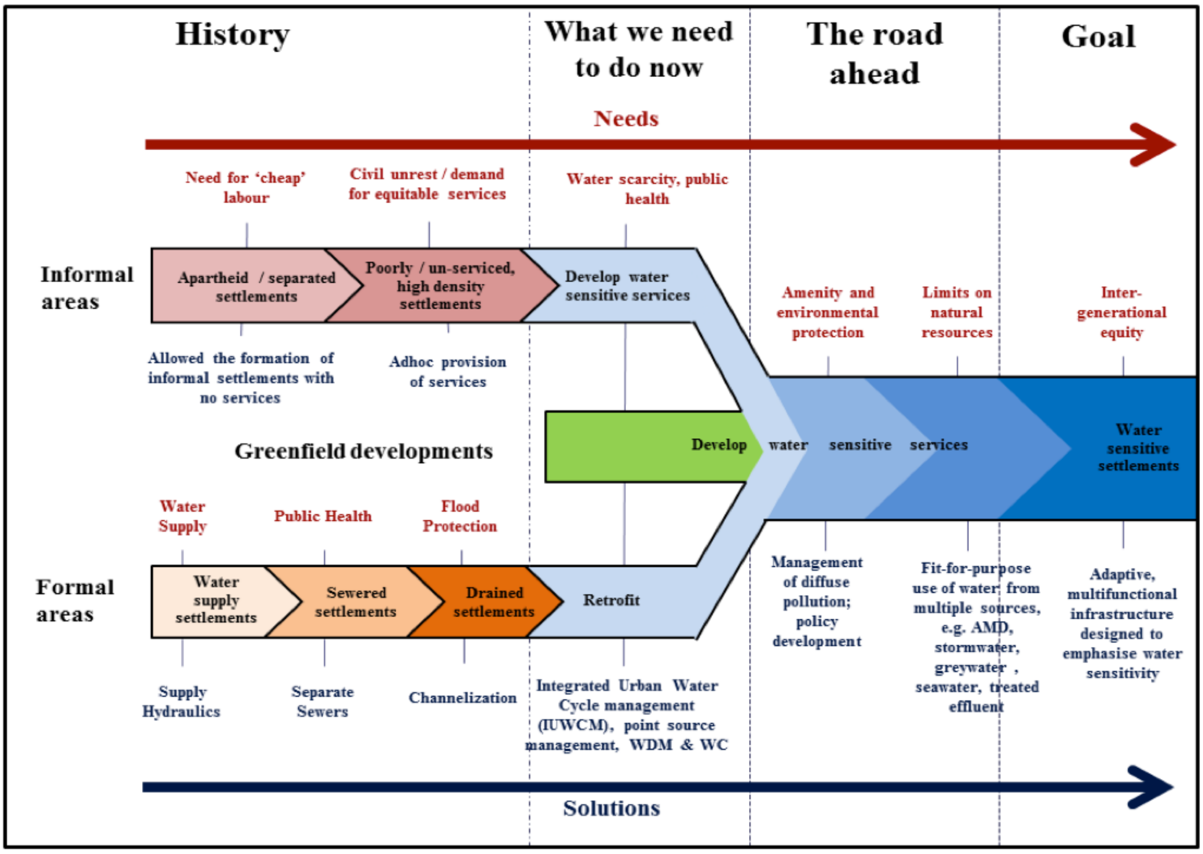


**Figure 18: Framework for Water Sensitive Settlements in South Africa, 'two histories, one future (by Armitage *et al*., 2014 adapted from Brown *et al*., 2009)**

This report does not go into the details of WSUD, since there is a great deal of literature available. Armitage *et al. (*2014) present a wide range of urban water infrastructure strategies which can be used to effectively incorporate WSUD into planning and design. Water management is often dealt with separately by different professionals, the holistic approach emphasised by WSUD requires that they be considered simultaneously Furthermore, Armitage *et al. (*2014) have acknowledged systems-based approaches to conventional water management of water supply and modes of ensuring water quality are required. New models of water capture, provision, treatment and governance need to be explored and developed to improve and enhance the effectiveness of interaction between the multiple actors who determine water use. Armitage *et al. (*2014) have called for systems approach with multiple objectives; one that takes into account community values and aspirations when dealing with water supply, wet and dry sanitation, biological and chemical treatment of associated contaminants, drainage, whilst also acknowledging the range of users. An integrated systems-based approach such as this has the potential to facilitate a change from 'water-wasteful' to 'water-sensitive' urban areas.

Major initiatives promoting water conservation and water efficiency such as stormwater harvesting are gaining prominence, particularly in respect of the of the provision of an alternative water source. This new paradigm is emerging in RSA with regard to recognising sustainable approaches to stormwater management. Well documented information on urban water infrastructure activities which incorporated WSUD aspects and researched manuals and guidance documents which have been published in RSA are made available at www.wsud.co.za.

## 6.1 WATER SENSITIVE URBAN DESIGN

Water Sensitive Urban Design advances the principles of sustainable development within the urban water management discipline. It is a tool focusing on the interactions between the urban built form and water resources management offering ecologically sustainable development (Wong, 2006). WSUD brings main components illustrated in Figure 19, which are water infrastructure and design and planning. This study dealing mainly with the stormwater management aspects of this approach looks at the SuDS approach and flooding of Stjwetla.

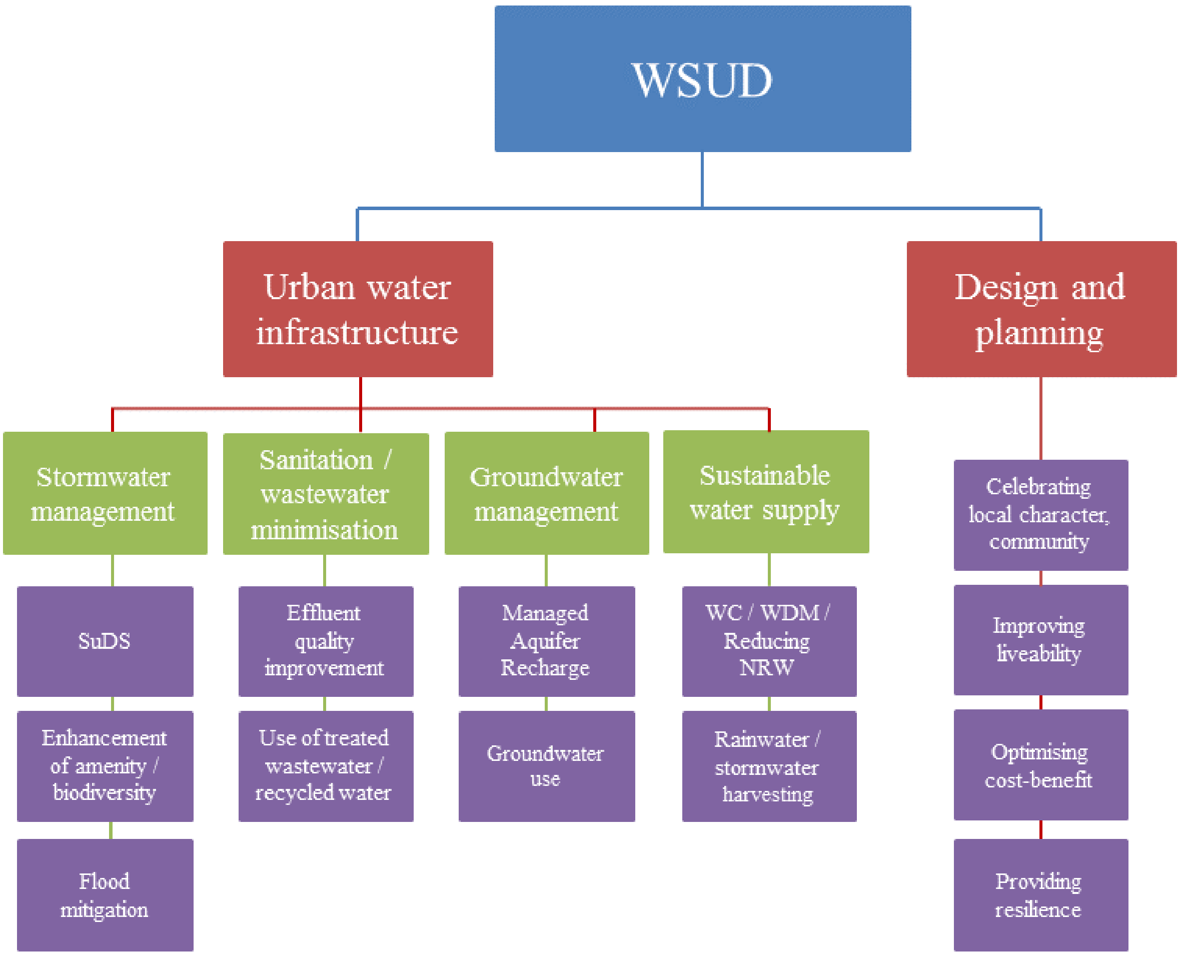


**Figure 19: Main components of WSUD activities (Armitage *et al.*, 2014)**

## 6.2 SUSTAINABLE STORMWATER DRAINAGE SYSTEMS (SuDS)

South African stormwater management of has mainly been focusing on quantity (flow) management by collecting runoff and channelling it to the closest watercourse. This often has resulted in the erosion of natural channels and pollution resulting in environmental degradation. SuDS offers an alternative approach through designing for water quantity management, water quality treatment, enhanced amenity, and the maintenance of biodiversity. SuDS offers an alternative approach to conventional drainage practices by attempting to manage surface water drainage systems holistically in line with the ideals of sustainable development. They achieve this by mimicking the natural hydrological cycle, often through a number of sequential interventions in the form of a 'treatment train'. The key objectives of the SuDS approach include: the effective management of stormwater runoff quantity and quality, promoting the amenity value, and the preserving / encouraging biodiversity value. South Africa's first Guidelines for SuDS has been published by the South African Water Research Commission (Armitage *et al.*, 2013). The research was designed to follow on from and extend WRC Project no. K5/1826, 'Alternative technology for stormwater management', which focused specifically on providing guidelines for the implementation of Sustainable Drainage Systems (SuDS) in South Africa.

Fisher-Jeffes *et al.* (2012) noted that simply publishing guidelines will not ensure the successful update of WSUD (with the stormwater component SuDS), there is a definite effort needed to engage with policy makers and individuals to make these technologies be trialled in South Africa. They argue that progress would likely be defined by the four sequential steps,

- Development of tools (manuals, guidelines, etc.).
- Transfer of knowledge to appropriate officials.
- Application of tactics for encouraging WSUD implementation (such as getting policymakers to write the information into relevant documents).
- Testing of water sensitive technologies and approaches through various trials (pilot studies, small scale developments, etc.).

The lack of published research on the application of SuDS in informal settlements has been well noted. Armitage (2011) indicates that the little literature that does exist is 'piecemeal and fragmented'. The small scale of public space, the lack of delivery of municipal services, and the physical fluidity and transience of these environments suggests a possible application of SuDS strategies (Jiusto and Kenney, 2016). From the literature SuDS has found most applications in formal settings, but there is a definite application gap toward informal setting. SWITCH (2014) advocated Integrated Urban Water Management (IUWM), loosely defined as 'a flexible, participatory, and iterative approach that integrates in a holistic way all components of the urban water cycle (water supply, sanitation, storm water management, and waste management).

Fitchett (2014) provides a case study of performing SuDS in Diepsloot informal settlement, applying the IUWM approach to attempt to mitigate some of the problems of the standing water. Moreover this case study further explored aspects of adaptive co-management, a theme that touches on inclusivity, self-respect of marginalised and vulnerable citizens (Fitchett, 2013). This case study provides evidence that SuDS offer significant advantages over some of the attempts by locals to imitate conventional systems, such as piping and concreted channels, in that some SuDS applications can be very low-cost, technically simple in installation and maintenance, and can provide a platform for community building. Conversely, learning from informal settlement action research can expand the body of knowledge on SuDS, especially by developing micro-scale interventions and through the use of recycled materials. The measures that can be implemented need to be driven by the residents, simplistic in their construction and easy to maintain, with materials easily available (preferably of no re-use value to discourage dismantling). From a SuDS perspective the case study provided substantial evidence that the water quality and living conditions at the site scale level can be improved. The key lessons learnt from this case study is the appreciation of local knowledge systems and social structures which are given equivalent value to conventional scientific and managerial knowledge. This is contrasted with the participatory approaches used when confronting the challenges of informal settlements (Fitchett, 2014) which are explored further in this study.

### 6.2.1 Applying SuDS to Informal Settlements

Further work exploring application of SuDS to an informal settlement, through a series of short, action-research oriented projects was conducted by the Worcester Polytechnic Institute Cape Town Project Centre (WPI-CTPC). As part of the interdisciplinary project program Button *et al. (*2010) prepared a guidebook by proposing SuDS methods within Monwabisi Park, an informal settlement in Cape Town. The team followed a systematic methodology in order to gather information and analyse the data, which included;

- Identifying "Hot Spots" – In narrowing down the focus of the project, the team identified 4 major "hot spots" of flooding along the C-section road and recorded their exact location using a Global Positioning System (GPS) as well as the software, Google Earth. These "hot spots" were identified as the areas that are most prone to flooding and had the greatest potential for improvement.
- Interviewing of Residents – Realizing that successful implementation was based not only on technical aspects, the team visited Monwabisi Park to gather raw data on the physical and social attributes from the local community members. The information gathered by the team included the overall frequency of flooding, current interventions put in place by residents and the reasoning behind their implementation, insights into collaborations between neighbours and feedback on their proposed solutions.
- Spatial Conditions of "Hot Spots" – To accurately depict the sizes of the "hot spots" and the features included within them, the team decided that taking measurements, such as the width and length of the road, the distance of the houses from the road and the slopes of the road, would be beneficial. This data was collected and inputted into a modelling software program, AutoCAD, where floor plans of each "hot spot" were produced.
- Generating alternative designs – Having surveyed the four different "hot spots", the team proceeded to evaluate the current interventions for effectiveness. They used this information to determine which SUDS solutions would be the most appropriate for each spot; concluding that soakaways, swales, infiltration trenches and wetlands would be the most suitable.
- Guidebook and Brochure – The team's final product varied for each audience they addressed. A guidebook (http://wp.wpi.edu/capetown/files/2010/12/Stormwater-guidebook-for-website.pdf) was produced for the future redevelopment endeavours, while a brochure was created for the residents of Monwabisi Park. This brochure

contains information on how to prevent flooding using simple, basic, widespread techniques.

The proposed methodology of this study ‘ideas towards water sensitive settlements’ was similar to the above however it was anticipated that software (specifically MUSIC) would find some application into achievable design principles to Stjwetla. This study aimed to further assess the potential (through MUSIC) of on-site uses of fit-for-purpose use. During the project initiation stage, specifically interviews with the community representatives it became clear that the issues around a water sensitive settlement – specifically in Stjwetla are far more complex than anticipated. More importantly, it became clear that this approach would result in a document that simply will not be implemented for the reasons that became evident during the course of this study.

# 7 MODEL FOR URBAN STORMWATER IMPROVEMENT CONCEPTUALISATION (MUSIC)

The Model for Urban Stormwater Improvement Conceptualisation (MUSIC) is a water quality decision support tool for stormwater managers. It helps the planning and design (to a conceptual level) of appropriate stormwater management systems from an individual development to a catchment level. The MUSIC modelling software was developed by researchers and practitioners of the former Cooperative Research Centre (CRC) for Catchment Hydrology and the current eWater CRC, and represents an accumulation of the best available knowledge and research into urban and rural stormwater management in Australia.

MUSIC estimates stormwater pollutant generation and simulates the performance of stormwater treatment devices (SuDS infrastructure) individually and as part of a treatment train (individual devices connected in series to improve overall treatment performance). By simulating the performance of stormwater quality improvement measures, MUSIC provides information on whether a proposed stormwater management system conceptually would achieve water quality targets, and if we can meet the relevant regulatory requirements on the parameters.

There have been several major impediments to the effective design, prioritisation and evaluation of urban stormwater treatment strategies. These stem from uncertainties about the likely water quality from catchments of different land use, uncertainties about the performance of stormwater treatment measures, particularly when combined in parallel or series, and an inability to compare the performance, benefits and costs of alternative stormwater treatment strategies. The development of MUSIC overcomes many of these limitations, and provides urban catchment managers with an easy to use decision support tool by which they can evaluate and compare alternative strategies aimed at protecting aquatic ecosystems from the impacts of urbanisation. The results of MUSIC simulations can be used to inform the decision making process associated with the economic risk analysis, prioritising and staging of the stormwater quality management strategy for the catchment. It must be noted that MUSIC is not a detailed design tool as it is conceptual rather that empirical. It does not use mathematical equations for specifying detailed designs of the treatment devices and other systems. MUSIC should be used in conjunction with other empirical tools as it does not take into account all aspects of water sensitive design and SuDS (eWater, 2011)

The development of a stormwater quality treatment system, or strategy to treat stormwater runoff though water sensitive design measures, is best provided as a series of ‘fit for purpose’ treatment measures placed sequentially to form a treatment train. As single treatment measure may not adequately address the full range of pollutants generated from a development site, a treatment train consisting of a connected series of individual treatment measures should be developed. This should consider the best operating environment for each treatment measure and must take into account the hydraulic and treatment capabilities of the treatment measures. The treatment train should be suitable for the site and development type. It may include a graduated level of treatment from primary through to tertiary that specifically aims to treat stormwater for the target pollutants.

As discussed above, each treatment measure operates over particular hydraulic loading rates (that is the quantity of water able to pass through a given surface area of the treatment measure) and pollutant size ranges. The pollutants typically targeted for removal by water sensitive design measures (such as sediment, nutrients) can have very large size ranges, as shown in Figure 20. The figure shows that a single treatment measure may not be suitable to treat certain pollutants. For example, while a vegetated swale may remove some nutrients, it will not be effective for the colloidal and dissolved material that a wetland will treat more efficiently. A swale could become a pre-treatment measure for a wetland, and so creates a treatment train.

Figure 20 also shows that to remove gross pollutants and coarse sediment, the hydraulic loading rate can be very high, whereas a much smaller hydraulic loading rate is necessary to effectively remove nutrients or metals. To remove nutrients either less water can be treated, or a much larger treatment measure is required to treat an equivalent amount of water. For this reason, treatment trains should focus on treating gross particulates first (such as larger organic matter and litter), then coarse particulates (sediment) and finally fine, colloidal and dissolved material. Configuring the treatment train this way also provides a pre-treatment or protection function to downstream treatment measures. Treatment devices sized to treat gross pollutants and coarse sediment will ensure that downstream devices are not damaged or impaired by excessive quantities of pollutants that they are not designed to treat. For example, a bioretention basin located downstream of a development site may become clogged with coarse sediment very quickly if no upstream sediment treatment measure has been provided eWater, 2011)

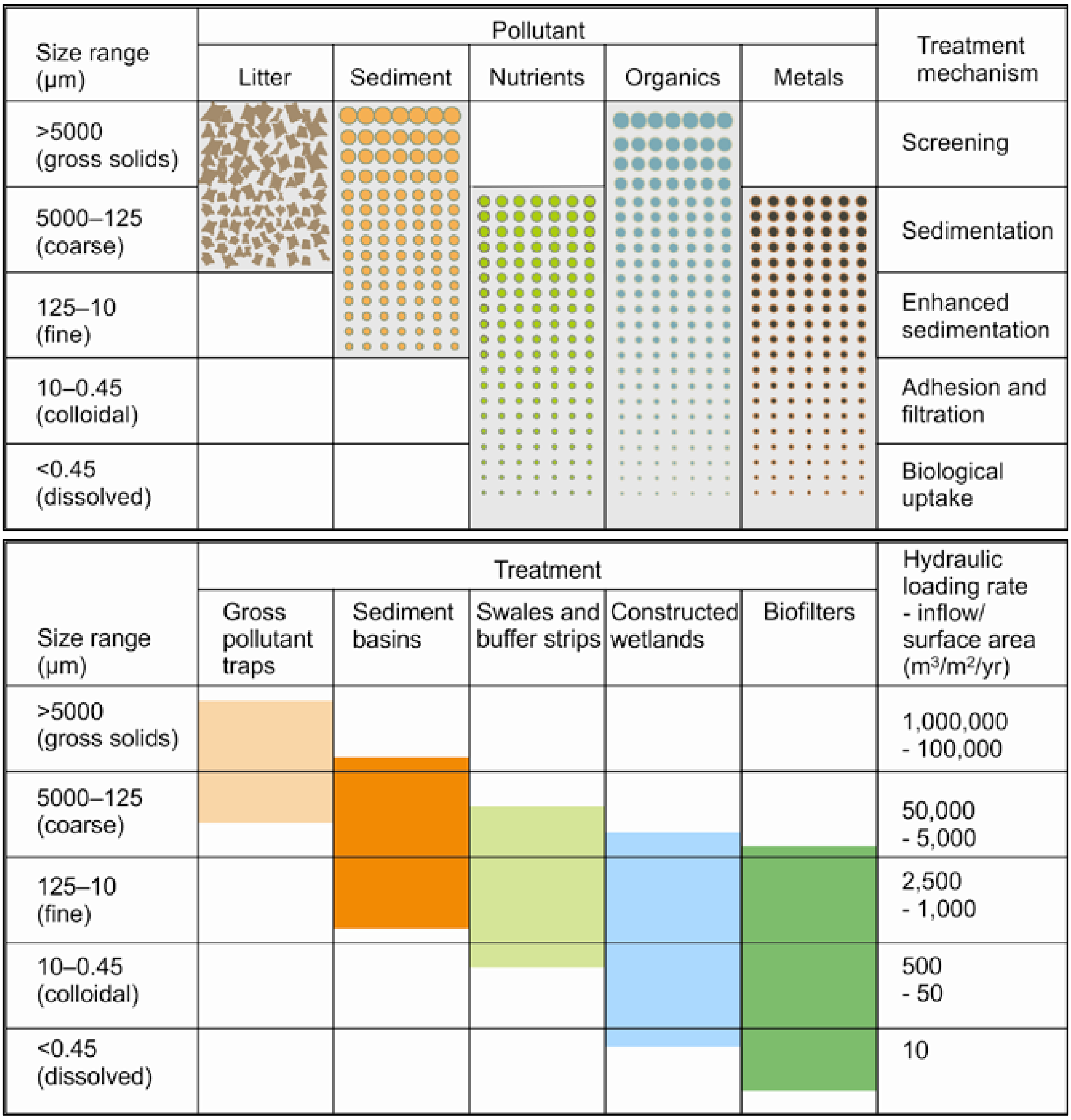


**Figure 20: Target pollutants and effective stormwater treatment measures (after Banens *et al.*, 2012)**

MUSIC is developed with specific treatment devices (see Figure 21) which can target respective pollutants (eWater, 2011), these include:

- **Ponds** are stormwater treatment measures such as open water bodies (without significant shallow vegetated areas in the predominant flow paths) and ornamental ponds. The treatment of stormwater is predominantly associated with temporary detention to reduce peak flows and facilitate settling of suspended solids. Other treatment processes promoted in pond systems include phytoplankton assimilation of soluble nutrients and ultra-violet disinfection. These processes are currently not explicitly included in the modelling algorithm. The model also has the capability to model the reuse of treated stormwater stored in ponds.

- **Rainwater Tanks** enable reuse of roof runoff for in-house or garden use. While some settling may occur in the tank, the main contaminant removal process is the diversion of impervious area runoff to pervious areas (via garden use) or to sewer (after in-house use). Effective use of rainwater tanks can reduce the directly connected impervious area of a catchment, and help to counteract the increase in impervious area that generally accompanies urbanisation through reduction in runoff volumes.
- **Sedimentation Basins** are open water bodies aimed predominantly at the removal of coarse and medium particles. Typically they operate at high hydraulic loading rates, and have fairly short detention times. The treatment of stormwater in sedimentation basins is achieved almost entirely by temporary detention to facilitate settling of suspended solids. No other biological or biochemical processes are simulated within the Sedimentation Basin node.
- **Detention Basins** are open or closed storages aimed primarily at reducing downstream peak flows although they also offer some removal of coarse and medium particles. Typically they operate at high hydraulic loading rates, and have fairly short detention times. The treatment of stormwater in detention basins is achieved almost entirely by temporary detention to facilitate settling of suspended solids. No other biological or biochemical processes are simulated within the Detention Basin node.
- **Gross Pollutant Traps** are devices for effective removal of solids conveyed by stormwater which are typically larger than 5 mm. They are often used as the first treatment element in a stormwater treatment train. There are many proprietary gross pollutant traps currently suitable for use in urban catchments and information on their performance is becoming available. As for media filtration systems, information on performance of these systems should only be sourced from published and peer-reviewed data.
- **Generic Treatment Nodes** allow you to define “transfer functions” for flows and water quality for stormwater quality treatment measures which are not explicitly modelled in MUSIC. Generic nodes can also be used to model such situations as flow diversion, flow dilution, contamination by sewer overflow, etc.


**Figure 21: MUSIC treatment nodes**

- **Buffer Strips** are commonly used as a source control measure, particularly for management of road runoff. They are effective in the removal of coarse to medium-size sediments and can be used as an effective pre-treatment measure for bioretention systems. They also can assist in reduction of peak flows for smaller events and may promote infiltration dependent upon the underlying soil conditions
- **Vegetated Swales** are open channel systems which use vegetation to aid the removal of sediment and suspended solids. These systems are subjected to fairly high hydraulic loading and the removal efficiency is dependent on the density and height of the vegetation in the channel. The vegetation can assist in reducing peak flows for a range of events (dependent on the swale width and length) and may also be beneficial in volumetric reduction through infiltration, dependent upon the underlying soil conditions.
- **Wetlands** are an effective stormwater treatment measure for the removal of fine suspended solids and associated contaminants, as well as soluble contaminants. They can also provide significant storage for a range of storm events. These systems use a combination of physical, chemical and biological processes to remove stormwater pollutants. They are commonly used as “end-of-pipe” stormwater treatment systems, but recent research has shown that they are scalable for application as near-source control measures. The model also has the capability to model the reuse of treated stormwater stored in wetland systems.
- **Bioretention Systems** (also known as biofiltration systems or rain-gardens) promote the removal of particulate and soluble contaminants by passing stormwater water through a filter medium, either for infiltration into surrounding soils, or for collection by an underdrain. This category is thus also used for modelling vegetated infiltration systems, whilst un-vegetated infiltration systems are modelled with the infiltration node. Well-designed bioretention systems can provide both flow management and water quality benefits. A range of factors affect the treatment performance of the bioretention systems, including the type and composition of filter media (e.g. loamy sand), the presence and type of vegetation used, and the presence of design enhancements such as the use of a saturated zone to enhance denitrification. In MUSIC, the prediction of bioretention system performance is based on extensive research undertaken by the Facility for Advancing Water Biofiltration (see www.monash.edu.au/fawb).

- **Infiltration Systems** reduce the volume of stormwater, and hence the frequency of runoff and the mass of contaminants carried, by infiltration into the bed of the basin. In MUSIC the infiltration node is used only to simulate the performance of un-vegetated infiltration systems (e.g. using gravel or sand filter media). Vegetated infiltration systems should be modelled using the Bioretention node (see above). In general, the use of vegetated infiltration systems is advocated wherever possible. In un-vegetated systems, coarse particulates are deposited on the floor of the basin. Dissolved material and very fine particulates infiltrate into the soil, hence the potential for contamination of groundwater needs to be addressed. Inflows in excess of the storage and infiltration capacity of the basin will overflow and continue downstream. By reducing the volume of surface runoff, infiltration systems help to counteract the increase in runoff volume and frequency that generally accompanies urbanisation.
- **Media Filtration Systems** are commonly modular or pre-fabricated systems which are used for filtering stormwater. These systems typically use a simple sand media, or a more specialised engineered media, and may be specifically tailored to provide water quality suitable for stormwater harvesting. The user can edit the properties of this node to match the specifications of the filtration system being used (such modification should be undertaken only using published and peer-reviewed data).

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## 7.1 RUNOFF MODELLING PROCESS

The detailed description of the MUSIC modelling process is provided by Wong *et al.* (2002). Briefly, the structure of the rainfall-runoff model and the conceptual representation of the processes involved are shown in Figure 22. The model allows for separate runoff generation processes on impervious and pervious portions of a catchment. The algorithm adopted to generate urban runoff is that developed by Chiew *et al.* (1997), which is based on a simplified model involving definition of the impervious area and two soil moisture storages, i.e. the shallow and deep soil moisture storages, as shown in Figure 22.

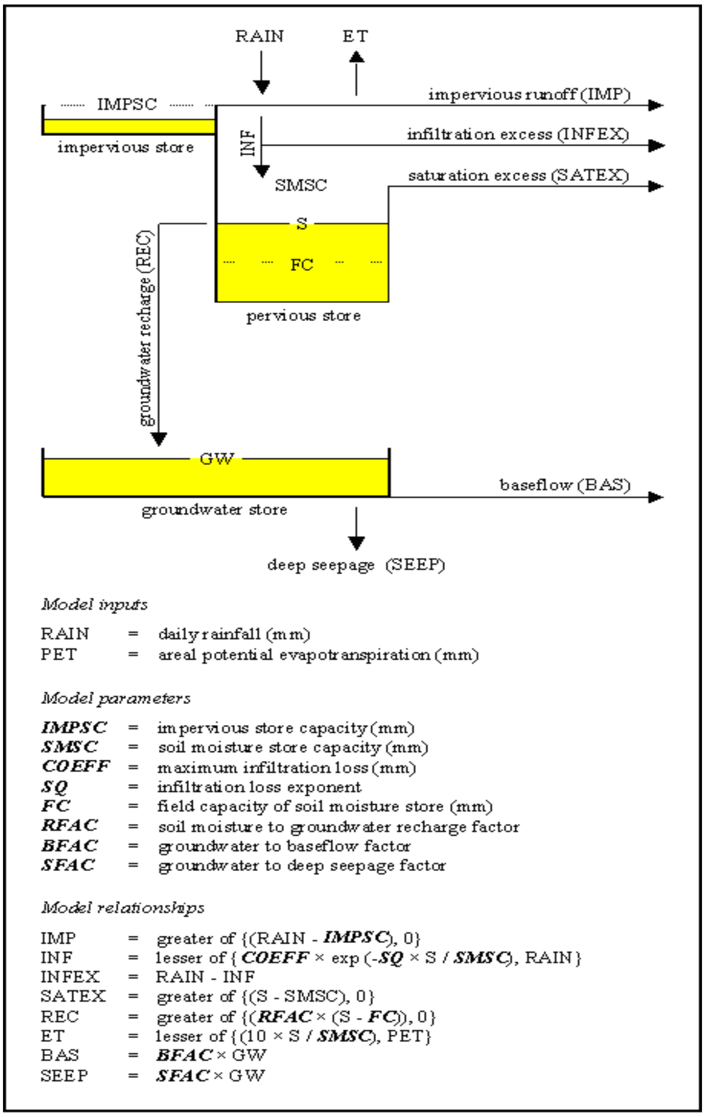


**Figure 22: Conceptual Rainfall-Runoff Model adopted for MUSIC (after eWater, 2011)**

The computational steps in the disaggregating procedure are described in greater detail within the MUSIC manual (eWater, 2011) as shown in Figure 23. All rainfall on the impervious area becomes runoff once a small storage capacity or initial loss is exceeded. The initial loss storage is emptied each day. Rainfall on the pervious part of the catchment will be infiltrated into the soil, with the infiltration rate of the soil being defined as an exponential function of the soil moisture storage. The infiltration rate is at a maximum when the soil moisture store is empty, and gradually decreases to a minimum when the soil moisture store is full. Runoff from the pervious area occurs when the rainfall exceeds the infiltration rate of the soil (infiltration excess runoff) and when the soil moisture store has reached its maximum capacity (soil saturation excess runoff). Evapotranspiration is subtracted from the soil moisture store. This is dependent on the amount of water in the soil store and the areal potential evapotranspiration rate. Soil moisture recharges groundwater whenever the soil moisture store exceeds field capacity. The recharge is calculated as a constant percentage of the storage above field capacity. The baseflow from groundwater is simulated using a linear recession of the groundwater store. An approximate daily runoff disaggregating procedure has been adopted to define sub-daily temporal patterns for the modelled daily runoff totals. The pervious and impervious areas are treated separately.

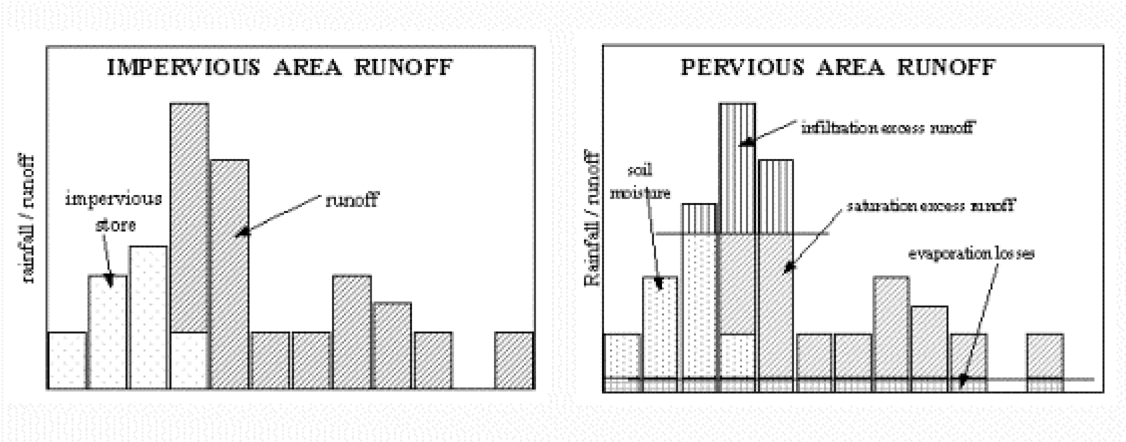


**Figure 23: Disaggregation of daily runoff into sub-daily temporal patterns (eWater, 2011)**

## 7.2 WATER QUALITY MODELLING PROCESS

The mechanisms involved in the removal of stormwater pollutants encompass physical, chemical and biological processes. Owing to the intermittent nature of stormwater inflow, physical processes associated with detention for sedimentation and filtration (either through vegetated systems or through an infiltration medium) are the principal mechanisms by which stormwater contaminants are first intercepted. Subsequent chemical and biological processes can influence the transformation of these contaminants. MUSIC uses two basic modelling procedures which are adopted in the unified model – hydrologic routing to simulate the movement of water through the treatment system and a first order kinetic model to simulate the removal of pollutants within the treatment system (Wong *et al*., 2001).

MUSIC estimates its default TSS, TP and TN concentrations generated rates based on statistical analysis of urban stormwater pollutants by Duncan (1999) (eWater, 2011). MUSIC derives its urban pollutant load relationship from a comprehensive review of worldwide stormwater quality in urban catchments was undertaken in previous studies by Duncan (1999). This review supplemented by local data specific to regional applications (in Australia) has formed the basis for default values of event mean concentrations for Total Suspended Solids (TSS), Total Phosphorus (TP) and Total Nitrogen (TN) adopted in MUSIC. These water quality constituents together with gross pollutants are the only pollutants fully modelled in music (i.e. with appropriate generation and treatment parameterisation (eWater, 2011).

### 7.2.1 MUSIC Input Requirements

The input data required by MUSIC includes the meteorological data, particularly rainfall and areal potential evapotranspiration data. The Daily Rainfall Extraction Utility (Kunz, 2004) was used to extract the rainfall data for a period of 10 years, which is considered a long enough period for water quality modelling. In this study case the rainfall data station for Kempton Park was used, since this rainfall dataset was considered representative (seasonal pattern and rainfall distribution). The rainfall patterns for Stjwetla are similar of the rainfall gauge, this specifically the amounts and the type of rainfall distribution illustrated in the graph (see Figure 24) and data (see Figure 25).

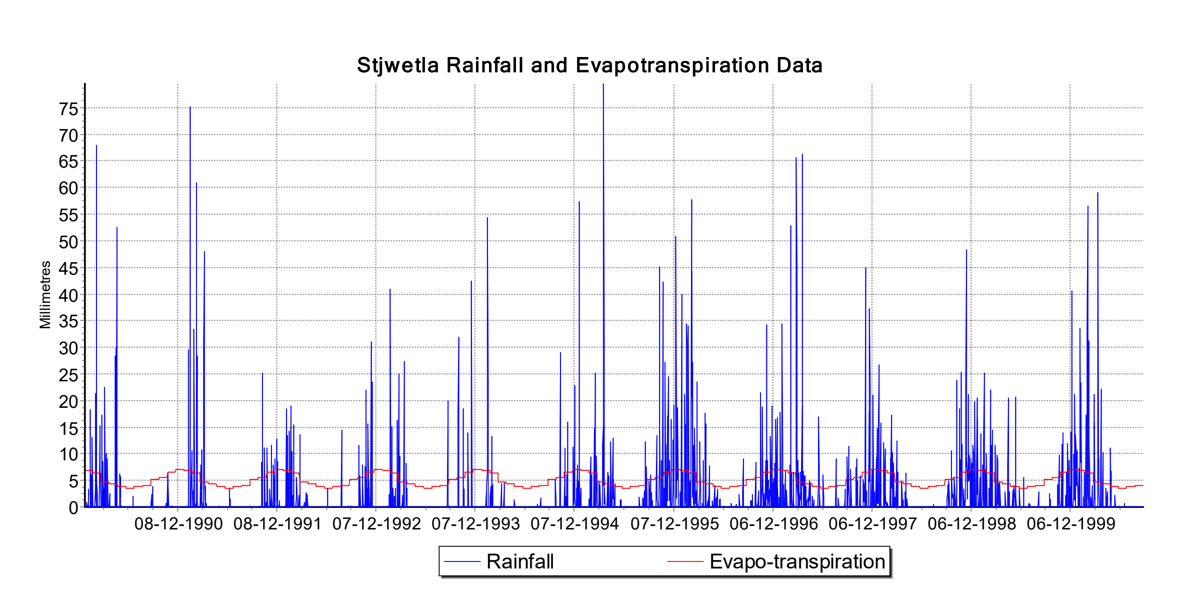


**Figure 24: Stjwetla catchment Rainfall and Potential Evapotranspiration graph**

| | Rainfall/Day | Evapo-Transpiration |
|---|---|---|
| mean | 1.715 | 5.114 |
| median | 0.000 | 4.623 |
| maximum | 79.500 | 7.116 |
| minimum | 0.000 | 3.570 |
| 10 percentile | 0.000 | 3.797 |
| 90 percentile | 4.500 | 6.923 |
| | **Rainfall** | **Evapo-Transpiration** |
| mean annual | 627 | 1868 |

**Figure 25: Stjwetla catchment Rainfall and Potential Evapotranspiration Data**

### 7.2.2 General Information – MUSIC Model setup

MUSIC uses source nodes to represent sub-catchments and land uses (eWater, 2011). Stjwetla in the MUSIC model was represented by one lumped urban node. Essentially, nodes created in MUSIC will represent the specific land uses in system. Each separate node would make it easier to target BMPs at specific land uses. However in this case the pre-developed node is presented by a forested node, which will allow for the representation of the different sub-surface flows. MUSIC can provide the user an advantage in this regard in setting up very complex systems and providing some very useful data to understand certain dynamics, which may not be achievable in very complex models. All source nodes are governed by the same generic hydrologic and water quality parameters in MUSIC. Therefore, to differentiate between the sources nodes, hydrologic parameters and pollutant concentrations were adapted to suit the conditions representative of Stjwetla.

### 7.2.3 Hydrological Parameters

Preliminary information that was specified to MUSIC included the total area of the Stjwetla (source node – in hectares) and the proportions of impervious and pervious area. This model assumes that area is lumped as on node, however if more detailed understanding is assessed MUSIC is capable of disaggregating the different nodes. The next dialogue box prompts the user to enter hydrological parameters which will be used as inputs for the rainfall-runoff model described in section 7.1 (above). These parameters include the impervious area properties, pervious area properties and groundwater properties. For the Stjwetla MUSIC model, all impervious source nodes were designated as 100% impervious as we assume this from the highly dense rooftops and exposed soil which become significantly compacted due to people walking on them. Subsequently the proximity to the Jukskei further removes the groundwater component in this study. The imperviousness represented in this study may be high but this assumption can be further illustrated in the research of low income, high density settlements on stormwater runoff undertaken in South Africa (Campbell, 2001; Ashton and Bhagwan, 2001; Wimberley and Coleman, 1993; Burke and Meyer, 2012). No calibration was performed for this case study, however the approach was to consider the higher end estimates of runoff by considering the area 100% impervious. eWater (2011) provide a comprehensive explanation of the parameters in the MUSIC manual.

### 7.2.4 Water Quality Parameters

MUSIC prompts the user to enter water quality parameters for generating TSS, TP and TN pollutants. The water quality is modelled assuming a log-normal distribution, where the focus in this study was only on the stormwater and not the baseflow component. This is based in the 100% impervious inputs to the model (as explained in the section 7.2.3, above). MUSIC prompts the user to enter water quality parameters (mean and standard deviation) for generation TSS, TP, TN pollutants. The stochastically generated method was selected, where a stochastically generated concentration is produced from a mean and standard deviation based on the inputted values. This method produces a pollutant generation from the Stjwetla based on the distribution parameter.

The concentration estimates that would be conveyed in the stormwater out Stjwetla were compiled by the average concentrations from expect pollutant concentration ranges previously measured in high density informal settlement measurements by references Ashton and Bhagwan (2001); Carden *et al.* (2007). These are presented in the Table 4, below. The pristine concentration estimates where default estimates currently incorporated in MUSIC, which have been tested by Duncan (1999). A stochastically generated method is selected in the model where this method produces more realistic interpretation of pollutant generation from the source node. The MUSIC model allows simulation of a wider range of pollutant types, however this should be done where sufficient data is available to characterise both generation and treatment performance (eWater, 2011).

**Table 4: Input parameter for the Stjwetla MUSIC Model**

| Site details | Stjwetla Settlement |
|---|---|
| Area | 12 ha |
| Rainfall | 628 mm (MAP) (0476396_W Kempton Park SAR) |
| Evaporation | 1868 mm |
| Average Slope | 2% |
| Pre-development | Grasses and bare soil |
| Infiltration into soils | Relatively Low |
| TSS | mg/l |
| Max | 126 |
| Mean | 79.4 |
| Min | 50.1 |
| P | mg/l |
| Max | 0.132 |
| Mean | 0.079 |
| Min | 0.047 |
| N | mg/l |
| Max | 1.46 |
| Mean | 0.84 |
| Min | 0.48 |
| Post-development | 0% Impermeable 100% Permeable |
| Infiltration into soils | Very Low |
| TSS | mg/l |
| Max | 4750 |
| Mean | 1000 |
| Min | 224 |
| P | mg/l |
| Max | 30.9 |
| Mean | 16.2 |
| Min | 8.5 |
| N | mg/l |
| Max | 67.6 |
| Mean | 17 |
| Min | 4.8 |

## 7.3 UNIVERSAL STORMWATER TREATMENT MODEL

The Universal Stormwater Treatment Model (USTM) is used the model the pollutant removal mechanisms for the stormwater measures like sedimentation pond, bioretention system and wetland system (Wong *et al*., 2001). It needs to be understood that pollutant removal occurs through physical, chemical and biological processes. However, due to the stormwater being assumed the dominant process in the urban catchment it has assumed that these processes translate as the dominant pollutant removal processes. Therefore, it is important to know that all the default USTM parameters within each treatment node are physical removal processes only. Thus the model simply does not account for on-going biological and chemical processes during the inter-even periods (eWater, 2011; Wong *et al*., 2001).

## 7.4 FIRST ORDER KINETIC (k - C*) MODEL

The USTM is the first order kinetic model which is applied to flow entering the sedimentation basin, bioretention system and wetland in the removal of pollutants. The overall effect on TSS, TN and TP as they move through the treatment measure are by the exponential decay relationship towards equilibrium or background concentration C*, where k is the exponential rate constant. A higher k value means a faster equilibrium and hence a higher treatment capacity of the treatment measure (provided C* is less than Cin). For some treatment measures C* is refined to event background concentrations, which applies only at high flow rates (eWater, 2011).

The inputs to MUSIC treatment measures are C*, k, q and Cin, where MUSIC will produce a Cout as final output for the respective treatment measure (eWater, 2011).

$$(Cout - C^*) / (Cin - C^*) = e^{-k/q}$$

where C* = background concentration (mg/L),

Cin = input concentration (mg/L),

Cout = output concentration (mg/L),

k = (decay) rate constant (m/y), and

q = hydraulic loading (m/y)

The USTM uses the continuously stirred tank reactors (CSTRs) to model turbulence and dispersion within the open water of a stormwater treatment measure. MUSIC assumes that as water move towards the outlet and tends to spread out due to turbulence. Therefore, the number of CSTRs considered has a large effect on the amount of mixing capability within the treatment measure. These are illustrated in Figure 26 below which provide the configurations applied in modelling hydrodynamic effects on water quality treatment (Wong *et al*., 2001).

It is therefore, important to appreciate that MUSIC does not model biological water quality treatment processes. Therefore, the modelling of open water surfaces using MUSIC requires transformation of the USTM to simulate biological removal processes occurring in the treatment measure.

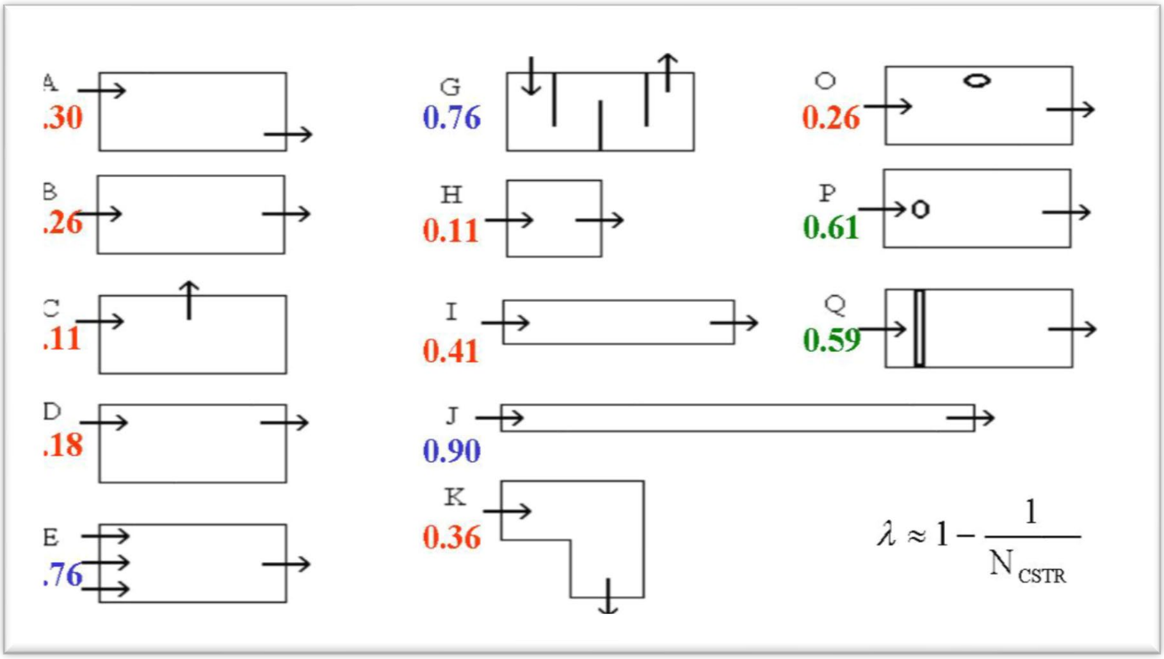


**Figure 26: Hydraulic efficiencies of stormwater treatment systems used to determine the number of CSTR to be applied in modelling hydrodynamic effects on water quality treatment (after Wong *et al*., 2001)**

These are some of the challenges that have been considered in the latest version 6 of MUSIC. The method of predicting treatment performance has been completely revised, drawing on extensive research undertaken by the Facility for Advancing Water Biofiltration (FAWB; see www.monash.edu.au/fawb). eWater (2011) state the treatment in a bioretention system is in fact modelled as two components, where:

- Treatment in the extended detention (ponding zone) is modelled using the normal USTM (the combination of a k-C* model running through CSTRs – see section above The Universal Stormwater Treatment Model (USTM)
- Treatment through the filtration media where in MUSIC the treatment performance is governed by an extensive 'lookup table', which determines outflow concentrations and/or removal rates for TSS, TP and TN. The lookup table takes into account all important characteristics of the bioretention system and its operating conditions, including
  - Filter media (input parameters): type, depth, porosity, hydraulic conductivity, particle size, composition (TN, TP and organic matter content),
  - Choice of vegetation (vegetated with effective nutrient removal species, vegetated with ineffective nutrient removal species, un-vegetated),
  - Amount of exfiltration (presence of lining, etc.),
  - Presence of a submerged zone (helps to ensure that the media does not dry out during long dry periods, and this drying out has been shown to result in leaching of nutrients upon rewetting of the media), and
  - Presence of absence of an underdrain.

It is understood that a large laboratory scale column study was conducted to assess the influence of the five biofilter design characteristics (i.e. vegetation, filter media type, filter media depth, hydraulic loading, and influent pollutant concentration). Each of the design characteristic was tested at discrete levels and thus the performance of biofilters was unknown between levels (eWater, 2011). Data from some of the studies makes reference to laboratory studies and analysis which include Hatt *et al. (*2007), Bratieres *et al. (*2008) and Henderson *et al. (*2007).

eWater (2011) further states that MUSIC has some limitations, i.e. 'It might be inaccurate when predicting treatment performance for systems with a filter media depth, influent pollutant concentration or submerged zone depth outside of the tested range. For example, while statistical analyses showed that to a large extent, treatment performance was not influenced by filter media depth, this might only be true within the range of 300 to 700 mm. The model also assumes that the filter media is sandy loam and that, if there is a submerged zone, the carbon source is fine sand mixed with pea straw and red gum. Thus, there is likely to be some uncertainty when systems with other types of filter media (such as sand or gravel) or other carbon sources are modelled. Furthermore, all columns tested in the laboratory studies had two transition layers. However, the number of transition layers in a biofiltration system might be an important factor in determining treatment performance.'

In order to model the treatment measures performance accurately, a rate constant must be calculated that represents first order microbial denitrification. Since MUSIC has adopted default rate constants for each of the treatment measures, they need to be better calculated based on the physical removal process alone. Since the Stjwetla treatment measures are not in place, in order to calculate this rate constant, reference could be made to laboratory experiments and field studies. However, since the set-up of the column tests, for example see test is not representative of the actual dynamics experienced in horizontal flow dynamics it was deemed that these might be bias estimates.

# 8 FINAL DESIGN MODELLING FOR STJWETLA

Since of the main objective of MUSIC is the ability to demonstrate the effectiveness of the SuDS infrastructure or treatment measures. A decision was made model infrastructure proposed from previous studies completed for City of Johannesburg (Bisnath *et al*., 2015), where they proposed use of the 'decommissioned sewage treatment plant as an attenuation pond/constructed wetland, where the stormwater outlets can be diverted into this facility, attenuated and purified.' Table 5, has been extracted from the report by (Bisnath *et al*., 2015), where this interventions is proposed as one of the many for the rehabilitation measures for the remediation measures of the Jukskei River. Bisnath *et al. (*2015) proposed (in table below) the creation of channels (pipes) from the east bank to the decommissioned treatment facility. This study therefore makes a simple assumption that stormwater from Stjwetla can also be conveyed into the facility.

**Table 5: COJ Intervention for attenuation/constructed wetland (extracted from Table 20, Bisnath *et al*., 2015)**

**Table 20: Proposed Attenuation/Constructed Wetland**

| Intervention Aspect | Description/Comment | Sub -Interventions |
|---|---|---|
| Storm water attenuation | A decommissioned sewage treatment plant exists near the Jukskei River opposite the Stjwetla squatter camp. Various storm water outlets (some of which are not in a good state) have also been identified on this side of the river. These storm water outlets, transport storm water from the part of the Alexandra Township opposite the Stjwetla Township. The decommissioned sewage treatment work can be configured to function as and attenuation pond and reduce flood risks in the area. | • Treat the water that currently exists in the decommissioned sewage treatment plant for the algae proliferation currently evident<br>• Investigate the capacity of the sewage treatment plant through hydrological studies and civil water infrastructure assessments,<br>• If needed, upgrade the sewage plant to the right capacity for storm water attenuation based on the storm water and runoff influx in the area<br>• Upgrade the sewage treatment plant with the right infrastructure<br>• Create a channel/s (pipes)that collect/s the storm water and run off from east bank to the attenuation pond/constructed wetland |
| Storm Water purification | The attenuation pond can also be constructed to include constructed wetlands features, to also serve the purposes of storm water and runoff purification. | • When upgrading the sewage treatment plant, incorporate constructed wetland features, i.e, wetland vegetation, filtration section, treatment section and polishing section<br>• Also investigate the reduced capacity of the plant to attenuate storm water due to the presence of wetland vegetation and soil, and upgrade the plant to account for the capacity lost. |

A number of factors must be considered when choosing the final treatment train for the site There is sufficient resources for example, Ashton and Bhagwan, 2001, Armitage *et al.*, 2015 that give guidance into possible water sensitive design measures or devices for developing a series of alternative treatment trains based on the site conditions, levels of pollutants and site opportunities and constraints. Any selection should consider primary treatment measures mainly to remove gross pollutants and coarse sediments, secondary measures mainly to treat finer materials, and tertiary measures to treat colloidal and dissolved materials. This study envisaged that the final treatment facility would be a wetland consisting of a sedimentation basin, a bioretention zone or macrophyte zone, an extended detention in open water and an oxygenation zone flowing back into the Jukskei (shown in Figure 27 and Figure 28, respectively. Since the biggest constraint of passive treatment solutions associated with informal settlements is space and no planning. Ultimately, if there is any environmental protection from informal settlements the establishment of any facility may have to consider locations downstream. Fortunately in this case the infrastructure of the sewage treatment works would prove large enough for the proposed treatment train.

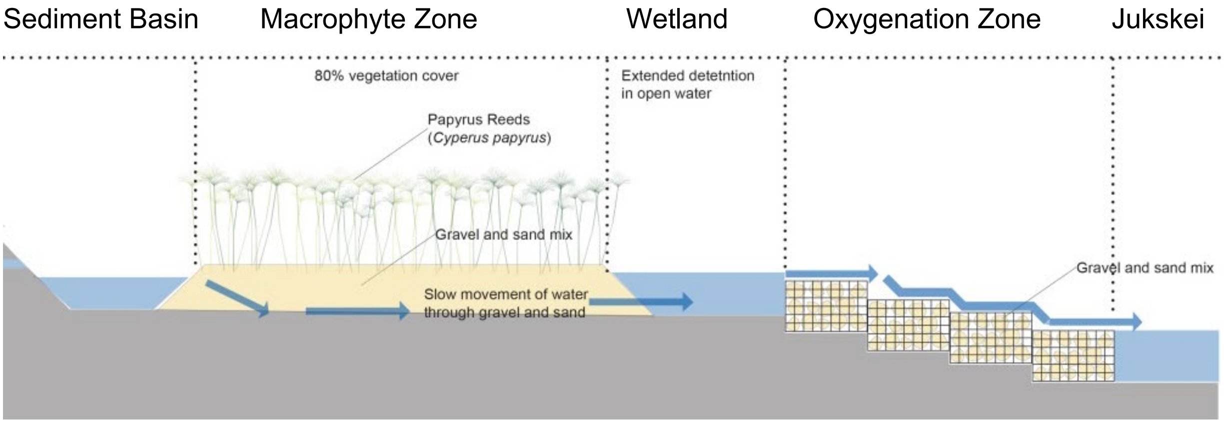


**Figure 27: Cross section through the treatment train layout**

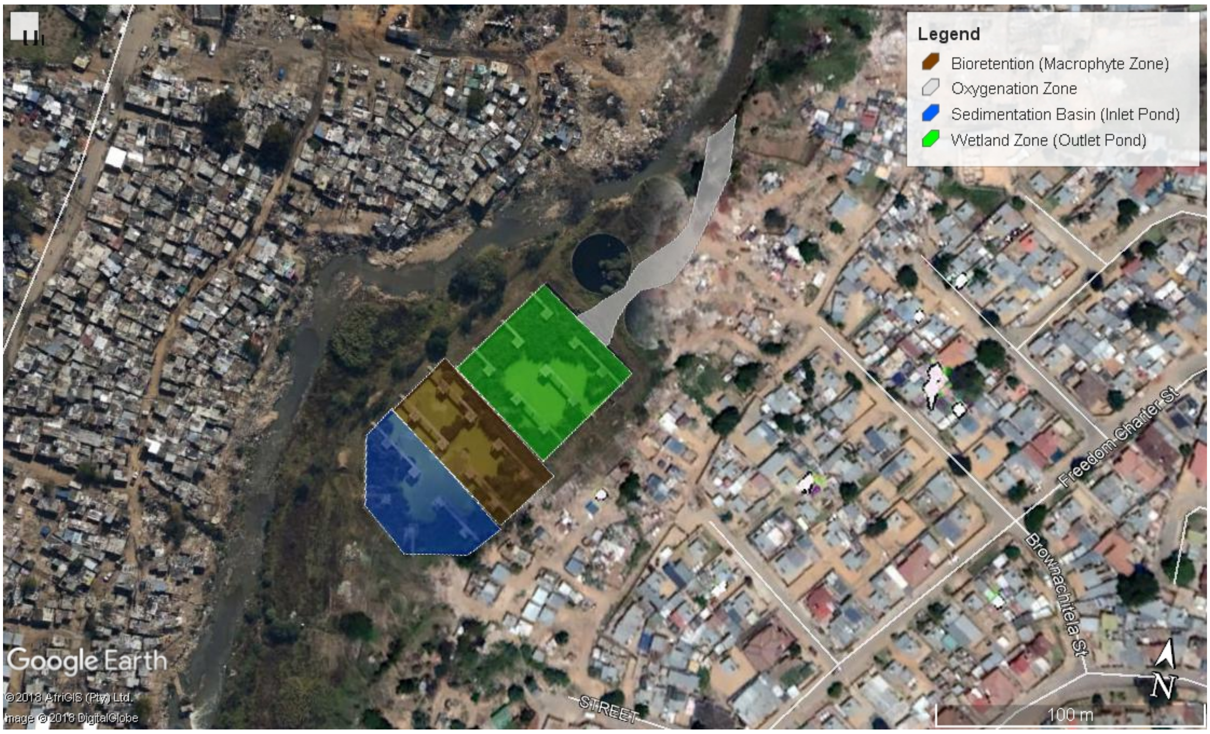


**Figure 28: Arial view of the treatment train layout**

The MUSIC nodes selected to represent this treatment train layout included the sedimentation basin node, the bioretention node and a wetland node (as depicted in Figure 29). Parameters of the respective treatment nodes were input into the model based on the some best management practice guidance. It must be noted that since no data was available to test input data parameter, default values were considered.

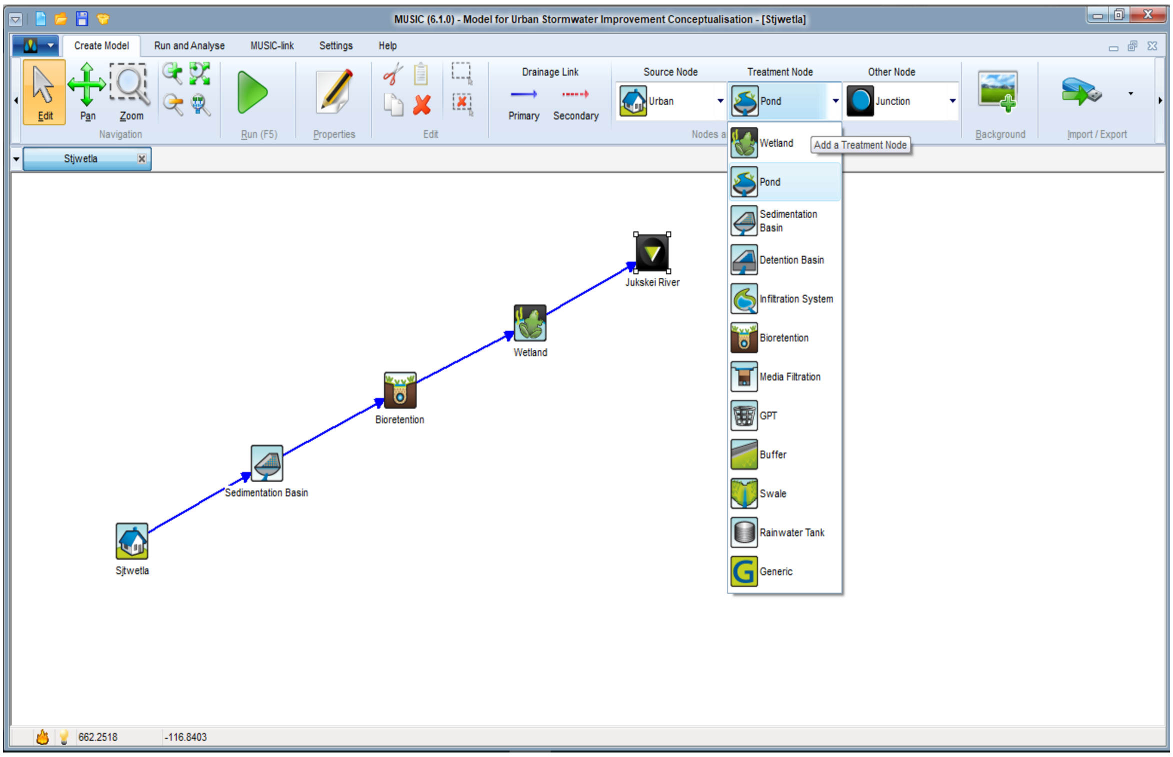


**Figure 29: MUSIC treatment nodes used to represent the components of the constructed wetland or treatment train**

## 8.1 SEDIMENTATION BASIN

Sedimentation basins are mainly used to remove fine and coarse sediment from stormwater, however, they may also be designed to act as a gross pollutant trap if an appropriate trash rack or similar is incorporated into their design. In MUSIC, detention basins, sediment basins and ponds are all modelled identically, but sedimentation basins will have a different k and C* value. It will be anticipated that high volume of sediment will be present in the runoff out of Stjwetla, therefore the sediment basin node should be used primarily where the system is to remove fine sediments (Banens *et al.*, 2012). The sedimentation node is depicted in Figure 30, and the input parameters to the node is are presented in Figure 31, below.

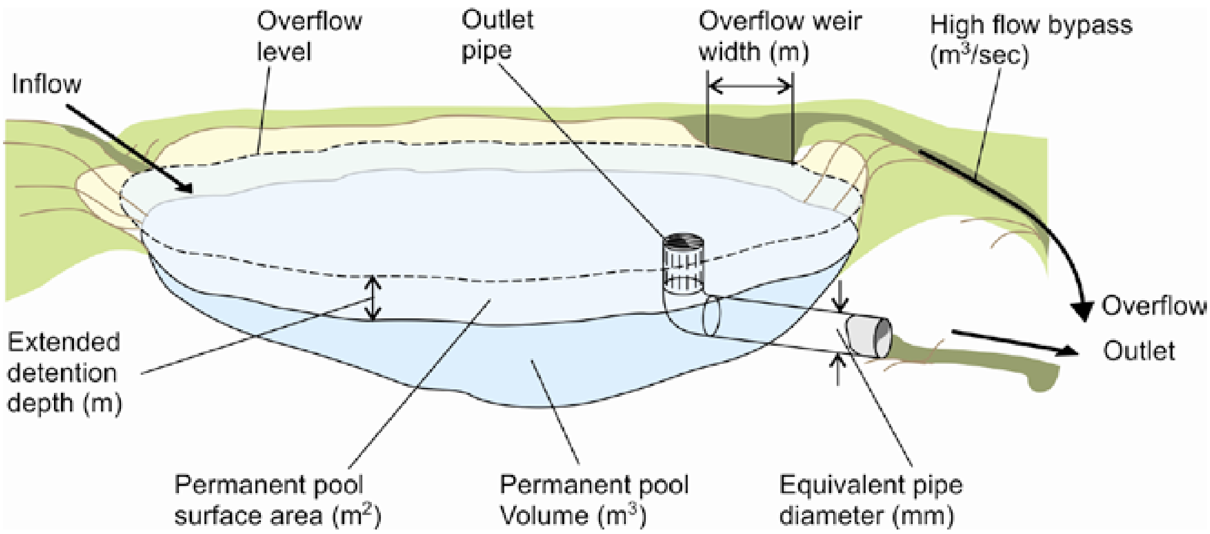

**Figure 30: A perspective view of a sedimentation basin (after Banens *et al.*, 2012)**

The inlet properties allow for all the runoff out of Stjwetla to enter the sedimentation pond. Where the storage properties were adjusted include and the evaporative loss as a percentage of the PET defines the water loss from the permanent pool. MUSIC calculates the notational detention time by the equivalent pipe diameter. The equivalent pipe diameter was adjusted until a value to the required detention time is achieved.

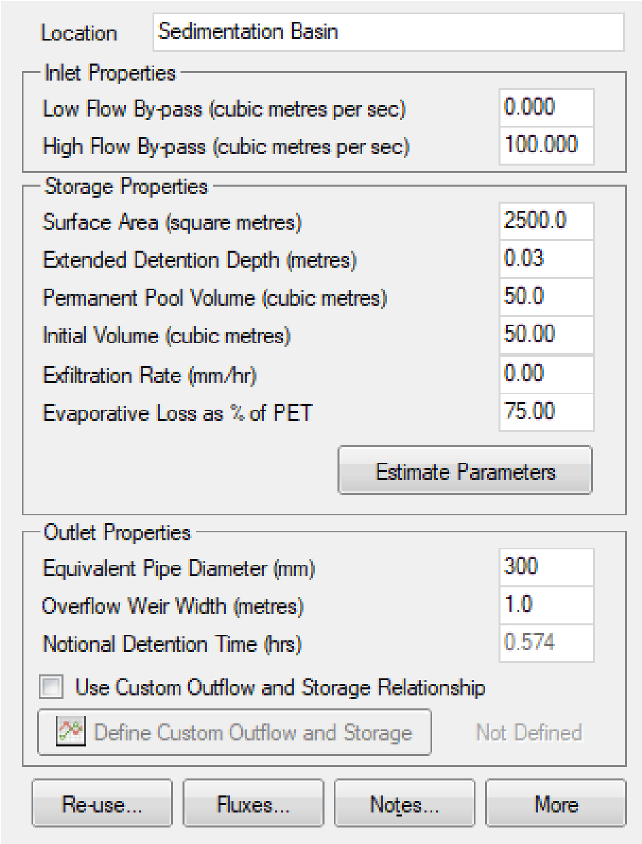


**Figure 31: Input parameters for the Sedimentation Basin**

## 8.2 BIORETENTION NODE

A perspective view of an advanced biofiltration is illustrated in Figure 32. According to Banens *et al*. (2012) designing a stormwater treatment system to reduce nitrogen and phosphorus loads, is best achieved through the use of either wetlands or bioretention systems. They highlight are some points below to configuring a bioretention node for optimal nutrient removal.

- Optimising a bioretention system is firstly about ensuring that the size is large enough to treat a significant proportion of the stormwater, but that it also drains quickly enough so that it is ready to capture the next event. Sizing a bioretention system is important and ideally should be around 2% of the upstream impervious catchment area. Anything greater than this 2% is going to be somewhat inefficient. The size of the bioretention node was for this study was set at 2%, since sufficient space is provided within the decommissioned plant. Hydraulic conductivity for the filter media was high, this was to ensure water moves through the system easy.

- The optimal removal of nitrogen is dependent upon the initial total nitrogen content of the filter media itself, and whether any submerged zone is used. Banens *et al. (*2012), further state starting with a value of between 400-500 mg/kg for the total nitrogen content for the filter media. If total nitrogen removal is not high enough consider employing a submerged zone. The submerged zone promotes denitrification under anoxic conditions, and thus provides greater nitrogen removal efficiency, but this will also cause phosphorus to leach out of the bioretention system and may impact on phosphorus removal efficiency. Initially, the model simulations resulted in consistent higher phosphorus concentration out of the bioretention system. It was then decided to place of the wetland node after the bioretention node to improve overall treatment of phosphorus.
- Banens *et al.* (2012), suggest the removal of phosphorus may be optimised by several methods. Firstly, ensure that the extended detention depth drains effectively as noted above, mainly that the system is ready for the next event. Since some phosphorus is removed through sedimentation on the surface. Secondly, they suggest setting orthophosphate content of the filter media to between 40-50 mg/kg to reduce the potential for phosphorus leaching from the system. Where a submerged zone in a bioretention system, the depth of that zone should be less than 300 mm as greater depths will lead to higher phosphorus leaching. Again this is what was observed in the modelling of this treatment unit where it was ultimately decided that since there is sufficient space in the decommissioned plant to size the unit appropriately, ultimately ensuring for a low submerged zone for the bioretention zone.
- A very important factor in the treatment node is to ensure that the model considers a vegetated surface by ticking the box for Effective Nutrient Removal Plants and ensure that appropriate deep-rooted moisture-tolerant plants are used in the design.
- Banens *et al.* (2012) note changing filter media and other parameters in the bioretention node in the model must reflect the design of the bioretention system, the availability of suitable filter media with the modelled nutrient content, and that which is constructed on- ground. The maintenance of bioretention systems in particular the regular removal of accumulated litter, fine sediment and debris, and ensuring that plants are healthy will assist in ensuring high nutrient removal efficiency.

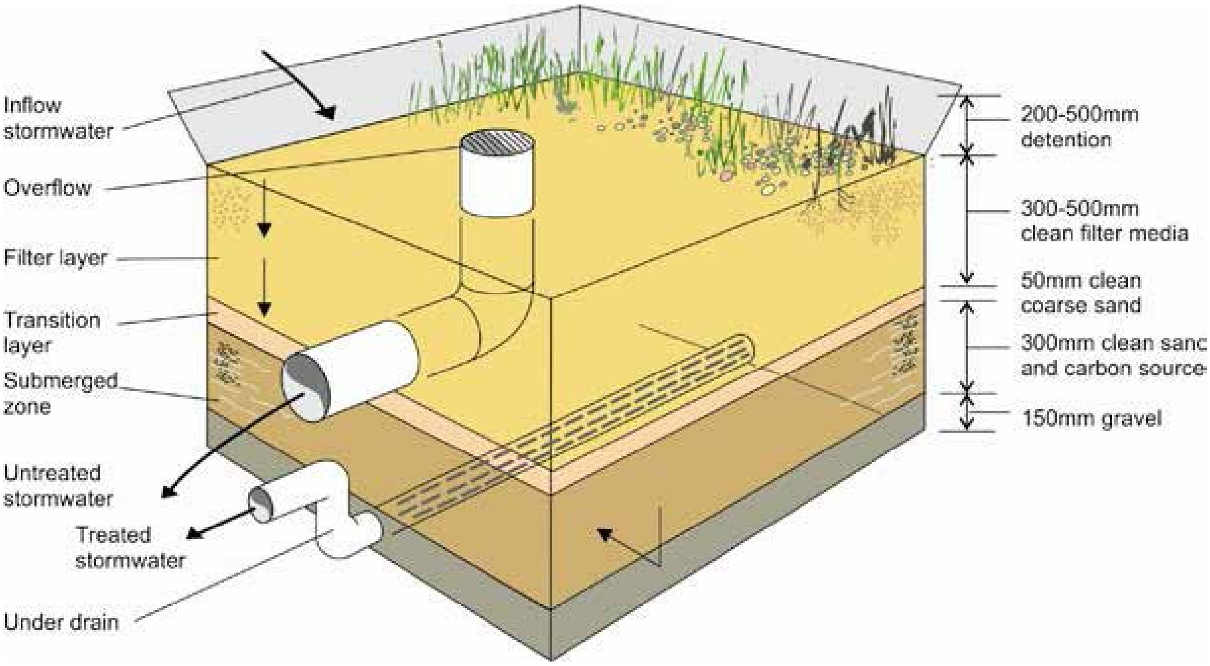


**Figure 32: Perspective view of an advanced biofiltration basin with a saturated zone (after Banens *et al.*, 2012)**

The inlet properties for this study ensure all the inflow out of the sedimentation pond to enter the bioretention node. All default parameter where left the same, except the storage properties were adjusted to ensure no exfiltration out of the unit and vegetation is considered with effective nutrient removal plants. The submerged zone with carbon was set to 0.4 meters. The input parameters (depicted in Figure 33) to ensure that a very shallow bioretention (macrophyte) zone is established in the model.

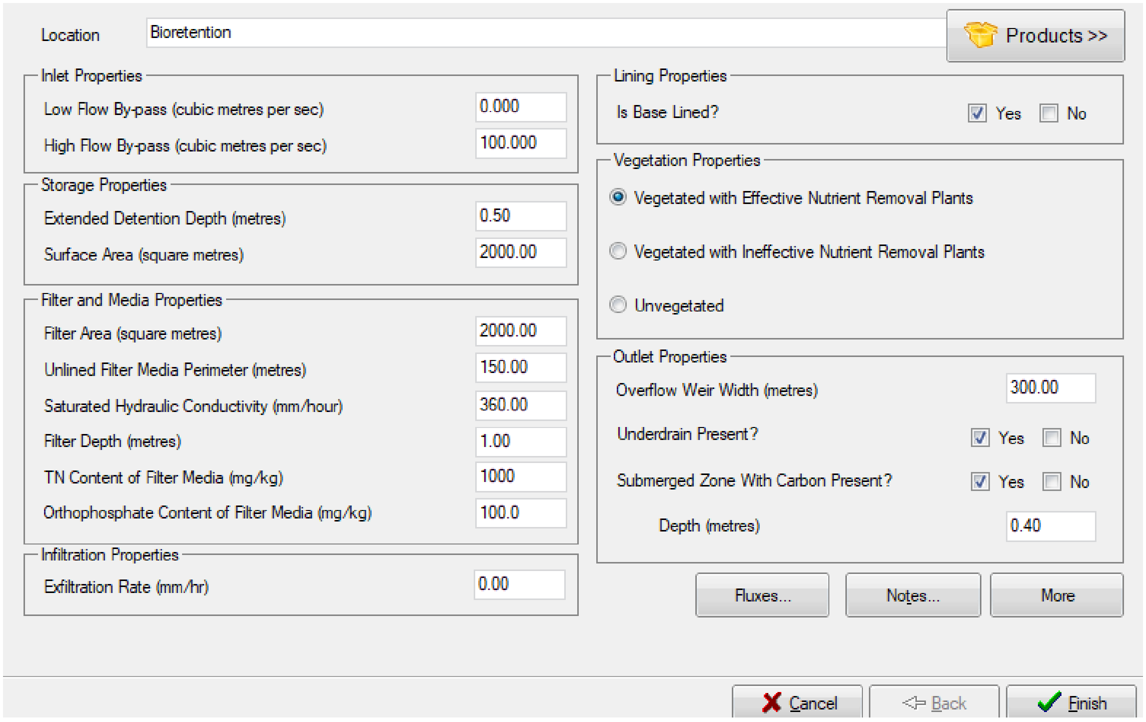


**Figure 33: Input parameters for the Bioretention Node**

## 8.3 WETLAND NODE

A perspective view of the wetland with inlet pond is illustrated in Figure 34, however it must be noted that no inlet pond was considered in the modelling the wetland node. It is anticipated that the sedimentation and the bioretention node would ensure that the fine particles are completely removed.

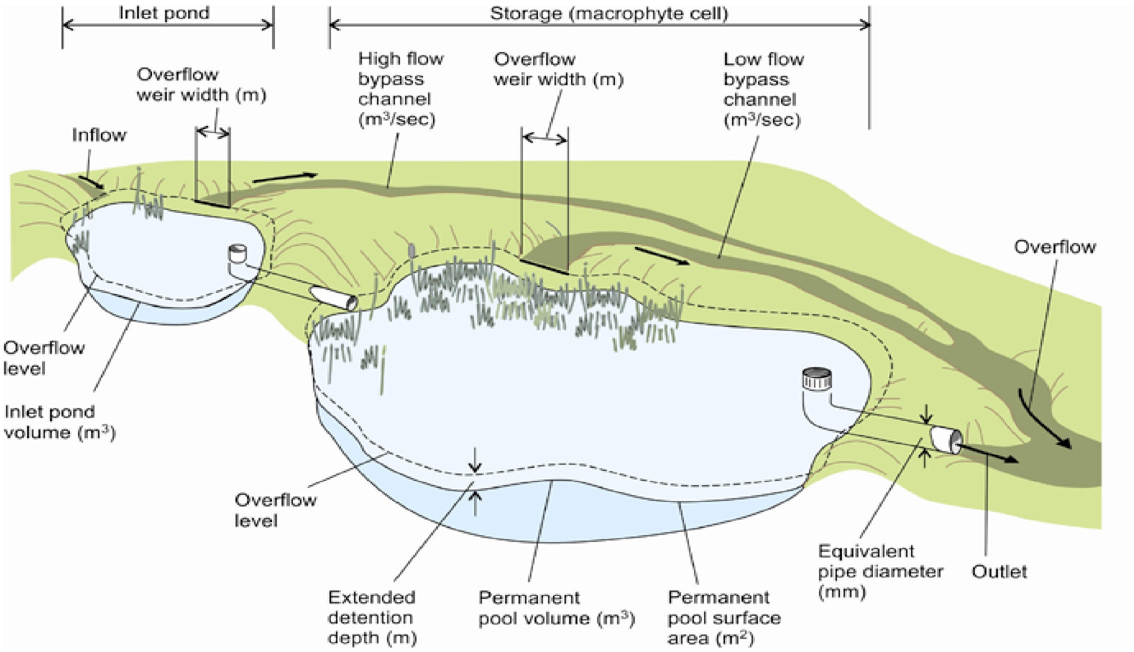


**Figure 34: Conceptual perspective of a wetland with an inlet pond as used in MUSIC (after Banens et al., 2012)**

The input parameters used in modelling the wetland node are depicted in the Figure 35, below.

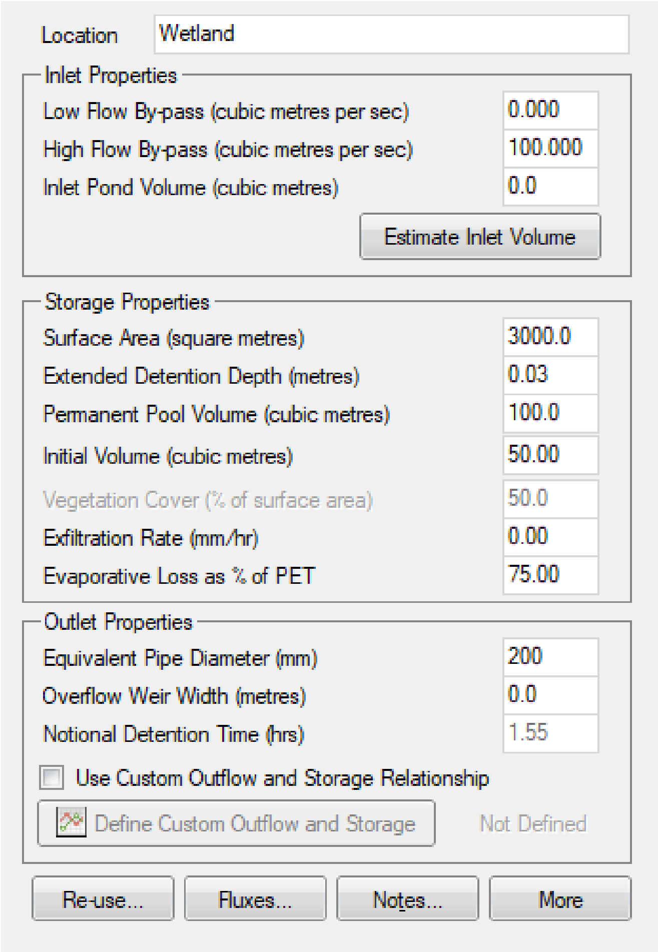


**Figure 35: Input parameters of a wetland (after Banens *et al.*, 2012).**

An outlet zone provides a cascade of water at the outlet before the discharge point. This will facilitate the aeration of water by allowing water to drop over an elevated area. The drop zone may have gabions over the surface to prevent erosion and facilitate the mixing of the water.

## 8.4 RESULTS

The Table 6 and graphs (see Appendix B) are MUSIC time series statistics, which were output from the model after conducting several simulations of the Stjwetla catchment. The alternative long term assessment using the MUSIC modelling approach with 10 year continuous actual historical rainfall data, 628mm per annum on average, indicates a treatment performance in the range of 98% to 68%. This MUSIC result potentially provides an over-estimate of the treatment performance, an upper bound estimate. The first order rate constants are the most important factors in defining contaminant clean up. It would be imperative therefore to define these estimates by using first order rate data from other experiments such as laboratory test by Milandri *et al. (*2012). However, it would be unrealistic to consider the first order rates results from a column test to accurately represent the horizontal flow movement dynamics. Some other first studies that provide data from of column design, construction and planting, as well as sampling and measurement are fully described in Allen et al. (2002) and Stein et al. (2006). However what needs to be expressed is that the dynamics of the bioretention or macrophyte zone are complex and would need to be done by numerical mechanistic modelling for subsurface flow. Hence, before the models can be applied as tools to refine bioretention design criteria and operational modes, there is a need to apply the models to a wide range of data sets to test their predictive power, reduce parameter uncertainty by calibration, modify process equations or extend the models with relevant processes.

**Table 6: Stjwetla treatment train (sedimentation basin, bioretention system and wetland system efficiency)**

| Treatment Train | Stjwetla load | Residual Load | % Reduction |
|---|---|---|---|
| Flow (ML/yr) | 81.1 | 72.2 | 10.9 |
| Total Suspended Solids (kg/yr) | 156000 | 1950 | 98.7 |
| Total Phosphorus (kg/yr) | 1280 | 5.53 | 99.6 |
| Total Nitrogen (kg/yr) | 2920 | 65.8 | 97.7 |
| Gross Pollutants (kg/yr) | 2630 | 832 | 68.4 |

## 8.5 SENSITIVITY ANALYSIS OF WETLAND

A sensitivity analyses was also been undertaken on a wetland node (only) to test the MUSIC modelling assumptions and default input parameters. Given all of the above and the uncertainty surrounding the theory and variability of parameters assumed, it is considered that the actual results may be too conservative.

For example a simple sensitivity analysis was performed on the wetland component by simply reducing the area ($m^2$) by a factor of 10 (i.e. 3000, 300, 30). The results presented in Table 7 and the graphs illustrated in Figure 36, show the simplistic approach with concentration load reduced by a factor. This would be indicative of how the model is simply associating the concentration loads by a simple look-up table.

**Table 7: MUSIC sensitivity analysis results for the wetland component at respective areas**

| | Stjwetla load | Residual Load | % Reduction |
|---|---|---|---|
| **Wetland 3000 $m^2$** | | | |
| Flow (ML/yr) | 81.1 | 78.7 | 3 |
| Total Suspended Solids (kg/yr) | 107000 | 2820 | 97.4 |
| Total Phosphorus (kg/yr) | 1230 | 42.9 | 96.5 |
| Total Nitrogen (kg/yr) | 2540 | 954 | 62.4 |
| Gross Pollutants (kg/yr) | 2630 | 832 | 68.4 |
| **Wetland 300 $m^2$** | | | |
| Flow (ML/yr) | 81.1 | 80.7 | 0.5 |
| Total Suspended Solids (kg/yr) | 148000 | 71800 | 51.6 |
| Total Phosphorus (kg/yr) | 1200 | 593 | 50.6 |
| Total Nitrogen (kg/yr) | 3180 | 2730 | 14.1 |
| Gross Pollutants (kg/yr) | 2630 | 832 | 68.4 |
| **Wetland 30 $m^2$** | | | |
| Flow (ML/yr) | 81.1 | 81.1 | 0 |

| | Stjwetla load | Residual Load | % Reduction |
|---|---|---|---|
| Total Suspended Solids (kg/yr) | 150000 | 138000 | 8.2 |
| Total Phosphorus (kg/yr) | 1170 | 1140 | 2.9 |
| Total Nitrogen (kg/yr) | 2430 | 2550 | -4.9 |
| Gross Pollutants (kg/yr) | 2630 | 832 | 68.4 |

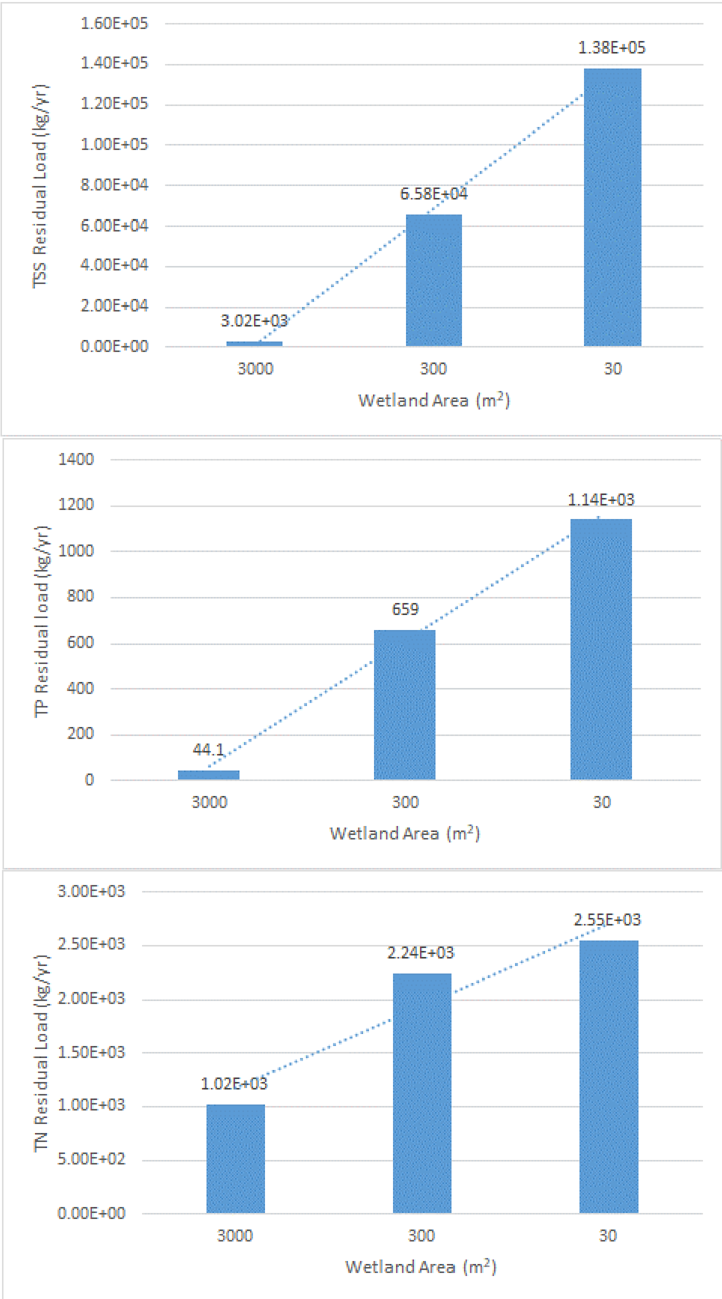


**Figure 36: Reduction load of the respective contaminants resulting from the wetland area being reduced**

## 8.6 DISCUSSION

MUSIC is a simple, user friendly, not a data intensive model to establish some indicative understanding of the water quality characteristics of the catchment. The major challenge with most models is the lack of calibration data. Furthermore, Mourad et al. (2005) argue that the reliability of the models does not increase with increasing model complexity. A major problem for stormwater managers in decision making involving water quality where the limitation in the current available and reliable monitoring data relating to the behaviours of different pollutants. However, irrespective of this data gap, stormwater managers are required to make decisions and adopt urban drainage schemes to achieve compliance This is where MUSIC would certainly prove an advantage, specifically towards initial assessment and a forward justification into feasibility of measures. As further field data becomes available it will be possible to calibrate and refine the described systematic approach using a more robust field data set, and also to classify removal processes using quantifiable (or at least end-point) values. However, in the interim period the described methodology provides relevant information, which can support and inform discussions related to pollution control as well as feed into the more comprehensive considerations required within an integrated approach to urban stormwater management of informal settlements.

This report described the development of a methodology, based on the input of theoretical data and knowledge, to identify the relative performances of treatment measures for the removal of pollutants commonly associated with stormwater. The study then assesses the order of preference for the use of measures to remove TSS, TN and TP with no existing field undertaken for Stjwetla. The model simulations demonstrate removal of contaminants for the systems although it is evident that the model possibly presents higher prediction of the ability to remove these contaminants. The model can easily be refined to more closely simulate the prevalent field conditions, if these are available. The predicted orders of preference for treatment train for the different pollutants can provide important inputs into existing modelling procedures where available data is deficient but the selection of appropriate k values is essential.

Studies undertaken by Imteaz *et al*. (2013) presented results indicating MUSIC’s predictions were inconsistent among different experimental setup used in different areas. These studies where more closely aligned to the urban setting for which MUSIC is better suited, however in general flow and TSS removal efficiencies predictions are fairly accurate. MUSIC’s predictions for TP and TN removal efficiencies for bioretention systems did not match with the experimental results.

- Based on this assessment it can be seen that MUSIC may not yet be suitable for this type of model scenario (informal setting). One of the reasons being the inability to plan for infrastructure in the informal settlements and subsequent lack of funds which will require maintenance of proposed infrastructure. Modelling passive treatment of informal settlements will require calibration to increase accuracy, which may actually be time consuming and require good experience (both with MUSIC and treatment measures).
- MUSIC will have a great potential in a multiple catchment scenario, where this study would not be realistic in terms lumping the entire catchment into one model. The simplicity lumping of MUSIC in this scenario may not be feasible for such a large scale

catchment. However, if treatment measures are considered for many difference catchments, MUSIC would be viable is defining certain measures. It may be possible that the results although bias may still point in the right direction. This will have to be confirmed with actual field or experimental data as proposed in section 9.

- Sensitivity analysis the parameter show that k and C* have a big impact on the
- The water quality emanating out of Stjwetla are based on statistical estimates, based on runoff and contamination (these in themselves are unpredictable). Therefore, it was not deemed necessary to undertake water quality sampling the high concentration estimates would be derived using the statistical method.

# 9 REQUIREMENTS FOR A DETAILED MODEL DESIGN

The overall objective of this chapter is to describe 'what are the actual requirements' to establish/define in application for detailed modelling a passive treatment facility / constructed wetland characterization and monitoring technologies. This chapter will recommend a suitable site-characterization techniques and monitoring methods, for the development of macrophyte zone. The suggested methods are based on previous studies performed by Morgan (2010) in undertaking an MSc degree. It can be expected that understanding of a macrophyte zone may be derived from field observations, this chapter describes the basic principles, advantages, and limitations of existing macrophyte zone characterization and monitoring methods using the field experiences. The methods discussed in this chapter can be used for the following purpose.

- Design and selection of experimental methods for field and laboratory experiments
- Design of macrophyte zone remediation systems
- Project planning and data collection.

A conceptual model is an interpretation or description of the physical system's characteristics and dynamics. The development of a conceptual model is an important step for site characterization because an inappropriate model "fit for purpose' can lead to significant errors in the development of mathematical and numerical models, thus adversely affecting predictions and planning of such passive treatment facilities. The development of a conceptual model must be based on the analysis and simplification of data collected during field-monitoring and laboratory experiments, simplification of hydrologic systems, and the representation of macrophyte zone parameters in models. In general, conceptual models that describe water flow include a description of the hydrologic components of the system and how mass is transferred between these components. Without a conceptual model, we do not know what tests to conduct, what parameters to measure, where to place probes, or what probes to use. Conversely, without such data, we cannot develop a conceptual model. This situation requires an iterative approach, in which we will conduct a series of observations and tests and, concurrently, develop a conceptual model of water flow and quality to refine our tests.

Conceptualisation begins with the theoretical understanding of the entire treatment system, followed by data collection and the refinement of that understanding. Characterization of natural (ambient background or baseline) conditions involves the following tasks:

- Locating, collecting, and organizing basic types of data from available published and unpublished sources; and
- Conducting specifically designed field, laboratory, and modelling studies for the sites selected.

It is imperative to develop a broad overview of the framework of the constructed (see Figure 37) wetland and identifying those issues that may assist or hamper the overall delivery of the passive treatment facility objective. This would specifically respond to the site conditions. Careful assessment and interpretation of the site conditions is a fundamental part of designing and development of a passive treatment system that can be effective. There are several key characteristics of a site that need to be understood as these can influence the level of confidence in providing an effective design. For simplistic purposes these should include the following factors; i.e. climate, soils, average slope, depth to groundwater. An overall water management plan should provide;

- Site plan showing location, size and dimensions of the facility and associated measures, and
- Conceptual design calculations to establish the quantitative estimates.

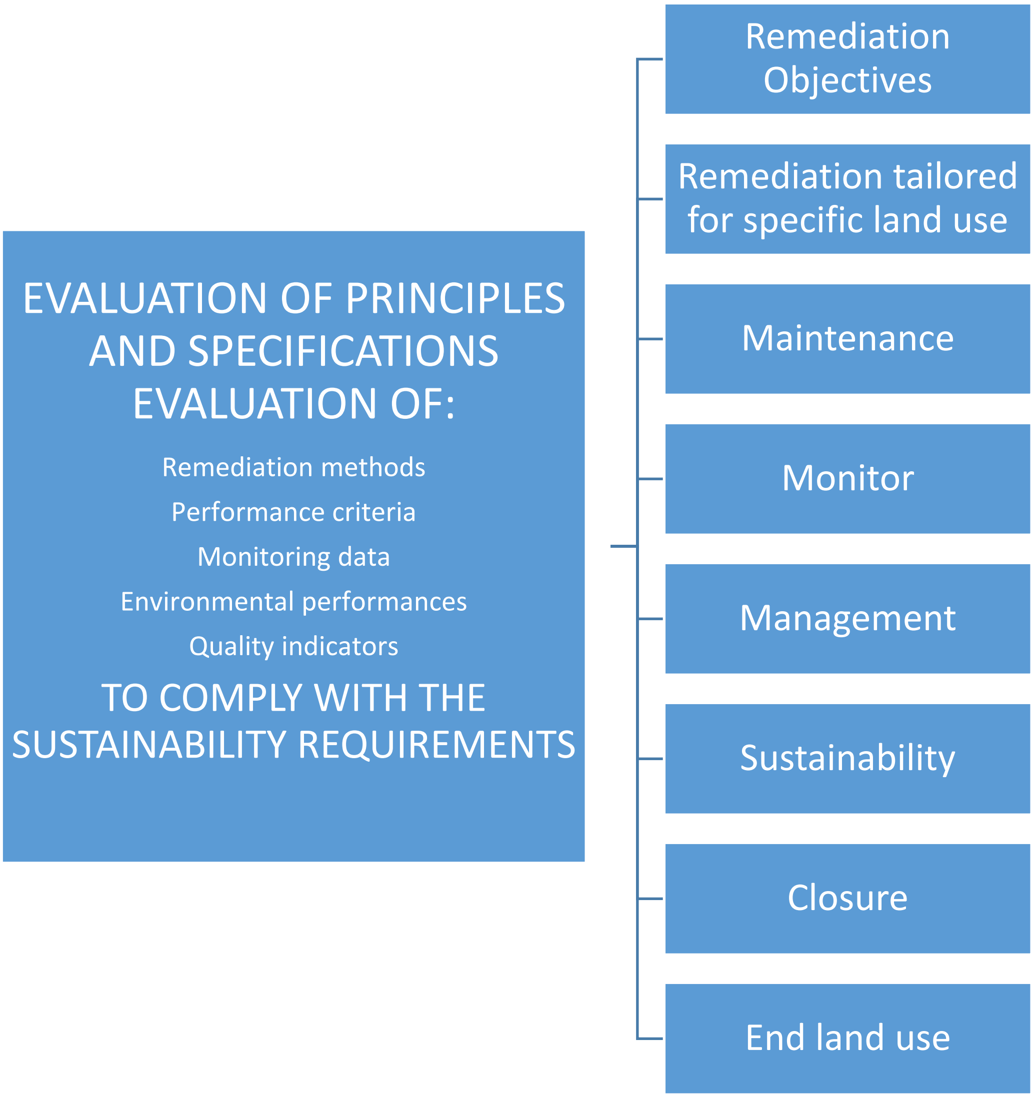


**Figure 37: The Generic framework of processes from the treatment facility or constructed wetland**

Remediation objectives have well-established criteria in place for water control measures and water quality requirements. Unfortunately there is a lack of information with respect to the informal settlement stormwater in relation to constructed wetlands for methods, management systems and monitoring criteria. Therefore it is essential to define the function that the constructed wetland must fulfil.

An overall and a very basic procedure for the remediation using constructed wetlands would comprise the following:

- Defining all impacts (insect habitat, pollution, odour, etc.).
- Limitations and risks associated with the identification of constraints
  - Natural (rainfall, floods, temperature, etc.);
  - Physical (slope length, slope gradient, aspect, texture, water holding capacity, etc.)
  - Chemical (pH, toxicity, nutrient balance etc.)
  - Biological (vegetation, micro-organism activity, etc.); and
  - Economical (resources distribution and allocation).
- Solution/method statement – using supportive information (data basis, theory, research, models, technology) to obtain innovative solutions.
- Validation – testing the solutions against the legislation requirements and the requirements of sustainable management.
- Capacity to implement the strategy.

Maintenance, monitoring and management programs should be developed with a sustainable end-land use in mind. The objectives of these programs need to be supportive to the closure phase to comply with the obligations and regulatory requirements. Sustainability is a measure of the likelihood that a particular land use will remain physically, economically and socially appropriate to that particular location for a significant period. For this particular program, success in terms of sustainability would ultimately need maintenance to the sedimentation basin and vegetation on the macrophyte zone and open water. Maintenance would only be required with regard to ensuring control of the vegetation, yet guarantee the macrophyte cover would be developed to the extent all objectives which are set out are achieved. Success would be achieved when the outflow concentration levels are within the required standards. However a major issue is that the infrastructure is located within the floodline as see in section 11.1.

Effective environmental planning often demands qualitative and quantitative predictions of the effect of future management activities. The conceptual design and appropriate models can be applied to solve a wide range of treatment facility related problems under very different situations. This study also aimed identify the most important variables in the development of the treatment facility, since the combination of flow, transport and processes in models is often only possible when simple solutions for each problem are applied to keep the mathematical complexity of the model low.

Development of an appropriate conceptual design (specifically the macrophyte zone) of water flow and pollution transport within the facility is critical for developing adequate predictive modelling methods and designing cost effective remediation techniques. These processes must still take into account the changes under natural climate. The complexity resulting from the effects of episodic preferential flow on a field scale must be taken into account when predicting flow and transport and developing the macrophyte zone. The change of water flow and contaminant transport, which is difficult to detect, poses unique and difficult problems for characterization, monitoring, modelling, engineering of the macrophyte zone, and remediation of contaminants. Lack of understanding in this area will lead to wrong predictions of contaminant transport and incorrect remediation actions. Therefore, it is imperative to develop a strategy to investigate the macrophyte zone including a comprehensive plan to assess these conditions specifically.

## 9.1 MACROPHYTE ZONE CHARACTERISATION AND MONITORING

The ability for plants to grow and perform well have been documented over the years mainly termed as phytoremediation. The performance of plant species removing nutrients from stormwater biofiltration systems were undertaken by Milandri *et al. (*2012). The three plant species, namely, *Agapanthus, Pennisetum* and *Stenotaphrum* absorbed over 80% of all nutrients and highly recommended species for inclusion in local (Cape Town) biofiltration systems. Generally, the performance of macrophyte pollution treatment depends on the growth potential and ability of macrophyte vegetation to develop sufficient root systems for microbial attachment and material transformations, and to incorporate nutrients into plant biomass (Kyambadde *et al*., 2004; Vymazal and Kröpfelová, 2009). Availability, expected water quality, normal and extreme water depths, climate and latitude, maintenance requirements and project goals are among the variables that should determine the selection of plant species for macrophyte and wetland zone, respectively (Stottmeister et al., 2003).

While there is a recognition that the improvement of water quality in treatment wetland applications is primarily due to microbial activity (Faulwetter *et al.*, 2009; Kadlec and Wallace, 2009), experience has shown that wetland systems with vegetation or macrophyte zone has a higher efficiency of water quality improvement than those without plants (Brisson and Chazarenc, 2009). The emphasis of constructed wetland technology to date has been on soft tissue emergent plants including *Cyperus papyrus, Phragmites, Typha* and *Schoenoplectu*s (Kadlec and Wallace, 2009).

Modelling horizontal flow in the constructed wetlands with intermittent loadings requires transient variably saturated flow models as these systems are highly dynamic, which adds to the complexity of the overall system. Based on profession experience Morgan (2009) of applicable models, the HYDRUS-2D model can be used to provide an estimate of the saturated and unsaturated flow conditions. It is thus suggested, for practical application:

- Undertake experiments to measure the porosity and the saturated hydraulic conductivity parameters of the proposed macrophyte zone material;
- Instrumentation and monitoring methods for determining the macrophyte zone material saturation should be assessed as these collective parameters are used to determine the flow rates. These parameters should be assessed as they are used in the HYDRUS-2D model for simulations of the water flow and ultimately assess the achievable targets of the bioremediation in the macrophyte zone.
- It may be possible to further establish the influence of the particulates and biomass growth on the hydraulic properties of the macrophyte zone, as these estimates could further increase its prediction water quality through the treatment system.

The HYDRUS-2D model is a finite-element model, which numerically solves the Richards' equation for saturated-unsaturated water flow. Richard's equation for one dimensional flow requires knowledge of the soil hydraulic functions, i.e. the soil water retention curve, describing the relationship between water content and the matric pressure head, and the unsaturated hydraulic conductivity function, defining the hydraulic conductivity as a function of pressure head.

The above soil properties presents a very broad understanding of the Darcy's Law through the macrophyte material, but it is essential that experiments be undertaken for composite samples. In order to adequately quantify the flow in the macrophyte zone, it is imperative that sufficient information of the porous media hydraulic characteristics and the dynamics of the interstitial water are assessed. There are numerous techniques for measuring and monitoring these variables. For example, the porosity is defined as the ratio of volume of voids to the total volume of the macrophyte material. The effective porosity defines the volume of water that a given volume of bulk porous medium can contain. Water content reflects the volume of the void space that is filled with water, relative to the bulk porous medium.

Soil hydraulic properties will be required in order to model transport of water in the macrophyte zone. The ability of a porous media to retain and transmit water is characterized by the relationships between water content, matric pressure head, within the profile and the hydraulic conductivity. The most substantial challenges for experimental and theoretical investigations of fluid flow in unsaturated porous media result from the extremely nonlinear behaviour of the hydraulic properties as a function of saturation and the highly irregular nature of pore geometry. The aim of these macrophyte zone studies will have to provide a perspective of saturated and unsaturated hydraulic characterization and measurement used for the suitable materials.

## 9.2 SOIL WATER MEASUREMENTS AND FIELD MONITORING EXPERIMENTS

The aim of this section is to provide understanding into direct observations into key hydrological processes and techniques in measuring soil hydraulic properties, monitoring soil water dynamics. The understanding of these measurements and data adds value as a reference for the evaluations of the soil and macrophyte media hydraulic behaviour, which ultimately is used in a model. Measurements of the macrophyte media may include;

- soil physical characteristics,
- water retention properties, and
- hydraulic conductivity characteristics as well and proposed *in-situ* material hydraulic characteristics.

Soil hydraulic characterisation may involve both makeup of proposed *in-situ* material and laboratory measurements. A consistent procedure must be adopted for characterising macrophyte material profile. The proposed material will be developed by testing the water retention characteristic, bulk density and particle size distribution determined in the laboratory. The particle size distribution and bulk density may be used to develop pedotransfer relationships, within the macrophyte zone material. However, since the macrophyte zone will be developed ensuring heterogeneity. Once the material is made up the contractors should be scrutinized and consistently monitored during construction. Monitoring the pore water for contaminants will be a difficult task and would require the use of indirect methods. There are, however, a number of sensing techniques for detecting moisture or the electrical changes due to moisture change that will be considered for monitoring. These techniques include tensiometers and TDR probes.

## 9.3 WATER RETENTION CHARACTERISTIC

Conventional methods of soil water retention characteristic determination include both laboratory and field techniques. Although many of the standard laboratory techniques can be used to determine the water retention characteristics of the porous media, the modified controlled outflow method is reported in detail. This method holds some promise for the accurate characterisation of the soil pore structure over the range of moisture contents close to saturation.

The following information and experimental methods presented in the below section have been established and modified from Morgan (2009). The retention characteristics samples can be used together with field measurements of both saturated and unsaturated conductivity to define the possible macrophyte material composite.

## 9.4 MACROPHYTE ZONE MONITORING

Shallow piezometers should be installed to measure the saturated water level dynamics through the macrophyte zone. Material moisture alone will not provide information on the driving force for unsaturated fluid flow in the macrophyte zone or allow the direction of water movement to be determined. The driving force for water movement in macrophyte zone materials is the matrix (or suction) potential, which is usually expressed in terms of a vacuum (using negative pressure units). The matrix potential of a given material is determined by the texture and moisture content of the material. For example, if two soils of two different textures (one fine, the other coarse) are placed in contact with each other and the water within them is allowed to reach equilibrium, water will move between them until they come to the same matrix potential. The moisture content of the fine-textured soil, having more small pores, will be appreciably higher than that of the coarse-textured soil. With the knowledge of the macrophyte material texture, the matrix potential can be estimated from the measured material moisture content; however, it is much better to measure the matrix potential directly with a tensiometer.

Tensiometers (constructed relatively cheaply) should be considered for measurement of the macrophyte zone material and ultimately establishing water pressure, which would translate to the water at the surface. Tensiometers can also be used to measure positive pressure in soils that are saturated and thus can be used for monitoring perched water tables, which is an objective of the relatively shallow macrophyte zone. Tensiometers have the advantage in that they provide a direct measure of the water potential. They require a continuous water column that extends from the measurement point to the pressure transducer located at the surface. A tensiometer typically consists of a porous ceramic cup or plate attached to a nonporous tube, with some means to measure a vacuum inside the tube. When the porous cup is placed in hydraulic contact with macrophyte material, and the cup and tube filled with water and sealed, a vacuum will develop in the tube as water flows from the ceramic into the soil. At equilibrium, the measured vacuum inside the tensiometer is equal to the matrix potential of the macrophyte material. An example of how the position of the tensiometers would be placed in the macrophyte zone in order to study the water within this macrophyte zone is illustrated Figure

38. It would be anticipated if these experiments are developed that experts in the field of vadose zone, such as Simon Lorentz would be considered advisors.

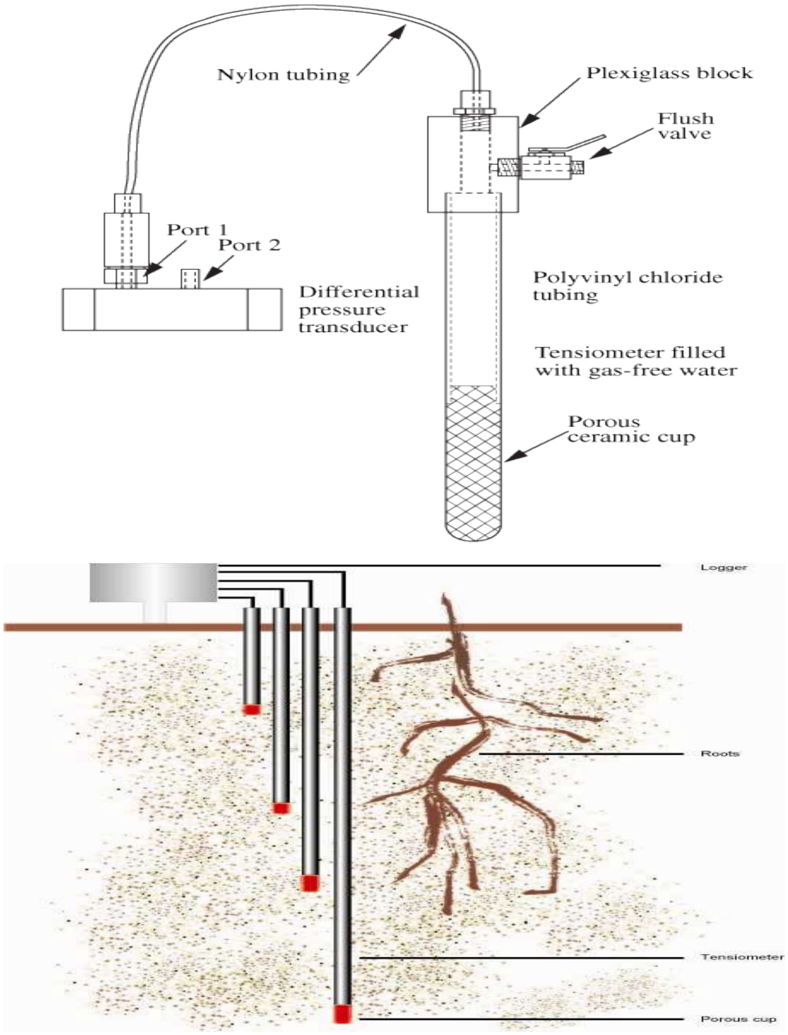


**Figure 38: Schematic of the root zone and components of the tensiometers (Morgan, 2010)**

## 9.5 QUANTIFICATION OF THE HYDROLOGICAL PROCESSES

The macrophyte zone will be constructed as an isolated unit; therefore the boundary conditions will be the sides and the bottom of the zone. In order to quantify the hydrological processes detailed observations of the surface and subsurface dynamics will need to be made at various experimental sites. Developing understanding of these mechanisms at these respective sites allow for some generalisation or insight into the classification of critical macrophyte zone flow criteria for estimating the outflow responses. Consequently, the macrophyte zone flow generation processes and contaminant breakdown can then be deduced from the hydrometric observations of the dynamics of soil water, and flow responses to the inflow and evaporation. It is recommended that these mechanisms should initially quantified using, physically based techniques. These techniques may be applied to the macrophyte zone in order to predict the outflow estimate and to define algorithms and methodologies for application to the macrophyte zone deterministic hydrological models.

## 9.6 MATERIAL AND STRATIGRAPHY

The landscape of the treatment facility must be characterised by a broad flat drainage system, with no dendritic drainage systems especially in the macrophyte zone. This will aim to ensure the ability for water to be spread evenly throughout the macrophyte zone. If the material conditions are constant, theoretically the floor gradients would ensure flow velocity in the macrophyte zone. The flow gradients may also be established by developing stratigraphic material units of varying hydraulic properties. For example, horizontal sandy units and be developed allowing water to build up (like sponge), spread the water throughout the unit and only flow out (at the bottom) when saturated.

Potential challenges of the macrophyte zone is the clogging of the media, which in turn creates surface flow. This results in reduced treatment efficiency since the water does not come into contact with the macrophyte material.

Experience has shown that simulation results match the measured data when the hydraulic behaviour of the system can be described well. A good match of experimental data to reactive transport simulations can then be obtained using literature values for the model parameters (Morgan, 2009).

## 9.7 DISCUSSION

Based on this very basic assessment it can be concluded that understanding parameters needs to be studied in much detail for the constructed wetland, specifically for the macrophyte zone material. The next part of this study may establish pilot scale experiments to define the achievable limits to which the constructed wetland may be applied. The pilot scale experiments would specifically assess the sensitivity of the parameters that drive the wetland objectives. A sensitivity analysis will identify the model parameters that would be understood in greater detail and considered of importance during water flow simulation. The pilot scale experiments would assess the parameter sensitivity comprise by making changes to the macrophyte zone hydraulic parameters and examining the subsequent changes in the output.

These results can then be used to assess changes to input parameters of the modelling in and assess the output changes which will be indicative of the parameter's sensitivity. Thus the modelling could be made simpler if a parameter hierarchy and effect could be identified. The sensitivity of a parameter can be placed higher on the sensitivity hierarchy depending on its effects or how much the parameter changes.

# 10 COMMUNITY ENGAGEMENT – APPROACH WITH STJWETLA

Preliminary visits and interactions with residents of Stjwetla together with research into a heterogeneous range of academic literature on resilience and studies of informal settlements in South Africa challenged our perception of the fundamental issues and the selected methodology. In particular, the technical design approaches such as the presented in this study above, ultimately fails based on all the factors identified in so many research and literature. Armitage (2011), presents all these factors and challenges and possible suggestions, but it is clear that collective action from Stjwetla themselves is required for complex dynamics of informal settings. Water problems in Stjwetla have social and technical components and can be conceptualized through paradigms such as the complexity systems (Malulu, 2016).

The challenges faced by the community of Stjwetla extend beyond water-related issues and require wider perspectives to designs and deeper involvement of communities for better use and applicability in the future. During the inquiry, community members have shared viewpoints and made apparent a number of intricacies in the interaction between lack of rights, flood risks, migratory pressures, and access to water which has so far been dismissed in the official discourse. This study illustrates how the connections of prevalent system dynamics topics in Appendix A. Furthermore, it has become more evident that local government does not have the capacity to service informal settlements like Stjwetla adequately, hence leading to more uncertain future. For example, the study carried out for the City of Johannesburg by Bisnath *et al.* (2015) for the development of an integrated rehabilitation and management plan for the Jukskei River Alexandra. Bisnath *et al*., 2015 considered water sensitive design principles as part of their management approach. The study proposed the relocation of the majority of the people from Stjwetla for the establishment of an eco-park. "Whilst the scope of this project is focused on capex interventions, it is imperative to keep in mind that for a more holistic rehabilitation approach, other operational interventions will have to be included in order to address the above mentioned aspects and to address other socio-economic issues (such as service delivery) from which many of the environmental issues arise which are aiming to solve in the first place. Failure to include operational interventions in the rehabilitation of the unit may result in a reverse of some of the problems that have prevailed." From a local government perspective, they would have ticked all their boxes. But the only real guarantee is that the City of Johannesburg will repeat these processes in the future with a different consultant. The author of this study is also guilty as the proposal of a passive treatment facility certainly adds some understanding towards a potential option, but this will not be a reality under the conditions presenting throughout this study.


**Figure 39: An "eco-park" proposed as the intervention (Bisnath et al., 2015)**

Research is indication engagement activities are more successful when aligned with the communities' existing knowledge therefore, identifying community knowledge about water related issues is an essential precursor (Parkinson *et al.,* 2007). One very important question that needed to be examined out of this study is 'what is water knowledge and subsequently what determines water related knowledge' particularly in the context of Stjwetla. Ideas towards water sensitive settlements presented in this section aimed to;

- Assess Stjwetla resident's water-related knowledge and examine the individual and contextual challenges/factors that influence this knowledge, ultimately their water-related attitudes which can then subsequently influence water sensitive behaviours.
- It is also widely recognised that the management of such systems requires an iterative, 'learning-by-doing' approach that is spontaneous in nature and builds learning into the next management cycle. We suggest that any attempt to define and implement viable and effective ideas towards water sensitivity, as well as rehabilitation measures, requires understanding that are complex systems showing the aforementioned characteristics. As a consequence, an adaptive management approach appears best suited to such complex systems (Fitchett, 2013)

## 10.1 STJWETLA SOCIAL LEARNING INQUIRY

Armitage et al. (2010) argues 'the effort to combine science with local and traditional knowledge to solve problems in which neither science nor local knowledge is sufficient by itself'. This leads to the 'adaptive' dimension of this approach; in environments sensitive to internal and external change, the management system that is generated from this shared knowledge needs to have feedback loops to be able to test and correct the new management systems. Underwriting this is a commitment to monitoring and evaluation, which feeds into the collaborative governance framework; a continuous learning circle. Therefore, adaptive co-management can improve risk management in the face of climate variability and other unpredictable external or internal factors (Armitage et al., 2010).

Social learning can be summarized as learning together to manage together (Rittel *et al.*, 2005). It means learning by the different governmental and non-governmental stakeholders to manage the issues in which they have a stake. This project considered a range of familiar cultural activities including the performance of song; dance; poetry; plays; story-telling and forum theatre. These activities engage communities, and their involvement allows them to personalize the associated water risks such as flooding, contamination associated with health and scarcity ultimately, assessing what are the required skills to manage these water critical situations. In this case, exploring theatre as one of the facilitation tools was used to help community to discover their own voice and listen to their own thoughts.

Social tools and methods were used in this part of the research which also employed a novel approach to water planning. Social learning programmes have the potential to generate a new understanding about innovative practices within Water Sensitive Designs through an inclusive approach to planning.This section describes the rationale for the study, the project design intentions and realisations, and the reasons for researching social learning in contexts water challenges for Stjwetla. The study aimed to test the water challenges presented by a social learning approach for science (as a form of practice) and society in the sustainable management context of water. Social learning implies that the different stakeholders learn to resolve these issues (content management). To do so, they have to relate to each other (social involvement). They have to come to a shared understanding of the problems at stake and the system to be managed, agree on a solution and ensure that the solution is implemented. The outcome of social learning is water management that better serves the interests of the different stakeholders (technical qualities). Moreover, stakeholders may feel more engaged, new skills may be acquired, new knowledge and insights may be obtained, trust may develop, relations may improve and institutions may change (relational qualities). This, in turn, changes the natural context and may improve management capacity (feedback). This process is illustrated in Figure 40.

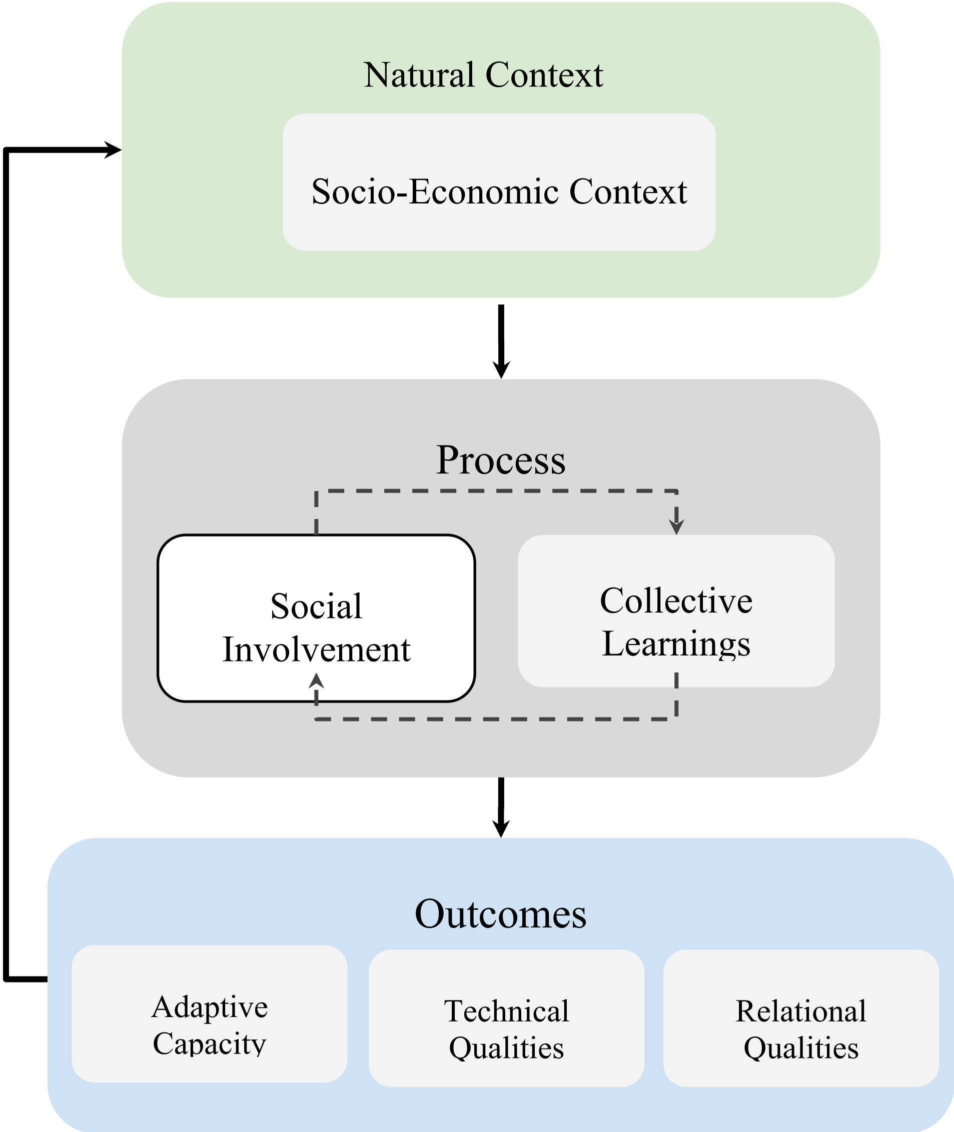


**Figure 40: Outline of the social learning process**

## 10.2 PARTICIPATORY APPROACH

Despite a near universal recognition that participatory process planning are a desirable policy goal for both water sensitive cities and the upgrading of informal settlements program, there is less certainty about what this might mean in practice, especially relating to sustainable development goals on how to simultaneously increase social equity and protect the environment. The participatory process in the literature still entails a plethora of terms such as social learning, social capital, networks, multi-stakeholder processes, soft systems, community, institutional development, and innovation systems, to describe its features. What all of these terms emphasise is that social outcomes also depend on agreement, negotiation, conflict, empathy, compassion, solidarity, reciprocity, power sharing, rules and collective wisdom. Human reasons for action are seen as important as are natural causes and rational choices.

Community workshops were aimed at behaviour and social change to build community resilience on with main topics related to water. These workshops took place in Stjwetla at the

Green Village hall. The workshops were structured in a way that participants worked in a big group and later in smaller groups. A couple of workshops held were used to introduce for welcoming participants and giving them orientation of the workshop as well as introducing the Macroscopia team. The workshops offered participants a platform to shared their issues of concern that inform the workshop processes and to create an enabling space for the participants to share life experiences. It is important to recognize the main goal of this research was to contribute to actual problem solving within the community, not to test theories of collective action.

This transdisciplinary initiative uses a mixed method approach ranging from the use of applied theatre to community mapping as facilitation tools for dialogue. It proposes new opportunities for sustainable designs approaches, building community resilience and promoting human development more broadly. The workshop look at how this community can build resilience, harnessing the community's knowledge, experiences and their proven adaptive capacity to promote and actively engage various knowledge communities in collective dialogue and action.

Critical Thinking – We carefully and cautiously chose interventions that enabled participants to assess their situation and to think critically about nurturing space for the new behaviours to take place through role play and other interactive methods barriers to behaviour change.

# 11 A RESILIENCE PERSPECTIVE

When this study commenced the recent floods of 09 November 2016 which had a devastating impact on the people of Stjwetla real. Macroscopia Labs presented workshops on resilience to flooding which was seen crucial for ideas towards water sensitive design. The workshops were particularly gear towards working with the residents situated at the banks of the Jukskei River. These residents are at risks of being affected by the flash floods adversely every year with no alternatives. The project is looking at how this community can build resilience towards the killer flash floods. Most of the workshop members are survivors of the floods that swept their homes and resulted in some lives lost.

Developing the capacity of individuals and communities to respond to the flooding issue and to understand how their interconnectedness and attitudes and practices put their lives at risks with the floods. More importantly what actions can they take as community to reduce the risk to life, based to the fact that Macroscopia would illustrate that due to the locations it is inevitable that they would be impacted by floods.

## 11.1 FLOODING

This flooding workshop used a mixed method approach ranging from the use of applied theatre to community mapping as facilitation tools for dialogue. It harnessed the community's knowledge, experiences and their proven adaptive capacity to promote and actively engage in collective dialogue and action. This process was designed to engage communities in knowledge integration in a reflexive manner and promotes collective actions. The area was severely affected by the November 2016 floods where more than 50 houses were swept away.

This initiative employed the use of applied drama and theatre and other different approaches including systems thinking as facilitation tools for dialogue. One aim was to achieve resilience building in marginalized communities against floods. This project endeavours to harness Stjwetla community's knowledge, experiences and their adaptation to the floods with the aim of building a health promotion framework, by developing personal skills, creating supportive environments, enabling dialogue and promoting community action. The workshops highlight the importance of bottom-up, grassroots approaches through participation in community work both from a theoretical and an empirical view.

It is evident the risks of Stjwetla flooding are high and therefore was identified as the location to determine the floodlines. The Stjwetla Informal Settlement is situated at the bank of the Jukskei River within Alexandra, Johannesburg. A large portion of the settlements is located within the flood plain and is regularly being flooded. The occurrence of the floods affected this `Stjwetla community in so many levels; it deepened the levels of poverty and poor health that fuelled widespread of diseases due to lack of water and sanitation. There have been a number of interventions from the government and other institutions;

- learning where research papers have been written;
- bridge built at the top of Stjwetla to protect the people from the floods. However, no active engagement was done with community on the ground and explain why that bridge is needed and how it protect them or even asking communities what they think is needed or can assist.

This is where Macroscopia saw a gap between the institutions of learning and the communities who gets flooded and to say how can we share the knowledge we hold/have as a community with learning institutions?  Macroscopia decided to look at other forms of innovations in working with communities to generate an effective and structured response to the flooding issue. As we worked together with Stjwetla community, what became clearer was the astounding understanding and response that came from this community once more of scientific knowledge on flooding and causes was shared with them.

## 11.2 FROM COPING TO ADAPTING

This was a first step in empowering community members of Stjwetla to actively participate in the process of upgrading their community. The Macroscopia team participated in a partnership between community members, and identified that food security is a way to cope with some of their challenges. A vegetable garden and nursery recycling project was initiated. Using 2 litre plastic bottles (waste) the community was able to develop hanging gardens which would use water and effectively drain throughout a system. There are lessons that be drawn from examining how the community are coping with the current conditions, which would be lack of resources (therefore using waste) and space.

**Figure 41: Recycling waste to create nursery**

**Figure 42: Development of the vegetable garden implemented with certain irrigation characteristics looking at water sensitive design**

The biggest lesson learnt in this study was the fact that the community garden which took a significant amount of time and effort by the Macroscopia team and the community was taken over by land grabbers for more housing. This was real lesson in resilience from the community to the facilitators of this project as ultimately there was not options to reclaim the land. The circumstance showed the realities on the ground, which has significant impact on the facilitators, however it was the community members themselves that needed to provide a support mechanism.

## 11.3 DISCUSSION

This inquiry used a mixed method approach ranging from the use of applied theatre to systemic games as facilitation tools for dialogue and collective understanding. Despite the growing recognition that participatory process planning is a desirable policy objective, the residents often find themselves excluded from these processes. This exclusion might be physical as informal settlements are often viewed as illegitimate or more subtle as the formal nature of the participatory process often favours the rationality of sometimes inaccessible professional jargon while excluding local stories. The approach of social learning is not only about eliciting additional knowledge but also aims to improving the understanding of complex interconnection that are relevant and may need to consider towards the ideas of water sensitive settlements. It also enables the different actors to better understand each other's perceptions of the problems which eventually helps to improve the relationships of actors and provides the basis for future sustainable collaboration and networking. While 'Water Sensitive Cities' and 'Upgrading Informal Settlements Program' may provide clear guidelines towards sustainable goals to achieve, these frameworks are principally developed within the research literature. The actual learnings about their applicability to diverse context can only be discovered in the 'learning-by-doing'. This often means that the community developing the framework is unlikely to be the community implementing the framework or the community affected by the framework. Such separation can lead to a mismatch both between research and management, between research and practice, and between proactive and local communities with researchers seeking to acquire rather than apply knowledge, and to produce generalizations rather than local solutions (Bosch *et al.,* 2003).

The growth of informal settlements with their unplanned and poorly serviced character intensifies the risks of social and ecological harm to their communities and to the wider urban area. While the probability of disasters occurring is high, residents often see a grim link between environmental preservation and poverty, and commonly mistrust environmentalists as elitists. Poor urban communities are often forced to make the no-win choice between economic survival and environmental quality. This is a legitimate choice in the informal context and this perception is accentuated by the illegal nature of the residence (together with the government's constitutional mandate to eradicate informal settlements) and the techno centric approach to water planning, where the rights of the people who live in these settlements often appear to be forgotten (Way, 2006).

This time and resource limited initiative illustrates how a resilience perspective can bring out additional knowledge and improve the understanding of complex interconnected problems surrounding the management of water in informal context. The followed approach also enabled both researchers and residents to better understand each other's perceptions of the problems which eventually helps to improve the relationships, the applicability of potential solutions while providing the basis for future collaboration and networking. The inclusion of applied theatre workshops in the participation process may offer new opportunities for stories and alternative voices to be incorporated in the planning process.

Lessons from this research show that approach to water sensitive designs in informal settlements should be based on local knowledge and resources, where activities and work are based more on trust that on contracts and where networks are netted locally. While these informal activities might be conceived as marginal, they occupy a central place in the economy and in the life of informal settlements with a unique ability to adapt to local conditions. Informal settlements evolve without formal planning, design, or legal guidelines and the scarcity of resources combined with compelling needs require ingenuity and alternative questions to traditional responses.

This represents a challenge and an opportunity for scientists, professionals and decision makers to imagine new ways of integrating different type of knowledge that can be synergistic rather than competing for legitimacy. The development of sensitive designs in informal settlements might provide a unique opportunity to integrate its residents in a more positive way with the wider city while strengthening local capabilities.

The need for public participation in making has been recognised through WSD and USIP but the nature of people's participation needs close scrutiny in order to see what it does and does not achieve. The social dimension is critical since the unjust society is unlikely to be sustainable in environmental or economic terms; "the social tensions that are created undermine the recognition of reciprocal rights and obligations, leading to environmental degradation and ultimately to political breakdown." (Haughton, 1999). In the planning process, inclusion is not necessarily achieved by increasing opportunities for deliberation between planners and residents, as power and exclusion reside in the process of deliberation, especially in the rigid spaces of formal planning hearings. Academic and professional jargon may remain inaccessible to residents, who grasp their living environment in terms of the flow of sensory and social interactions. So the framework of rationality may exclude softer, yet meaningful, local stories.

# 12 CONCLUSIONS

Whilst technical solutions are recommended where passive treatment technologies are the main focus in the literature, in the absence of adequate social and institutional planning and support, sustainable success is low. Solutions are often implemented without due regard to consequences, as evident in this study. The success of solutions in the developed countries, where institutional support, skilled personal capable of managing the full implementation of technologies cannot simply be translated into the informal settlements environment.

It is evident through this literature review process, that as researchers/specialists we are comfortable in our technical capabilities, which ultimately makes us work in silos of comfort. Therefore, we access the same resources (journals, articles, etc.), which allow us to develop similar conclusions. Ultimately, producing volumes of information, but no real innovation come from all this research. This study demonstrates that research in its self is very structured, and although it did become more evident that the technical solutions which may be provided in this study will never be implement we continued with the analysis. Therefore, little room is allowed for the researcher to learn and produce information that could be regarded as providing significant impact the problems and challenges of informal settings.

Project limitation, such as financial aspect, timelines do not allow researchers to challenge themselves. We ultimately produce a product but will not be an effective tool in any way or form. For example, the researchers in this study learnt better ways to communicate with the communities and learnt how to do it better next time, but finding the ability to express non-technical learnings into a technical report proved to be challenging (only to resort back to the technical aspects as a primary focus).

Water quality modelling is complex and furthermore so for informal settlements, where data is difficult to find. The lack of data is indicative of the challenges, such as no formal planning and dynamic within the settlements. To date these dynamics have been studied in some detail, however there is still no real solutions provided in the literature, particularly with regard to formal infrastructure to manage and mitigate pollution. Currently, the literature recommends treatment solutions which are aligned towards passive treatment technologies.

It is often preferable to begin with simple models when a decision, in terms of which passive treatment technology is suitable. Is it possible that the bias in the model, may be consistently bias in the solutions it provides, however still point one in the right direction? If this approach proves to be true then building up from a simple model over time, by adding additional complexity as justified by the collection and analysis of additional data. The approach is considered in this study. This strategy aims to make efficient use of resources. It targets the effort toward information and models that will reduce the uncertainty as the analysis proceeds.

Models should be selected (simple versus complex) in part on the basis of the data available to support their use. This study sets out an approach that could be considered for a detailed model design and the requirements for undertaken such a study.

A very important question that is to be examined out of this study is ‘what is water knowledge and subsequently what determines water related knowledge’ particularly in the context of that community? Therefore can the idea of water sensitive settlements be achieved and what would these be in the context of the informal settlement? A community-based inquiry was conducted with a group of residents from Stjwetla informal settlement in Alexandra, Johannesburg. As many other informal settlements, Stjwetla’s context is characterised by poor access to services, the absence of health and education facilities and unsuitable environments as the area gets regularly flooded by the adjacent Jukskei River. This social learning approach was adopted to reconnect water issues with its societal context and to be able to take into account the complexity and uncertainties associated with human, natural and built environments.

This inquiry used a mixed method approach ranging from the use of applied theatre to systemic games as facilitation tools for dialogue and collective understanding. Despite the growing recognition that participatory process planning is a desirable policy objective, the residents often find themselves excluded from these processes. This exclusion might be physical as informal settlements are often viewed as illegitimate or more subtle as the formal nature of the participatory process often favours the rationality of sometimes inaccessible professional jargon while excluding local stories.

New concepts such a WSUD must allow the opportunity to re-think the above. Can the opportunity with these ‘fresh ideas’ allow us to think of new ways to do things, since the concepts challenge researchers. Principles of WSUD is not completely new, but it affords the previously disadvantaged to be recognized and push for change and representation. Although there are just a few examples of the research related to informal settlements in South Africa, initiatives undertaken internationally recognize the need for more representation from the communities.

More localized, technology-based approaches should be developed with varying scientific solutions to help close some of the gaps/challenges identified in the literature. The community based knowledge approaches is growing, where there is increasing recognition to promote solution aligned scientific published research.

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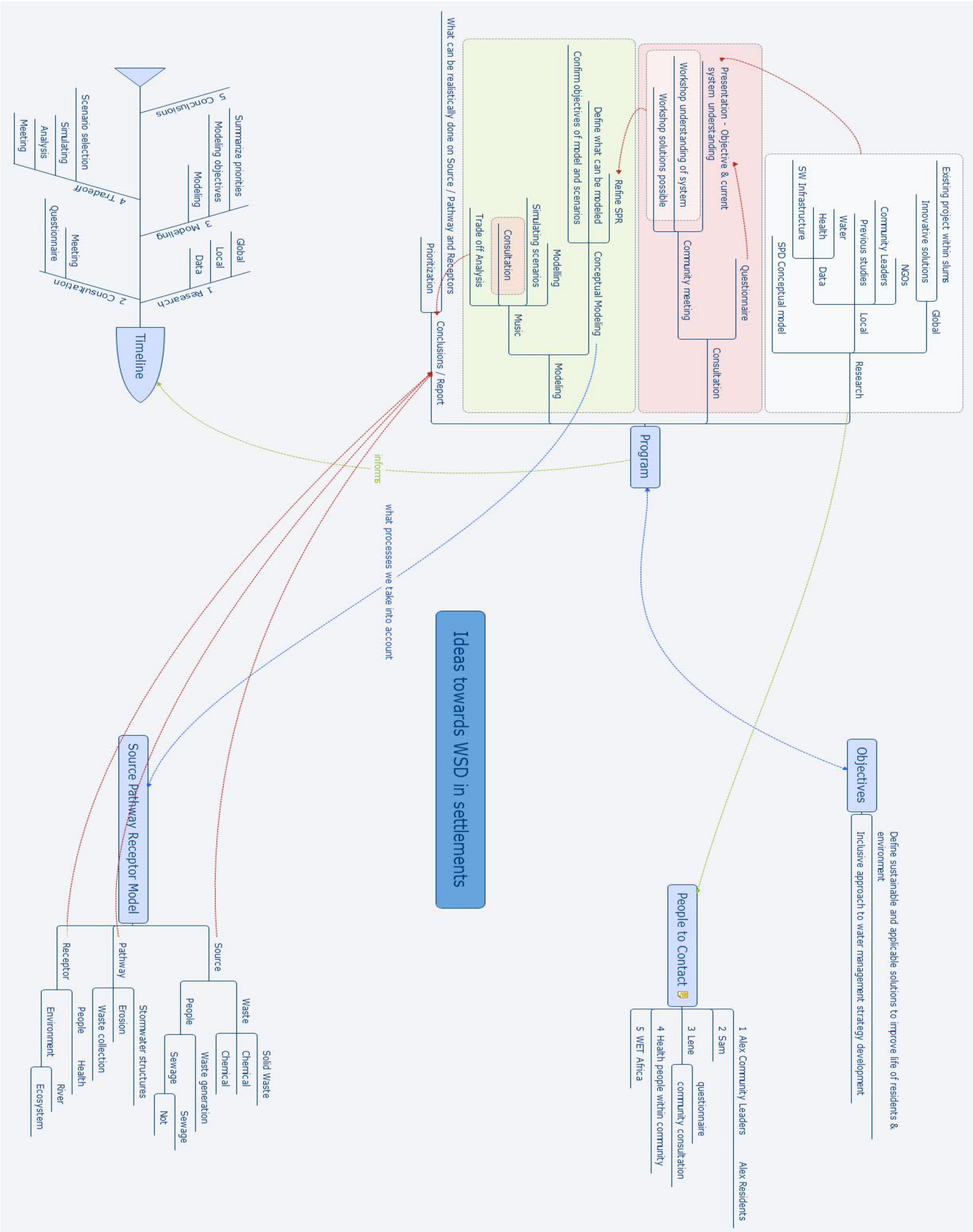
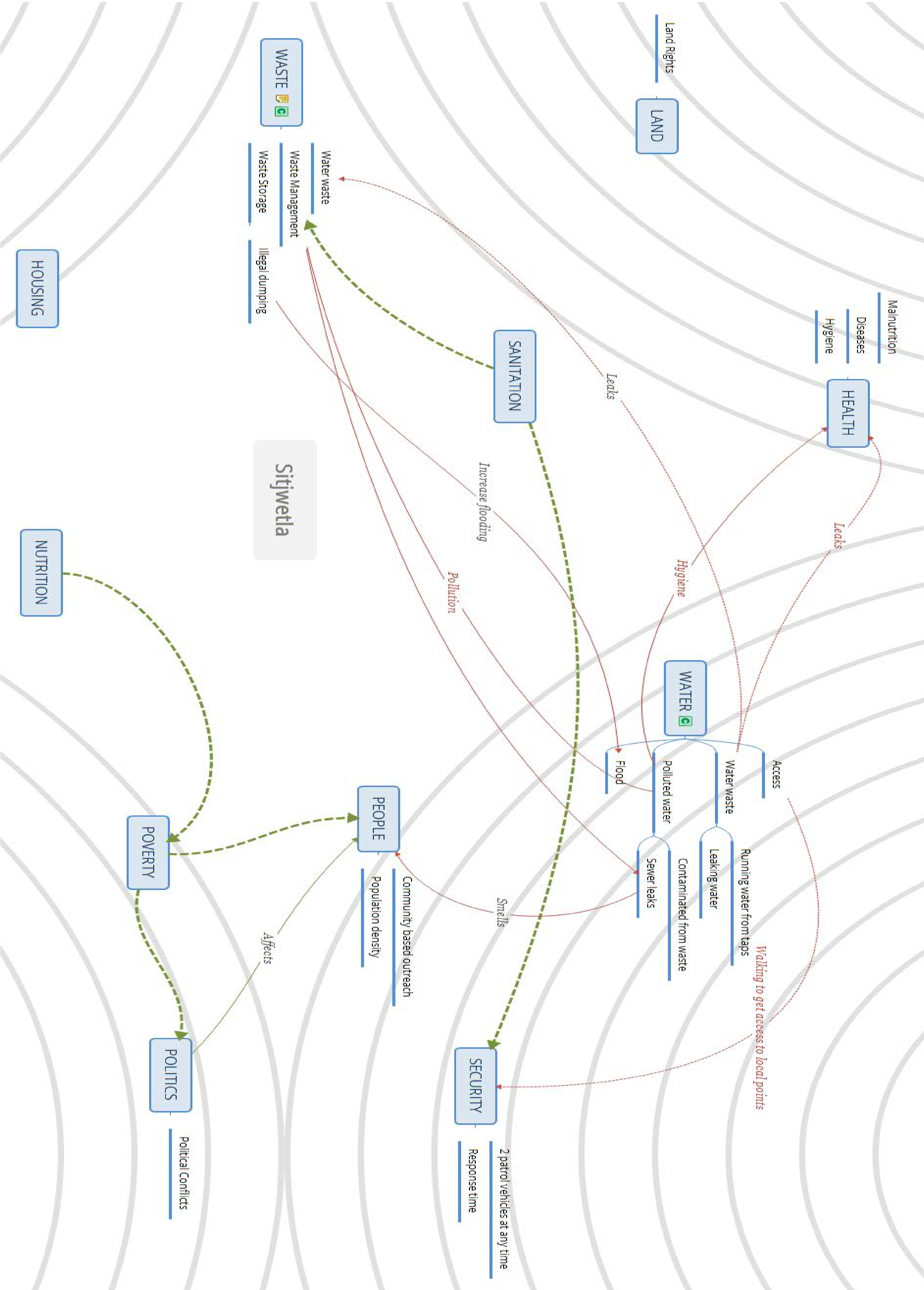
WRC (2014) Annual Report, 2013/2014, Report No. RP127/2014, ISBN 978-0-621-42728-8

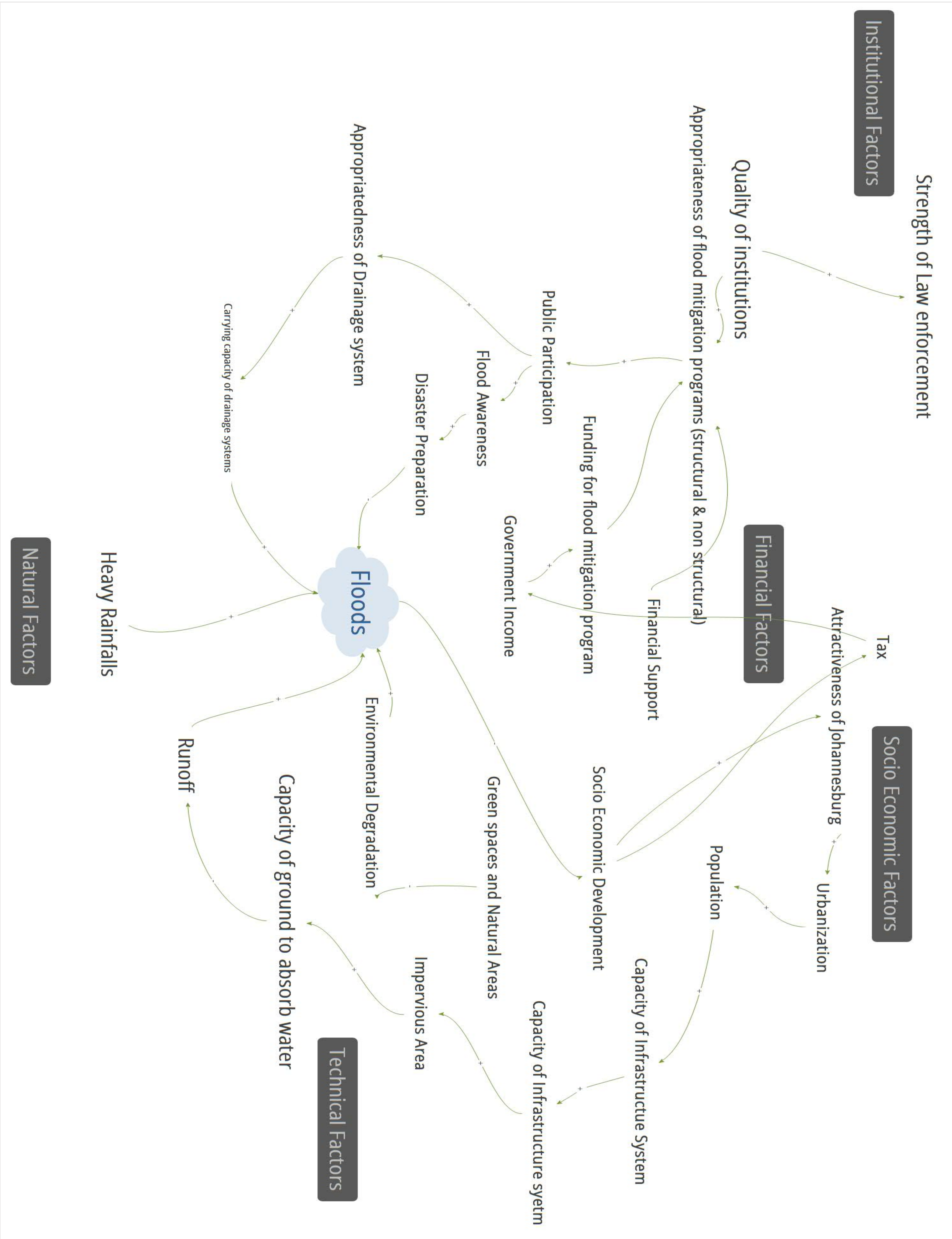
# APPENDIX A: CONNECTIVITY FLOW CHARTS



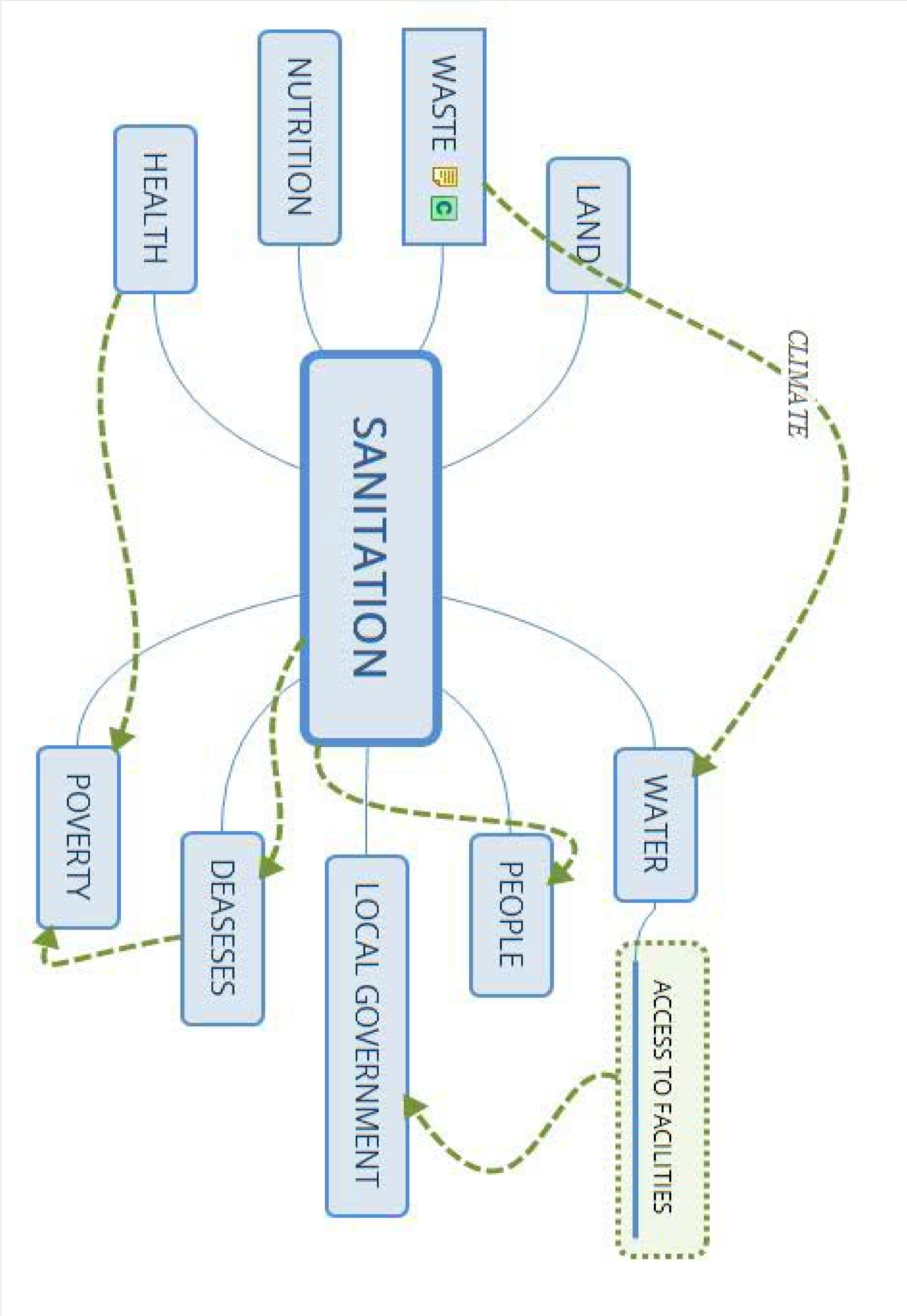

**Appendix A 1: Flow Diagram and Connections for Ideas towards Water Sensitive Settlements**




**Appendix A 2: Flow Diagram and Connections for Stjwetla**

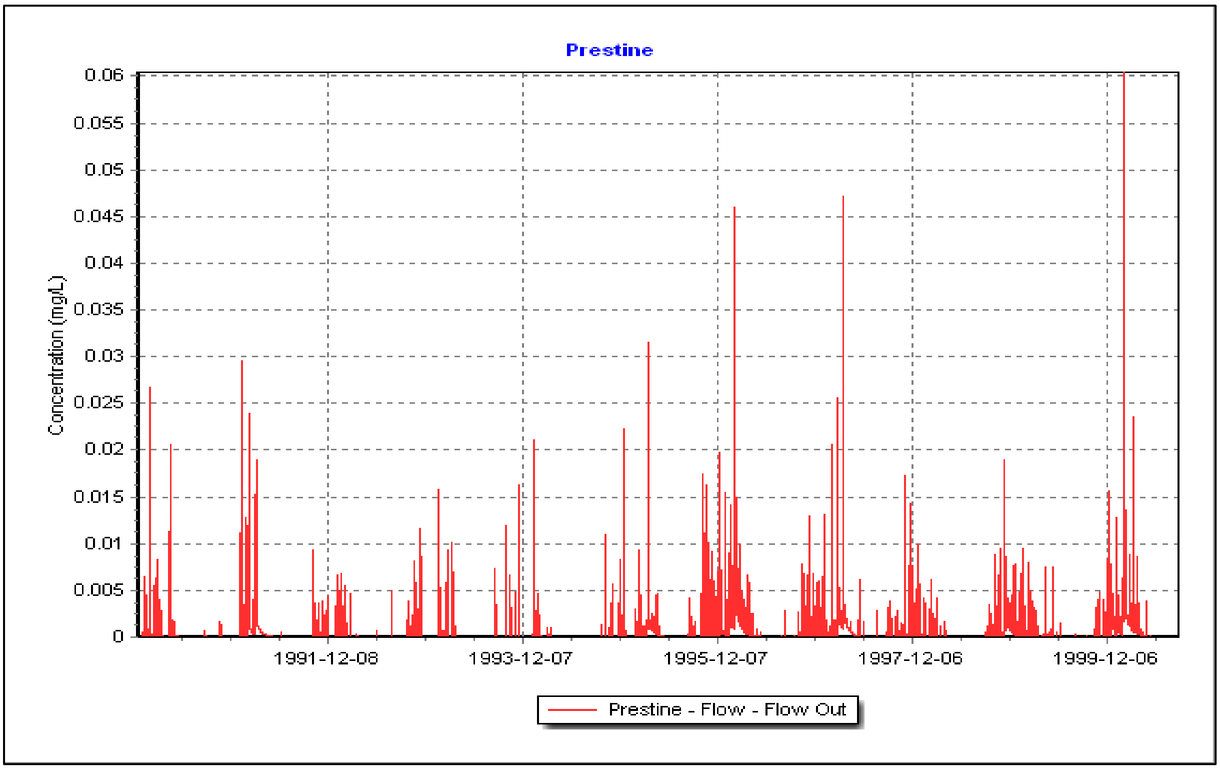


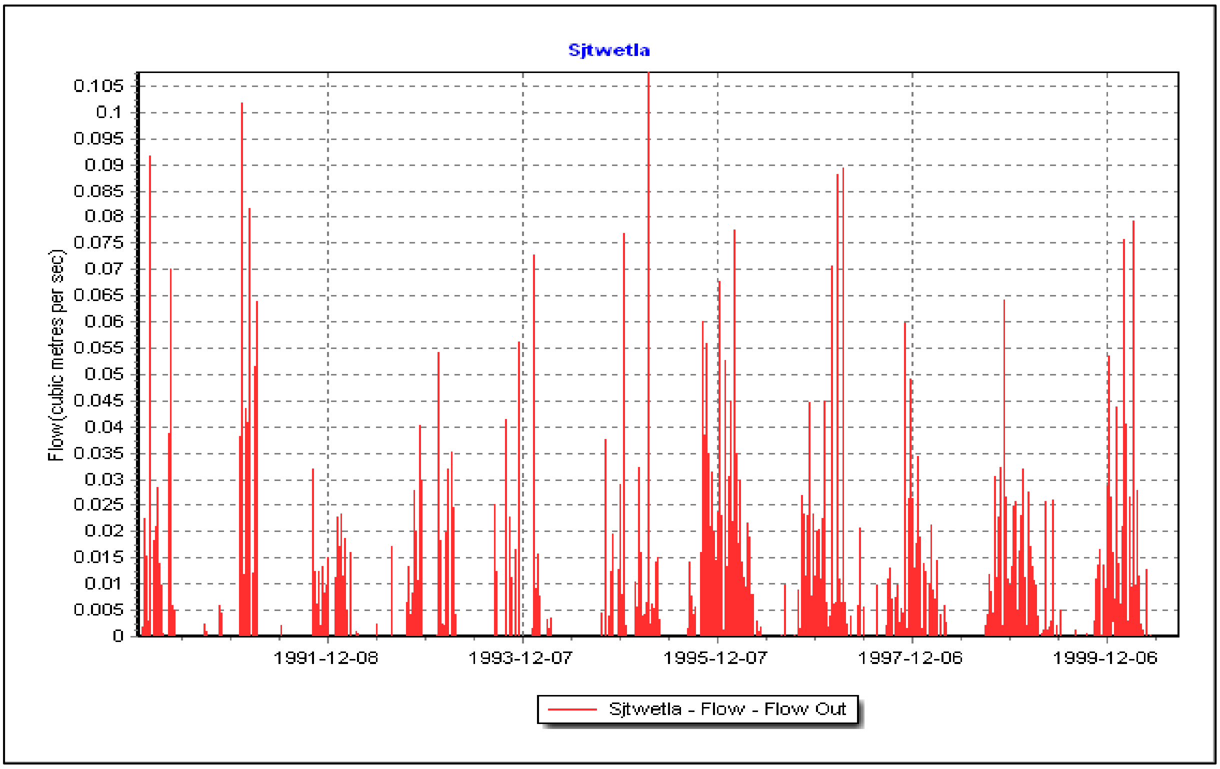

**Appendix A 3: Flow Diagram and Connections for Floods**



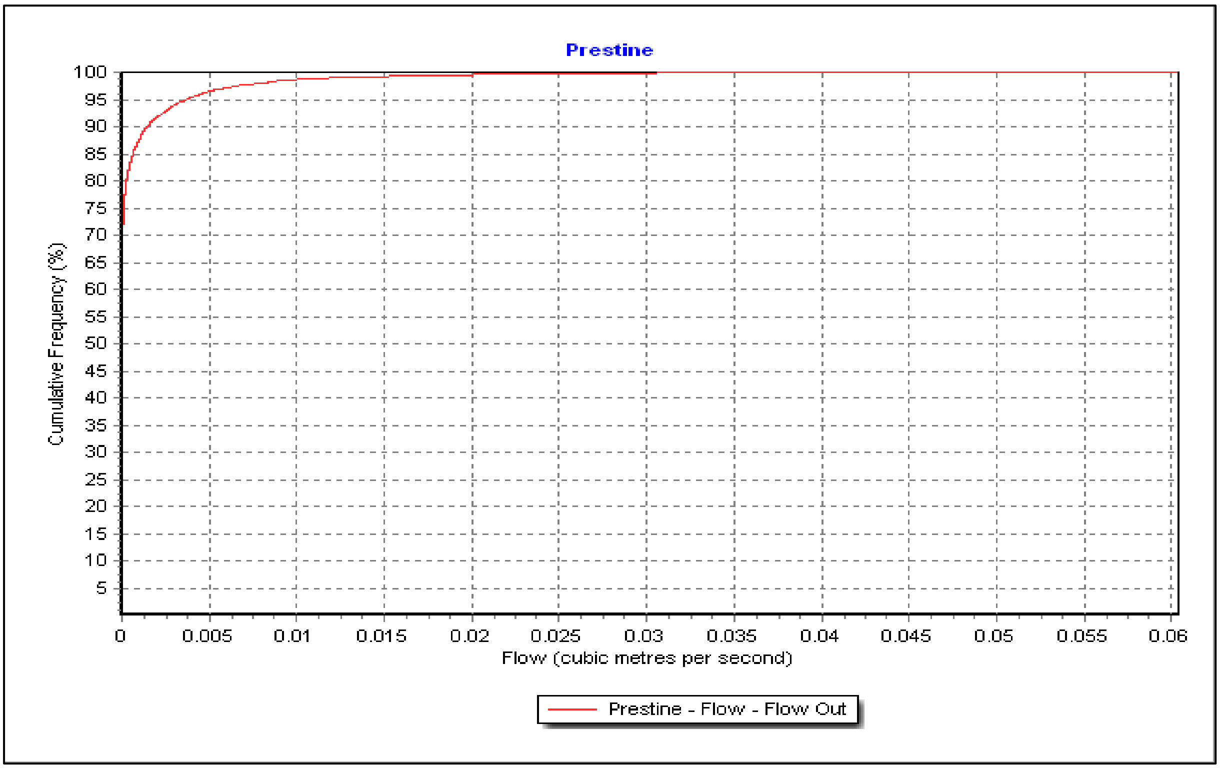

**Appendix A 4: Flow Diagram and Connections for Sanitation**

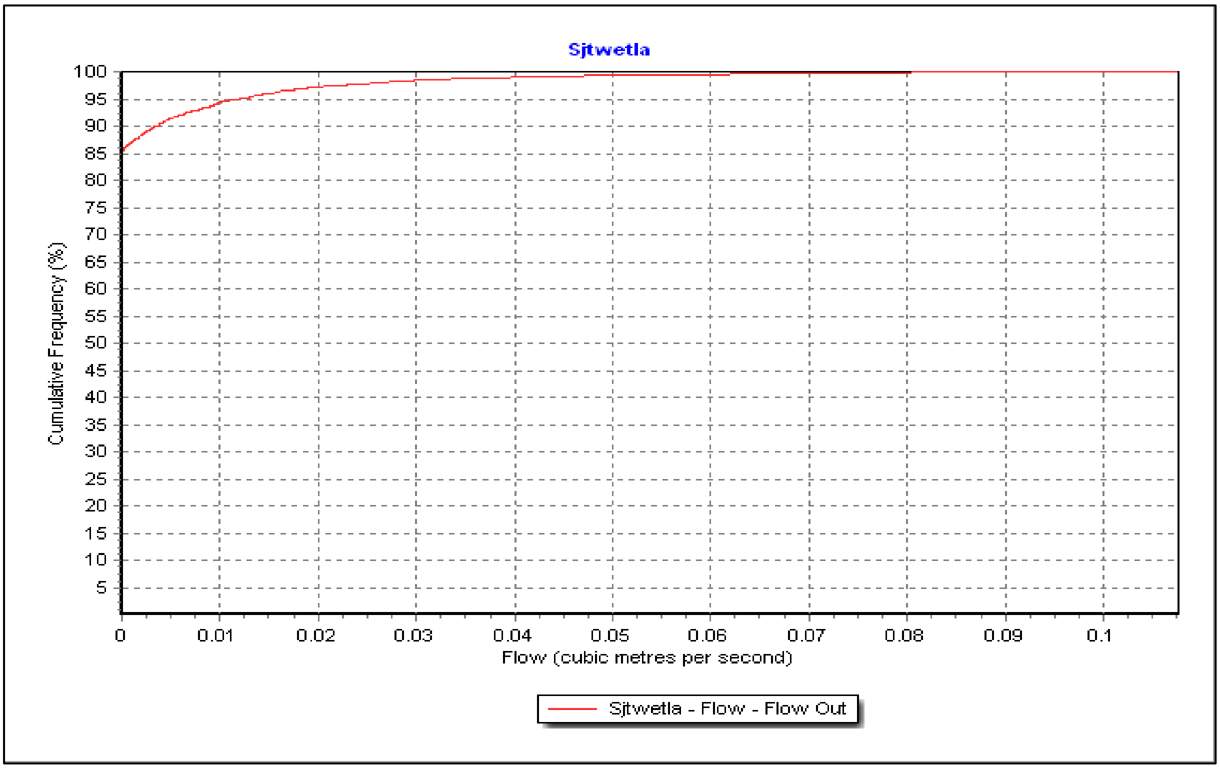
## APPENDIX B: MUSIC MODELLING RESULTS



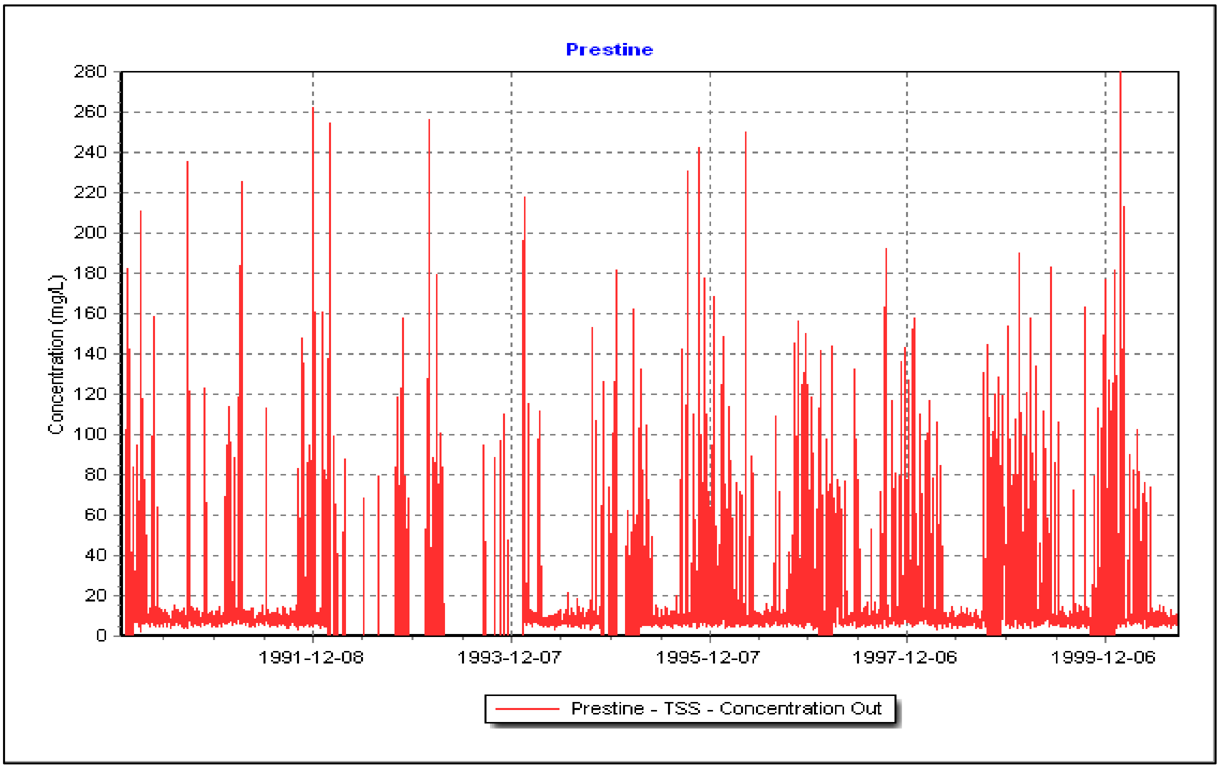



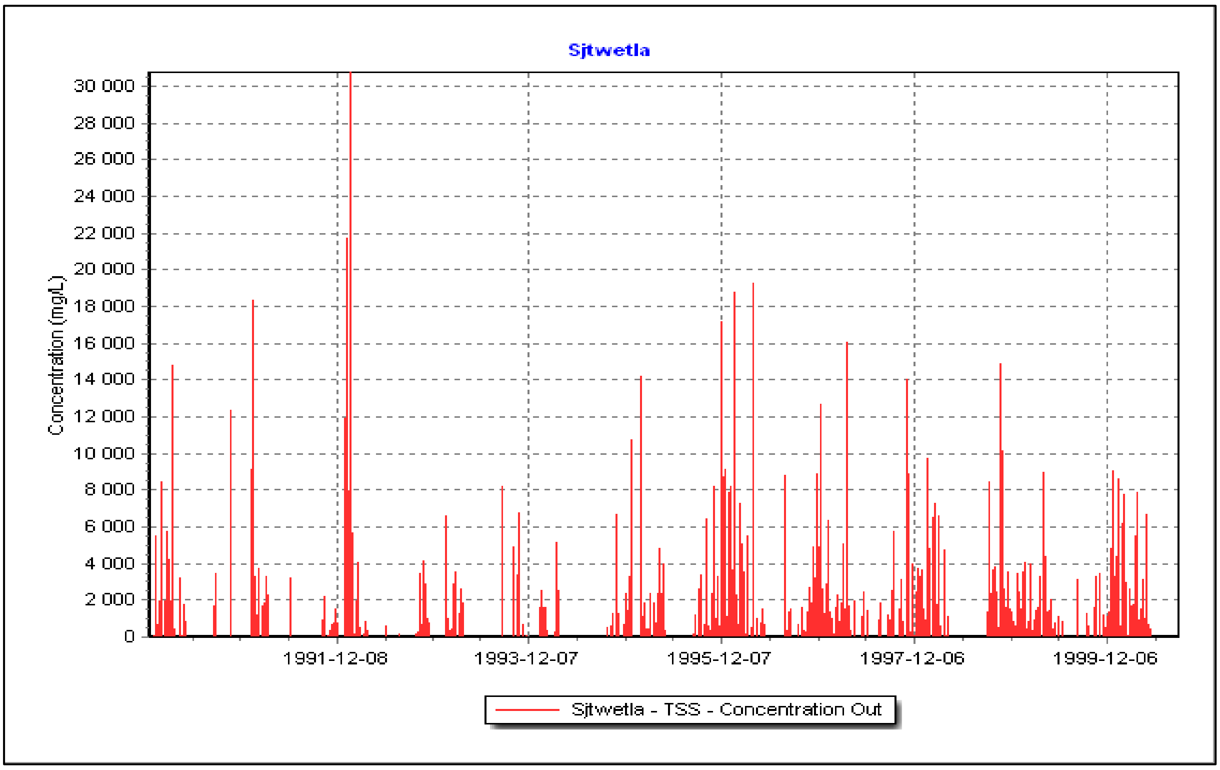

## Appendix B 1: Comparison of flows



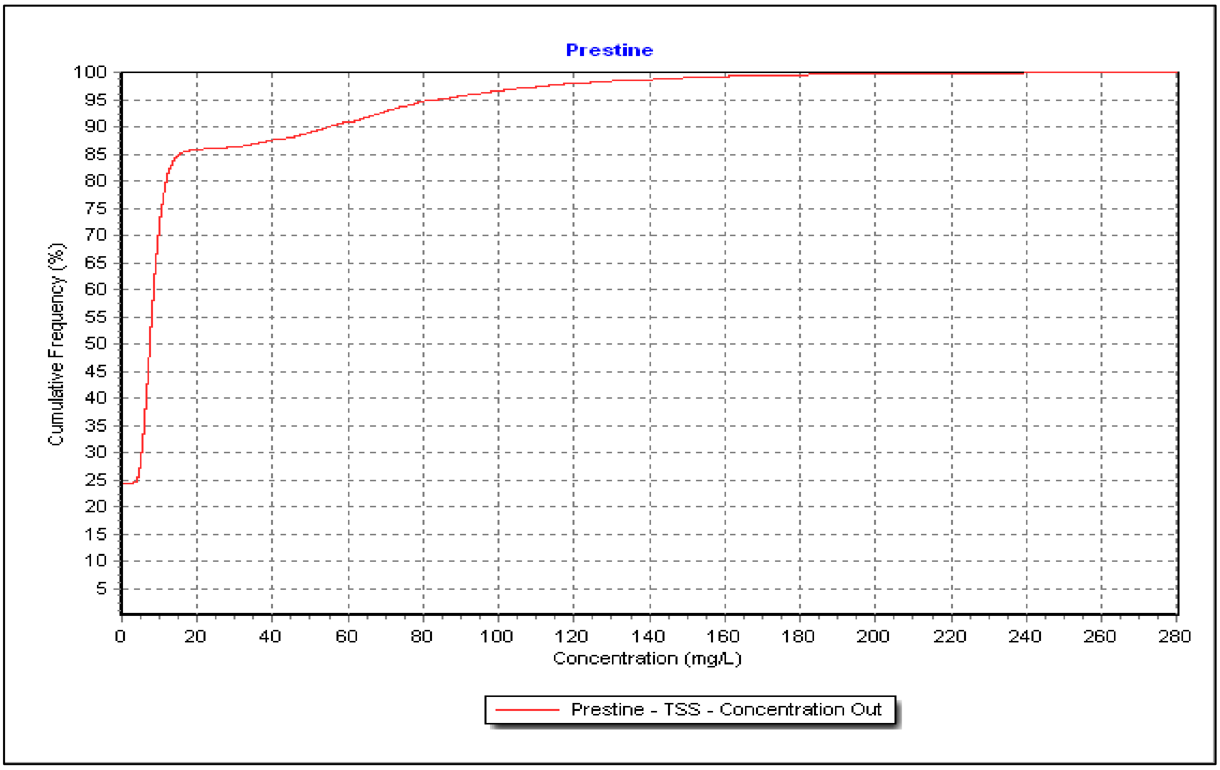



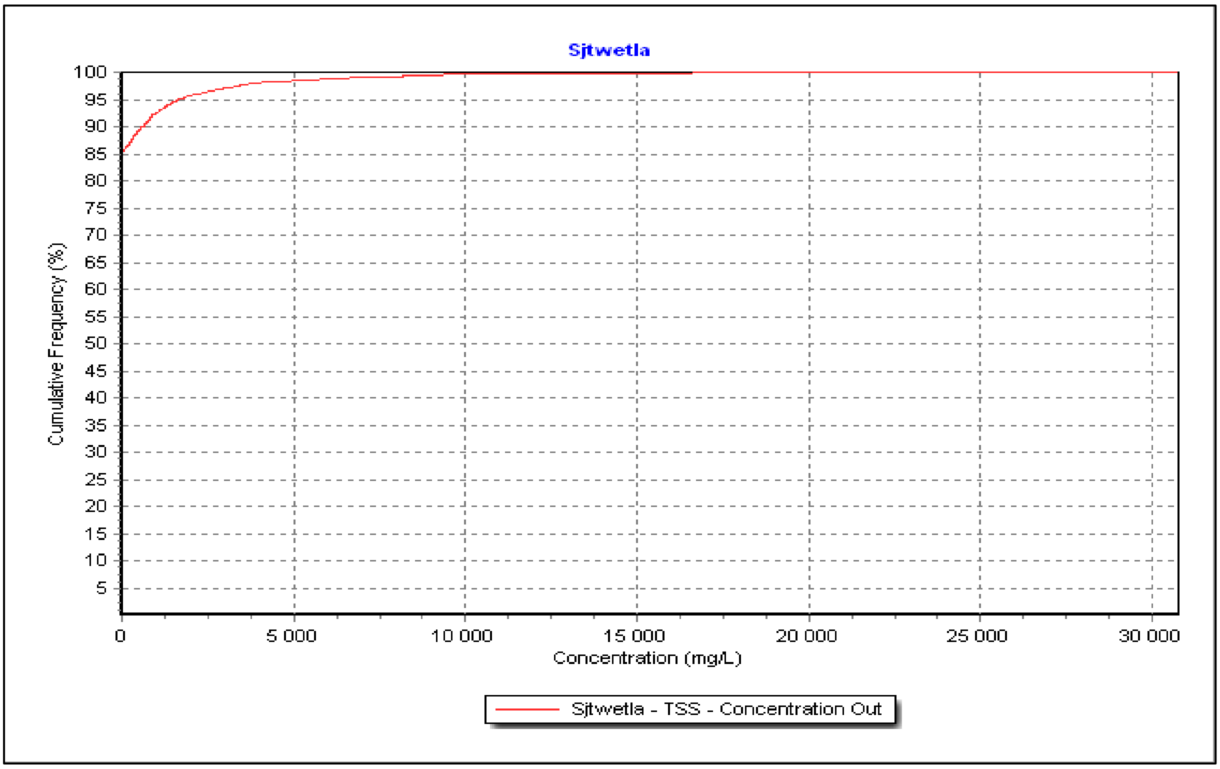

## Appendix B 2: Comparison of the cumulative frequency curves for flow



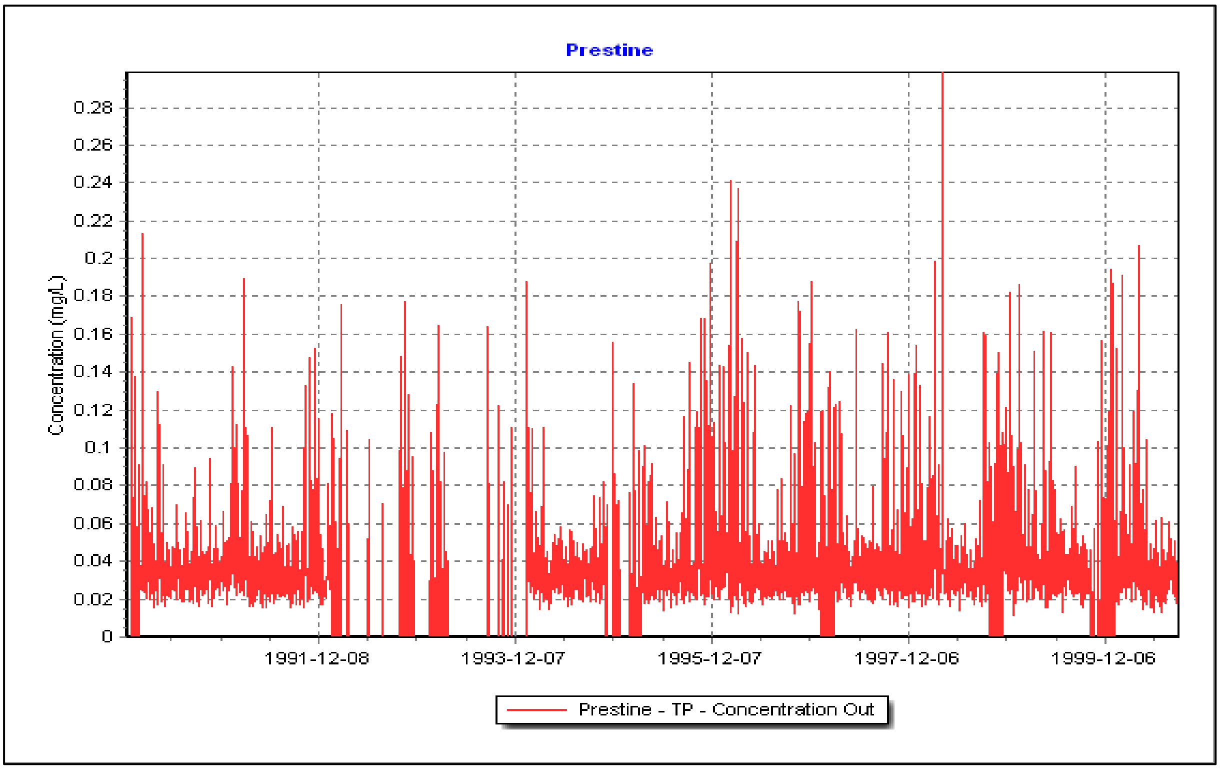



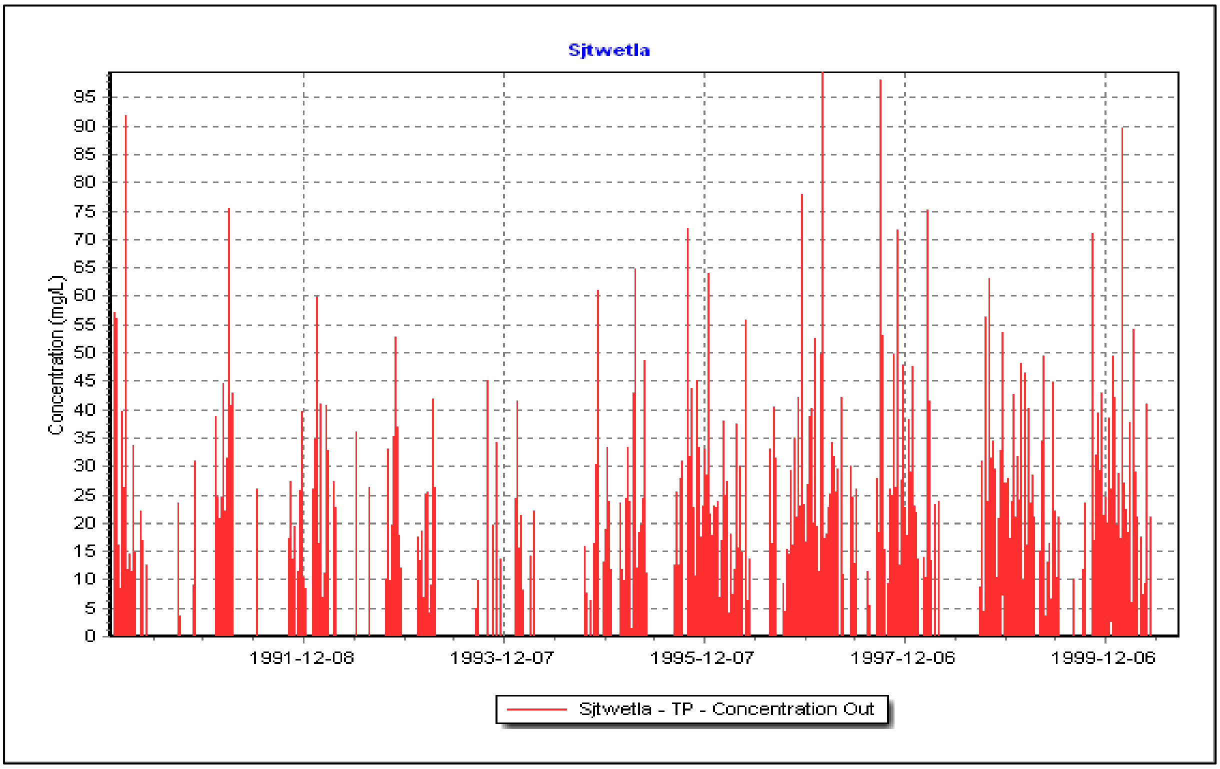

## Appendix B 3: Comparison of TSS concentrations



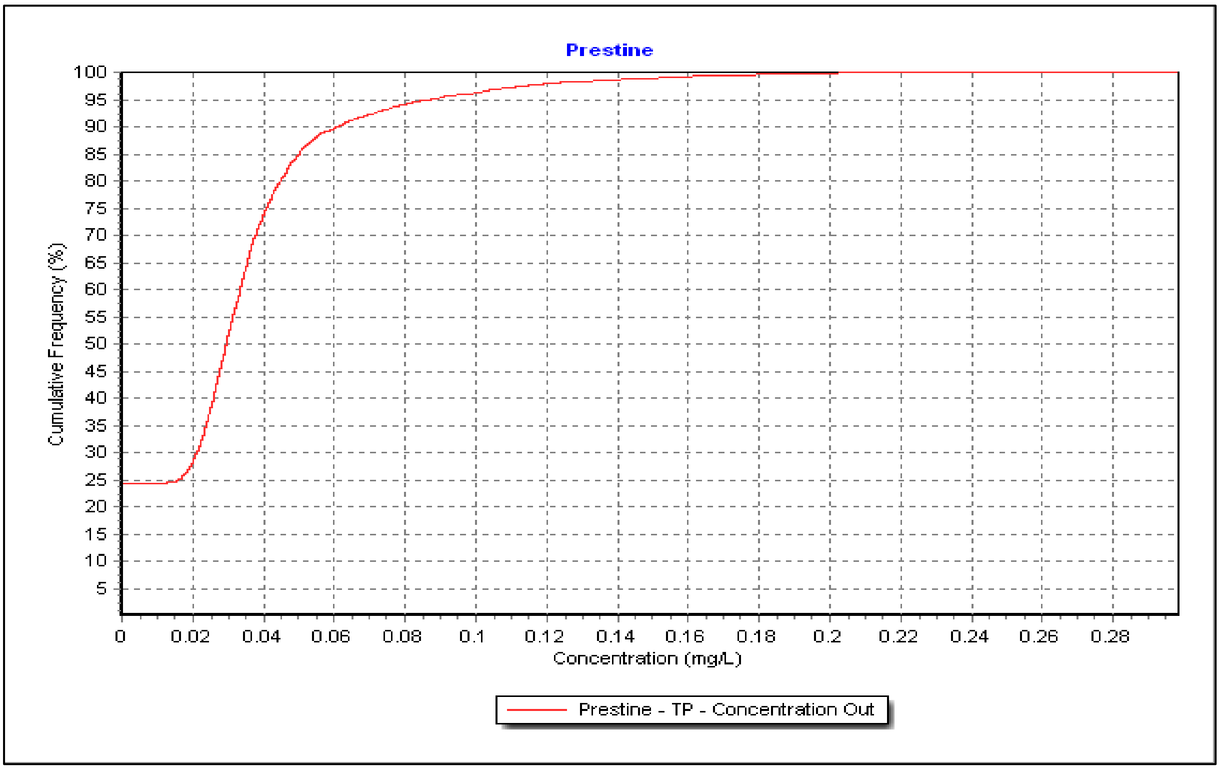



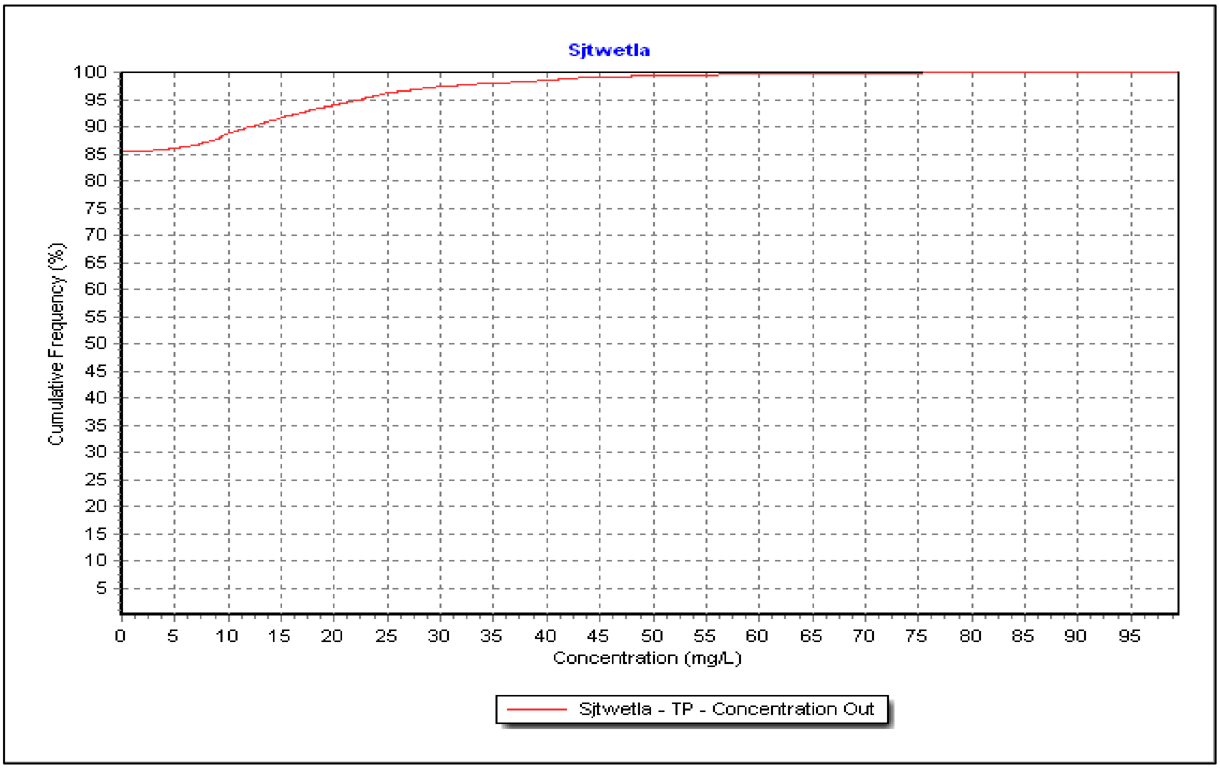

## Appendix B 4: Comparison of the cumulative frequency curves for TSS



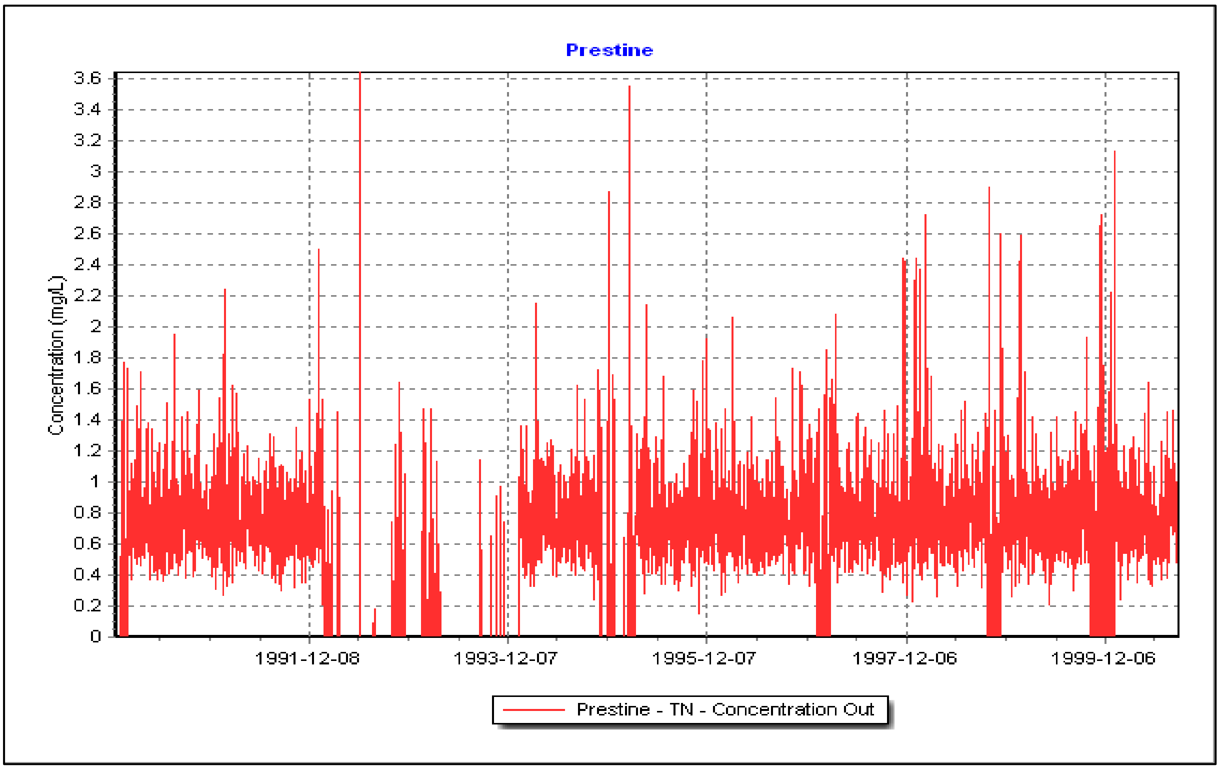



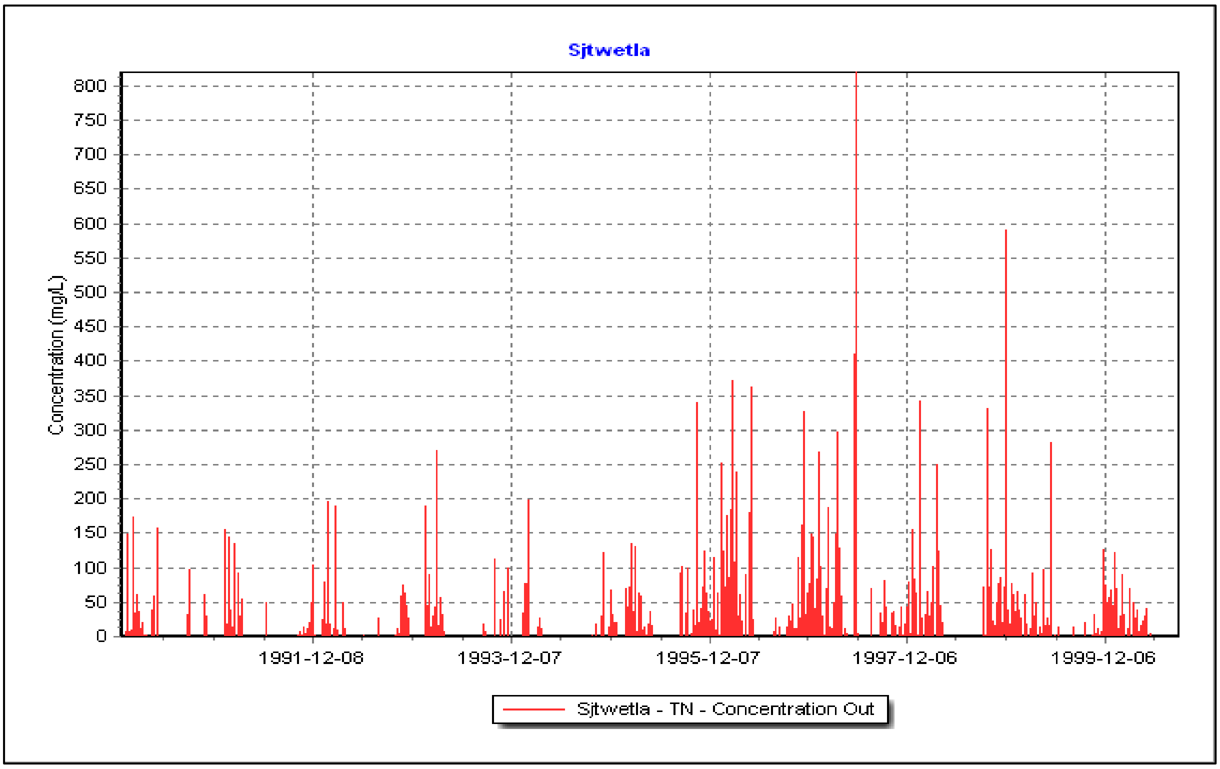

## Appendix B 5: Comparison of the TP concentrations



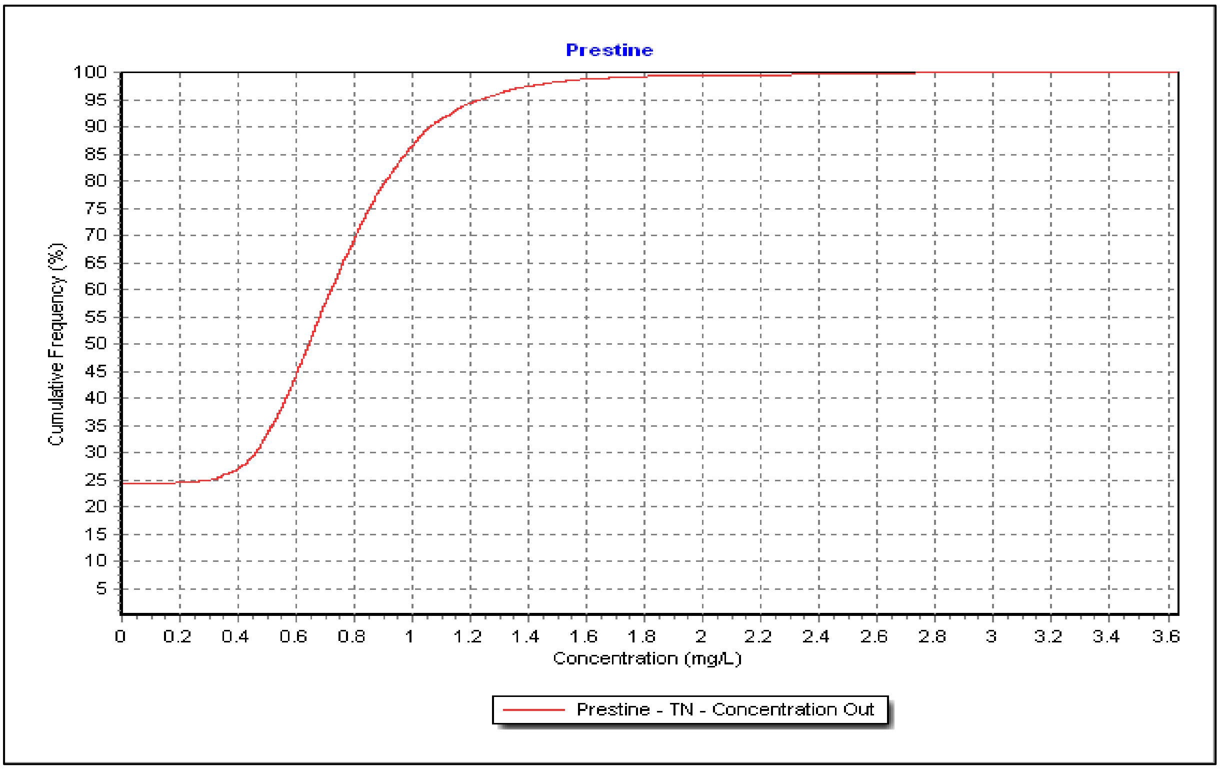



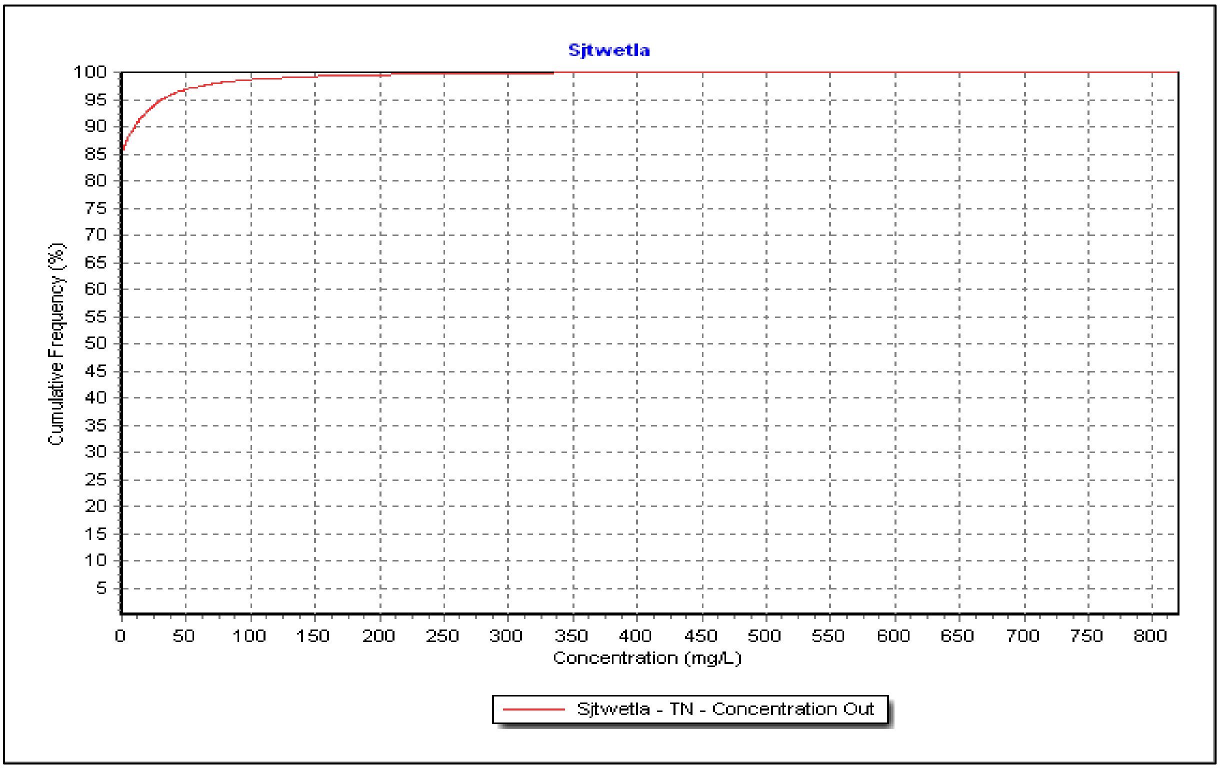

**Appendix B 6: Comparison of the cumulative frequency curves for TP**




**Appendix B 7: Comparison of the TN concentrations**




## Appendix B 8: Comparison of the cumulative frequency curves for TN