Response of urban and peri-urban aquatic ecosystems to riparian zones land uses and human settlements: A study of the rivers, Jukskei, Kuils and Pienaars

Report to the

Water Research Commission

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Executive summary

The negative impacts of land use on aquatic ecosystems have generated conditions that are conducive to the devastation of goods and services emanating from water resources. In South Africa, the problem has been at its worst in urban and peri-urban areas where settlements and other land uses developed over several decades during which environmental legislation was absent. In more recent years, when legislation has been enacted, weak monitoring and enforcement has perpetuated the degeneration of goods and services emanating from aquatic ecosystems. The degrading land uses include industry, mining, agriculture and human settlements. In more recent times, starting in the mid-twentieth century, the rate of aquatic ecosystem degradation escalated due to the establishment of land uses in close proximity to, or on riparian areas to wetlands and other sensitive parts of the aquatic ecosystem. The use of sensitive riparian areas in urban and peri-urban areas has been due to high rates of urbanisation, which is driven by the community's need for socio-economic improvement, while municipal service provision is not increasing at the same pace.

Early industrial and mining practices in South African urban areas set the scene for environmental degradation including the extensive aquatic ecosystem damage that has affected most water resources over the years. The influences from historical mining practices, coupled with the lack of legislation to protect the environment, as well as limited knowledge of the long-term impacts of historical economic practices, have created conditions where prolific damage to aquatic ecosystems has persisted over a long period, exceeding 150 years in the case of the Kuils and Jukskei catchments, which were two of the case studies in this research.

The impacts of the above-mentioned land uses have been escalated by the development of human settlements and other associated land uses on riparian areas. The establishment of numerous informal settlements increased rapidly after the end of apartheid in the 1990s. The mushrooming of informal settlements on sensitive ecosystems has been blamed on past land use practices, settlement legislation, policies and social engineering that sought to segregate and exclude the majority of people from planned settlement structures. Past legislation such as the *Natives Land Act,* Act 27 of 1913, the *Development Trust and Land Act,* Act 18 of 1936 and the *Black (Urban Areas) Act,* Act 21 of 1923 laid the foundation for the establishment of 'locations' for black people in the peripheries of towns and cities. There have been frequent instances when communities did not have access to land or housing and had to use any

identified open spaces and risk forced removals. This has resulted in settlements on riparian areas, wetlands, river banks and other sensitive ecosystems, which had not been demarcated for settlements. In addition to their environmentally precarious locations, the informal settlements were not provided with water and sanitation services, a situation that exacerbated the degradation of the aquatic ecosystem when surrounding areas were used for waste disposal and polluting water uses took place within the water bodies. Limitations in legislation for protecting the environment were also instrumental in how settlements were created, with devastating consequences to the environment. In the absence of environmental legislation, the establishment of past settlements did not take into consideration any possible adverse effects on the surrounding ecosystems; rather, settlements were established out of necessity, or in response to land ownership laws passed to ensure segregation of groups from one another.

Given South Africa's discriminative practices of the past, the post-apartheid Constitution has made provisions to address the plight of those without or with poor settlement dwellings. National legislation stresses that once informal settlements have any form of structure that residents call a home, these residents can only be relocated to another area if the owner of the land or the responsible authority can provide suitable alternative shelter. The *Prevention of Illegal Eviction and Unlawful Occupation of Land Act,* Act 19 of 1998, requires due process to be followed before any eviction of communities with formal or informal structures. These legislative measures have tended to maintain the continued existence of some settlements that are located in riparian areas and other sensitive ecosystems.

Apart from informal settlements, formal settlements are also a source of aquatic ecosystem degradation. Historically, formal planned settlements in urban areas were located close to water sources. These settlements expanded until they covered a large area of rivers and riparian areas. During developments in these areas, most of the rivers were canalised, piped or blocked to form dams. Underground water pipes were also laid to drain the area and accommodate the erection of buildings, road services and other urban infrastructure. This resulted in major hydrological changes to many rivers, loss of riparian areas, loss of goods from the water body, as well as loss of other river, wetland or water body functionality. Further damage in planned settlements has come from effluents from industries and wastewater treatment plants, and in some cases, return flows from gardens and irrigation lots. Wastewater treatment works (WWTW), which are some of the most polluting establishments in urban and peri-urban areas, were established in formal areas to treat wastewater from domestic and industrial uses. Effluent from WWTWs generates new flows in a water system and persistently loads nutrients and associated bacteria into the receiving natural water channels. The population in most urban settlements has been increasing as people migrate into these areas, where they hope to secure employment or better livelihoods from nearby sources of opportunities. The results of increased population have been overloading of wastewater and sewer pipes, which tend to suffer frequent bursts thus polluting affected water bodies with sewage effluent.

Many central business district (CBD) areas in formal settlements contribute to river degradation, especially in the form of physical degradation. Litter and other physical elements of degradation that result from the development of infrastructure or other human activities are carried into rivers through storm water and contribute to the prevailing conditions. The impacts of urbanisation and human settlements on aquatic ecosystems can be summarised as listed in Table i below:

Table i: Major impacts of urbanisation on aquatic ecosystems (Adapted from Ekurhuleni Metropolitan Municipality, 2003)

Hydrology	Morphology	Water quality	Habitat and ecology
Increased frequency of erosive floods	Stream channel widening and 'undercutting'	Pulses of sediments during construction activities	Shift from external to internal stream production
Increased volume of surface runoff	Increased stream bank erosion	Increased pollutant wash-off	Reduction in diversity of aquatic flora and fauna
More rapid stream velocities	Shifting bars of coarse-grained sediments	Nutrient enrichment leading to benthic algal growth	Reduction in diversity and abundance of fish
Decrease in dry-weather base flow	Elimination of pool/riffle structure	Bacterial contamination during dry and wet weather	Destruction of wetlands, riparian buffers and springs
Increased erosive energy in surface flow	Imbedding of stream sediment	Increased organic and inorganic loads	High turbidity and altered aquatic environment
Flow connectivity between riparian area and flow channel is lost	Stream relocation/ enclosure/ channelisation	Higher levels of toxins and trace metals reduce oxygen	Environment becomes less habitable, aquatic life is reduced
Obstructions in the waterway create stagnant water and alter flow characteristics	Stream crossings form fish barriers	Increased water temperature and accumulation of pollutants	Aquatic life diversity is distorted due to concentrated pollution in sediments where some aquatic life is based
Water flow in urban areas carries solid waste, other trash and debris	Water flowing with debris causes more channel alterations due to increased erosive force	Trash/debris accumulates in water	Solid waste, other trash and debris increase oxygen demand from the water, thus altering environment for aquatic life

Given the water stress in South Africa, the heavy reliance on surface water systems for most of the potable and non-potable water supply, the natural aridity of the region and the and the decreasing water quality which will be exacerbated by climate change, it is evident that South Africa cannot afford to ignore the degraded state of aquatic ecosystems, making their rehabilitation an urgent necessity.

Study objectives

This study aimed to investigate the impacts of land use and human settlements in urban and peri-urban areas on aquatic ecosystems.

To accomplish this main objective the project focused on the following aims:

- To investigate available literature and understanding from past studies and records that deal with degradation of natural resources as a result of settlements in riparian areas.
- To investigate the regulatory framework that governs human settlements, including processes associated with spatial planning as well as effectiveness of the implementation thereof.
- To investigate issues arising from the influx of people into areas that are characterised by sensitive ecosystem and infrastructural resources, including water provision, access and use.
- To undertake case studies to understand human-induced impacts on sensitive aquatic ecosystems as well as changes in ecological dynamics, particularly due to informal settlements.
- To investigate the impacts of riparian land-use activities on aquatic ecosystems' goods and services.
- To develop a framework to propose how ecological resilience can be attained, or how a balance can be struck between human settlements and good ecosystem function.

Study approach

In order to design an effective framework aimed at improving the state of rivers nationwide, this study relied first on generating an understanding of the current state of knowledge regarding the subject. A review of literature on the subject of the study was accomplished through assessing local and international publications and other available records. Records from archives and the South African history of settlements and river management were used to obtain historical context and understand how the current state of affairs was created over the years. The changes that were made in legislation and ecosystem management were also explored to determine what is possible within the provisions of current legislation as well as to understand the constraints where changes are recommended.

The knowledge gained from literature was supplemented with consultations with various role players. Stakeholders from municipalities, government and non-governmental organisations were consulted to present a better understanding of the current state of knowledge and how it is being applied in activities that have the potential to degrade the water ecosystem or to stop degrading practices. Investigations revealed gaps between the legal and institutional provisions and implementation. These gaps, which have the potential to perpetuate the current path of degradation, were unpacked in the articulation of recommendations and the way forward.

Three case study areas were used to investigate the current state of the waterways, the nature of degradation, factors surrounding issues of ongoing degradation, as well as the climate in which all this is taking place. The waterways in the case study areas were investigated in terms of water quality, nature of degradation, settlements, pollution problems, degradation of riparian areas and possible rehabilitation as well as resilience approaches. Degradation was linked to physical locations through a rehabilitation framework that was developed as part of this study. A water quality rating table was developed with a system applied to allow visual illustration of the water quality status at real life locations in the case study waterways. The rehabilitation framework also provided a platform for generating prioritised options for rehabilitation for specific locations based on the data inputs and parameters entered to characterise the variables associated with the nature of the degradation and the institution involved in the rehabilitation effort.

The aquatic ecosystem description and degradation were captured in the aquatic ecosystem rehabilitation framework, a software tool developed as part of the study. Consideration of the waterway in the framework involved sections of the waterway, called reaches, where each reach defined a section with similar degradation and for which similar rehabilitation options are envisaged. The structure of the river was described through several objects to depict the water system, the settlements in riparian areas and how they generate the degrading agents. The objects were developed in a generic format so that they can be used in different locations of the waterway and in other waterways that were not part of the case studies. The changes to be made when applying the object-oriented methodology in other catchments are minor data and parameter changes to represent the new area. In the methodology, the state of the aquatic ecosystem and its degradation were evaluated using a description of riparian land uses, water flow, and chemical, biological and physical characteristics of the affected water. Recommendations regarding the nature of redress were identified and entered in the framework based on the overall state of degradation of each river reach. The methods were developed with the aim of extending the use to other catchments that were not part of the case studies.

Findings and analysis

The investigations showed that urban rivers in the country are in a degraded state. All the case study waterways have been degraded beyond a tipping point or ecological threshold. These water bodies no longer have the capacity to recover from degradation using natural processes, and they have also lost all their resilience and integrity. The investigations in the case studies showed that human settlements, whether formal or informal, tend to have adverse effects on river health, contributing to physical, chemical and biological degradation. Of all forms of riparian land uses, informal settlements and waste water treatment works were found to cause most of the pollution that has damaged the rivers and the associated riparian areas. In most instances, the river channels have already gone through many alterations over the years due to work associated with establishment of land uses, especially human settlements in urban and peri-urban areas.

The nature of degradation observed and analysed in the case study waterways can be characterised into physical, chemical and biological, as discussed below.

Physical degradation

Altered channels: All three case study rivers had river sections that have been converted into manmade canals, tunnels, culverts and pipes. This is most evident on the Jukskei and Kuils Rivers.

Altered hydrology: The flow volumes are increasing in all the case studies. In all cases the settlements are supplied with water from another catchment area and then the grey water or return flows are released locally, thus supplementing the volumes from local precipitation. Over the years, increasing effluent from developments in the Kuils River catchment has changed the flow of the river from ephemeral to perennial.

Erosion: Increased flow volumes have resulted in increased incidences of flash floods as well as increased hydraulic energy in the water, which translates into higher erosive forces. Riparian areas as well as river channels have been physically degraded due to the flow.

Waste: The concentration of solids in the waterways, and other pollutants associated with humanactivities, has been increasing. In the Pienaars and Jukskei Rivers, the volume of floating trash from informal solid waste disposal sites located in the river channels and on riparian areas has been evidently increasing. In all the case studies, the concentration of bacteria loads and nutrients in waterways has been increasing more rapidly in the past ten years. This includes the concentration of phosphates, sulphates, nitrates and nitrites, as well as the bacterial load as observed through coliform counts for E. coli and faecal coliform.

Colouration: Darker colouration of water with high levels of turbidity: Water in all the study areas had dark colouration and various odours associated with degrading organic matter, and in some cases faecal pollution. In the Jukskei River, grey flows of raw sewage could be observed coming out of the riparian settlements. In these areas, the E. coli count was so high that it exceeded 5 million cfu/100 mL.

Construction: There is an escalation in informal settlements on river banks and the riparian areas of the Pienaars and Jukskei Rivers. Several new settlements were observed in open areas around the rivers during the three years ending in October 2016. In the Kuils and Jukskei Rivers, a couple of large scale formal housing complexes were developed in the riparian areas during the same period.

Chemical degradation

Chemical degradation was evaluated in the rehabilitation framework using a rating table applied to water quality records. In the rating table, the limits of pollutant loads for various uses were considered. The pollutant load denoted as “very bad” was for cases where humans will suffer health-related ailments if they interact with the water or when the water ecosystem balance will be highly impaired if such pollutant concentration ends up in the waterway. All the case studies showed a high level of incidences where nitrate and nitrite concentrations were above the set limit of 3 mg/L, which defined a "very bad" nutrient load. The Kuils and Pienaars Rivers had several chemical analysis readings where nitrate + nitrite nitrogen concentration exceeded 10 mg/L. The Kuils and Pienaars Rivers also showed frequent cases where phosphate concentration was excessively high. The concentration detected frequently exceeded 5 mg/L of ortho-phosphate and phosphorus. The high phosphorus load could be attributed to domestic sources especially detergents, faeces and urine from settlements in the catchment area. Given the volumes of Pienaars River water flows that are affected by the continuous phosphorus load, the implications have been very bad, resulting in a hyper-eutrophication state forming in the Roodeplaat Dam. The Kuils River is also approaching eutrophic status in the stagnant waters in lower reaches of the river. According to data from the Department of Water and Sanitation (DWS)'s Resource Quality Information Services (RQIS), the phosphorus load in the Pienaars River is now approaching 100 tonnes per year. This load of phosphorus is deposited in the Roodeplaat Dam. Extrapolation of the phosphorus loading trends revealed that the phosphorus load will increase to 110 tonnes per annum by 2018 and then escalate to 144 tonnes by 2023. Similar estimates were obtained based on population projections and a total phosphorus load per person of between 1.5 and 2 grams generated per day. The nitrites, nitrates and phosphorus loads are emanating from the settlements associated with the flows in all cases.

Biological degradation

The displacement of species: Few living organisms can be observed and some plants have been lost in the rivers in the case study areas. Occasional crabs were observed in the water. The rivers suffer frequent pollutant load spikes and a generally higher than acceptable bacteria load. Extremely high levels of E. coli and faecal coliform counts were noticed in the rivers investigated, before wastewater treatment works and also after the location of discharge from wastewater treatment works. Both the faecal and E. coli counts exceeded a million cfu per 100 mL of water when the recommended limit should be a maximum count of 500. These incidences of bacterial load peaks are becoming more frequent and peaking at increasingly high counts in the records observed for the last ten years. The most rapid increases in bacterial load were identified in the water quality records for the Pienaars River, for the period starting in 2003.

Absence of fish and other food sources in the water: Some fish were observed within the first 100 metres of the Kuils River and in the very upper sections of the Pienaars River. The whole of the Jukskei River exhibited water that was devoid of life with the exception of occasional crabs. The water bodies in the three case study areas did not seem to have the ability to sustain living organisms that should have been in the water, if a healthy ecosystem balance had been maintained.

Extensive analyses of DWS RQIS data, in addition to field observations of the case study areas, aided the proposal of rehabilitation approaches that would help build resilience and a healthy balance in aquatic ecosystems in urban and peri-urban areas.

Options for rehabilitation

Investigation of rehabilitation options showed that the success of rehabilitation initiatives in degraded waterways depends on several factors. At the top of these factors is what happens to the degrading impacts during and after the rehabilitation process. If the degrading impacts remain active, a sustainable solution can never be reached. For the waterways considered in the case studies, degradation was ongoing. As such, rehabilitation initiatives have to incorporate programmes to stop further degradation while dealing with the degradation due to past impacts.

Considering water quality, it was noted that degradation was getting worse. Worsening of water quality was observed from past records where bacterial load, concentration of phosphates, nitrates and nitrites was getting worse with frequent spikes of very poor conditions affecting all the waterways. The frequency of incidences of spikes that show conditions when very bad water quality incidences occur are becoming worse with time. In terms of poorly located settlements on sensitive aquatic ecosystems, the problem was also getting worse in the three case study areas. Observations made during site visits showed increases in new settlements and other land uses on riparian areas.

Based on the investigated waterways and the literature on aquatic ecosystem degradation, once an aquatic ecosystem is degraded, it can no longer be restored to pristine conditions; rather, a new acceptable and sustainable state of the aquatic ecosystem has to be defined and solutions developed to reach this ideal state.

It was observed that there are many instances where the sources of degradation cannot be excluded, relocated or stopped, at least in a short time frame, due to a number of factors. There are also instances where some settlements that are located on riparian land cannot be relocated because constitutional provisions have not yet been satisfied. In addition, instances were observed where changing a poorly located planned development such as a wastewater treatment plant, is not practical. Other cases where the river is now surrounded by a CBD or a prioritised developmental area were noted to create permanent constraints in waterway rehabilitation. In all these cases, the options for rehabilitation have to be weighed against the constraints and the advantages to be derived using suggested economic appraisal methods. The envisaged rehabilitation solution should address a futuristic state of health of the waterway where the negative influences of historical, current and future land use activities are mitigated or reduced to acceptable and sustainable levels.

The development and implementation of rehabilitation/resilience options should follow a four-stage process:

Stage 1 Identification and consideration of all possible rehabilitation/resilience options

Stage 2: Initial selection of rehabilitation/resilience options

Stage 3: Final selection of rehabilitation/resilience options

Stage 4: Prioritisation and setting a time frame for implementation of options

The identified four stages should also run parallel with the options that are set to stop the degrading factors. In terms of water quality, the starting point for rehabilitating urban rivers should be to seek to stop all further degradation such as the various forms of pollution from WWTWs and effluent from other land uses. Current legislation makes provision for certain levels of pollution to be allowed into the rivers if the concentration of pollutant is below specified limits. However, in most urban rivers in the country, the return flows contribute a large percentage of the flow volume such that the natural river cannot dilute the pollution or purify the degradation caused using natural processes.

The rehabilitation approaches and actions proposed in this study were based on the investigations carried out in the case studies and from literature. These rehabilitation actions and approaches were presented in multilevel criteria tables that considered the following: the nature of the goods and services affected by a certain kind of degradation (e.g. loss of riparian zone functionality), the priority level for the rehabilitation option proposed, the applicable legislation/by-laws that can be used as guidelines for successful implementation, and the institutions responsible for successful implementation. The rehabilitation option selection criteria applied included consideration of the geographical location of the aquatic ecosystem, the location of the damage along the reach of the system, the type of aquatic system, rainfall seasonality in the region, the impacts of the culture and religion of the residents in the region where the aquatic system is located, resource availability in terms of human resources and financial resources, political will to prioritise rehabilitation and resilience of degraded systems, as well as the possible adverse or additional positive effects that may result from the selection of a possible rehabilitation option.

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Acronyms and abbreviations

ASPT	Average score per taxon
BCR	Benefit-cost ratio
BOD	Biological oxygen demand
CBA	Cost-benefit analysis
CBD	Central business district
CoCT	City of Cape Town
COD	Chemical oxygen demand
CoGTA	Cooperative Governance and Traditional Affairs
CoJ	City of Johannesburg
DARD	Department of Agriculture and Rural Development
DEA	Department of Environmental Affairs
DMR	Department of Mineral Resources
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
EC	Electrical conductivity
EDCs	Endocrine-disrupting compounds
ESA	Ecological Society of America
FAII	Fish Assemblage Integrity Index
GIS	Geographic Information Systems
HAM	Habitat Assessment Matrix
HI	Hydrological Index
HIA	Habitat Identity Assessment
IBI	Index of biotic integrity
IDP	Integrated development plan
MIRAI	Macro-invertebrate response assessment index
NEMA	National Environmental Management Act
CoHRE	Centre on Housing Rights and Evictions
NGOs	Non-governmental organisations
NPV	Net present values
NRC	National Research Council
PMG	Parliamentary Monitoring Group

RHP	River health programme
RQIS	Resource Quality Information Services
RVI	Riparian vegetation index
SANBI	South African National Biodiversity Institute
SANS	South African National Standard
SASS	South African scoring system
TDS	Total dissolved salts
TSS	Total suspended solids
UMCES	University of Maryland Centre for Environmental Science
UN-Habitat	United Nations Habitat
US CIA	United States Central Intelligence Agency
WHO	World Health Organization
WQI	Water Quality Index
WWTW	Wastewater treatment works

1 Introduction and background

1.1 Introduction

The majority of South Africa's waterways have been subjected to alterations and modifications that have resulted in various forms of ecosystem degradation. The negative consequences of anthropogenic degrading practices in water ecosystems started several hundred years ago and continue to this day in areas where early settlements were established. The South African National Biodiversity Institute (SANBI) (2014) estimates that more than half of South Africa's rivers are degraded and PMG (2006) postulates that the nature of the degradation that affects the waterways is characterised by nutrient enrichment, faecal pollution, salinity and toxicity, as well as acid mine drainage. The degradation is a result of extensive land use activities by the mining, manufacturing and processing industries, agriculture, infrastructure development, and the establishment of human settlements. The degradation is worsened by the establishment of land uses in close proximity to, or on, riparian areas, wetlands and other sensitive areas that significantly influence aquatic systems. Ouyang, Zhu & Kuang (2006) point out that the use of sensitive riparian areas in urban and peri-urban areas is due to high rates of urbanisation driven by the community's need for socio-economic improvement, while municipal service provision is not increasing at the same pace.

Most large cities and human settlements have been built around watercourses in order to benefit from the services that these ecosystems provide (Francis, 2012; Everard & Moggrodge, 2012). The impacts of these modifications around watercourses are widely discussed with respect to urbanisation, which has taken the blame for the bulk of land use changes (Huizenga & Harmse, 2005; Everard & Moggrodge, 2012; Boyle, Lavkulich, Schreier & Kiss, 1997). The relationship between land use and aquatic ecosystem degradation is one that has been explored for decades in the quest for a sustainable balance between the functionality of aquatic and terrestrial ecosystems (Rapport, 1989). Land uses that include mining, industrial activities, agricultural activities, infrastructural development, and the location of human settlements have been highlighted as pressure systems that can lead to the modification of an aquatic ecosystem (ESA, 2000).

In South Africa, the degradation of aquatic ecosystems is driven by historical factors that have resulted in the modified state of rivers observed today. The influences from South Africa's historical mining culture, the historical lack of environmental protection legislation, as well as the laws that governed the locations of certain human settlements have set in motion the fragmentation of land, loss of riparian zones for many aquatic ecosystems, and the direct degradation of these systems. Once water resources have been polluted, it is difficult and, in most cases, impossible to return them to a pristine state. This results in loss of water resources and escalations in costs for purifying the water.

1.2 Background

Many past studies have highlighted the influences of land use on some of South Africa's rivers; however, the gap between the identification of the problem and sustainable rehabilitation remains wide. This is due to the limited focus of past studies as influenced by limited budgets, lack of interest at higher levels of decision making and, in some cases, limited understanding of the multiple stressors affecting many waterways. Studies have tended to focus on magnifying the impacts of prominent stressors and ignoring what were envisaged as insignificant factors. Some of the perceived prominent river stressors in South Africa included chemicals from industry and mining activities, agricultural land uses, solid waste and biological stressors from human settlements and physical degradation due to urban developments.

Human settlements have been reported in many studies as key agents of aquatic ecosystem degradation (Miller & Hobbs, 2000; Fatoki, Muyima & Lujiza, 2001; Alberti, 2010); however, the historical factors that resulted in the location of some of these settlements have not been duly explored such that the danger of repeating the degrading process is always there. In order to fully understand ecosystem degradation in response to human settlements, it is imperative that the underlying factors in settlement patterns observed today are well understood. With hindsight of basic knowledge on the underlying factors, appropriate settlement patterns can be established and practical rehabilitation approaches developed and implemented.

In addition to human settlements, socio-economic driven migration has resulted in an unsustainable form of urbanisation that results in extensive unplanned land-use patterns that cause water ecosystem degradation. Increasing populations in some regions increase the pressures on the available water and sanitation systems in those regions, subjecting them to frequent system failure and general service provision gaps.

In the past, urbanisation was also driven by the locations of South Africa's identified mineral resources, subjecting the aquatic ecosystems of some regions of the country to more pressure than other regions. The exploration and mining activities in these regions, in addition to the effluents released, increased the stress on aquatic ecosystems. Given that mining in South Africa dates back from over a century, with about 6 000 mines abandoned over the years without proper decommissioning and closure procedures, the damage that has been experienced in waterways is catastrophic. The lack of appropriate legislation to enforce acceptable mine closure procedures has been blamed for the current state of degradation and there are many open cases where mines are still to be closed even though their owners have long left. In regions such as Johannesburg, the North West and Mpumalanga, the effects of mining on some of the aquatic ecosystems are very evident and will take many years to address (Du Preez & Steyn, 1992; Naicker, Cukrowska & McCarthy, 2003).

In addition to mining, industrialisation of some regions has subjected the aquatic ecosystems to poor quality effluents that have been discharged over the years and, in some instances, these industrial activities are still threatening the ecosystem, in spite of recent environmental protection legislation such as the *National Environmental Management Act* (NEMA), Act No. 19 of 1998. Heavily contaminated effluents are discharged due to lack of adequate monitoring of industries in most regions. As a result, many rivers contain high levels of industrial pollutants, and are unable to provide the goods and services they did before the degradation.

Furthermore, agricultural activities such as land grazing and clearing affect catchment areas and riparian zones, which subsequently leads to degradation of the aquatic system. This is due to the loss of natural hydrological processes including the functioning of riparian zones, which act as a buffer between the catchment and the waterway. Correctly functioning riparian zones support the maintenance of a healthy aquatic ecosystem by preventing harmful pollutants from reaching associated rivers, as well as retarding the flow regimes to stop physical waterway damage from the hydraulic effects of fast-flowing water, and reduce the erosion-causing particles in the flowing water. There are other highly polluting ventures such as coal mining, leather tanneries, sand mining, chicken farming, and small-scale brickmaking ventures that impact aquatic ecosystems and these are also discussed in this study.

The identified aquatic ecosystem degradation stressors show that South African waterways suffer from varied pressures; one river could be subjected to multiple stressors simultaneously without any mechanism being considered to stop further damage or rehabilitate to address the damage caused already. This means that efforts to rehabilitate aquatic ecosystems are always challenged by a massive backlog and have to focus on multiple stressors including the small-scale stressors that are constantly increasing the system degradation and are usually overlooked. This way, a holistic rehabilitation programme can be established to take the ecosystems towards an ideal state of aquatic health.

The ideal state of an aquatic ecosystem entails ecological integrity and the ability to support social well-being, as well as to contribute to economic development (Roux, 1999). However, the ideal state (Figure 1) is still difficult to achieve because economic development and the improvement of social well-being often involve land use activities that negatively impact aquatic ecosystems. As a result, many rivers located in areas with land use activities are degraded.

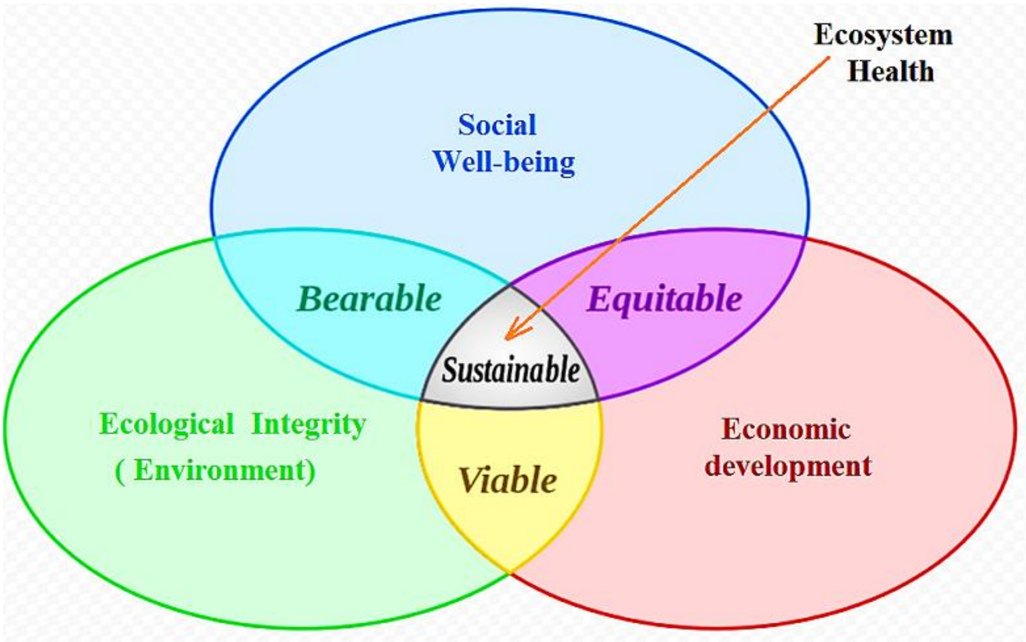

Figure 1: Ideal state of ecosystem health (Adapted from Roux, 1999)

Konrad and Booth (2005) somewhat captured the impacts of land uses on aquatic ecosystems, especially in the context of human activities for urban development. A modification of these activities and land uses is schematically illustrated in Figure 2 to show the impact of land uses in the South African context as they impact aquatic ecosystems.

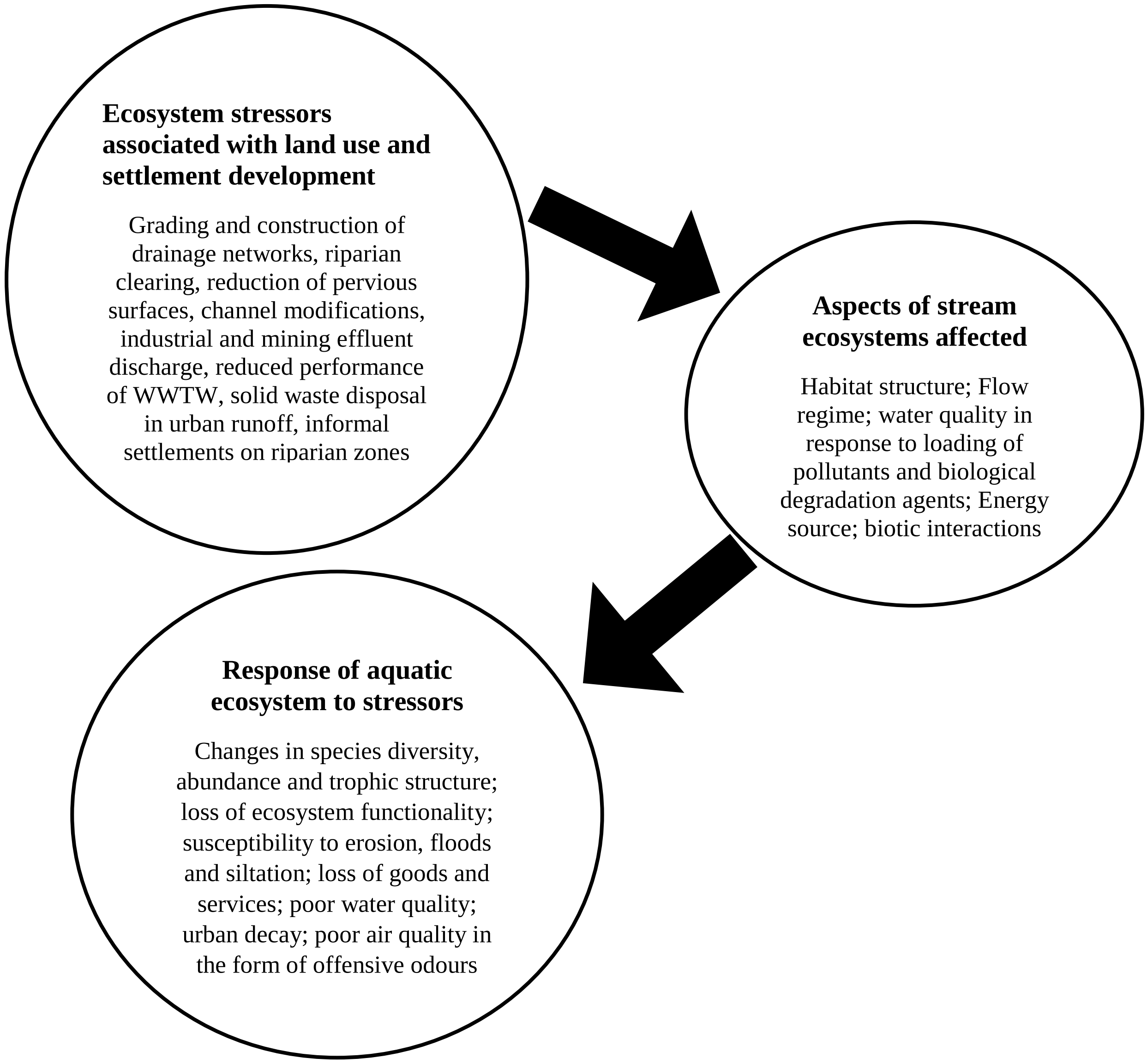

Figure 2: Response of aquatic ecosystems to land uses (Adapted and modified from Konrad & Booth, 2005)

1.2.1 Objectives of the study

This study aimed to investigate the impacts of land use and human settlements in urban and peri-urban areas on aquatic ecosystems.

To accomplish this main objective the project focused on the following aims:

- To carry out a literature study on work previously done on challenges regarding informal settlements and consequential degradation of natural resources.
- To investigate the regulatory framework that governs human settlements, including processes associated with spatial planning as well as effectiveness of the implementation thereof.
- To investigate issues arising from the influx of people into areas that are characterised by sensitive ecosystem and infrastructural resources, including water provision, access and use.
- To undertake a case study on human-induced impacts on sensitive aquatic ecosystems and changes in ecological dynamics particularly due to informal settlements.
- To investigate the impacts of riparian land-use activities on aquatic ecosystem goods and services.
- To develop a framework for proposing how ecological resilience can be attained; or how a balance can be struck between human settlements and good ecosystem function.

1.2.2 Motivation for the study

Migrant communities who have no income and land of their own tend to settle on marginal lands, often close to wetlands, swamps, dams, rivers, power lines and road servitudes. In South Africa, the legislation stresses that, once such informal settlements have any form of structure that residents call a home, these residents can only be relocated to another area if the owner of the land or the responsible authority can provide suitable alternative shelter (RSA, 1997; RSA, 1998; COHRE, 2005). The *Prevention of Illegal Eviction from and Unlawful Occupation of Land Act,* Act 19 of 1998 (RSA, 1998), requires due process to be followed before implementing any eviction of communities with formal or informal structures. At the same time, the *Municipal Systems Act,* Act No. 32 of 2000 (RSA, 2000) defines the legal duties of municipalities to include providing all community members within the municipal boundaries with essential services, including housing and water. As such, it is usually difficult to evict people from informal and formal settlements in riparian areas without going through expensive legal processes.

Many variables are at play in the establishment of informal settlements on sensitive ecosystems. The level of development and service delivery experienced by communities in their previous settlements is usually the main push factor. The push factors work in tandem with pull factors such as the migrant communities' need for employment in urban areas as well as some level of basic access to water from nearby rivers. Given the fact that such communities have the least financial resources in any society, they tend to locate themselves "close to formal job opportunities or points of entry to the informal economy", (Centre on Housing Rights and Evictions (COHRE), 2005; CoCT, 2004).

Communities in informal settlements that are riparian to rivers, dams and wetlands tend to use the goods and services from these water resources. Services from the water resources include being the source of water for domestic uses, bathing and washing in these water bodies, fishing if there are fish and crabs, as well as direct and indirect use of the waterway for waste disposal (Jagals & Grabow, 1996). Negative impacts of human settlements and land uses on such riparian zones are very widespread and tend to spread along the pathways taken by the affected water. The widespread waste disposal that ends up in natural waterways results in much damage to the aquatic ecosystem. In most instances the damage is so catastrophic that these aquatic ecosystems, which should have been providing goods and services, become major sources of disease and much suffering for the same communities that should benefit from them.

In large settlements such as in Gauteng Province, much of the environmental damage in waterways can be traced to activities that cover the whole length of waterways to reach distant locations several hundreds of kilometres away through flows in river systems that are discharging highly polluted water into the major rivers draining the catchments. Similar environmental damage is also reported in other metropolitan areas of South Africa.

The impacts of riparian settlements and other land uses cannot be isolated from the general catchment hydrology and the river flow hydraulics. Fualing (2009) observes that riparian zones act as a link between aquatic and terrestrial ecosystems. Fualing (2009) emphasises the importance of investigating the hydrological relationship between riparian area and the upland ecosystem. Thomas, Chingombe, Ayuk & Scheepers (2010) carried out such hydrological investigation and observed that the increasing load of nonpoint pollutants in rivers such as the Kuils and Eerste Rivers, which pass through dense Cape Town, was due to settlements and other land uses located all over the catchment area including non-riparian areas several kilometres from the waterways.

Degraded aquatic ecosystems are unable to provide the much-needed goods and services that keep both the aquatic and surrounding terrestrial systems functional; hence they become environmental burdens, and may be the source point for degradation of other unaffected systems. Aquatic ecosystems are important in the stabilisation of ecological cycles (Scheffer Carpenter, Foley *et al.*, 2001), hence the preservation of these systems should be regarded as a high priority requirement to ensure their functional advantages to the environment are unperturbed.

The focus of how institutions have sought to address problems associated with informal settlements has usually been driven by policies, politics, and financial constraints and, in some instances, the need to address historical settlement issues including tendencies to avoid disruptions to the current settlement balances. Environmental considerations such as the need for aquatic ecosystem health have received little consideration when settlements are planned in urban areas. The study sought to understand how national programmes are being rolled out with the objective of enhancing understanding of the impacts of riparian land uses on future municipal and government plans as well as programmes for remedial action in affected environments and the communities concerned.

1.2.3 Aquatic ecosystem degradation and riparian land uses

Ecological processes are extensively linked to land use, and thus human interactions have, to a large extent, an impact on the ecosystem's dynamics (Alberti, Booth, Hill *et al.*, 2007). The challenge facing land use and its management brings together conflicting goals and uses of the land in the quest for a sustainable balance. Though riparian human settlements have a direct impact on the aquatic ecosystem, there is a chain of activities that affects the aquatic ecosystem. These various important functions of land use include agriculture, mining, infrastructure for human settlements, aesthetic and religious values (ESA, 2000). Urban land use activities have caused the fragmentation of continuous habitats through changing the land cover by clearing, establishment of settlements, agricultural activities and changing the natural waterways through the use of canals, bridges, culverts, pipes and other forms of infrastructure. All these uses have negatively affected the natural ecosystem balance (Miserendino, Casaux, Archangelsky *et al.*, 2011).

Historically, most urban settlements were established in the vicinity or on the banks of waterways to take advantage of the services and goods that were readily available. However, the important characteristics of the waterways have been overshadowed or eliminated by extensive overuse and degradation, as well as destruction of aquatic habitats, which in turn led to deterioration of water quality. These changes in land uses create conditions that are threatening to wild life and human livelihoods (Francis, 2012). Urbanisation, especially the use of riparian areas for settlements, has impacted on aquatic ecosystems. In 2003, the Ekurhuleni Municipality identified the multiple impacts of urbanisation on aquatic ecosystems (Table 1). According to the report, urbanisation affects aquatic ecosystems in four ways: hydrology, morphology, water quality, and habitat and ecology.

Table 1: Major impacts of urbanisation on aquatic ecosystems (Adapted from Ekurhuleni Metropolitan Municipality, 2003)

Hydrology	**Morphology**	**Water quality**	**Habitat and ecology**
Increased frequency of erosive floods	Stream channel widening and "undercutting"	Pulses of sediments during construction activities	Shift from external to internal stream production
Increased volume of surface runoff	Increased stream bank erosion	Increased pollutant wash-off	Reduction in diversity of aquatic flora and fauna
More rapid stream velocities	Shifting bars of coarse-grained sediments	Nutrient enrichment leading to benthic algal growth	Reduction in diversity and abundance of fish
Decrease in dry-weather base flow	Elimination of pool/riffle structure	Bacterial contamination during dry and wet weather	Destruction of wetlands, riparian buffers and springs
Increased erosive energy in surface flow	Imbedding of stream sediment	Increased organic and inorganic loads	High turbidity and altered aquatic environment
Loss of flow connectivity between riparian area and flow channel	Stream relocation/enclosure/ channelisation	Higher levels of toxins and trace metals reduce oxygen	Environment becomes less habitable, aquatic life is reduced
Obstructions in the waterway create stagnant water and alter flow characteristics	Stream crossings form fish barriers	Increased water temperature and accumulation of pollutants	Aquatic life diversity is distorted due to concentrated pollution in sediments where some aquatic life is based
Water flow in urban areas carries solid waste, other trash and debris	Water flowing with debris causes more channel alterations due to increased erosive force	Trash/debris accumulates in water	Solid waste, other trash and debris increase oxygen demand from the water, thus altering environment for aquatic life

In a pristine environment, nutrients are largely recycled and absorbed in the system. This is not the case in urban settlements where the pollutant load exceeds the self-purification potential of the receiving waterway. Water quality is thus adversely affected and subsequently its usefulness to the surrounding communities and other users is compromised (Varis, 2006). In the absence of functional drainage systems, erosion occurs, leading to increased turbidity and sedimentation in receiving water resources (Tsenkova, 2010). In more recent times, deterioration of aquatic systems in urban areas has been attributed to human settlements, urban agriculture and industrial activities. These developments give rise to the production of waste whose disposal poses a risk to the aquatic environment, resulting in habitat loss and water pollution (Kulabako, Nalubega & Thunvik, 2007).

1.2.4 Human settlements

Early urban and peri-urban settlements in South Africa were developed in a way that was dictated by racial prejudices, supported by racial settlement legislation through numerous acts and other legal tools that guided governance in the period starting from the 1850s to the early 1990s. The few white settlers formed the core of urban settlements with other groups failing to get defined allocations of land parcels on which to settle, or they were restricted to settling outside the early central districts and industrial areas. Legislation such as the *Natives Land Act*, Act No. 27 of 1913, the *Development Trust and Land Act*, Act 18 of 1936, and the *Black (Urban Areas) Act*, *Act* 21 of 1923, laid the foundation for the establishment of "locations" for black people on the peripheries of towns and cities (Liebenberg, 2010). There were frequent instances where communities that had not received land allocation to settle on resorted to using any open spaces, resulting in settlements on riparian areas, wetlands, river banks and other sensitive ecosystems that the developers had not demarcated for settlement. Interestingly, post-1994, even more settlements continue to spring up along rivers and other sensitive ecosystems as socio-economic-driven migration from rural areas continues to increase at an unpredictable rate. In the present dispensation, South Africa has national legal instruments that govern human settlements and in a way "protect" informal settlements, as the government faces numerous challenges in addressing the housing problem for its urban poor. More so, the apartheid era left a huge gap in housing, with the processes involved in addressing housing gaps not being inclusive, and very complex to change.

South Africa and its cities have continued to attract many migrants who end up exerting excessive pressure on service provision as they settle in places where services are already strained. At the current rate of service provision, housing, basic water supply and sanitation are not catching up with the growing demand for services. The problem is worsened by the settlement patterns of unemployed and low-income earners. Numbasa and Koczberski (2012) observe that migrant populations normally have little to no income, and tend to settle around unused parcels of land including environmentally sensitive areas. The impacts of the settlement patterns of the poor resonate throughout the general catchment hydrology, affecting areas that are far from the point of settlement.

The problems associated with poor settlement patterns have a long history. In the past, the establishment of settlements did not take into consideration any possible adverse effects on the surrounding ecosystems (Smith & Hanson, 2003). Rather, settlements were established out of necessity, or in response to land ownership laws passed to ensure segregation of groups from one another (Liebenberg, 2010). Some of these laws include the *Natives Land Act,* Act 27 of 1913, and the *Group Areas Act,* Act 41 of 1950, which resulted in Africans being constrained to less than 7% of South Africa’s total land area, and where sanitation and other services were not provided by government or were provided at levels that were well below the demand (Terreblanche, 2002). The lack of water and sanitation services in the designated black areas resulted in the community relying on surrounding rivers for potable and non-potable water, as well as for disposal of waste (Huchzermeyer, 2004; Mahlakoana, 2010; Marara, Palamuleni & Ebenso, 2011). By the time the first environmental legislation – the *Environmental Conservation Act,* Act 73 of 1989 was passed, many rivers had been excessively degraded and the population density of informal settlements had grown to such an extent that they could not be easily relocated. As a result of population densification, surrounding rivers continue to be subjected to high levels of pollution as communities in these areas are not adequately served by services such as sanitation.

The anthropogenic impacts that come about as a result of urbanisation accumulate over time and bring about permanent changes to the ecosystem. Densely populated human settlements in urban areas continue to grow rapidly while service delivery lags behind. The result is increased pressure on available services, regular sewage spillages, prevalence of unofficial dumping all over the settlement area, including waste dumping inside the waterways. All these contribute to the unhealthy changes that are taking place in the aquatic system. Hatt, Fletcher, Walsh *et al*. (2004) suggest that success in addressing the effects of urbanisation would require isolating those elements of urbanisation that contribute most towards pollution, so as to have a targeted approach at management level. Malmqvist and Rundle (2002) add that some sources of human impacts are easy to identify, as in the case of point source discharges, but the likely situation is that multiple factors contribute towards the deterioration of a local ecosystem. The current trends in urbanisation present a host of uncertainties that are coupled with the current and envisaged changes in the climate, economic challenges and migration. The approach to sustainable urbanisation has been a complex web of multilevel governance where solutions have not been readily available (Ernstson, Leeuw, Redman *et al*., 2010).

1.2.5 Study approach

1.2.5.1 Current understanding

In order to design an effective framework aimed at improving the state of rivers nationwide, this study relied first on the development of current understanding regarding the subject. A review of literature on the subject as well as the state of knowledge in this area of study was accomplished through assessing local and international content. Records from archives and the South African history of settlements and river management were used to obtain historical context and understand how the current state of affairs was created over the years. The changes made in legislation and ecosystem management were also explored to determine what is possible within the provisions of current legislation as well as understand the constraints where changes are recommended.

The knowledge gained from literature was supplemented with consultations with various role players. Stakeholders from municipalities, government and non-governmental organisations were consulted to present a better understanding of the current state of knowledge and how it is being applied in all aspects of activities that have a potential to degrade the water ecosystem or to stop degrading practices. Investigations revealed gaps between the legal and institutional provisions and the implementation. These gaps, which have the potential to perpetuate the current path of degradation, were unpacked in the articulation of recommendations and the way forward.

Three case study areas were used to investigate the current state of the waterways, the nature of degradation, factors surrounding issues of ongoing degradation, as well as the climate in which everything is taking place. The waterways in the case study areas were investigated in terms of water quality, nature of degradation, settlements, pollution, degradation of riparian areas and possible rehabilitation, as well as resilience approaches. Degradation was linked to physical locations through a GIS framework. This framework was also developed to present targeted rehabilitation and resilience options for a selected case study area.

1.2.6 Case studies

In this study, understanding the impact of human settlements and land use in urban and peri-urban areas on waterways was achieved through the use of case studies. The three case studies that were used were:

- The Jukskei River in Johannesburg: This river was selected because land uses and both formal and informal settlements are present alongside sections of the river reach; hence it provided an interesting observation view point for this study. In addition, the Jukskei was reported as a degraded system as far back as the 1970s (Wittmann & Förstner, 1976), yet failure to rehabilitate the river called for a need to understand in great detail the multiple stressors that increased it degradation.
- The Kuils River in the Western Cape: The Kuils River is part of the Eerste River catchment that drains into the wetlands where the Khayelitsha informal settlement is located. Again, this provided a well-informed observation view point regarding the impacts of settlements on waterways and waterway components.
- The Pienaars River runs from the east of Pretoria in the City of Tshwane, through the township of Mamelodi, into the Roodeplaat Dam. The Roodeplaat catchment has been reported to be hypertrophic from as far back as 1976 (Steyn, Toerien & Visser, 1976) as a result of inputs into the Pienaars River. By selecting this catchment as a case study, the source of continuous nutrient loading that continues to degrade the catchment can be understood in great detail.

The Jukskei River is one of the largest rivers in Johannesburg, and is the southernmost river of the Crocodile River (west) basin. It has a reach of 50 km, and runs through affluent suburbs such as the Waterfall Estate in Johannesburg, and informal settlements such as in the township of Alexandra. The degradation of the Jukskei has been reported in a number of studies (Vogel, 1996; Sibali, Okonkwo & McCrindle, 2008; Sibali, Okonkwo & McCrindle, 2010), and these studies have highlighted the impacts of settlements around the Jukskei, indicating that the observed degradation of the waterway is a result of the presence of informal settlements, among other factors.

The Kuils River is located 25 km east of Cape Town, and its entire reach runs through the city. Several informal settlements have been established alongside the river, and it runs through the densely-populated settlement of Khayelitsha. The Kuils River is also the discharge point for many WWTW, and its quality has progressively degraded over the past decades.

Observations and assessments of data obtained from the Department of Water and Sanitation (DWS) Resource Quality Information Services (RQIS) and the three municipalities where the waterways are located provided information on the state and nature of degradation in the selected ecosystems. Based on the identified causes of degradation, rehabilitation approaches are proposed through the use of a rehabilitation and resilience decision support framework.

The three river systems selected were highlighted as far back as the 1970s as degraded in a number of past studies; hence, this study aimed to understand in great detail the nature of river health stresses and contributing factors to degradation. Influences such as agriculture, past and current mining activities, informal small-scale businesses and human settlements were studied to understand the degree to which they affected the state of the rivers and associated riparian areas. Some of the past assessments conducted by other institutions, including the Water Research Commission (WRC) and DWS, to establish the state of water quality and biodiversity in these rivers gave some indications on the trend of degradation over the years and the possible causes.

1.2.6.1 Waterway rehabilitation framework development

A methodology was developed to represent and assist in providing solutions for aquatic ecosystem degradation, associated causes, as well as to determine the best rehabilitation approach. The framework for waterway rehabilitation was developed to provide an illustration of a waterway, break the waterway into reaches, and allow the user to capture both observed and determined waterway degradation cases. Degradation is to be captured for both instream and riparian areas. The framework incorporates input tools for use in capturing aquatic ecosystem degradation impacts such as settlements, effluent loads, instream infrastructure, alterations of the channel, clearing of riparian area, modification of river banks, and dumping of rubbish in the stream.

Possible rehabilitation options were investigated and captured in the framework where they are assessed against observed and determined impacts that are entered by the user for specific cases of degradation. The user divides the river or stream into reaches that are sections with similar degradation, and for which similar rehabilitation or resilience solutions are required. The structure of the river was described through several objects to depict the water system that can consist of the main river, wetland, canal sections, tunnel or culvert sections and dams. The programming approach was object-oriented such that degradation cases are also described using objects, with different properties from the water system objects. The objects defining reaches and degradation were developed in a generic format so that they can be used to describe other waterways with changes to the variable and fixed properties.

The changes to be made when applying the methodology in other catchments include data changes in addition to defined properties. In the methodology, the state of the aquatic ecosystem and its degradation are evaluated using a description of its flow, and chemical, biological and physical degradation. Recommendations regarding the nature of rehabilitation are optimised using the inputs entered by the user under the section/forms on constraints and enablers. The method developed in the framework was developed for use in other catchments, and is not restricted to the case study rivers.

1.2.6.2 Cell phone application for ecosystem rehabilitation support

The participation of community members and other stakeholders in waterway upkeep and rehabilitation was enabled through the development of a cell phone-based application, NXT2U. The app was developed using Android Studio and SDK Tools connected to a Google GIS system where the backend is provided by an internet-based database.

The app, NXT2U, was developed to be freely available for loading to user cell phones. The app allows for casual interaction and more formal interaction based on the user registering for use. This software was developed to allow community members to enter information about the state of the rivers or other waterways to a common database. The app platform was developed with the ability to capture real time images of identified degradation or pollution, and allow the user to enter further details in the form of descriptions and other data that could be used to understand the nature of the degradation or pollution. This information is stored on an online server that decision makers and other personnel can access from their varied locations. Through this app, those responsible for addressing the ecosystem or waterway degradation problem can update the status once the problem is resolved. The app allows all users to see the progress in resolving identified aquatic ecosystem problems. The system is set to work in conjunction with the waterway rehabilitation application developed in this project.

1.3 Report structure

This report consists of six chapters. In Chapter 1, an introduction is followed by a section detailing the study background where the objectives of the research, the study approach and the case studies are discussed.

Chapter 2 focuses on aquatic ecosystem degradation. In this chapter, the impacts of land uses on aquatic ecosystems in South Africa and their associated riparian zones are discussed. The impacts of human settlements, industrial effluents, past and current mining activities, infrastructural development, as well as agricultural land uses are unpacked to communicate detailed information on how these activities affect riparian zones and rivers. Information gleaned from the case studies highlighting the various forms of degradation and the multiple stressors on the aquatic systems studied are explained in detail.

In Chapter 3, the discussion focuses on the state and nature of ecosystem degradation in the three case studies, i.e. the Pienaars, Kuils and Jukskei Rivers. In the discussion of the case studies, instream and riparian degradation is accounted for. The land uses, including settlements in each of the case study areas and how they impact on the aquatic ecosystem, are characterised to bring understanding of the various factors that are causing ecosystem damage. The investigations lead to a summary of possible rehabilitation approaches and actions.

Chapter 4 discusses the rehabilitation of degraded aquatic ecosystems. In this chapter, the factors surrounding the rehabilitation options and how these options will be prioritised for implementation are discussed. Chapter 4 also defines the impacts, resilience and rehabilitation approaches, as well as timelines for implementing suggested redress options.

In Chapter 5, the study conclusion captures the factors established from the study for the various scenarios investigated as well as other scenarios investigated from past literature and experiences. The section also discusses what was found to be the causative environment that needs to be addressed if degradation is to be successfully arrested

Chapter 6 is the recommendation chapter where the way forward is discussed given the factors established in the course of the research. This section includes targeted recommendations that are set to be applied in the case study areas, as well as general recommendations that could be applied in any other similar environment that is experiencing similar degradation challenges.

2 Aquatic ecosystem degradation

2.1 The status of South Africa's rivers

The key findings of the freshwater component of recent national biodiversity assessments (SANBI, 2011) are that South Africa's aquatic ecosystems are highly threatened. Just over half of South Africa's rivers are in good condition if main rivers and tributaries are considered together; but only a third, if main rivers are considered alone. Of the 223 aquatic ecosystems, only 46% are not threatened. Of the 13 identified different estuary types, only three are not threatened (Nel & Driver, 2012). The study also found that some water catchments have more areas of rivers that are threatened when compared to others.

Figure 3 provides an illustrative summary of the ecological status of some of South Africa's rivers. The illustration categorises rivers roughly from north (Luvuvhu and Letaba catchments in Limpopo Province) to the south of the country (the Berg in the Western Cape).

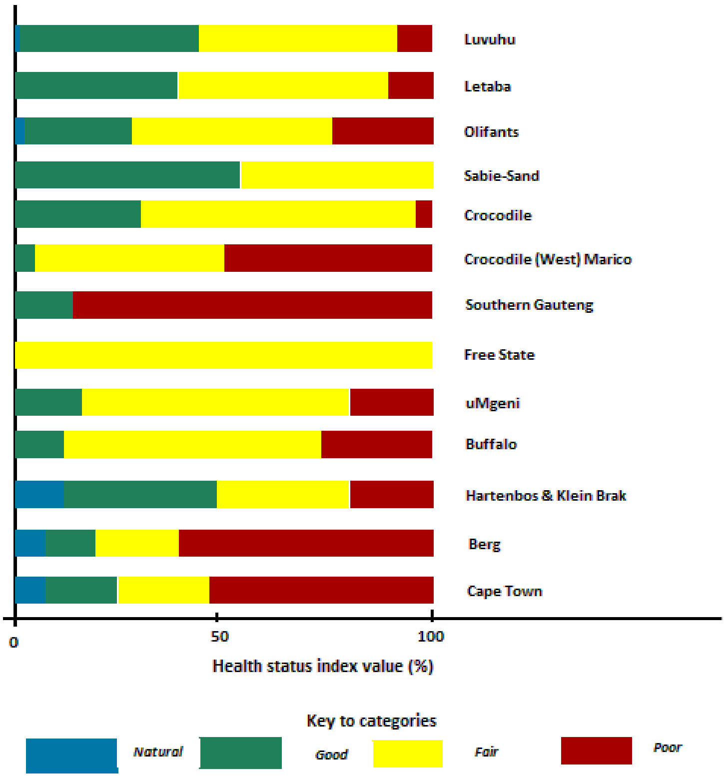

Figure 3: Eco-status of all river systems reported by the RHP up to 2004, arranged from north to south (DWAF, 2006)

The eco-status classifications shown in Figure 3 highlight that a very high proportion of rivers in southern Gauteng are in poor condition. This river system drains the Johannesburg and the Witwatersrand areas in Gauteng Province, which is highly urbanised (DWAF, 2006). The Witwatersrand is also historically a gold-mining area, which has left a legacy of acid mine drainage, heavy metal pollution and uranium pollution. The Hennops River in the area is said to be polluted as a result of urban landscape informal settlements, industries and agriculture. The Luvuvhu River system, however, has the greater proportion of its rivers in a good or fair state. The land uses around the Luvuvhu River system include commercial and subsistence farming and conservation areas and the area is less urbanised than southern Gauteng (DWAF, 2006).

Wetlands make up only 2.4% of the country's area. Of the 800 wetland ecosystem types, only a third is not threatened. The Klip River wetlands are important for their water purification functions in the greater Johannesburg area. The wetlands filter pollutants from industries, acid mine drainage and urban storm water runoff, but they have been greatly compromised by human activities within the catchment (Van Vuuren, 2008).

2.2 The concept of ecosystem resilience

The concept of resilience is used to elucidate how successfully an aquatic system copes with disturbances. A river is subject to natural disturbances such as changes in flow and temperature, and anthropogenic disturbances such as water abstraction and water pollution; however, its ability to remain unmodified highlights a resilient state. Carpenter & Cottingham (1997) define a resilient system as one that remains largely intact after a disturbance. Karr (1999) describes resilience as the system's ability to regain its health after a disturbance. A third definition of resilience is the amount of disturbance that a system can absorb before the system redefines its structure and respective processes, thereby moving the system from one state to another state (Holling, 1986; 1996, in Vergano & Nunes, 2006). The concept of resilience has been criticised as being hard to define and even harder to measure (Karr, 1999). However, it does have the advantage of directing attention to the holistic effects of a range of stressors, as opposed to only focusing on stressors in isolation, and to the question as to how much combined stress a system can take before it is irreparably damaged.

2.2.1 Tipping point

Ecologists have developed the concept of a "tipping point" or "ecological threshold", which is "the point at which the ecosystem loses its capacity to recover, or at which its resilience and integrity are lost" (Thompson, 2011). Thompson (2011) states that a "tipping point", (illustrated in Figure 4 below), can be reached rapidly as a result of a chronic change that wears away the capacity of an ecosystem to recover.

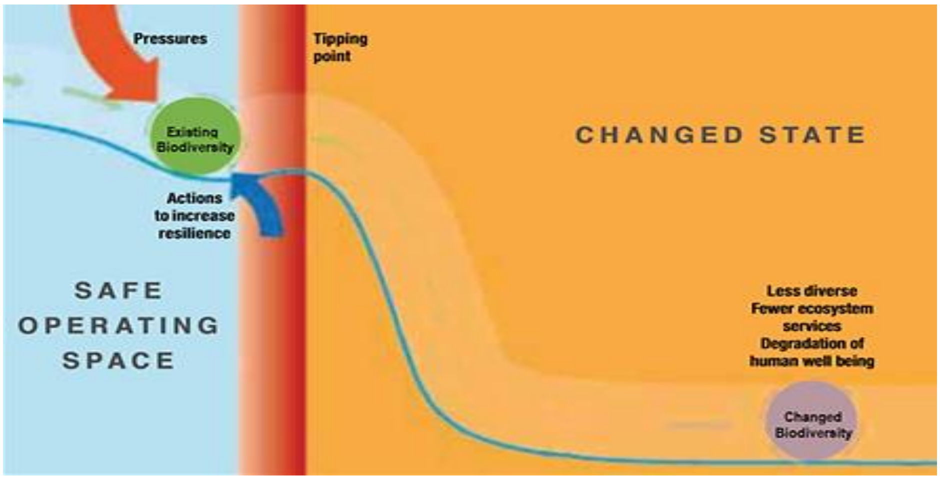

Figure 4: Illustration of the concept of a "tipping point"

Source: Secretariat of the Convention on Biological Diversity, 2010 (in Thompson, 2011)

The variety of biological species within an ecosystem adds to its resilience in times of disturbance (Elmqvist, Folke, Nyström *et al.*, 2003). This is a result of the replication of ecological functions by some species. Functions such as nitrogen fixation or degradation of biomass can be carried out by more than one species, which may have different adaptation capacities. Thus, in the case that a disturbance occurs and affects one species negatively, the other species remain to maintain the system functions thereby stabilising the system (Leslie & McCabe, 2013).

2.3 Urban stream syndrome

Walsh, Roy, Feminella *et al.* (2005) reviewed studies of urban stream syndrome. They defined urban stream syndrome as, "the consistently observed ecological degradation of streams draining urban land" (Walsh *et al*., 2005:706). Their interest was in finding consistent ecological factors that changed along with the degree of urbanisation that could be used to characterise this phenomenon. They were searching for the symptoms, the mechanisms driving it, and priorities for rehabilitation. Four symptoms that occurred consistently in all studies were identified as: a change in hydrology, change in water chemistry, altered channel morphology and change in biological composition. These are explained in detail in section 2.7 under physical, chemical and biological forms of degradation.

2.3.1 Drivers of urban stream syndrome

Walsh *et al.* (2005) examined evidence relating to the drivers of urban stream syndrome. They proposed that the most important driver was urban storm water runoff, which, in almost all urban areas in the world, was managed by directing the flow through piped connections directly into streams. In cities, impervious areas have increased and are designed such that water is quickly drained away to prevent flooding. This subjects many urban streams to agents of urban decay that subsequently lead to degradation. In natural environments, much more water would be absorbed into the ground and reach streams more slowly, filtered by soil and riparian vegetation.

In urban areas, streams are constantly subjected to disturbance and scouring from fast flows. Human litter, leaf litter, heavy metals and hydrocarbons from roads, even from areas quite far from streams, are delivered directly to streams, sometimes also carrying thermal pollution if runoff travels over hot, impermeable surfaces (Pegram & Görgens, 2000).

Another factor mentioned by Walsh *et al*. (2005) as a potential driver of the urban stream syndrome is water escaping from the reticulated water supply or sewerage networks that leaks or spills into storm water drainage systems or into streams. This had been earlier identified as an important driver of pollution in South African water bodies (Pegram & Quibell, 2003). A further driver is deforestation or loss of riparian vegetation. However, the authors point out that as changes in land use and deforestation happen concomitantly, it is difficult to separate the effects. Some studies have tried to do this by comparing paired streams with and without riparian forests along an urban gradient but the results so far are conflicting. Walsh *et al.* (2005) suggest, however, that the loss of riparian vegetation might greatly limit the possibility of rehabilitation of a degraded river.

In South Africa, a lot of attention has been paid to poorly functioning wastewater treatment works and poor sanitation in informal settlements as causes of urban stream syndrome. Walsh *et al*. (2005) recognise that the management of wastewater effluent is important for reversing urban stream syndrome. However, they argue that the fact that streams are in poor condition in cities where wastewater effluent is well managed indicates that the hydraulic efficiency of storm water drainage is the primary factor. The next section addresses the issue of dense, poorly serviced settlements, which are an important contributor to nonpoint source pollution in South Africa, and a key focus area of this study. Walsh *et al.* (2005) remind us that while poorly serviced settlements are a problem that urgently needs to be addressed, it should not be assumed, without investigation, that they are the primary contributors to degradation of urban streams.

2.4 Catchment area and riparian land uses

Rivers are linked to their catchment through the transportation of organisms, nutrients and sediments in the same manner. The riparian zones connect the catchment to the watercourse and act as the transition zone from the rest of the catchment to the watercourse (Naiman & Décamps, 1997). Thus, settlements and other land uses on riparian zones cannot be isolated from the general catchment hydrology and hydraulics. Since riparian zones act as a link between aquatic and terrestrial ecosystems, Fualing (2009) emphasises the importance of investigating hydrological relationships between riparian areas and upland ecosystems. Thomas *et al*. (2010) observed that the increasing load of nonpoint pollutants in the Kuils and Eerste Rivers that pass through dense settlements in the Cape Town metropolitan area was due to settlements located all over the catchment area, including non-riparian areas several kilometres from the watercourses. In the Western Cape metropolitan area, the high pollutant loads were aggravated by widespread informal settlements, informal waste disposal in the catchment area, inadequate storm water conveyance systems and polluted subsurface flows in the sandy soils. In investigations of urban rivers in Gauteng, including the Klip and Jukskei

Rivers, Henning, Mphake, Mdala, *et al*. (2007) documented the river damage associated with disruptions to both the hydrology and hydraulics of the associated river flows.

Harding, Benfield, Bolstad *et al*. (1998) reported that aquatic ecosystems are not only being affected by current land uses, but have been perturbed for a considerable amount of time from land uses in the past when the rate of socio-economic developments and urbanisation were at an all-time high. In South Africa, urbanisation is still increasing at an unprecedented rate due to lack of development in many regions driving rural populations into urban and peri-urban areas. The population densification in urban and peri-urban areas has resulted in the deterioration of riparian zones and waterways in affected catchments. The impacts of population densification on aquatic ecosystems are worsened by the inadequate provision of sanitation and other services, which are being provided at a low rate if at all.

2.4.1 Direct degradation in aquatic ecosystems

The challenges facing the aquatic ecosystem and its management are a result of conflicting goals that highlight the need for a sustainable balance between ecosystem health and human needs. These human needs include a variety of land use activities. These land uses have caused the fragmentation of continuous habitats through the channelising of rivers and clearing of riparian areas along streams and rivers, and have negatively affected ecosystem balance (Miserendino *et al.*, 2011). Ecological processes are sensitive to land use, and indeed human interactions in the proximity of waterways have direct impact on the ecosystem's dynamics (Alberti *et al*., 2007).

In a pristine environment, nutrients are largely recycled and absorbed in the system. This is not the case in urban settlements where water resources become the dumping ground for solid waste and raw wastewater. Water quality is thus adversely affected and subsequently the usefulness of the water to the population that depends on it (Varis, 2006) is compromised. In the absence of functional drainage systems, erosion occurs, leading to sedimentation in receiving water resources (Tsenkova, 2010). Deterioration of urban water ecosystems has been attributed to human settlements, urban agriculture and industrial activities. These developments give rise to the production of waste whose disposal poses a risk to the aquatic environment, resulting in habitat loss and water pollution (Kulabako *et al*., 2007).

2.4.2 Degradation in riparian zone functionality

The widespread interest in the functionalities of riparian zones (Figure 5) derives from scientific studies on their contribution and importance to river ecology, and ultimately catchment hydrology (Naiman & Decamps, 1997; Groffman, Bain, Band, *et al*., 2003; Karisa, 2010). It is against this backdrop that riparian zones have been so widely considered in catchment management programmes (Allan, Erickson & Fay, 1997).

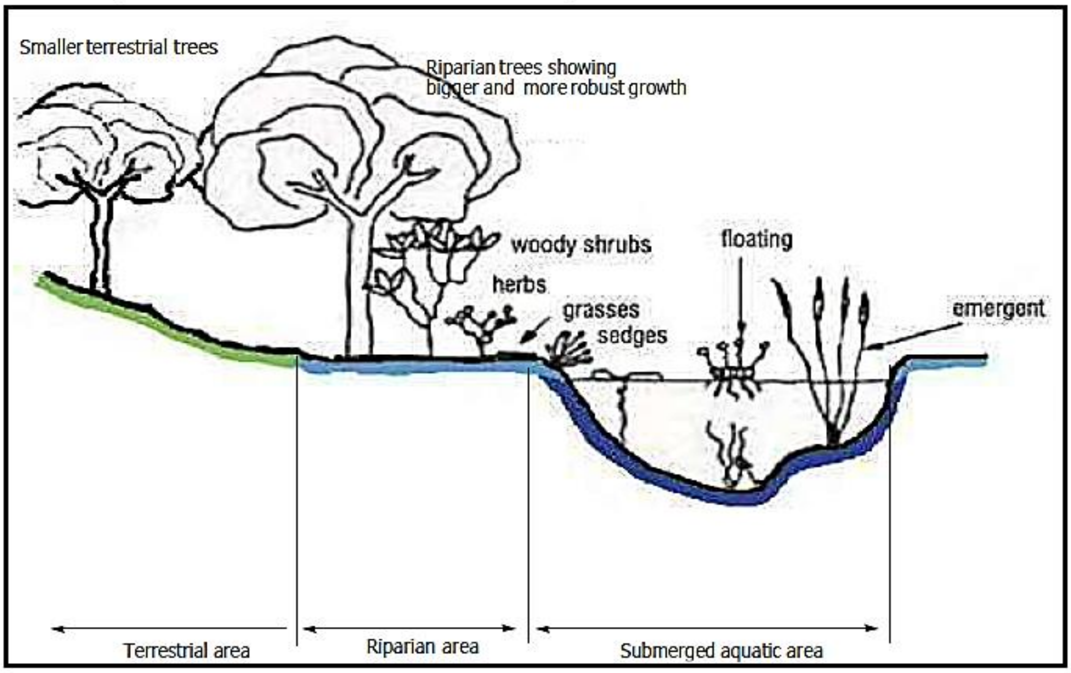

Figure 5: River channel cross-section showing riparian area (Adapted from DWAF, 2005)

The nature of impacts suffered by water ecosystems due to land uses depends on the nature of the activities involved and the location of the activities in relation to the watercourse. Activities that are directly connected to the watercourse, such as an effluent discharge or abstraction point, have some of the most severe impacts. On the basis of studies in the USA, Zaimes (2007) reports that there were many different types of human activity that cause major alterations to riparian areas. Pusey and Arthington (2003) observe that the ability of the riparian zone to reduce nutrient and sediment loading from surface runoff was beneficial to the biotic life in waterways, ensuring functionality and productivity of aquatic systems. The effect of nitrate/nutrient depletion in riparian zones has also been reported by Cooper (1990). This suggests that the riparian area acts as a buffer between two systems with the aim of keeping both systems at equilibrium. In the absence of riparian zones, siltation was seen to affect the diversity and species richness of aquatic ecosystems (Rabeni & Smale, 1995). Lowrance, Sharpe and Sheridan (1986) suggest that riparian zones are important sinks for sediments. Carlyle and Hill (2001) examined the effects of riparian zone hydrology, lithology, and redox chemistry on the dynamics of groundwater phosphate concentrations. The results reported show that the presence of riparian zones resulted in well-organised concentrations of soluble reactive phosphorus in the riparian zone.

Changes and modifications in and around urban watercourses and their associated riparian areas have led to their degradation and given birth to new conversations around ecosystem resilience and rehabilitation.

2.5 Degradation due to habitat settlements

Recent years have seen the continued degradation of urban aquatic ecosystems from anthropogenic influences. In Africa, this degradation is mainly exacerbated by massive migration to urban areas which are perceived to be the local economic hubs (Cohen, 2006). The urban population growth rates have been rising steadily to a point where authorities cannot keep up with formal service provision such as water supply and sanitation (UN-Habitat, 2013). South Africa has not been exempted from this trend in migration. Due to the high rate of migration and the limitations in the provision of housing, a large proportion of migrants ends up settling in informal settlements. These informal settlements are usually located in areas that seem vacant, such as flood plains, river banks, riparian zones, dry river courses, wetlands, servitude areas for high voltage power lines, roads and even recreational parks. However, this does not mean that formal settlements are not also major drivers of urban stream syndrome previously explained and major contributors to aquatic ecosystem degradation.

2.5.1 Degradation due to formal settlements

Past studies of aquatic ecosystem degradation in South Africa have focused mainly on informal settlements and their irrefutable contribution of degradation elements. However, studies of formal settlements show that these planned structures, although they are supplied with water and sanitation services, affect aquatic ecosystems to a great extent. Historically, formal settlements were located in areas close to rivers in order to ensure a stable water supply to these settlements. Examples of these include Tshwane, which is located on the Apies River, Pietermaritzburg on the Msunduzi River bank, Nelson Mandela Bay on the Swartkops River and Cape Town located on many wetlands and around some of the city's rivers such as the Kuils River, the Eerste River and the Salt River. As a result of these formal settlements, the rivers have been subjected to changes in hydrology and changes in water quality.

- **Hydrological changes**: The locations of many formal settlements in South Africa have resulted in changes to the flow paths of the rivers that run through them. Many rivers have been canalised and piped (e.g. the Apies River in Tshwane and the Kuils River in Cape Town), while some sections of some rivers have been enclosed to make room for infrastructure (Rundgreen, 1992; King, Scheepers, Fisher *et al.*, 2003). These activities have resulted in major flow regime changes and loss of biotic components in such rivers. As a result, the health of such rivers has been greatly compromised and their ability to withstand external pressures has reduced significantly. In addition to changes in flow regime, path and flow cycles, the establishment of formal settlements has initiated land use activities that result in the hardening of riparian zones due to construction activities in formal settlements (Winter & Mgese, 2011). Hardening of riparian zones results in loss of functionality and loss of riparian vegetation. As a result, rivers that flow through formal settlements are more susceptible to urban pollutant loads and exhibit features of the urban stream syndrome previously described.
- **Reduction in water quality**: Urban runoff from road networks and bridges is often piped and directed into surrounding rivers. During high temperature seasons, chemical solutes are easily carried in runoff into the rivers in addition to solid waste and litter that are typical of formal urban areas (Noble & Hemens, 1978; Armitage & Rooseboom, 2000). These contribute to physical forms of degradation in rivers, and very often, chemical constituents from solid waste dissolve in the rivers to affect the chemical balance. Chemicals that contribute to eutrophication, such as nitrates and phosphates, are very common in South Africa, and have been persistent indicators of reduced water quality due to the presence of formal settlements and their associated components such as WWTWs (Noble & Hemens, 1978; Oberholster & Ashton, 2008).

  Cases of eutrophication were reported as far back as the late 1940s (Steyn, 1945; Louw, 1950). Investigations in dams that were fed by water flowing through the cities of Johannesburg and Pretoria exhibited some of the first recorded cases of major water pollution. The Hartebeespoort Dam, built in 1923, Roodeplaat Dam, built in 1955, and Rietvlei Dam, constructed in 1934, are the dams that continue to receive most of the polluted effluent and urban runoff from Gauteng. These dams now exhibit characteristics that are consistent with a hyper-eutrophic state. Chemical degradation factors from formal settlements also exhibit themselves in the form of unwanted chemicals and salts. Chlorine and phosphates are commonly discharged from households into rivers and contribute to the degradation of rivers in terms of high salt formation, and the eutrophic state of the river.

Formal settlements also affect water quality in terms of high sewage contamination of aquatic systems. Increasing populations in the Gauteng area, for example, have put a lot of pressure on sewage conveyance systems, giving room for frequent bursts and outflows. The Emmarentia Dam and Zoo Lake in Johannesburg, both constructed before 1912, also continue to receive occasional sewage discharges and other pollutants that maintain the dams in a eutrophic state (DWAF, 2003). In addition to the chemical contributions of sewage effluents and outflows, biological degradation is a common characteristic of many rivers in urban areas with exceedingly high counts of faecal matter and E. coli.

By the 1950s, pollution of rivers became an official concern resulting in further research into the hydrobiology of the Great Berg River (Harrison & Elsworth, 1958). Investigations into the immensely polluted Jukskei/Crocodile system (Allanson & Gieskes, 1961), Tugela River (Oliff, 1960) and the Vaal River (Chutter, 1963) were also carried out. All of these rivers are greatly influenced by surrounding formal settlements.

2.5.2 Degradation due to informal settlements

2.5.2.1 History of informal settlements

Globally, informal settlements are regarded as the biggest contributors to the degradation of aquatic ecosystems. This is mainly due to the lack of proper water conveyance and sanitation systems in these settlements as a result of lack of planning prior to establishment (Richards, O'Leary & Mutsonziwa, 2007). The history of informal settlements in South Africa is largely connected to colonial settlement plans, followed later on by enforced racial segregation in the country's apartheid era. It is this era that reinforced laws and policies to subdue and segregate the non-white communities, resulting in the formation of many of the informal settlements thriving today. The result was that a large part of the population did not have rights to recognised formal settlements. Table 2 below shows some of the past legislation that had a major bearing on the current nature of formal and informal settlements in the country.

Table 2: Legislation that influenced past and present settlement policies and patterns

***Black Land Act,* Act 27 of 1913:**
The *Black Land Act* prohibited blacks from owning or renting land outside designated reserves (approximately 7% of land in the country); commenced 19 June 1913. Repealed by section 1 of the *Abolition of Racially Based Land Measures* Act No 108 of 1991.

The *Native Affairs Act,* Act 23of 1920:
The Native Affairs Act was a spin-off of the South African Native Affairs Commission report of 1905. It paved the way for the creation of a countrywide system of tribally-based, but government appointed, district councils modelled on the lines of the Glen Grey Act of 1894. The principal of separate, communally-based political representation for Africans was extended by the 1936 Representation of Natives Act.

The Class Areas Bill of 1923:
This Bill proposed compulsory residential and trading segregation for Indians throughout South Africa.

***Population Registration Act,* Act 30 of 1950**
Required every South African to be racially classified. The classification was to be used in entrenching an unequal society, a society where, among other ills, access to housing and services was a privilege for a few.

***Group Areas Act,* Act 41 of 1950**: Forced separation between races through the creation of residential areas designated for certain races.

***Prevention of Illegal Squatting Act,* Act 52 of 1951**
Gave the Minister of Native Affairs the ability to displace blacks from public and privately-owned land and to place them in resettlement camps.

***Bantu Authorities Act,* Act 68 of 1951**
Created black homelands, regional authorities and abolished the Native Representative Council.

***Natives Laws Amendment Act,* Act 54 of 1952**
Limited the number of blacks who could have permanent residence in towns to those who had been born in a town and had lived or been employed there continuously for no less than 15 years.

***Promotion of Bantu Self-Government Act,* Act 46 of 1959**
Classified black people into eight ethnic groups. Each group had a Commissioner-General who was appointed to create a homeland. In turn, each homeland would be able to govern itself without white intervention.

***Bantu Homelands Citizens Act,* Act 26 of 1970:** Removed black South African citizenship and required all black people to become a citizen of the homeland designated for his/her ethnic group.

The oppressive governments that ruled South Africa during the latter part of the nineteenth century and most of the twentieth century restricted African residents from settling in certain areas. The land that was available for Africans was congested, with few services being provided. At every opportunity, the African inhabitants were seeking to relocate to areas closer to sources of employment. The decade just before, and the one after, the end of apartheid saw an increase in the formation of informal settlements as the population influx controls were relaxed. Some of these informal settlements were off-shoots from the densely populated townships to areas where they were closer to urban areas and employment (Guillaume & Houssay-Holzschuch, 2002).

Most of the large cities in South Africa continue to fail to provide basic services for the affected communities. In a media statement report by the City of Cape Town (CoCT, 2013), the city mentioned the plight of the affected communities as an unfortunate product of past injustices that cannot be undone. In Cape Town, the social inequalities caused by apartheid segregation, and in more recent years by economic forces, moved environmental sustainability issues into the background of more urgent issues such as poverty and its subsequent effect on lack of access to municipal services (Ernstson *et al*., 2010). South Africa's history also affected how legislation was formulated after apartheid in aiming to redress past injustices. DWS, then the Department of Water Affairs and Forestry (DWAF), made this statement: "While the Department of Water Affairs and Forestry has the clear mandate to manage the country's water resources, the need to rapidly redress the inequities of the past forms the core of most of the policies and strategies of the new government. As such many government departments are actively engaged in forming and executing policies with respect to housing and services provision" (DWAF, 1999). This indicates that there was an urgency to right the wrongs of the past, and the burning issues in this regard included the provision of housing for the urban poor.

2.5.2.2 Impacts of informal settlements on water quality

The most prolific impact of informal settlements on aquatic ecosystems is in the form of reduced water quality where runoff from the settlements discharges into local watercourses. This runoff is heavily polluted by nutrients, sediments from erosion and faecal matter. The provisions for monitoring pollutant discharge into watercourses do not allow for discharge from settlements. As a result, the water flowing out of settlements, especially informal settlements, is usually of a worse quality than the effluent from a waste water treatment works (WWTW). The result in the receiving water body is depletion of oxygen, eutrophication and toxicity, leading to fish kills and loss of biodiversity (Owusu-Asante & Ndiritu, 2009). High density human settlements produce high waste volumes. In the case of informal settlements, the absence of a waste disposal system and other services means that the pollutants end up in the environment in massive volumes. DWS has guidelines regarding how to deal with sanitation for settlements in sensitive ecosystem. Table 3 below captures some ideas and responses on dealing with the settlements.

Table 3: Impact of informal settlement location on sanitation provision, and possible solutions (Adapted from DWAF, 2002)

Informal Settlement location	Possible situation	Permanency	Sustainable development possibility	Options
Private land	Owner willing to sell	Good possibility if funds are available to purchase the land	Good if located near economic centres, otherwise questionable	Purchase the land and embark on housing development project or install temporary services until a more suitable location is developed
	Owner unwilling to sell	Uncertain unless either owner willing to develop or can negotiate to sell	Not good since no security of tenure	Support owner to develop acceptable basic services or negotiate to purchase and embark on housing development or install temporary services until a more suitable location is developed
Environmentally unsuitable land	Possible danger to residents (flooding)	Non-permanent unless steps are taken to prevent flooding etc.	Poor since occasional flooding or other factors will means residents will be unwilling to invest	Install temporary services until a more suitable location is developed. Construct prediction systems to prevent flooding or other environmental problems, then embark on housing development project
	Sensitive or protected ecosystems	Non-permanent unless steps are taken to save ecosystem	Dependent on other factors but good if eco-tourism is possibly related to the ecosystem	Install temporary services until a more suitable location is developed. Construct systems to protect the ecosystem then embark on housing development project

The amount of waste produced in these settlements reduces the natural ability of the receiving aquatic ecosystem to cleanse itself (DWAF, 1999). Substandard sanitary conditions in urban informal settlements are exacerbated by overcrowding, and this introduces the issues of solid waste management and domestic waste disposal. Considering the low access to the cities' service infrastructure, it leaves residents with no choice but to dispose of the waste in an unregulated manner. Much of the waste finds itself in watercourses, ditches and trenches, posing a risk to aquatic ecosystems (Tsinda, Abbott, Pedley *et al*., 2013; Karisa, 2010; Amba, 2010).

Management of grey water from informal settlements has provided an area of various studies in such settlements (Rodda, 2011; Armitage, Winter, Spiegel, *et al*., 2009). Grey water from informal settlements not connected to a sewer system has been characterised as unusable and a possible health risk, and thus cannot be considered for re-use (Rodda *et al*., 2011). The key contaminants identified are nitrogen, phosphorus, COD, lead, suspended solids and faecal coliforms (Owusu-Asante & Ndiritu, 2009). In the light of these findings, the quality of the grey water is also unsuitable for the receiving aquatic ecosystem in its polluted state. Carden, Armitage, Winter *et al*. (2007) note that grey water from dense settlements must not be allowed to stagnate, infiltrate the soil and subsequently the groundwater, and to enter surface water resources if health and environmental risks are to be avoided. Environmental issues associated with informal settlements are perceived as secondary issues that will be solved by adequate delivery of basic services such as water and sanitation.

The effects of informal settlements can be better understood through the assessment of water quality indicators and are explained in detail where the state of water ecosystems in case studies is discussed, painting a picture of the state of degradation as a result of habitat settlements and their associated components.

2.6 Degradation due to other land uses

2.6.1 Degradation due to industry and mining

South Africa has a long mining history stretching back for more than 100 years. In the past, at least 6 000 mines have been abandoned or left without being rehabilitated by absentee mining houses (Wagner, 1973; DMR, 2009), creating conditions for widespread acid mine drainage and leaching of pollutant compounds into surrounding aquatic ecosystems. In addition to abandoned mines, ongoing mining operations in districts such as Johannesburg, the North West and Mpumalanga have continued to contribute to the degradation of surrounding aquatic ecosystems by releasing heavy metals, acid and salts of undesirable quality (Naicker *et al*., 2003; Durand, 2012; McCarthy, 2011). Some of these compounds adsorb to the bottom soil of rivers creating a degradation plume that is constantly released into the river, making it difficult to clean up. Durand (2012) points out that "one of the most consistent and pressing problems caused by mining has been its impact on the water bodies adjacent to the Witwatersrand mining district in Johannesburg." Roychoudhury and Starke (2006) point out that there were deposits of trace metals in the Blesbokspruit in South Africa due to mining activities conducted in close proximity. Increased metal concentrations of zinc and copper in fish from the Olifants River in Mpumalanga have been linked to the impacts of mining activities on aquatic ecosystem health (Kotze, Reyers, Schonegevel *et al*., 2006).

It is interesting to note that metal loading of rivers does not necessarily result in the death of fish. Instead, there is an accumulation of metals in the fish (Figure 6) that cannot easily be detected, causing health concerns for residents who fish in the area and consume the fish from the river. The effect of mining on aquatic ecosystems therefore goes beyond environmental degradation to valid human health concerns as some of these metals have been reported to cause illnesses such as cancer (Järup, 2003; Matés, Segura, Alonso *et al*., 2010).

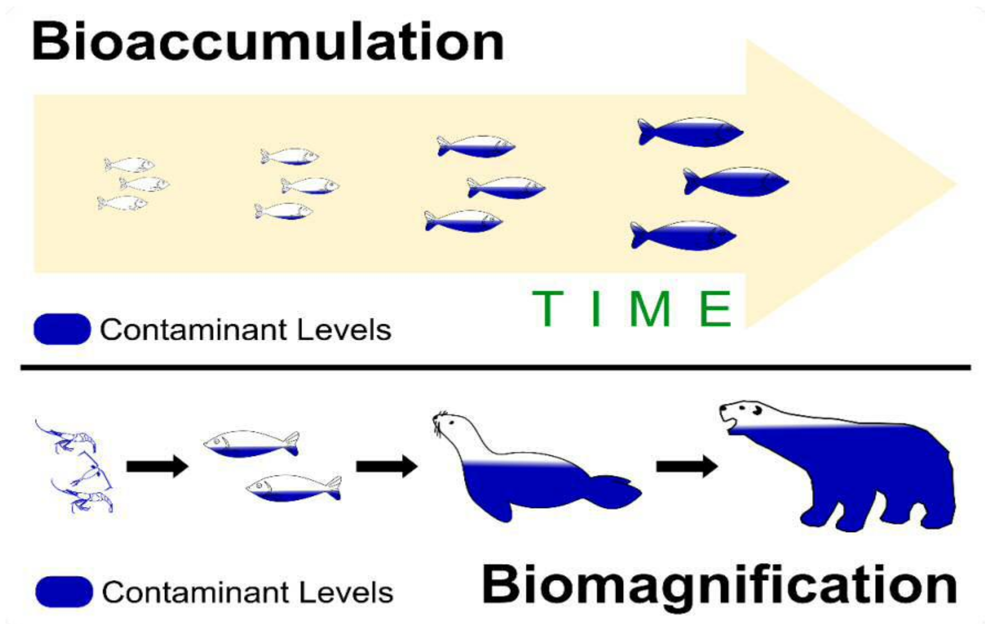

Figure 6: Bioaccumulation and bio-magnification of harmful chemicals in aquatic organisms (Olenick, 2013)

Derelict mines continue to leach harmful compounds as they are often left unmonitored. Examples of aquatic systems that have been heavily affected by abandoned mines include the Edendalespruit in Tshwane and the Hennops River in Johannesburg (Glass, 2006).

In addition to mining, there are other major manufacturing industries in South Africa that use harmful chemicals in their processes. The effluents from these industries are often treated to a primary level prior to the disposal of effluent, which will be relatively poor quality when compared to what could come out of tertiary level treatment. Some of the chemicals reported to be present in these effluents are endocrine-disrupting chemicals, while others are unregulated compounds that often result in dire health effects (Petrovic, Eljarrat, De Alda *et al*., 2004; Yoon, Ryu, Oh *et al*., 2010). Sugar mills, leather processing industries, paper mills, agrochemicals, and pesticide manufacturing industries are some of the defaulting industries identified in this regard, and can be regarded as highly polluting ventures. Even if industries are adhering to the law in their waste discharges, there is still much that is not understood about the chemicals that are being discharged and we are even more ignorant of the impact of the interaction and accumulation of chemicals (Rockström, Steffen, Noone *et al*., 2009).

Industries also contribute to conversion of land to impervious surfaces. Commercial and light industrial areas are often found in urban areas. They have similar water quality impacts to formal residential areas except that heavy metal loading may be higher due to increased traffic, while pathogen and sediment wash-off are often lower (Braid, 2014). Heavy industries may also be found in urban areas. Even if these are complying with licence regulations, they may contribute to atmospheric emissions that are deposited in the area and become a nonpoint source of pollution, which is washed off into storm water (Pegram & Görgens, 2000).

2.6.2 Degradation due to informal businesses

Informal businesses in South Africa are major aquatic ecosystem degradation elements as they are often left unmonitored by the responsible organisations. More often than not, the focus of environmental protection agencies is on the large-scale industrial outlets that are already known to produce pollutants in their effluents. Unfortunately, the loads from informal businesses contribute significantly to the degradation of aquatic ecosystems as they are often untreated due to lack of proper treatment infrastructure. A very common example is small-scale brick manufacturing businesses, whereby the wastewater produced during the process is contaminated extensively with $CaCO_3$ and is disposed of directly into rivers. The Luvuvhu

River is one of the rivers exposed to this degradation (Kleynhans, 1996). Another highly degrading informal business that contributes to aquatic ecosystem degradation is small-scale mechanic workshops where engine oil from cars is drained and left to seep through the soil before being carried in runoff. Small-scale mining and abandoned mines that have not been rehabilitated are usually not regulated and also contribute to pollution (GDARD, 2011). As a result of lack of adequate monitoring structures, many of these businesses have contributed to degradation yet still remain overlooked.

2.6.3 Degradation due to infrastructure and development

Due to increasing urbanisation, the development of infrastructure in South Africa is of high priority. Most of the infrastructure that is currently being developed is motivated on the basis that it will serve the needs of people while creating an environment that is sustainable. However, the result is usually that the decision makers tend to favour the potential economic benefits and place less focus on the ecosystem benefits or possible degradation to the aquatic ecosystem. The creation of dams to increase water supply has been highlighted to have ill effects on water flows and riparian zones. According to Sawyer, Cardenas, Bomar *et al*. (2009), dams result in large fluctuations in river flows, and these fluctuations are often carried downstream for long distances. The creation of such infrastructure affects the thermal, hydrological and geochemical dynamics of riparian zones, affecting the natural state of rivers (Sawyer *et al*., 2009). The river health programme (RHP) of the Department of Water Affairs (now DWS) also highlights that most dams in South Africa do not cater for the downstream needs of the river, resulting in downstream degradation as species richness and distribution in the river is adversely affected (Mantel, Hughes, and Muller, 2010).

A Development Bank of Southern Africa study by Karani (2008) highlights that the continuous construction of roads in South Africa has resulted in the displacement of species, increased pollution of aquatic systems due to increased erosion, and undesirable hydrological effects on rivers. This is also expressed by other authors such as Mafela and Teixeira-Leite (2015), who point out that a proposed road network was going to adversely affect the Mtwalume River, resulting in undesirable consequences in terms of functionality and productivity, some of which include habitat/ vegetation destruction, flow modification and hydrological impacts, erosion and sedimentation impacts, and water pollution.

New infrastructural developments are, however, not the only sources of river degradation. Systems that were put in place to preserve the health of rivers have become agents of degradation. The poor performance of WWTW systems in some regions has resulted in the direct disposal of waste into waterways, resulting in chemical and physical degradation, and microbial contamination. This affects ecosystem health greatly, and results in a major decline of aquatic life, which in turn affects the functionality of the ecosystem. Sometimes, the wastewater conveyance system is prone to leaks. As sewerage is often constructed close to rivers, the sewage leaks into the adjacent rivers, never reaching the WWTW. A study by Wensley (2012) for the DWA shows the performance rating of WWTWs in South Africa, based on capacity exceedance, effluent compliance, skills deficit, delivery and functionality. With only 26% of the WWTWs being rated as good/excellent, it is no surprise that faecal contamination of waterways is very dominant, while many informal settlements settle for the direct disposal of faecal and household wastes into rivers. High concentrations of endocrine-disrupting compounds (EDCs) from WWTW effluents disposed into rivers have also been reported by Olujimi, Fatoki, Odendaal *et al*., (2012) as a result of the lack of adequate treatment systems to detect and address these compounds.

The 2013 Green Drop Report (DWA 2013a) indicates that half of the country's 824 wastewater systems are in a poor or critical state. Problems range from technical issues such as design weaknesses, overloaded capacity, faulty equipment and machinery (Momba, Tyafa, Makala *et al*., 2006) to financial, i.e. lack of resources (Du Preez, Toerien, and Dama-Fakir, 2013) and managerial – shortages of staff, lack of senior personnel, poor management of staff, poorly functioning municipalities (Du Preez *et al*., 2013; Cooperative Governance and Traditional Affairs (CoGTA), 2014). Du Preez *et al*. (2013) documented a process of working with uThukela Water to refurbish WWTWs in KwaZulu-Natal. They state that "Years of inadequate investment in infrastructure expansion, maintenance and repairs leaves plants in poor conditions which are not compliant in terms of effluent standards and often overloaded" (2013:4). Other issues they identified included vandalism and incorrect use of systems, for example putting solid waste in pit latrines. When sewage that has not been properly processed is discharged into water bodies, it contributes to high levels of bacteria and nutrients in water. The increased nutrient load results in faster algae growth and accumulation. The result is oxygen depletion at some levels of the water body and subsequently eutrophication. During warmer periods after flooding events, further loads of organic matter in the water body can result in toxic algae. Water will also develop an undesirable look, smell and taste. The polluted water clogs irrigation equipment and water treatment equipment, increases costs of water treatment, poses a health risks to local inhabitants or recreational users; and increases risks to aquatic life.

2.6.4 Degradation due to agriculture including livestock grazing

Agricultural practices in riparian areas can have a negative impact on water bodies through the clearing of riparian vegetation (CoJ, 2008). In 2009, the total cultivated land area in Gauteng stood at 21%, showing the presence of agricultural activities even in such an urbanised province. In addition to agricultural activities such as tilling of the soil and clearing of land, which physically affect the land (Lowrance, Sharpe & Sheridan, 1986), livestock grazing results in the removal of the natural vegetative cover and increases the susceptibility of river banks to erosion. Furthermore, livestock faecal matter can release pathogens and nutrients into aquatic ecosystems (GDARD, 2011). These impacts are exacerbated by significant bank destabilisation (habitat destruction) that occurs where livestock have direct access to wetlands and rivers (Pegram & Görgens, 2000).

Armour, Duff & Elmore (1991) reiterate that overgrazing by livestock in riparian areas has resulted in considerable damage to these zones. Their report highlighted that grazing in riparian zones has resulted in changes in water quality and stream morphology, in addition to the increased addition of sediments due to bank degradation and increased soil erosion. The removal of riparian vegetation does not only remove the beneficial binding effects of roots on the soil, but also results in a reduction in the hydraulic coarseness of the river bank, and an unprecedented and disproportionate increase in river flow velocity near the bank of the river (NRC, 2002).

In addition to the ill effects of overgrazing, faecal dumping by livestock can be washed into aquatic ecosystems increasing pathogenic contamination and threatening the biotic life present in the system (Meehan & Platts, 1978). The increased concentration of faecal dumping by livestock was reported by Klapproth and Johnson (2009) to increase the concentration of faecal coliforms in water, hence resulting in reduced water quality, which in turn threatens the biological functionality and productivity of the affected river.

A study by Scott (1999) highlights the impact of timber plantations on stream flow normality in some of South Africa's catchments. The study shows that the clearing of riparian vegetation results in disproportionate yields of water in streams, leading to a disproportionate stream flow, thereby leading to a modification of the aquatic system. Arthington, Marshall, Rayment *et al*. (1997) report that sugarcane production in close proximity to riparian zones interfered with and modified the linkages between vegetated riparian areas.

The NRC (2002) states that agricultural activities can affect the hydrology of riparian areas and associated rivers, and even lead to the alteration of the geomorphology of these areas and subsequent removal of riparian vegetation. The report further states that the "harvest of riparian zones, followed by the subsequent conversion to other plant species via forestry, agriculture, livestock grazing" are associated causes of modified riparian zones. Livestock grazing has been identified as one of the major causes of riparian zone modification (Kauffman & Krueger, 1984; Fleischner, 1994; Belsky, Matzke & Uselman, 1999).

Agricultural practices also increase the chances of alien species invasion in riparian zones. Riparian zones are naturally characterised by unique vegetation that aids the stability of the biogeochemical processes in the river (Narrow, 1987; Naiman & Décamps, 1997; Tabacchi, Lambs, Guilloy *et al*., 2000). The invasion of alien species poses a threat to natural riparian vegetation, and may result in the modification of the riparian zone, and subsequently the associated river (Van Wilgen, Reyers, Le Maitre *et al*., 2008; Hood & Naiman, 2000).

The common alien plants that reduce water availability, reported in South Africa, include eucalyptus and pine, peanut butter cassia, mulberry and lantana plants. It is also reported in this study that irrigated lands and orchards in the area reduce the riparian zones to a narrow strip. Furthermore, the removal of riparian vegetation as a result of agricultural practices and land grazing in the Luvuvhu catchment area was reported (RHP, 2001). In the Tshwane area, there are many agricultural holdings, and these contribute to the eutrophication of the Roodeplaat Dam catchment. Agricultural land uses affect the riparian vegetation making it impossible for the riparian areas to prevent nutrient loading of the waterway. They also make the river susceptible to erosion during periods of high rainfall intensity and duration.

2.7 State and nature of ecosystem degradation

2.7.1 Chemical degradation

The commonly measured chemical indicators of water quality include dissolved oxygen, biological oxygen demand, chemical oxygen demand, total solids and suspended solids, pH, levels of nitrogen and phosphate, as well as electrical conductivity. The chemical indicators discussed below are based on the DWS's interpretation as presented in DWAF (1996a).

Dissolved oxygen (DO): The maintenance of adequate dissolved oxygen concentrations is crucial to the survival and functioning of aquatic biota. In water bodies, there is a natural diel variation (24-hour cycle) in dissolved oxygen. Concentrations decline through the night to a minimum near dawn, then rise to a maximum by mid-afternoon. Therefore, the time at which samples are taken has an influence on the DO reading.

Biological oxygen demand (BOD): This is often measured using the BOD 5 test. The BOD measurement determines the amount of biodegradable organic matter in water. This is an aggregated water quality parameter that indicates the amount of biodegradable organic material by measuring the amount of oxygen consumed over a five-day period. When high levels of organic matter are in the water, oxygen is taken away from use by aquatic organisms. The aquatic organisms will not thrive when oxygen levels deteriorate.

Chemical oxygen demand (COD) is another test commonly used to indirectly determine the amount of biodegradable organic material in water.

Total solids is used to describe the concentration of solid material that is left in a container after evaporation and drying of a water sample. Total solids includes both total suspended solids, which is the portion of total solids retained by a filter, and total dissolved solids, the portion that passes through a filter. Increased solids in water bodies distort the living environment for natural organisms. The solids also reduce the amount of light that can penetrate the water body to sustain natural life forms.

Total suspended solids (TSS) are solids that can be trapped by a filter. To measure TSS, the water sample is filtered through a pre-weighed filter. The residue retained on the filter is dried in an oven at 103 to 105°C until the weight of the filter no longer changes. The increase in weight of the filter represents the TSS.

pH: The relative proportions of the major ions, and in consequence, the pH of natural waters, are determined by geological and atmospheric influences. Some streams are naturally more acidic than others and their biota are often adapted to these conditions. Most fresh water in South African urban areas tends to have a pH that is slightly above neutral, and sometimes much higher, due to alkaline compounds that are added in WWTWs. However, water that is released after acid mine drainage in areas that are being mined or were mined in the past is acidic. The pH of water bodies is affected by factors such as temperature, the concentrations of inorganic and organic ions, biological activity – for example, the rates of photosynthesis and respiration – and the season. The pH can affect the availability and toxicity of constituents such as trace metals and ammonium. Industrial activities generally cause acidification rather than alkalinisation of rivers. Acidification is normally the result of three different types of pollution, namely low-pH point source effluents from industries, such as pulp and paper, and tanning and leather industries; mine drainage, which is nearly always acidic; and acid precipitation resulting largely from atmospheric pollution caused by the burning of coal, which produces sulfur dioxide, and the exhausts of combustion engines (nitrogen oxides).

Nitrogen: The term inorganic nitrogen includes all the major inorganic nitrogen compounds, ammonia (NH3), ammonium (NH4+), nitrite (NO2) and nitrate (NO3-) present in water. Inorganic nitrogen stimulates aquatic plant growth and algae. Surface runoff from the surrounding catchment area, the discharge of effluent streams containing human and animal excrement, agricultural fertilisers and organic industrial wastes are major sources of the inorganic nitrogen entering aquatic systems. Site-specific conditions, especially the availability of phosphorus, are critically important in modifying the influence of inorganic nitrogen on eutrophication. A target water quality range should be derived only after case- and site-specific studies.

Phosphorus: Phosphorus is an essential macronutrient. However, in fresh water, the implications of high concentrations of phosphorus or phosphates are usually devastating. The phosphates and phosphorus cause algae, water hyacinth and other plants to grow faster than can be accommodated in the water body. The forms of phosphorus in water are continually changing because of processes of decomposition and synthesis between organically bound forms and oxidised inorganic forms. Elevated levels of phosphorus can result from point source discharges, such as domestic and industrial effluents, and from nonpoint sources that include atmospheric precipitation, urban runoff and drainage from agricultural land, especially where fertilisers have been applied. The most significant effect of elevated levels of phosphorus is the stimulation of the growth of aquatic plants. A target water quality range should be derived only after case- and site-specific studies.

Total dissolved salts/electrical conductivity (EC): The total dissolved salts (TDS) concentration measures the quantity of all dissolved compounds in water. Since most dissolved substances, such as sodium chloride, carry an electrical charge in water, the TDS concentration is directly proportional to the EC of water. Because EC is much easier to measure than TDS, EC is a rapid and useful surrogate measure of the TDS content of those waters with a low organic content. The EC is a measure of the ability of water to conduct an electrical current due to the presence in water of ions such as carbonate, bicarbonate, chloride, sulphate, nitrate, sodium, potassium, calcium and magnesium, all of which carry an electrical charge. Many organic compounds dissolved in water do not dissociate into ions, and consequently they do not affect the EC. The TDS will be affected by the geology of the rocks that the water has been in contact with. Salts accumulate as water moves downstream because salts are continuously being added through natural and anthropogenic sources. Domestic and industrial effluent discharges, and surface runoff from urban, industrial and cultivated areas, are examples of the types of source that may contribute to increased TDS concentrations.

Evaporation also leads to an increase in the total salts. Changes in the EC values provide useful rapid estimates of changes in the TDS concentration, once the relationship between EC and TDS has been established for a particular water body. However, changes in EC values provide no information on the changes in the proportional concentrations of the major ions.

Walsh *et al.* (2005) acknowledge that water quality impairments will be greater in areas where management of sewage and industrial waste is not efficient. However, an interesting finding is that increased pollution has been reported to occur even at low levels of urbanisation (Hatt *et al*., 2004, in Walsh *et al*., 2005). Any study on water chemistry must take into account the fact that natural climatic and geological differences will affect water chemistry. Other important factors would be the historical land use, the sources of supply of pollutants, and factors in the catchment and stream processes that affect nutrient retention.

2.7.2 Physical degradation

The physical parameters used in assessing water quality include water temperature, turbidity, colour and odour.

Temperature: Temperature affects the biological functions of aquatic organisms and affects the water chemistry. Surface water temperatures fluctuate naturally with the time of day and the season along the longitudinal changes of a river course, and with the water depth. Aquatic organisms have upper and lower thermal tolerance limits, optimal temperatures for growth and temperature limitations for migration, spawning and egg incubation. Higher temperatures reduce the available dissolved oxygen in the system thus affecting respiratory functions.

Elevated water temperatures increase metabolic rate, including respiration, and, therefore, elevated temperatures affect the oxygen demand of aquatic organisms. Inter-basin water transfers, discharge of water from impoundments and discharge of heated effluents from industry and power stations can all be sources of temperature changes in aquatic ecosystems. Loss of tree cover and exposure of impervious surfaces in urban watersheds can increase average summer stream temperatures by 4°C (Galli, 1991; Braid, 2014). A general rule of thumb is that water temperatures should not be induced to vary by more than 2°C from the background average water temperature considered as normal for that site (at that time of day and season). It is anticipated that the climate will warm up over the 21st century leading to warmer water temperature conditions (DEA, 2013).

Turbidity: Turbid water is cloudy or opaque, caused by the presence of certain materials in the river. The materials that cause water to be turbid include clay, silt, finely divided inorganic and organic matter, algae, soluble coloured organic compounds, microscopic organisms, industrial waste and sewage. Suspended sediment has many direct and indirect effects on aquatic biota. Examples are abrasion or clogging of the gills of fish and reduction of light affecting the growth of aquatic plants. Reduced light will also affect the relationships between predators and prey (James & Heck, 1994). When the sediment settles to the bottom of a water body, it can smother the eggs of fish and aquatic insects or suffocate newly hatched insect larvae. Particles also provide attachment places for pollutants, notably metals and bacteria. Storms and heavy rainfall can cause an increase in turbidity as particles are washed from surrounding land into water. Fast-flowing water also stirs up sediment on the bottom of rivers. Turbidity is measured by shining a light through the water and is reported in nephelometric turbidity units. The turbidity of a river is an indication of levels of waste and dissolved solids, hence indicating the level of degradation. Turbidity and colour can be attributed to the disposal of wastes from surrounding settlements, leakages from drainage infrastructure, manmade diversions from infrastructure and disposal of effluents by industries in close proximity. A study of the Luvuvhu River catchment in Limpopo conducted as part of the Limpopo environmental outlook report in 2015, highlighted that construction activities in the area, and the presence of infrastructural developments such as bridges contributed to the turbidity of the river. Compton and Maake (2007) reported that the Orange River in South Africa is one of the most turbid rivers in the world, as a result of soil erosion and runoff that results in siltation of the river. Increased siltation of rivers will affect specie distribution and the flow regime of the river.

Colour and odour: The colour and odour of water can give an indication of whether it is contaminated or not. Suspended sediment will have the same colour as the surrounding soil. If water is coloured differently from the soil around it, for instance being milky or appearing unnatural, it may point to chemical contamination (Braid, 2014). Green water often indicates algal growth, and water coloured black or grey may point to contamination by sewage. Other indicators of pollution are the presence of foam or an oily sheen on the water (Braid, 2014).

2.7.3 Biological degradation

Biological degradation is usually indicated by faecal and total coliforms as well as other microbial agents of degradation. Faecal coliforms are associated with human and animal waste. The sources of contamination are municipal wastewater discharge that has not been properly treated, or direct contamination. The most commonly measured bacterial indicators are total coliforms, faecal coliforms and enterococci (Noble, Moore, Leecaster *et al*., 2003, in Jordaan & Bezuidenhout, 2013). According to South African regulations, 100ml of water should be absolutely free from faecal indicator species, while limited levels of total coliforms are allowed (Jordaan & Bezuidenhout, 2013). Pathogens may die off in less than a day or in a couple of weeks, depending on the environmental factors in the system. Higher temperatures, solar radiation, nutrient deficiency, pH and predation increase the bacterial die-off rates (Pegram & Görgens, 2000).

In South Africa, a lot of emphasis is placed on the total and faecal coliform content of the water. Standard regulations (SANS 241) state that the total and faecal coliform count of a water sample should be between 0 and 5 in every 100 mL of water. Paulse, Jackson and Khan (2009) examined the biological quality of the Plankenberg and Diep Rivers in the Western Cape. The study reports that the total and faecal coliform content of the rivers exceeded acceptable limits, indicating river degradation. Obi, Potgieter, Bessong *et al*. (2002) investigated the microbial quality of rivers in rural Venda communities and report that high levels of faecal coliforms and total coliforms are present in the rivers, posing a threat to the communities that often utilise them for potable and recreational purposes. The sources of biological degradation include the direct disposal of sewage into waterways – a common disposal technique in informal settlements due to the lack of proper sanitation services. Agricultural land use and grazing also increases the chances of faecal contamination of water. When animals are grazing, they often excrete their waste in the same area. During occasions of increased rainfall, the waste is carried in runoff into the rivers, hence biological degradation is inevitable. In addition to total and faecal coliforms, other biological degradation agents that can be found in aquatic ecosystems include viruses, fungi and yeasts that thrive in polluted environments with high levels of organic matter.

2.8 Aquatic ecosystem health indices and policing

2.8.1 Aquatic ecosystem health indices

Bunn, Abal, Smith *et al*. (2010) state that "stream ecosystem health monitoring and reporting need to be developed in the context of an adaptive process that is clearly linked to identified values and objectives, is informed by rigorous science, guides management actions and is responsive to changing perceptions and values of stakeholders". The criteria that were considered in the selection of suitable indicators of aquatic system condition in South Africa are described in DWAF (1996b). The first point in Box 1 below relates to the ability of an indicator to respond strongly to the disturbance gradient, while not being over-responsive to natural variability. Freshwaters are often characterised by large natural fluctuations in flow or water level, which can cause temporary loss of biodiversity. This dynamic aspect of rivers has to be taken into account (Barmuta, Linke, and Turak, 2011).

Box 1: Indicators of ecosystem condition

Suitable indicators of ecosystem condition should:

1. be sensitive to a range of changes/stresses and allow for the detection of trends (i.e. give a strong signal), while being stable in response to a natural variability (i.e. with low noise)
2. generate information (in the form of indices) that can be easily understood
3. be easy to measure
4. be founded in science
5. be representative of the overall state of the environment
6. be acknowledged by experts to measure or represent important aspects of river condition
7. be appropriate for measurement at river-reach scales and over annual time periods
8. be cost effective
9. be sensitive to management intervention, i.e. show change as a result of management intervention
10. integrate environmental effects over time and space.

Rivers are grouped in terms of their state of health into four classes. The four classes are influenced by the environment, such as effluent discharge and human settlements. The four classes of river health, according to DWA (currently known as DWS) are explained in Table 4.

Table 4: River health classification and the associated ecological and management perspective (DWA, 2004)

River health class	**Ecological perspective**	**Management perspective**
Natural	Non-existing/negligible modification of instream and riparian habitats and biota	Protected rivers, relatively untouched by human hands; no discharge or impoundments leading to the river
Good	Biodiversity still largely intact	Some human-related disturbance, but mostly of low impact potential
Fair	Sensitive species may be lost; lesser abundance of biological populations are likely to occur or sometimes higher abundance of tolerant or opportunistic species occur	Multiple disturbances associated with need for socio-economic development, e.g. impoundment, habitat modification and water quality degradation
Poor	Habitat diversity and availability have declined; mostly tolerant species present are often diseased; population dynamics has been disrupted (e.g. biota can no longer reproduce or alien species have invaded the ecosystem)	Often characterised by high human densities or extensive resource exploitation Management intervention is needed to improve river health, e.g. to restore flow patterns, river habitats or water quality

There are also two groups of aquatic ecosystem health indices – primary indices and secondary indices. Primary indices monitor the biological health of a river by focusing on the changes in the biotic components of the system. There are two important primary indices used for the assessment of river health. These are the index of biotic integrity (IBI) developed by Karr (1999), and the riparian vegetation index (RVI) developed by Kemper (2001).

The IBI assesses the health of a river based on the quality of fish and invertebrates present in the river. This is the primary system utilised internationally for waterway health assessments (Kotze *et al.*, 2004). In South Africa, a similar index known as the Fish Assemblage Integrity Index (FAII) is more commonly applied. The factors often considered when using the IBI for river health assessments include species richness, which is often an indication of oxygen depletion, and/or physical and chemical degradation (Plafkin, Barbour, Porter *et al*., 1989).

The RVI assesses the state of the riparian vegetation. It assesses the functionality and ecological integrity of the vegetation present in the zone (Kemper, 2001). Ideally, the riparian zone should remain unmodified and unperturbed by land use activities; hence any observed modifications to the riparian vegetation, such as the absence of vegetation or encroachment of foreign species is an indication of river health degradation.

The FAII assesses the species richness of fish in river segments, taking into consideration the expected distribution of fish in a river. This index takes into consideration three factors, namely, the relative tolerance of indigenous fish species expected to occur in different segments of the waterway, the abundance of species in different segments, and the general health rating of the fish in different segments. The different scores of these factors provide adequate information about the ability of the river to support fish, i.e. biotic components (Kleynhans, 1996).

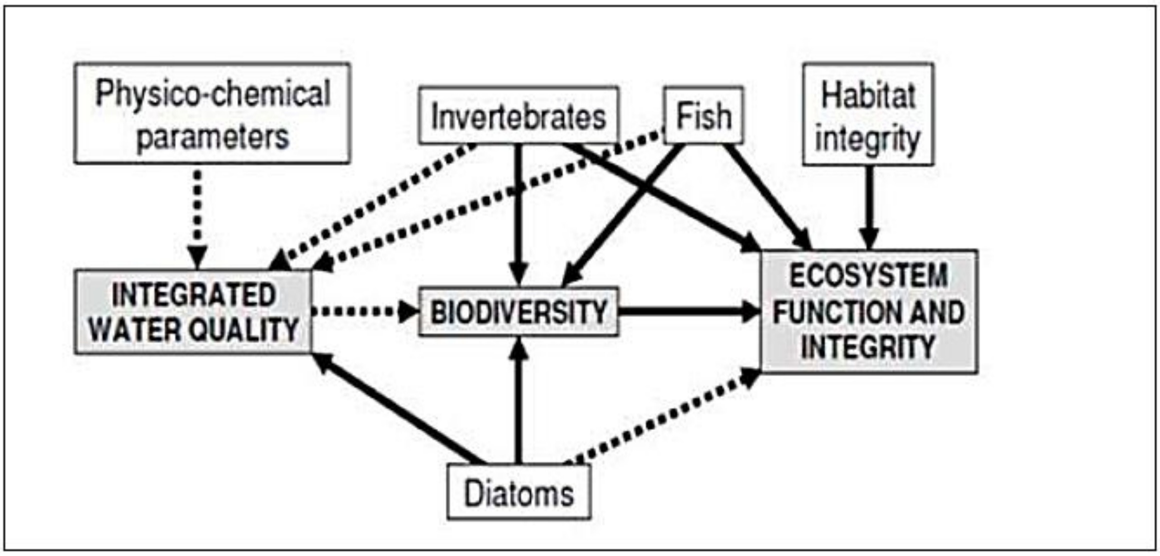

Figure 7: Relationship between different ways of measuring river health (DWAF, 2008)

Diatom species composition is an index that monitors the diatoms in an aquatic system. Diatoms are single-celled algae that occur widely in water. They are unique among the algae in having silica cell walls. Different species have different water quality preference and tolerance (DWAF, 2006). They are sensitive to changes in nutrient concentrations (DWAF, 2008) (Figure 7). After identification of the dominant diatom species in water samples, conclusions can be drawn regarding the water quality at a particular site, provided that the water quality preferences of these species are known. Rimet (2012) reports that Newall, Bate & Metzeling (2006) observed that diatoms were more closely related to water quality variables, whereas macro invertebrates were primarily related to catchment and habitat features. Rimet (2012) also notes that diatoms can be a useful measure of water pollution in severely affected water courses in which macro-invertebrates are no longer present but diatoms are still present.

Secondary health indices have also been developed to assess the health of rivers and other waterway components. The most important indices include the habitat assessment indices (which include the habitat identity assessment and the habitat assessment matrix), the hydrological index and the water quality index.

The habitat identity assessment (HIA) index evaluates the health of a river based on the biotic and abiotic components within the catchment area. The index takes into consideration the impacts of disturbances and compares rivers being studied to established undisturbed and modified rivers to reach a score rating. The habitat assessment matrix (HAM), on the other hand, assesses the health of a river by evaluating primary, secondary and tertiary components.

The primary components include the stability of the bottom substrate, presence or absence of instream cover, embeddedness of the river, as well as the flow velocity and depth of the river. Secondary components often assessed include bottom scouring and deposition, channel alteration and stream sinuosity, while the tertiary components include the state of modification of the riparian zone.

The hydrological index (HI) aims to provide a hydrological context in which biomonitoring sampling takes place. The index provides information on flow conditions prior to, and during, the sampling period. This helps provide information on the extent of stress on indicator organisms. The HI relies on historical published data on hydrological flow, and is not resource intensive. The water quality index (WQI) was specifically designed for South Africa, and it gives valuable interpretation to biological assessments. Factors investigated when using the WQI include oxygen concentration, eutrophication, turbidity, presence of faecal coliforms and dissolved substances.

2.8.2 Policing indices and limits

The DWS uses specific indices, based on the above-mentioned health assessment indices, to determine the actual state of a river which is represented by an appropriate score. These specific indices have been developed for the South African context and include the macro-invertebrate response assessment index (MIRAI) and the South African Scoring System (SASS).

2.8.2.1 The macro-invertebrate response assessment index

Ideally, biotic indices would be calculated using quantitative macro-invertebrate sampling. However, as such methods are resource intensive, a qualitative method has been developed known as the South African scoring system (SASS) (DWAF, 2008). SASS is described as a rapid biological assessment method. A variety of macro-invertebrate organisms (e.g. snails, crabs, worms, insect larvae, mussels, beetles) require specific habitat types and water quality conditions for at least part of their life cycles. A change in the structure of aquatic invertebrate communities is a sign of changes in overall river conditions (DWAF, 2006). Dallas (2000) reports the advantages of using riverine macro-invertebrates as a biological indicator of river health, as summarised by Rosenberg and Resh (1993), as follows:

1. Macro-invertebrates are ubiquitous in rivers and can therefore be affected by environmental disturbances in many different types of aquatic systems and in most biotopes within these waters.
2. Sensitivity to stress varies with species and the large number of species within a community offers a spectrum of responses to environmental stresses.
3. In their aquatic phase, macro-invertebrates are largely non-mobile and are thus representative of the location being sampled, which allows effective spatial analyses of disturbance and pollutants.
4. Their life-span is long enough to allow elucidation of temporal changes caused by disturbances, while short enough to ensure observation of re-colonisation patterns following such a disturbance.
5. Macro-invertebrates are relatively easy to identify to family, and degraded conditions can often be detected by an experienced biologist or technician with only a cursory examination of the macro-invertebrate assemblage (Barbour, Gerritsen, Snyder et *al*., 1999).

6. Sampling is relatively easy, requires few people and inexpensive equipment, and has very little detrimental effect on the resident biota.

2.8.2.2 South African scoring system

The SASS index has been developed and refined over several years in South Africa (DWAF, 1996a; Dickens & Graham, 2002; Dallas, 2007). It is now in its fifth version, known as SASS 5. The methodology involves sampling for macro-invertebrates from three different biotopes: bedrock, marginal vegetation and sand, gravel or mud, using a net or hand picking. Taxa noted are recorded for the biotope where they were found. Macro-invertebrate families are scored according to their sensitivity to deterioration in water quality. Highly pollution-tolerant species are given a low score and highly sensitive species are given a high score. Three index values are obtained:

7. The total score (sum of scores for the taxa present)
8. The number of taxa present in the sample
9. The average score per taxon (ASPT) where ASPT = total score/no. of taxa.

Of the three scores, the average score per taxon (ASPT) has been found to be the most consistent over all biotopes (lowest CV%) (Dickens & Graham, 2002). The SASS was originally developed to monitor organic pollution, but it has subsequently been widely applied, successfully, to measure the biological effects of other pollutants (Ollis, Boucher, Dallas *et al*., 2006). SASS 5 is easy in the sense that it does not require expensive equipment, but appropriate competency-based training is essential (DWAF, 1996a). Reference conditions have not been established for all regions in South Africa but have been developed for the national sites.

There are no indices that currently assess the impact of human settlements on aquatic ecosystems in the South African context; however, the DWS and Department of Environmental Affairs (DEA) have implemented an assessment procedure that evaluates the possible impact of an establishment on a river, wetland or riparian area. This is schematically illustrated in Figure 8.

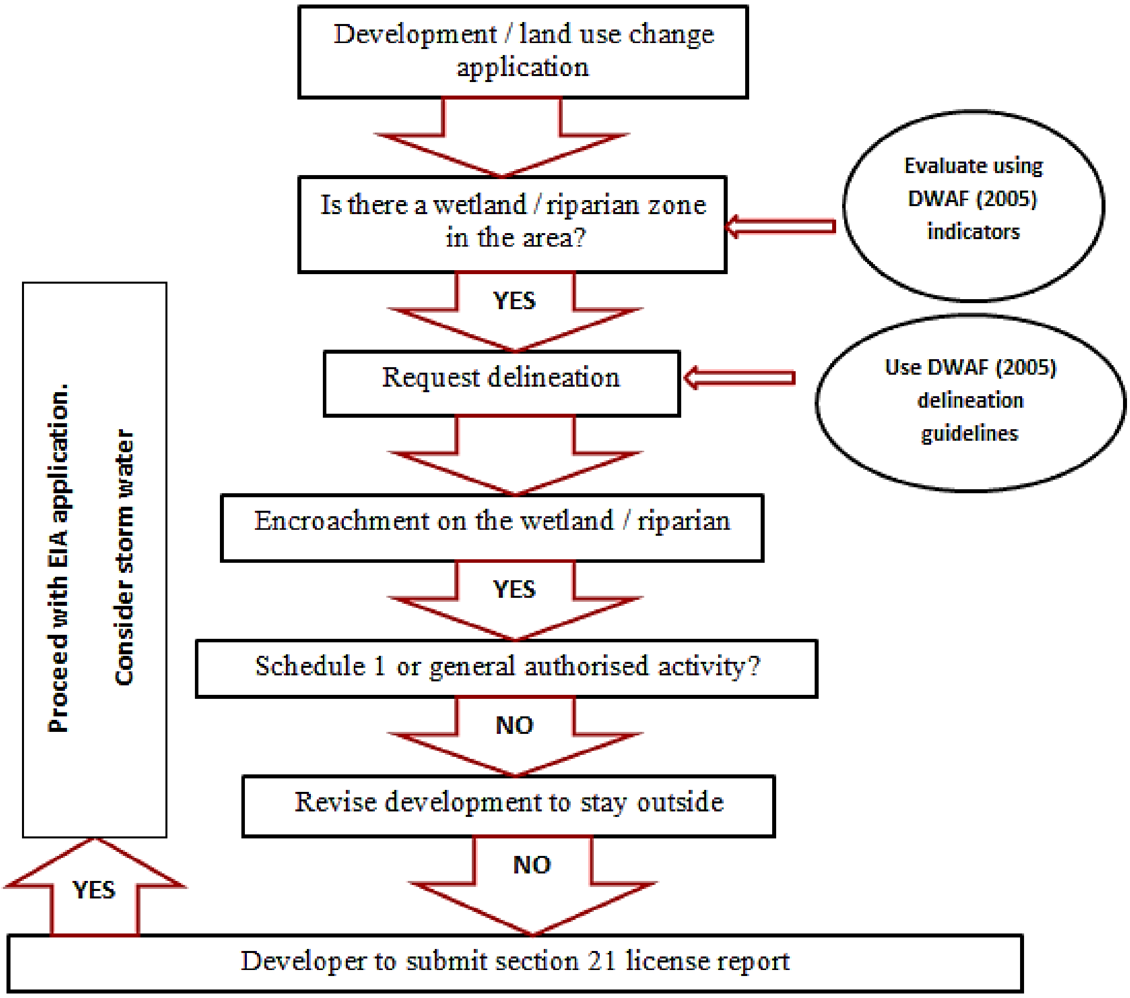

Figure 8: Assessment procedure for establishment of settlements and other forms of land use to ensure protection of aquatic ecosystems and riparian areas

3 State and nature of ecosystem degradation in case studies

3.1 Jukskei River

The Jukskei River (Figure 9) stretches over a distance of 50 km in which it traverses the eastern, northern and western parts of the Johannesburg Metro (Figure 9). It springs from the Bezuidenhout Valley in the east of Johannesburg, and flows through a heavily built-up area consisting of formal and informal residential areas, retail centres, industries and agricultural zones, before it converges with the Crocodile River, which flows into the Hartebeespoort Dam (Schoeman, 1976). The river drains an area that has been settled as far back as the mid-nineteenth century when Dutch settlers started farming in the area. The area grew rapidly after gold was discovered, becoming a municipality in 1897. These rapid developments in the area resulted in the river being modified into a network of canals, channels and underground conduits in some sections. There are several other alterations in the river due to constructed dams, rapids, bridges, flow attenuation structures and abstraction points. Effluent is discharged into the river from settlements and facilities, such as WWTWs, industries and retail centres, adding to the Jukskei waterway's ecosystem change. Some of the areas through which the Jukskei River flows are built-up, densely populated and characterised by weak service delivery, thus exposing the river to degrading factors. Although extensive degradation of the Jukskei River has been reported since the 1980s, a holistic picture of the contributing factors seems to be unexplored.

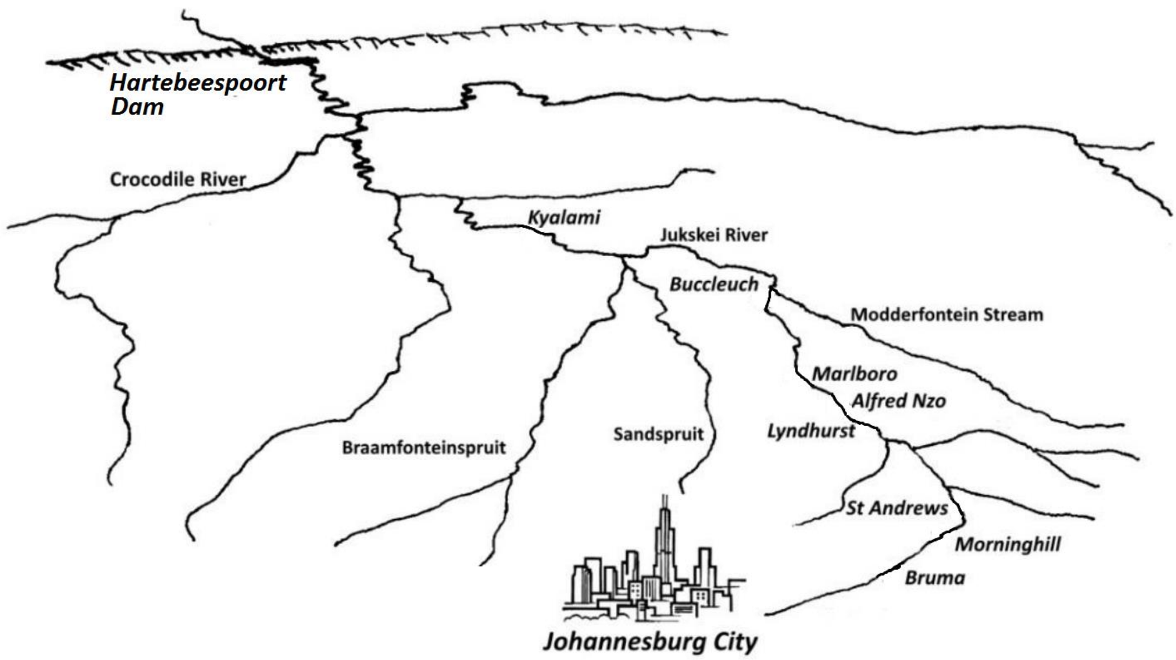

Figure 9: Jukskei River and its tributaries (Adapted from Edenvale River Watch, 2016)

The Jukskei River's catchment area includes the Ekurhuleni Municipality where dolomite, quartzite and amphibolite soils are predominant. Observations of the riparian vegetation of the Jukskei area show some alien vegetation invasion. The research team made two field visits, stopping at various points along the river. Invasive trees such as eucalyptus and syringa (melia azedarach), as well as kikuyu grass, were noted. The activities of residents of informal settlements such as in Alexandra have denuded some parts of the Jukskei River completely of its riparian vegetation, increasing the extent of waterway degradation. The river has no riparian area in most built-up areas, as these areas have been cleared, altered and built on (Figure 10).

Figure 10: Jukskei River showing a section in Alexandra Township where the riparian area has been built on, the river channel altered and flow disrupted by volumes of solid waste

Tributaries of the Jukskei River are usually highly polluted due to continuous water flows sustained by polluted effluents and other discharges from surrounding settlements and other land uses. The settlements in the area, especially the densely populated townships and the many informal settlements, have inadequate sanitation services thereby contributing to the pollution in the Jukskei River. In the upper catchment, poorly served areas include the townships of Alexandra, Linbro Park, Modderfontein, Far East Bank and Lombardy East. Other densely populated settlements with poor sanitation services that cause pollution in the lower reaches of the Jukskei River include Kya Sands informal settlement, Zandsspruit and Diepsloot Townships. Furthermore, there are numerous other unnamed informal settlements in open areas in the catchment that have no services; hence these communities dump their waste in open areas and water bodies. Water quality monitoring records for the Jukskei River obtained from the DWS RQIS showed higher levels of pollution in the upper half of the catchment.

The water quality records show that the major pollutants include bacterial load from sewage and nutrients in the form of phosphates, nitrates and nitrites. The river pollution is at its worst in the upper catchment and this pollution is fed through the whole waterway. There are frequent incidences when the water quality records show the pollution levels to be well above DWS guideline limits for safe use.

The investigation of aquatic degradation and rehabilitation led to the development of a rehabilitation framework. The framework makes a distinction between instream and riparian degradation. The assessment of instream degradation makes use of water quality measures, while riparian degradation describes degrading land uses and other practices that damage the health of the riparian zone. This framework uses the degradation levels defined to show when the situation is calling for rehabilitation. The degradation levels used in the framework are defined as shown in Table 5 below. In Table 5, when a variable is “bad” or “very bad”, the recommendation made by the framework is to provide rehabilitation. For E.coli and nitrates, “very bad” refers to when the E.coli count in colony-forming units (CFUs) is more than 500 per 100 millilitres and when nitrates plus nitrites exceed 3 mg/L (Table 5). In the Jukskei River, E.coli counts reach very high values that are measured in the magnitudes of several millions (5 700 000) just after Alexandra Township and nitrates plus nitrites reach a maximum of 36.6 mg/L, instead of acceptably good levels of around 1 mg/L, at the point where the river crosses the N1 road (Table 6). The nitrates and nitrites values could even be higher further upstream, just after the Alexandra crossing, where the other pollutants peak. However, this could not be confirmed as the records available do not include readings for nitrates and nitrites.

The records of all water quality variables also show that very bad water quality is persistent for the stations where incidences were recorded such that incidences of “very bad” quality readings are frequently followed by more “very bad” records. “Very bad” incidences of pollution do not take place as isolated events but rather as repetitive occurrences that do not seem to be under any form of control. Table 6 shows that E. coli counts are worse than 500 CFU/100mL in all the records captured. The concentrations of nitrates and nitrites are worse than 3 mg/L in 98.9% of the records taken in the last year of records (2014). Nitrite is poisonous to animals and may cause cancer. At the high levels found in the Jukskei, nitrite would cause immediate fish kills if there were fish in the river.

The areas with the worst performing water quality indicators are where the dense township settlements discharge their direct and diffuse effluent into the Jukskei River. According to the data, the Alexandra Township and surrounding settlements are associated with the areas on the river with the worst pollution levels, at the gauging station closest to Marlboro Road.

Table 5: Water quality assessment rating table with colour coding as applied in case studies

	Very Bad	Bad	Fair	Good	Very Good
EC-Phys-Water (ELECTRICAL CONDUCTIVITY) (mS/m)	>100	70 - 100	50 - 70	30 - 50	=<30
Ca-Diss-Water (CALCIUM) (mg/L)	>181	121-180	60-121	40 - 60	=<40
Cl-Diss-Water (CHLORIDE) (mg/L)	>600	400 - 600	200-400	100-200	<100
F-Diss-Water (FLUORIDE) (mg/L)	>2.5	2.0 - 2.5	1.5-2	1-1.5	=<1
NO3+NO2-N-Diss-Water (NITRATE + NITRITE NITROGEN) (mg/L)	>3	2.0 -3.0	1.5-2	1-1.5	=<1
SO4-Diss-Water (SULPHATE) (mg/L)	>1000	200 - 1000	100-200	50-100	=<50
pH-Diss-Water (PH) (pH units)	<4.5 or >10.0	4.5-5.5 or 9.0-10	5.5-6.5 or 7.5-9.0	6.5-6.8 or 7.2-7.5	6.8-7.2
PO4-P-Diss-Water (ORTHO PHOSPHATE AS PHOSPHORUS) (mg/L)	>3	2 - 3	1.5 - 2.0	1 - 1.5	=<1
E.COLI-Susp-Water (ESCHERICHIA COLI) (cfu/100mL)	>500	126-500	35-126	1-35	0
FC-Susp-Water (FAECAL COLIFORM COUNT) (cfu/100mL)	>200	100-200	30-100	1-30	0

Table 6: Jukskei River water quality assessment results for selected variables

Maximum values for selected water quality variables in last year of record						
Monitoring Station ID	185640	88648	90186	185688	191611	100000782
Location	Upstream at Bruma Lake	Marlboro Road Crossing	N1 Crossing	Lone Hill Area	After Northern Farm	Dowstream at Copperfield
EC-Phys-Water (ELECTRICAL CONDUCTIVITY) (mS/m)	117	-	146	-	56	64
Ca-Diss-Water (CALCIUM) (mg/L)	35.1	-	98.6	-	-	-
Cl-Diss-Water (CHLORIDE) (mg/L)	34.6	-	-	-	64	70
F-Diss-Water (FLUORIDE) (mg/L)	0.44	-	4.07	-	-	-
NO3+NO2-N-Diss-Water (NITRATE + NITRITE NITROGEN) (mg/L)	13.8	-	36.6	-	6.7	9.4
SO4-Diss-Water (SULPHATE) (mg/L)	39.8	-	252.7	-	-	201.4
pH-Diss-Water (PH) (pH units)	8.6	-	8.4	-	8.3	9.3
PO4-P-Diss-Water (ORTHO PHOSPHATE AS PHOSPHORUS) (mg/L)	1.04	-	5.9	-	2.2	4.4
E.COLI-Susp-Water (ESCHERICHIA COLI) (cfu/100mL)	1700000	5700000	-	240000	130000	170000

% number of Incidences when water quality variable is worse than "Very Bad" in last year of records.						
Water Quality Monitoring Station ID	185640	88648	90186	185688	191611	100000782
	%	%	%	%	%	%
EC-Phys-Water (ELECTRICAL CONDUCTIVITY) (mS/m)	2	-	72	-	0	0
Ca-Diss-Water (CALCIUM) (mg/L)	0	-	0	-	-	-
Cl-Diss-Water (CHLORIDE) (mg/L)	0	-	-	-	-	-
F-Diss-Water (FLUORIDE) (mg/L)	0	-	8.8	-	-	
NO3+NO2-N-Diss-Water (NITRATE + NITRITE NITROGEN) (mg/L)	35.9	-	98.9	-	85	-
SO4-Diss-Water (SULPHATE) (mg/L)	0	-	0	-	-	-
pH-Diss-Water (PH) (pH units)	0	-	0	-	0	0
PO4-P-Diss-Water (ORTHO PHOSPHATE AS PHOSPHORUS) (mg/L)	0	-	3.3	-	0	2
E.COLI-Susp-Water (ESCHERICHIA COLI) (cfu/100mL)	93.3	100	-	76	76.5	75

Water quality data from DWS shows that the Jukskei River has been subjected to extensive biological degradation for a considerably long period of time, with records showing that degradation started just after the turn of the twentieth century, as evidenced by the early legal challenges brought about by farmers who complained of the Johannesburg Council causing a nuisance when it started dumping sewage water into a portion of Klipspruit Farm in 1904. The Johannesburg Council only started to partially purify the sewage waste in 2010 after several more legal challenges and also when the whole of Klipspruit Farm had been converted into a sewage dumping farm (EWISA, 2009). Over the years, several sewage plants have been built around Johannesburg, most of which release their effluent into the Jukskei River, causing much degradation. In the past ten years, bacterial load peaks that exceed tens of thousands of CFU of E.coli have been reported along the Jukskei River. Figure 11 shows the E. coli count records from the Jukskei River at a sampling point (DWS Gauging Station: 88648) located where the river crosses Marlboro Road downstream of Alexandra Township. It can be observed that peaks in E.coli count vary over the course of the years from 550 000 CFU/100 mL in 2003 to 5 700 000 CFU/100mL in December 2014.

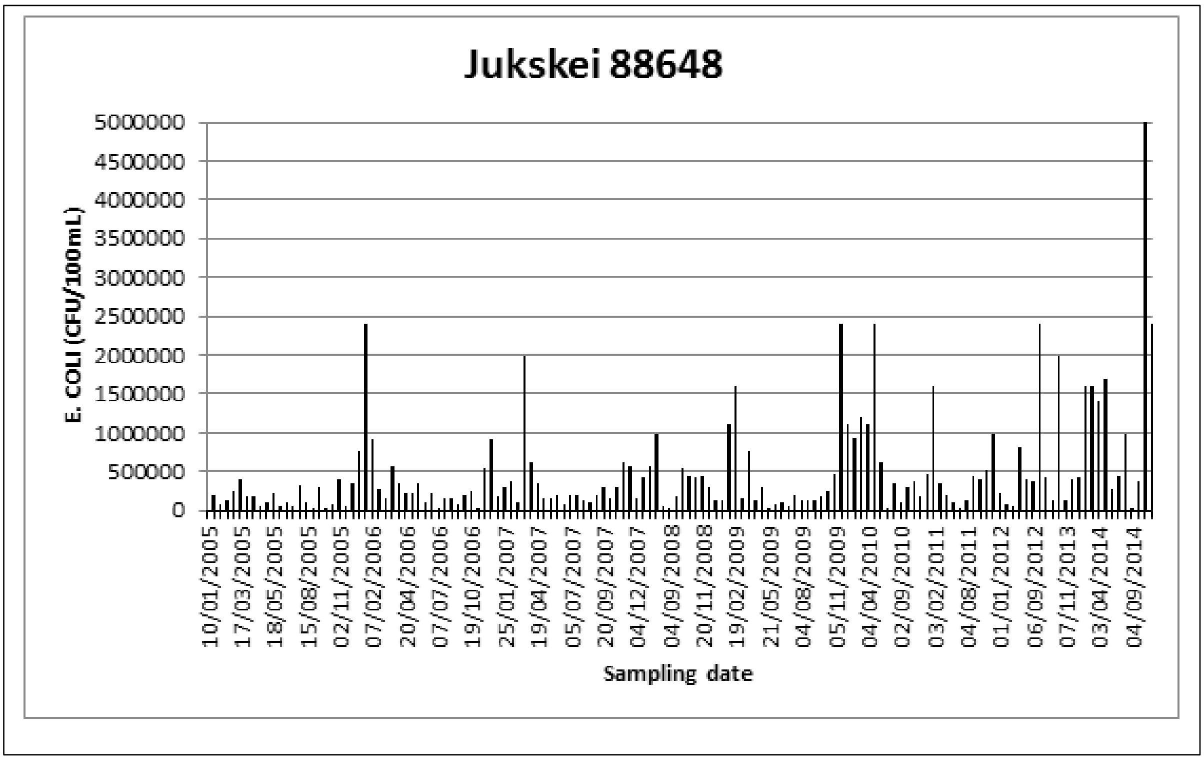

Figure 11: E.coli counts in the Jukskei River at sampling point located at Marlboro Crossing, Johannesburg, from January 2005 to January 2015

The high E.coli counts at point 88648 (Marlboro Bridge) can be attributed mainly to urbanisation and expansion of settlements with poor sanitation in the area upstream of Marlboro. E.coli degradation of the Jukskei River upstream of the Marlboro Bridge has steadily increased over the last decade in spite of municipal programmes to discourage pollution.

Edenvale River Watch (2016) also reported an escalation of bacterial pollution of up to 100 times over a ten-year period.

The higher E.coli count at the Marlboro point is due to the Alexandra Township and other settlements immediately upstream of this point and around the Bruma Lake. The population of Alexandra, a densely populated township, has been increasing rapidly as a result of socio-economic driven migration. The demand for services, especially water and sanitation, increased rapidly as the population increased, resulting in the sanitation provision systems being strained. The result has been frequent bursts in sewer pipes as well as raw sewage spillage into storm water and ultimately into the river. Several points where storm water drains released sewage into the river were observed during the study period. Past reports also point to the direct pollution of the Jukskei River by settlements, especially townships that are located along its banks (Van Veelen & Van Zyl, 1995; Matheeb & Barnes, 2001; Huizenga & Harmse, 2005). Due to historical legislative tools that governed land ownership rights, designated African settlements such as Alexandra Township were established without adequate planning and services. By 1916, Alexandra Township had a population of 30 000 people (Maylam, 1990; Jochelson, 1990), which has now increased to more than 180 000 inhabitants. Increased migration from rural areas is resulting in increases in shack dwellings. These shacks are usually located in sensitive areas that seem vacant, such as the Jukskei River banks. Reports from the Edenvale River Watch show that the Jukskei is highly degraded biologically at points where dense human settlements and derelict buildings are located, such as the Johannesburg CBD, Bezuidenhout, Bruma area, Alexandra Township, Kya Sands Informal area, Buccleuch and Rietfontein (Figure 12).

Other sampling points along the reach of the Jukskei River have shown similar trends of degradation. At the DWS sampling point numbered 185640, located 150 m downstream of the Bruma Lake, E.coli levels are very high, exceeding peak values of over 2 000 000CFU/100mL from 2005 until 2014. The area upstream of Bruma Lake is relatively better when compared to the area immediately upstream of Marlboro Bridge. The type and density of settlements in the catchment areas for these two points are also different, with areas upstream of Bruma Lake being less densely populated with larger formal houses, in comparison with areas immediately upstream of Marlboro, where the settlements are mostly densely populated townships with both formal and informal dwellings.

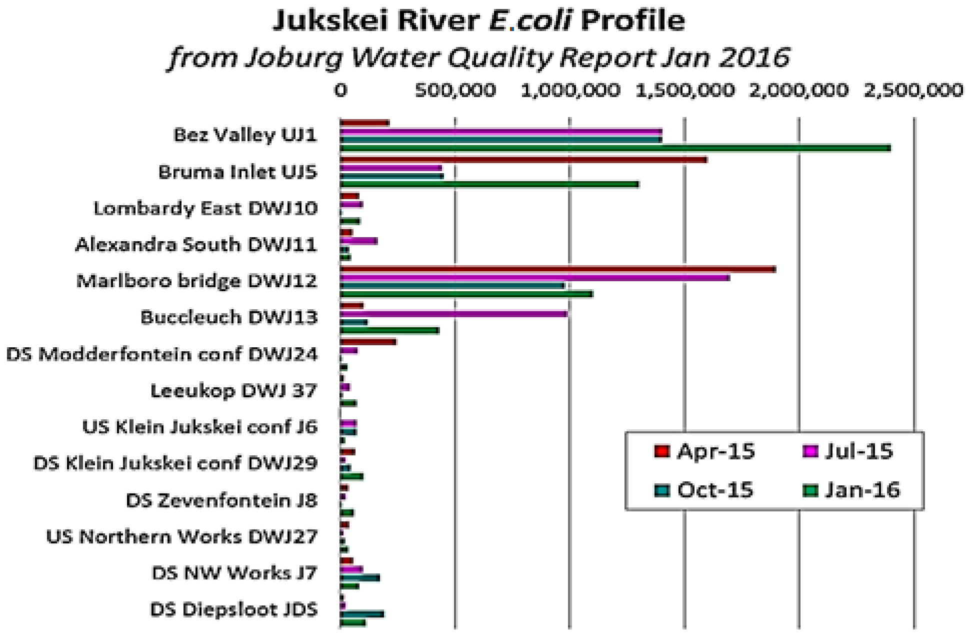

Figure 12: E.coli count for Jukskei River from the most upstream gauging station to the exit points before the confluence with the Crocodile River (Adapted from Edenvale River Watch, 2016)

The records also show that EC is usually higher than acceptable as the river crosses the N1 with 72% of records being higher than 100 mS/m. The high levels of EC measurements indicate high levels of salts in the water, especially sodium (Na^{+}), calcium (Ca^{2+}), potassium (K^{+}) and magnesium (Mg^{2+}). Phosphates are also occasionally high with concentration values reaching 5.9 mg/L instead of the acceptable levels of approximately 1 mg/L. The high nutrient loads due to phosphates, nitrates and nitrites, as well as the associated algae growth cause loss of dissolved oxygen in the water resulting in conditions that are not ideal for most aquatic life.

3.2 Kuils River

The Kuils River is a major tributary of the Eerste River (Figure 13). It rises in the Kanonkop area of the Cape Flats, flows southwards to False Bay, and runs within the Cape Town Metropolitan area over a distance of 30 km to its confluence with the Eerste River. The confluence is 4 km from the Eerste River Estuary in False Bay. In its upper reaches, the river flows as a small stream through urban residential areas with inflows from small tributaries, which also drain built-up areas consisting mostly of houses, light industries and other dwellings for human habitation. The river was previously a seasonal river flowing only in the rainy season until the increased discharge from settlements made it a perennial river. Further increases in flow volumes were brought about by drainage from other areas outside of the Kuils River's natural catchment (DWAF, 2005). The gradient of the catchment is very low, such that the river flows slowly through meanders as it approaches False Bay. The catchment area of the Kuils River consists of recent deposits of loose sand and dune formations underlain by extensive clay lenses. There are scattered deposits of gravel, sandstone and conglomerates together with irregular developments of silicrete and calcrete that occur throughout the area. The area is characterised by aeolian and alluvium sands (Van Schoor, 2001). The geology of the Kuils River catchment is characterised by sandy soils that are porous with high seepage rates and a potential for high subsurface flows. The area is low lying and some sections are below the water table such that polluted subsurface flow is decanted into the surface water bodies.

The Kuils River was originally characterised by seasonal wetlands in its lower reaches; however, extensive disturbances to the river's regime and the effects of anthropogenic activities have caused most of these wetlands to be lost. The deterioration of the Kuils River is driven by a number of human activities that include channelisation, canalisation, and hydrological changes due to water that is drained from other catchment areas, infrastructure development, housing, industry, fish farming, agriculture, and discharge from wastewater plants, among other factors.

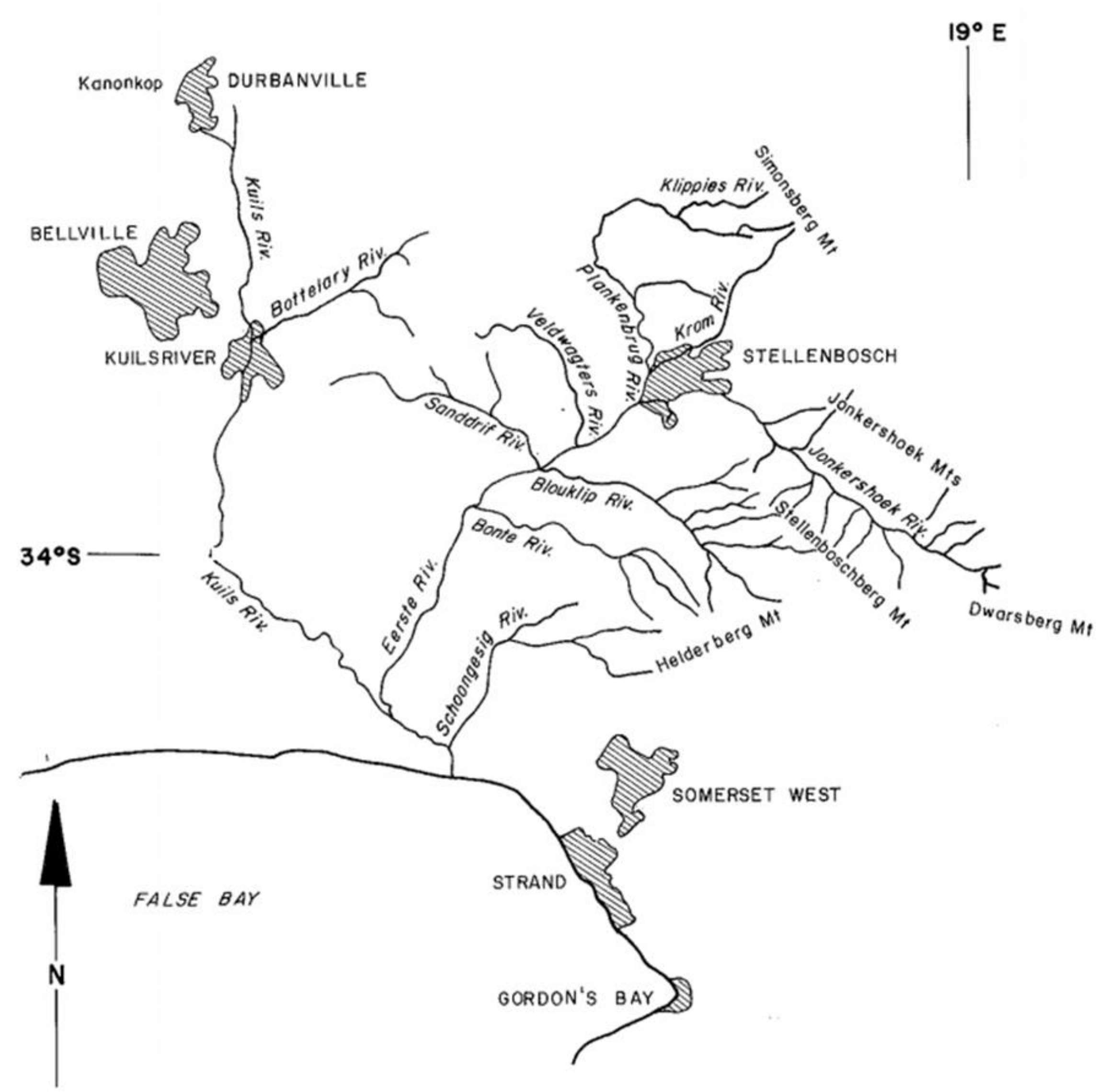

Figure 13: Eerste River Catchment showing the Kuils River

Mwangi (2014) reports that the main sources of pollution in the Kuils River are domestic and industrial effluent, solid waste from households, and runoff from agricultural areas. The study reported that the Kuils River was becoming eutrophic as a result of high nutrient concentrations and stagnant flows in several of its sections. The investigations carried out in this study also confirm the high nutrient loads in the river.

In Kuils River, the recorded water quality variables show that there are incidences when the water quality is worse than the ranges denoted as "very bad" for EC, pH, nitrites (NO2), nitrates (NO3) and phosphates (PO_4). These are values above 100 mS/m for EC, above 3 mg/L for NO3 + NO2, and above a pH of 10, as well as above 3 mg/L for PO_4 (Table 8). In this waterway, the monitoring station just after Bellville WWTW shows the worst pollution in terms of bacterial load with recordings being well above 500 counts for E.coli, for 85% of the records for the period starting in 2003 and ending in July 2013. In addition, pH was observed to be occasionally higher than acceptable in 2014. The pollution in the upstream location of Kuils River is associated with Bellville WWTW and the catchment area that covers Bellville, Durbanville, Kraaifontein and parts of Kuils River townships.

- The bacterial load seems to decrease as the river progresses downstream; however, the nutrient load remains very high with increasing frequency of incidences when phosphate concentration is very high (the incidences change from 20% of continuous records to 33% at the most downstream measuring station 1000009587, while the frequency of incidences when nitrites and nitrates are excessively high decreases from about 1 in 2 incidences upstream (just after Bellville WWTW, Figure 14) to 1 in 4 at the last monitoring station (1000009587) just before discharge into the sea (Table 8 and Table 9).

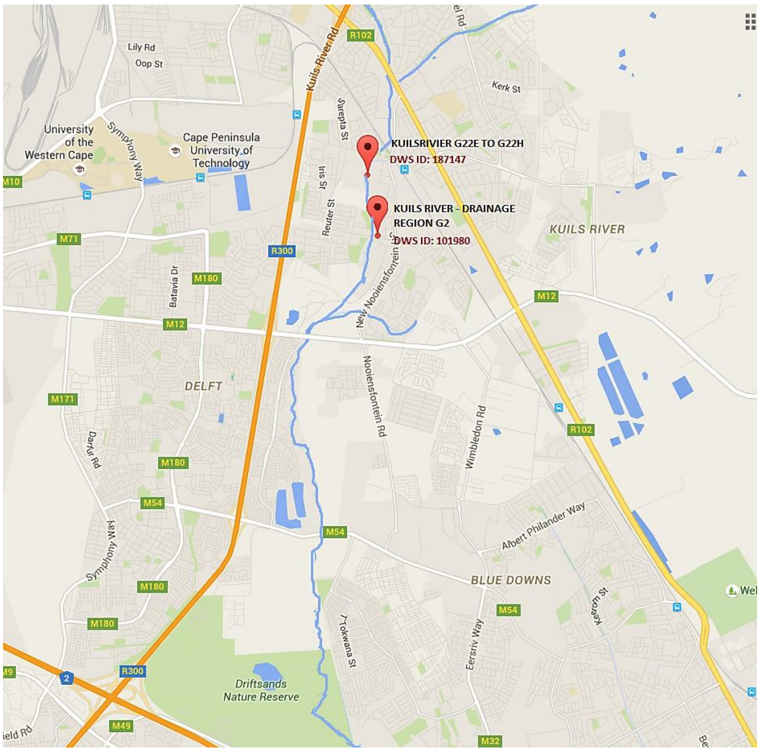

Figure 14: Location of the water quality measuring stations on Kuils River just after Belleville Township

The concentration of pollutants in the Kuils River decreases as the river progresses to the sea. The distribution of settlements has no relation to this spatial change in concentration of the pollutants. It is rather the interactions between surface water and ground water. The area is sandy, with a high-water table, and it is common to see large ponds of stagnant water in the river and also in the shallow river basin, which are seemingly unconnected to the main river flow. It is these groundwater-surface water interactions that result in a net flow of water into the river and dilute the pollutants.

- The impacts of settlements in Kuils River is better understood when the terrain and the geology of the area are accounted for. The area is generally flat, with a high-water table and stagnant water ponds. The geology is porous sandy soils that allow much seepage and underground flow as well as recharge that is seemingly feeding disconnected water bodies that together with the main river constitute the Kuils Waterway. These groundwater flow paths mean that water is usually quickly drained through seepage in the upper sections of the catchment and then it recharges the surface water in the lower sections.

The high E.coli readings at monitoring station 187147, which are in magnitudes of millions in some incidences, have been recorded as from the early 2000s. Records before this date qualify as unacceptably high but peaked to magnitudes that were always below a million count. In the period between 1996 and 2011 the population in the Kuils River catchment increased six-fold, resulting in the increased bacterial load in the receiving waters.

The nature of pollutants and their relationship to settlement patterns were further analysed using a recently developed aquatic ecosystem rehabilitation framework. The framework, that is discussed in more detail in section 4.2, was developed to determine the state of pollution and identify cases where rehabilitation is required, followed by supporting the user in identifying the most appropriate rehabilitation options. The levels at which rehabilitation is required when water quality is considered were determined using pollutant load threshold (Table 7). Using the framework knowledge derived from the earlier project work, pollutant loads were classified into five categories that are referred to as very bad, bad, fair, good and very good. It was determined that the level of pollutant load from “bad” to “very bad” will require rehabilitation. The framework was also equipped with routines to carry out multi-criteria analysis and optimisation of rehabilitation option selection. Table 7 below provides an illustration of the contamination levels and classification thresholds.

Table 7: Water quality assessment rating table as applied in Kuils River

Selected variables for draft presentation work					
	Very Bad	Bad	Fair	Good	Very Good
EC-Phys-Water (ELECTRICAL CONDUCTIVITY) (mS/m) Result	>100	70 - 100	50 - 70	30 - 50	=<30
NO3+NO2-N-Diss-Water (NITRATE + NITRITE NITROGEN) (mg/L) Re	>3	2.0 -3.0	1.5-2	1-1.5	=<1
pH-Diss-Water (PH) (pH units) Result	<4.5 or >10.0	4.5-5.5 or 9.0-10	5.5-6.5 or 7.5-9.0	6.5-6.8 or 7.2-7.5	6.8-7.2
PO4-P-Diss-Water (ORTHO PHOSPHATE AS PHOSPHORUS) (mg/L) R	>3	2 - 3	1.5 - 2.0	1.1 - 1.5	=<1
E.COLI-Susp-Water (ESCHERICHIA COLI) (cfu/100mL) Result	>500	126-500	35-126	1-35	0

Table 8: Kuils River water quality assessment results for selected variables

Highest values for selected water quality variables in last year of record					
Monitoring Station on Kuils River	187147	101980	200000109	183040	1000009587
EC-Phys-Water (ELECTRICAL CONDUCTIVITY) (mS/m)	-	96.6	114	-	98.9
NO3+NO2-N-Diss-Water (NITRATE + NITRITE NITROGEN) (mg/L)	-	9.41	15.7	-	9.8
pH-Diss-Water (PH) (pH units)	10.2	8.4	8.1	10.3	8.7
PO4-P-Diss-Water (ORTHO PHOSPHATE AS PHOSPHORUS) (mg/L)	-	5.8	10.4	-	5.7
E.COLI-Susp-Water (ESCHERICHIA COLI) (cfu/100mL)	1413600	-	29000	241960	-

% number of Incidences when water quality variable is worse than "Very Bad" in last year of records.					
Monitoring Station on Kuils River	187147	101980	200000109	183040	1000009587
	%		%		%
EC-Phys-Water (ELECTRICAL CONDUCTIVITY) (mS/m)	-	0	13.3	-	0
NO3+NO2-N-Diss-Water (NITRATE + NITRITE NITROGEN) (mg/L)	-	55.3	60	-	24
pH-Diss-Water (PH) (pH units)	2	0	0	2	0
PO4-P-Diss-Water (ORTHO PHOSPHATE AS PHOSPHORUS) (mg/L)	-	21.1	33.3	-	33.3
E.COLI-Susp-Water (ESCHERICHIA COLI) (cfu/100mL)	99	-	47	85	-

The levels of un-ionised ammonia (NH_3) in the Kuils River were assessed. It was observed that the un-ionised ammonia (UIA) trend over the years is similar to the E.coli concentration trends (Table 8). Meade (1985) observes that NH_3 (UIA) is 300-400 times more toxic than NH_4. It is poisonous to fish at levels less than 0.1mg/L. This could explain why this large river has no fish except in the first 100 metres of the river. Figure 15 shows that the un-ionised ammonia

(NH_3) is usually much higher than 0.1mg/L and exceeds 1 in some instances. The high levels of un-ionised ammonia create conditions that cannot sustain most aquatic life.

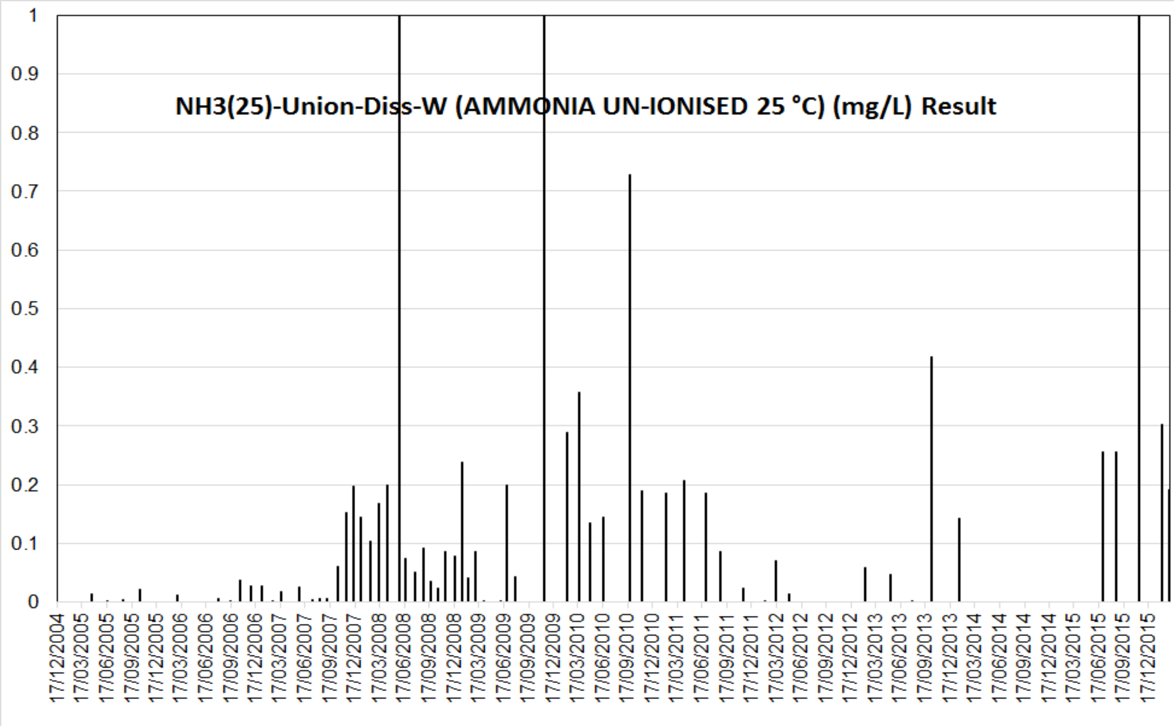

Figure 15: Records of readings for un-ionised ammonia (NH3) concentrations at gauge 200000109, Kuils River

The Kuils River shows a rapidly increasing biological pollutant load over the years, especially as shown by the escalating peak values in the period 2006 to 2015. At sampling point 183040, on Kuils River, which is located near the Zandvliet Bridge after Khayelitsha Township, peak E.coli count records exceed 200 000 CFU/100mL (Figure 15). The levels of bacteria in the river increased, as shown by the E.coli analysis that was on average giving a count of 4 058 in the period November 2002 to November 2005 and escalated to an average of 14 609 in the period 2010 to 2013, a four-fold increase. During these time periods the population of Khayelitsha Township alone increased six-fold, showing a very probable link between the population of community members and the water quality degradation.

There are three major wastewater treatment plants that discharge their effluent into the Kuils River. These are Bellville, Scottsdene and Zandvliet WWTWs. These plants operate well beyond their capacity, due to the rapidly increasing population in the areas served as well as the additional load due to all year rainfall, which also ends up in the wastewater conveyance system. Figures 16 and 17 show the levels of pollutants immediately downstream of the Zandvliet WWTW and the Bellville WWTW respectively. Based on the bacterial load counts, the river water quality has been consistently better at recording station 183040 as shown in Figures 16 and 17. Zandvliet WWTW was refurbished and extended in 2006. However, the the rehabilitation does not seem to have affected the regular occurrence of pollutant peaks given a count that is in terms of thousands in the record period. The very high coliform count, which exceeds a million in some instances, shows cases when the plants were completely overwhelmed or malfunctioning.

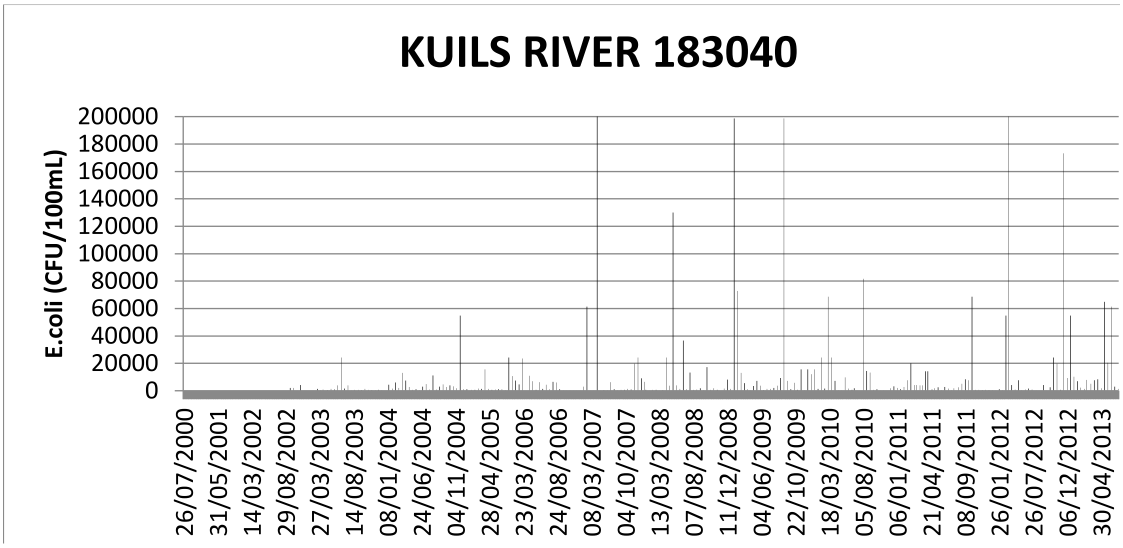

Figure 16: Record of E.coli counts in Kuils River at Zandvliet Bridge downstream of Zandvliet sewage works

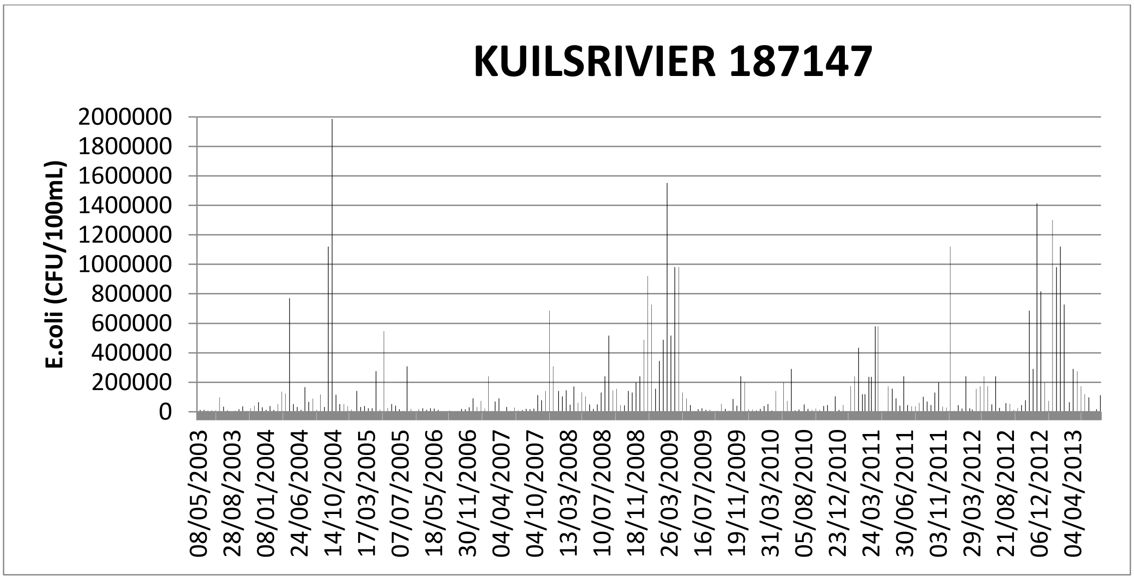

Figure 17: E.coli counts in Kuils River 100 m downstream of the Bellville WWTW discharge point from May 2003 to June 2013

Apart from the water quality impacts on the river, the river hydrology has been distorted over the years. Figure 18 shows that peak flows are increasing rapidly over the years and they are also occurring more frequently. The regular flow volumes have also been increasing as shown by the cumulative flows as shown in Figure 19, where the gradient of the cumulative flow is becoming steeper with time as the total volume of water flow per unit time increases. The major changes in hydrology also affect organisms in the waterway. The levels of frequent peaks also mean that the river is in flood more frequently over time. The hydrological changes in the river are attributed to the changes in land use, especially increased effluent, storm water and faster flows on paved surfaces. The rainfall patterns have not changed over the corresponding period.

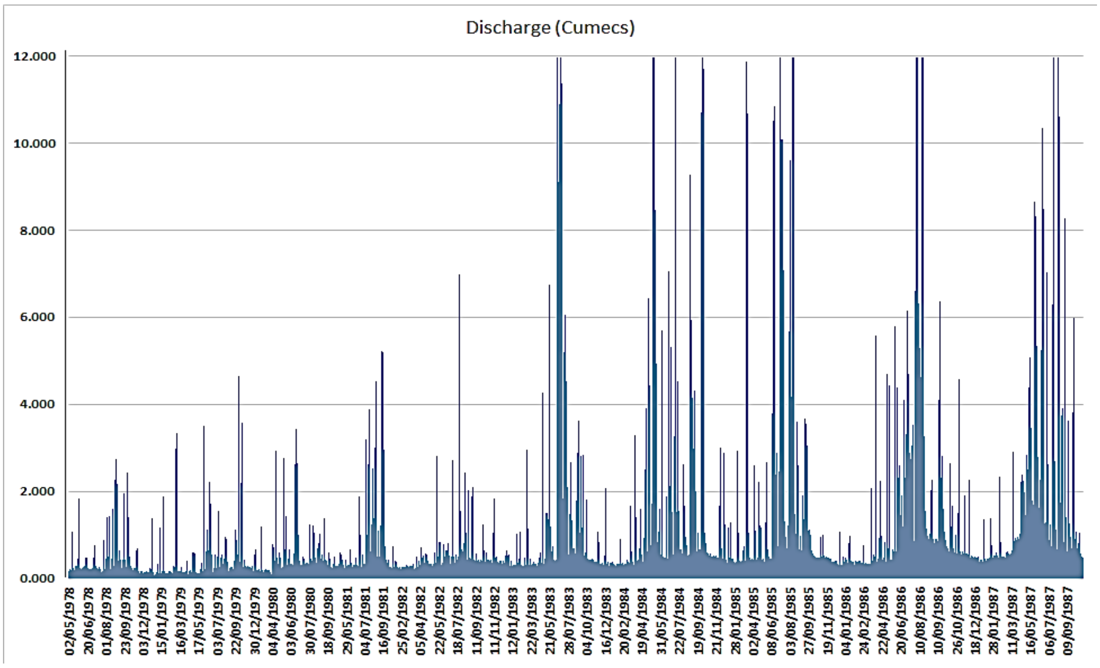

Figure 18: Daily flow volume for the Kuils River from the period 1978 to 1987, from the station located at coordinates 33°56'32.3"S 18°40'24.8"E, just after Bellville Township

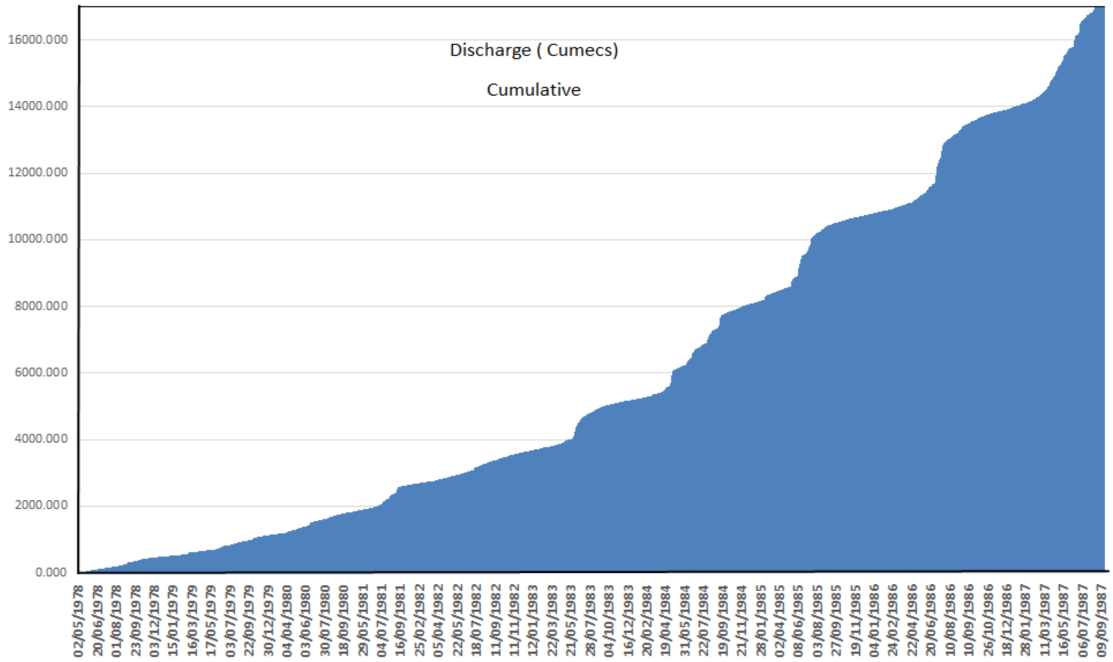

Figure 19: Kuils River upper catchment cumulative flow for the station located at coordinates 33°56'32.3"S 18°40'24.8"E, just after Bellville Township

3.3 Pienaars River

The Pienaars River is a part of the Crocodile River catchment. It originates from the east of the Tshwane Metropolitan area and flows northward to discharge into the Roodeplaat Dam in the north-eastern area of Tshwane. The Pienaars River drains the areas to the east of Pretoria, which include farming areas, eastern suburbs and the densely populated settlement of Mamelodi, as well as several informal settlements that have been established in the catchment area over the last two decades. The river contributes approximately 25% of the flows into the Roodeplaat Dam and 75% of the nutrient load (Pieterse & Rohrbeck, 1990).

The volume of flow in the Pienaars River has been increasing at an exponential rate as a result of grey water effluent from various water uses, especially domestic use (Figure 20). Peaks in quantity of total flow that exceed 40 million m^3/annum are now frequently experienced in the dry season while in the past such flow volumes were associated with very high rainfall. The increasing flow volume and pollutant load are due to increasing return flows emanating from the rapidly expanding settlements in the catchment. The settlements in the Pienaars River catchment area are supplied with potable water from the Orange River. Return flows from water use in the Pienaars River catchment and grey water from the inhabitants or industries is released into the Pienaars River. This water movement results in direct net flow increases in the catchment. As population and other water usage activities increase, more water is transferred from the Vaal River and released as effluent and other discharges into the Pienaars River catchment resulting in a steady increase in flows (Figure 20).

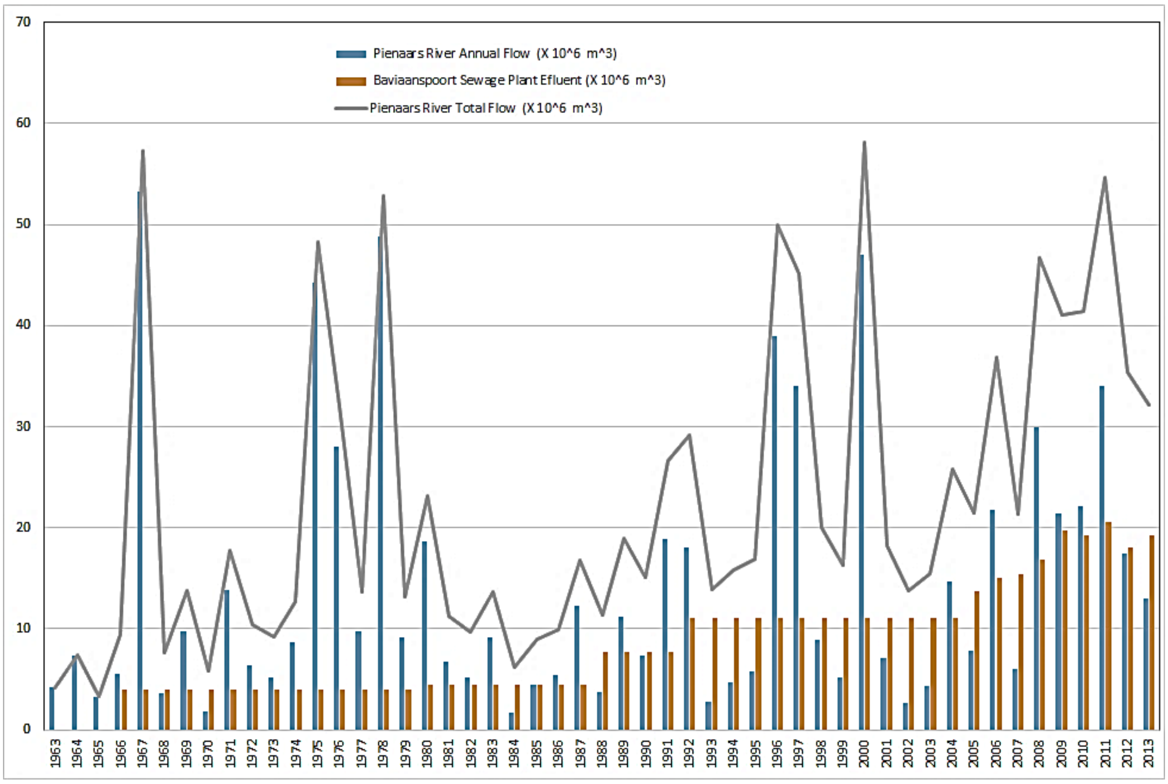

Figure 20: Pienaars River annual flow volumes in million m^3 per annum (Data from Silberbauer & Esterhuyse, 2014)

One of the major pollutants observed in the Pienaars River is phosphorus. According to data from DWS's water quality services, the phosphorus load in the Pienaars River is now approaching 100 tonnes per year. This load of phosphorus is deposited in the Roodeplaat Dam. When compared with the data presented by Dyson (2009) on heavy rainfall events, the peaks in flow volume (Figure 20) and quantity of phosphorus load in tonnes (Figure 21) correlate. When pollutant loads peak, rainfall is seen to peak at the same time. The (summer) rainfall season ending in March of 1976 had the highest rainfall in the period reaching 968 mm. The last high rainfall peak was experienced in the rainfall season ending in 2000 when annual rainfall peaked at 793 mm (data from Dyson, 2009). This corresponds with the peak in the volume of flow in the river, which was 58.1 million m^3 that year. The phosphorus load peaked to an annual load of 39 tonnes for the same year. These observations show that more runoff results in more phosphorus being carried into the river.

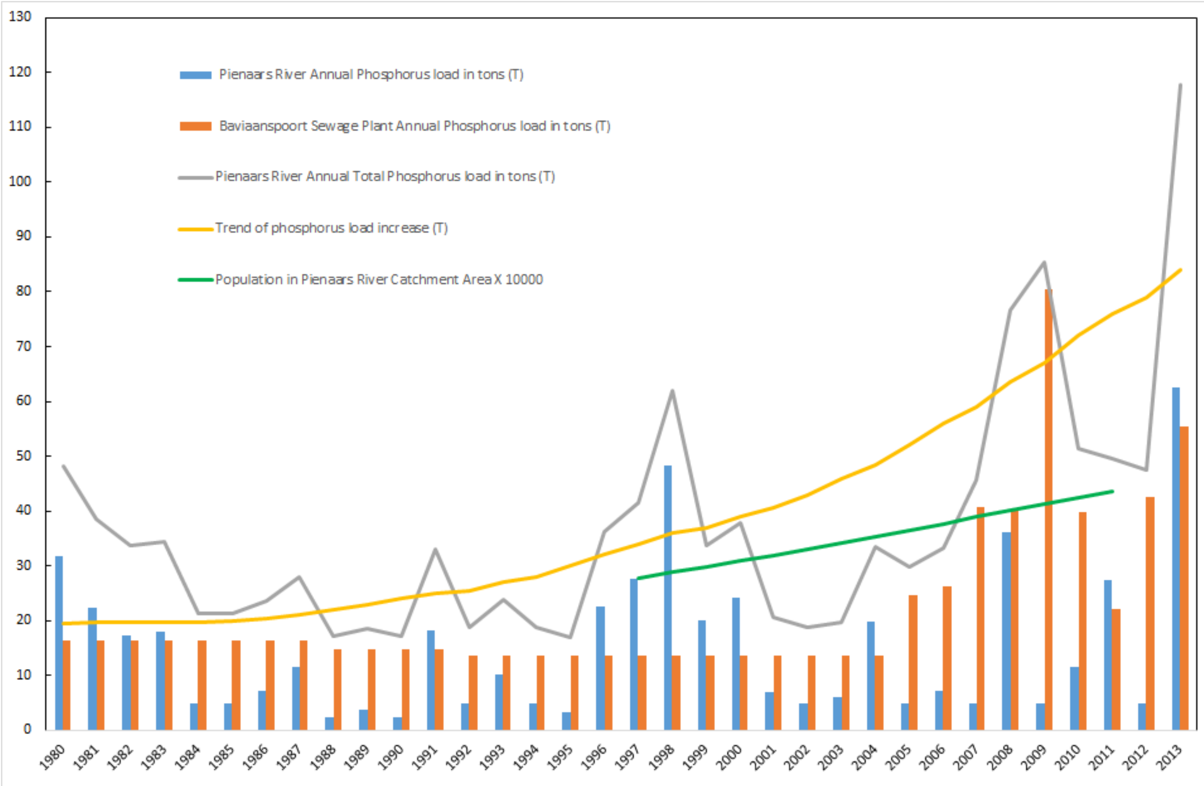

Figure 21: Annual total phosphorus load estimates in tonnes (Total phosphorus data from Silberbauer & Esterhuyse, 2014) Phosphorus load and population trend added

Plotting the volumes of phosphorus passing through the Pienaars River just before entry into the Roodeplaat Dam shows that the pollutant volume has also been increasing at an exponential rate as shown in Figure 21. The rate of increase in phosphorus load has been escalating with time such that in the period 2010 to 2013 the rate of increase changed twofold when compared to the rate of population increase of 3.6% per annum in the catchment area. On the basis of the phosphorus load trend line, this averages the annual increases, the volume of phosphorus increased by 8 tonnes from 2003 to 2008, and by 20 tonnes, in the period 2008 to 2013. Extrapolation of the trend revealed that the phosphorus load will increase to 110 tonnes by 2018 and to 144 tonnes per annum by 2023. The high concentration of phosphorus/phosphates in the Pienaars River can be attributed to the high usage of domestic household products that contain high phosphate levels within the area. The graphical analysis shows that more of these phosphorus-containing products are being used possibly due to economic and market conditions in addition to the population. Phosphates are added to washing powder to make them foam. Low foam washing powder is usually preferred for washing machines.

Water quality data from monitoring stations on the Pienaars River shows that for all measuring stations located after the densely populated settlement of Mamelodi Township, recorded peak values were above the condition denoted as "very bad" for the following variables: $NO_3 + NO_2$, PO_4, E.coli and faecal coliform count (Table 9). Bacterial pollution was always "very bad" for the three stations below Mamelodi Township with coliform counts in terms of tens of thousands and reaching millions of counts for at least 90% of the records available in the last two years ending in the first quarter of 2016 (Figure 22). The very high concentration of pollutant loads creates uninhabitable aquatic conditions for most forms of living organisms.

Table 9: Pienaars River water quality assessment results for selected recorded variables

Maximum values for selected water quality variables in last year of record				
Water Quality Monitoring Point ID on Pienaars River	**90174**	**90237**	**90239**	**189121**
	Downstream point after Baviaanspoort WWTW	**Efluent from Baviaanspoort WWTW**	**Point after Mamelodi Township**	**Upstream at Boschkop Dam in a farm**
EC-Phys-Water (ELECTRICAL CONDUCTIVITY) (mS/m)	83.7	79.6	67.5	43.5
Ca-Diss-Water (CALCIUM) (mg/L)	35.62	55.254	56.8	37.1
Cl-Diss-Water (CHLORIDE) (mg/L)	66.87	76.786	52.6	12.4
F-Diss-Water (FLUORIDE) (mg/L)	0.69	0.584	0.591	0.252
NO3+NO2-N-Diss-Water (NITRATE + NITRITE NITROGEN) (mg/L)	22.625	30.3	18.805	0.69
SO4-Diss-Water (SULPHATE) (mg/L)	90.22	83.14	52.5	21.19
pH-Diss-Water (PH) (pH units)	8.54 (min=8.1)	8.6 (min=6.8)	8.9(min=6.9)	8.37 (min=8)
PO4-P-Diss-Water (ORTHO PHOSPHATE AS PHOSPHORUS) (mg/L)	3.96	6.5	6.38	0.019
E.COLI-Susp-Water (ESCHERICHIA COLI) (cfu/100mL)	241960	1553100	770100	9
FC-Susp-Water (FAECAL COLIFORM COUNT) (cfu/100mL)	760000	5300000	510000	-

% number of Incidences when water quality variable is worse than "Very Bad" in last year of records.				
Water Quality Monitoring Point ID on Pienaars River	**90174**	**90237**	**90239**	**189121**
	%	**%**	**%**	**%**
EC-Phys-Water (ELECTRICAL CONDUCTIVITY) (mS/m)	0	0	0	0
Ca-Diss-Water (CALCIUM) (mg/L)	0	0	0	0
Cl-Diss-Water (CHLORIDE) (mg/L)	0	0	0	0
F-Diss-Water (FLUORIDE) (mg/L)	0	0	0	0
NO3+NO2-N-Diss-Water (NITRATE + NITRITE NITROGEN) (mg/L)	64	86	48	0
SO4-Diss-Water (SULPHATE) (mg/L)	0	0	0	0
pH-Diss-Water (PH) (pH units)	0	0	0	0
PO4-P-Diss-Water (ORTHO PHOSPHATE AS PHOSPHORUS) (mg/L)	17	18	4	0
E.COLI-Susp-Water (ESCHERICHIA COLI) (cfu/100mL)	94	95	100	0
FC-Susp-Water (FAECAL COLIFORM COUNT) (cfu/100mL)	97	84	97	-

The nitrates and nitrites are likely to be from both domestic activities and the fertilisers used in farming in the upper catchment area. In the period 2010 to 2015, the concentration of nitrites and nitrates in the river showed an increasing trend. However, the increases are not as defined as those observed for phosphorus. This difference shows that with time most of the degradation in the catchment will be attributed to domestic uses rather than farming and industry.

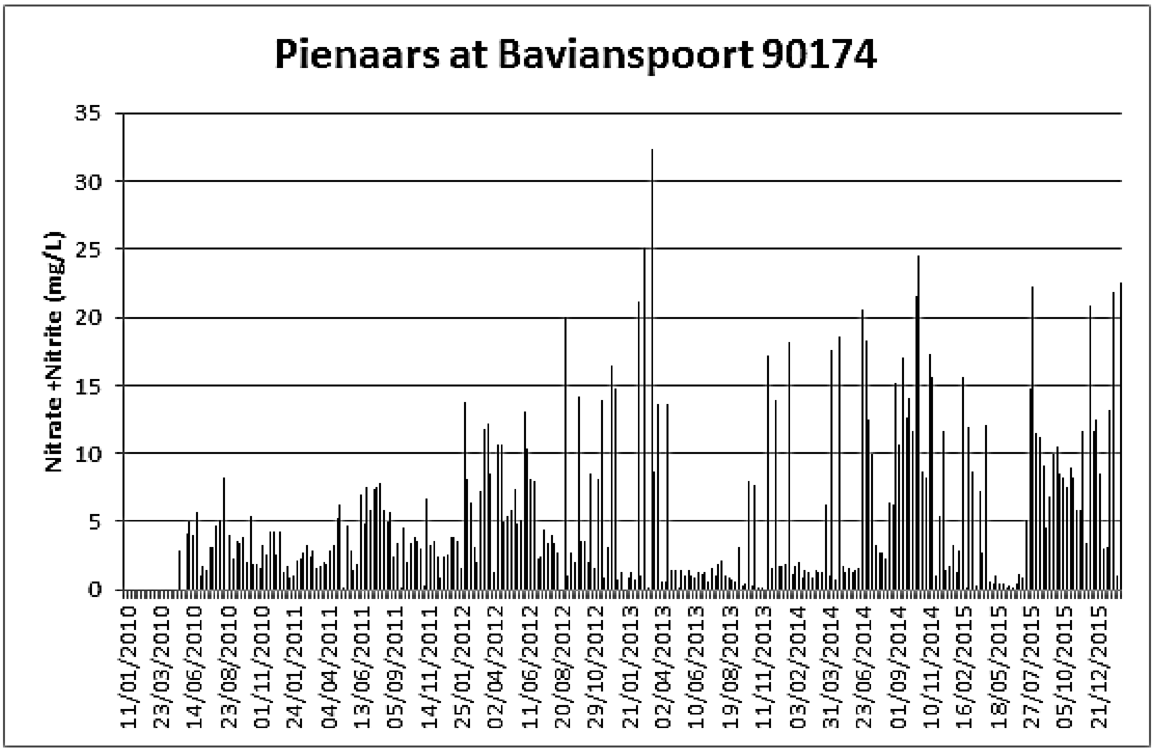

Figure 22: Nitrate + nitrite concentration in the Pienaars River at Bavianspoort from January 2010 to December 2015. Acceptable limit = 0.05mg/L

Assessments of E.coli counts (Figure 22) reveal E.coli counts were exceeding 1 000 000 in some years. The water quality measurement station used to measure the E.coli count illustrated in Figure 22 is before the Bavianspoort sewage treatment facility. The sewer lines run along the rivers and leaks from them can be a cause, which result in bacteria ending up in the river, rather from the discharge from the sewage works. The census of 2011 showed that, like most of Tshwane, 21% of households in the catchment area did not have access to toilets, either flush or chemical-type toilets. Other forms of sanitation used usually result in faecal pollution of aquatic ecosystems. This could explain the excessively high loads of bacterial pollution as shown by the coliform counts (Figure 23).

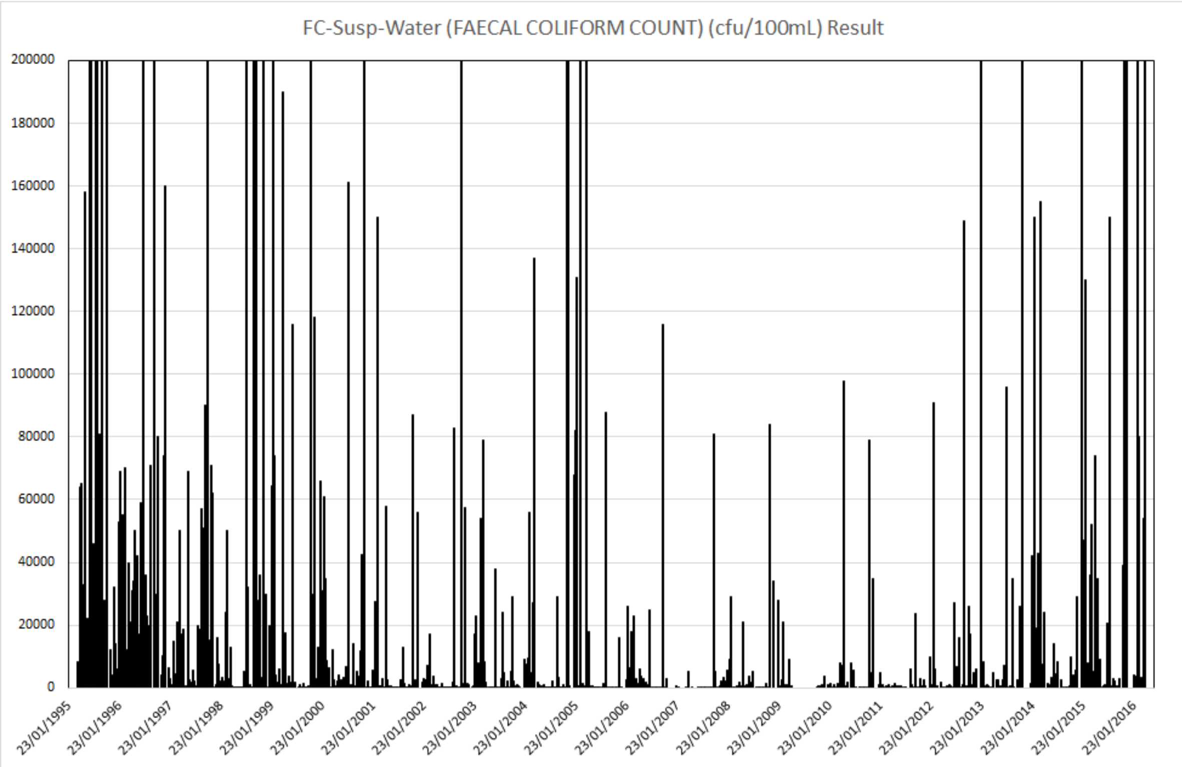

Figure 23: Faecal coliform count for Pienaars River upstream of the sewage plant at DWS Station 90239 for the period from January 1995 to February 2016

Closer analysis of records of E.coli counts for the period March to August 2016 show persistent excessive E.coli counts over the whole period, as shown in Table 10 below. In addition to sanitation practices, malfunctioning sewage conveyance systems could have been adding to this seemingly permanent state of aquatic system deterioration. A walk along the river during the research process showed that there were several areas where the sewage pipes are located very close to the river, including in the riparian areas.

Table 10: E.coli count in the Pienaars River at a location downstream of Mamelodi Township in 2016 for all the days when records were taken in March to August 2016

Sample date	Sample Start Time	E.COLI-Susp-Water (ESCHERICHIA COLI)
29/03/2016	10:11:00	54000
11/04/2016	10:04:00	342000
23/05/2016	10:01:00	48392
06/06/2016	10:00:00	770100
20/06/2016	10:10:00	344800
04/07/2016	11:00:00	260300
18/07/2016	10:35:00	488400
01/08/2016	11:30:00	272300
15/08/2016	11:37:00	344800

Consultation with the personnel responsible for wastewater treatment showed that the use of disinfectants, especially chlorine, was excessively high. The reason for excessive use of chlorine is that the personnel are aware of the shortcomings of the treatment processes, including many cases where raw sewage is discharged due to system malfunction. The Pienaars River exhibits generally high levels of chlorides for all the monitoring points except the most upstream station in the farming area. The presence of chlorides in high concentrations in the Pienaars River, where organic matter is also decaying, creates another form of degradation in the water system. The chlorine and decaying matter combine to form various derivatives of chlorine and carbon, especially the soluble and volatile chloroform, a trihalomethane (THM). Other derivatives of THMs are also formed. These THMs cause cancer as well as other chronic illnesses (Cedergren, Selbing, Löfman *et al*., 2002; Gopal, Tripathy, Bersillon *et al*., 2007). These pollutants have been observed to create purification complications at the water treatment plant that is located downstream of the Pienaars River. The World Health Organization (WHO) has revealed that high incidences of rectal cancer and bladder cancer have been reported in patients who had been exposed to low doses of THMs over long periods, with increased incidences for those who were exposed for over 35 years (WHO, 2004). THMs are completely soluble in water and usually remain in the water after the purification process. The chlorides also kill bacteria and organisms that are important to the health of other aquatic species, thus disturbing the health and balance of the aquatic environment.

Given the nature of degradation experienced in the three rivers evaluated in this study, rehabilitation has to be prioritised by all stakeholders. The following section is focused on rehabilitation and developing resilience in the degraded aquatic ecosystems.

4 Rehabilitation of degraded aquatic ecosystems

The success of rehabilitation initiatives in degraded waterways depends on several factors which include the nature of the solution applied, state of degradation, waterway characteristics, land uses involved, hydrological factors, ongoing impacts, the institutional and legislative provisions, as well as the resources available to take the remediation programme through. Successful rehabilitation is only achievable if the conditions or circumstances that have caused the degradation are addressed or eliminated as part of the solution.

Given the nature of the degradation and the long history of degradation in most South African urban and peri-urban aquatic systems, polluted sediments have also accumulated in the waterways, especially in slow-flowing or stagnant waters such as dams and wetlands. The pollutants left in sediments will continue to be released into the water body and ecosystem over time, creating another dimension to the continued degradation of the water even while rehabilitation is ongoing and new pollution has been stopped. There is a need to ensure that the rehabilitation solutions involve addressing the continued threat of further pollution from the sediments. Options for rehabilitation in urban and peri-urban areas have to sustain an acceptable balance of prevailing realities and ecosystem sustenance. In many instances, some of the sources of degradation cannot be relocated or stopped, at least in a short time frame, due to various factors. There are instances where a settlement that is located on riparian land cannot be relocated because constitutional provisions are not yet satisfied. There are also instances where changing a poorly located planned development, such as a wastewater treatment plant, is not practical in the planning period due to time or inadequate resources. There are also cases where the river is now surrounded by a CBD or a prioritised development. In all these cases the options for rehabilitation have to be weighed against the constraints and the advantages to be derived. The envisaged rehabilitation solution should address a futuristic state of health of the waterway where the negative influences of historical, current and future land use activities are mitigated or reduced to acceptable and sustainable levels.

Options for rehabilitation of aquatic ecosystems can be divided into long-, medium- and short-term actions and approaches. Approaches differ from action-based solutions in that they involve policy shifts, legislation, institutional changes, strategic updates, and cultural and religious reorientations rather than actionable projects with direct results. In order to successfully select appropriate actions and approaches for river rehabilitation, a multi-criteria approach is applied. In this evaluation, some of the variables that have to be considered include goods and services affected by the degradation of the aquatic ecosystem, the type of aquatic ecosystem under consideration, the nature of the impacts causing the degradation, the sensitivity of the ecosystem to the degradation threat, as well as the nature of the catchment area affected. All these criteria for selection are discussed in the following section.

4.1 Selection criteria for rehabilitation options

4.1.1 Geographical location of degradation in the waterway

Geographical location, in consideration of waterway degradation, can be considered under three categories, namely, rainfall seasonality (Figure 24), eco-regional classification (Figure 25), and location of degradation along the river reach in terms of upstream/downstream positions (Figure 26).

In considering rainfall seasonality, DWS recommends six classifications, namely, all year, winter, early summer (December), mid-summer (January), late summer (February), and very late summer (March to May).

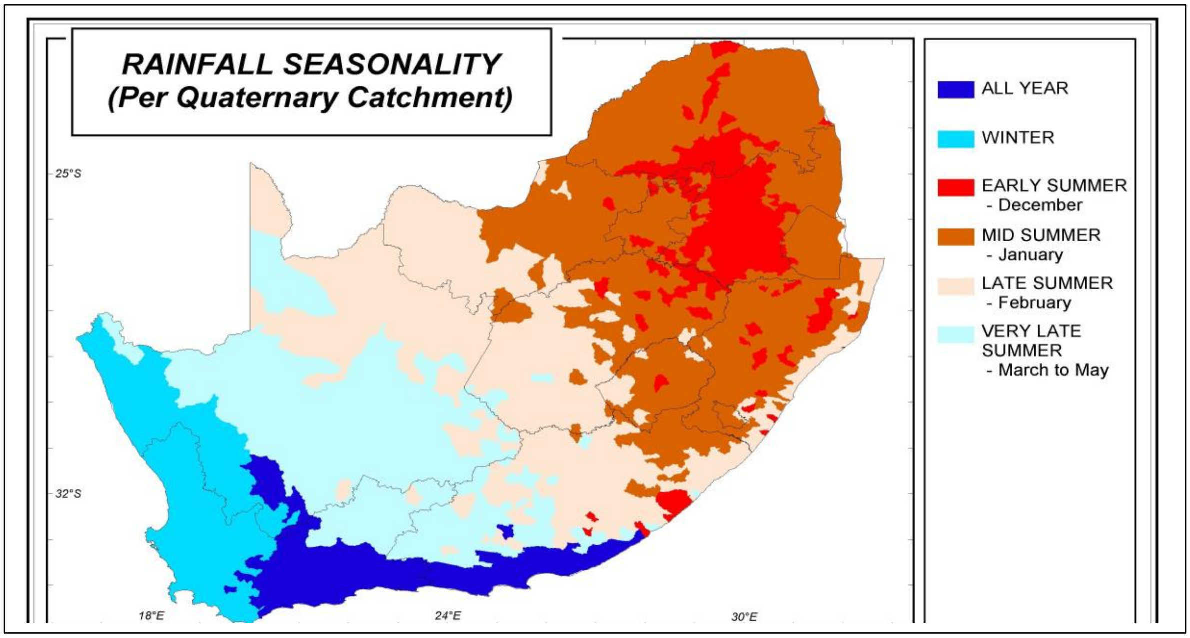

Figure 24: Rainfall seasonality in South Africa (DST, 2009)

It is important to note that many of the proposed options are not sensitive to rainfall, hence rainfall seasonality is not to be taken into consideration at every turn. Options that require the introduction of plant species, however, require knowledge of rainfall seasonality of the region and the season in which the required vegetation can thrive.

In terms of ecological classifications, the DWS has classified South Africa into 31 eco-regions in the Level 1 delineation that was carried out in 1995. The 31 Level 1 eco-regions were delineated on the basis of physiography, climate, rainfall, geology and potential natural vegetation. The classification used was hierarchical, involving the delineation of eco-regions with a progressive increase in detail at each higher level of the hierarchy. The same characteristics or variables are used with increasing detail for higher level eco-region classifications. The detail applied in Level 1 was such that the delineation did not include geo-morphological classification according to zones, segments and waterway. Level 1 eco-regions do not as yet account for information on biological habitat segments for fish, invertebrates and riparian vegetation. These are set to be captured in more detailed higher level eco-regions. The 31 eco-regions are presented in Figure 25, and regions can be denoted according to the number assigned by the DWS. The waterway character established at a data-rich site can be applied in another area in the same eco-region. Using the classification information for eco-regions, rehabilitation and resilience options that are applicable in one region can be selected for another region on the basis of similarities of specific characteristics of the eco-regions.

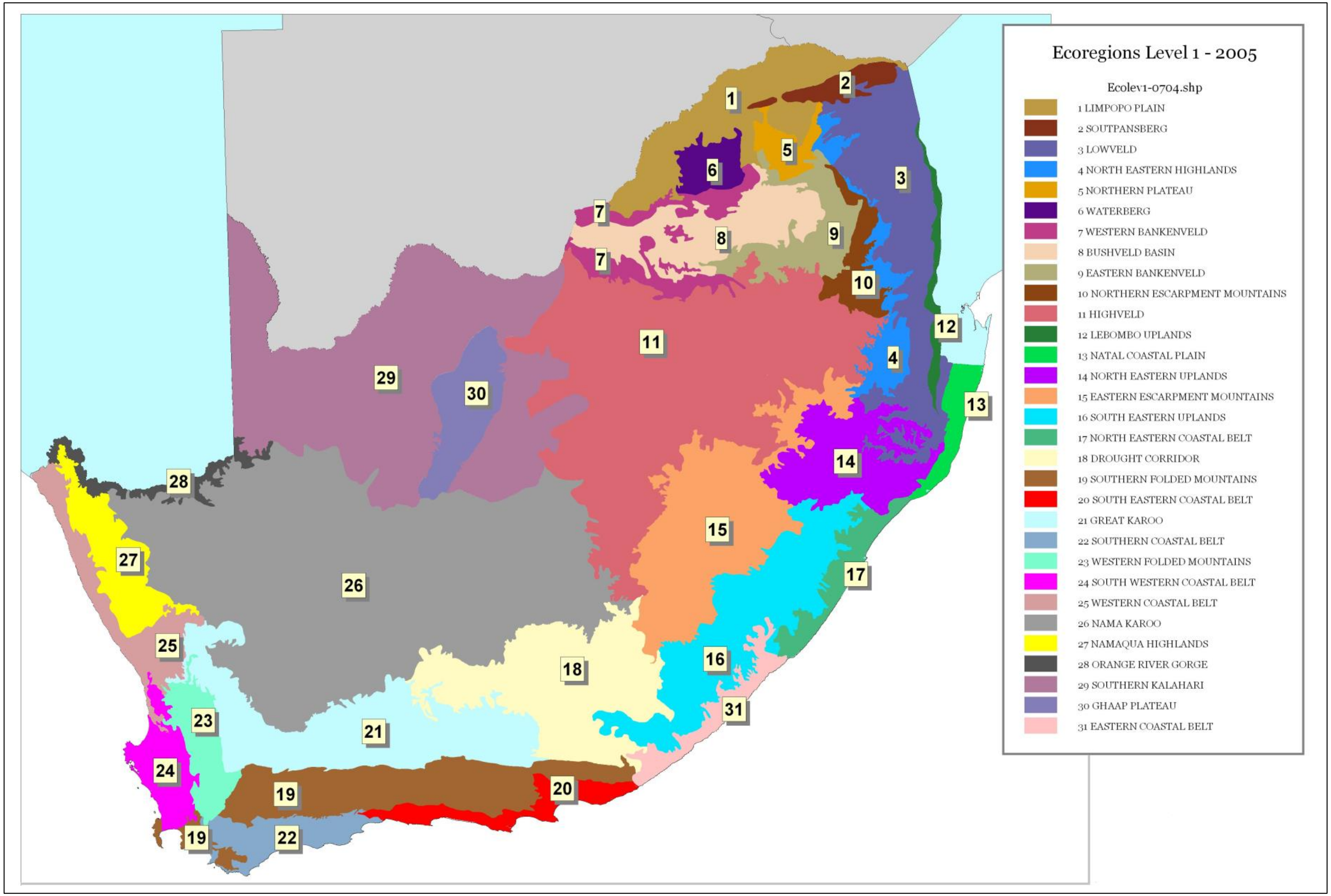

Figure 25: Eco-regional classifications for South Africa (DWAF, 2006)

Selection of resilience options is also affected by the location of the degradation in terms of actual position along the waterway. Table 12 below shows the different location considerations along the waterway reach. Figure 26 gives an illustration of these positions on the waterway.

Table 11: Classifications according to location of actual damage within the waterway

Location of damage most prolific damage	Denotation
Upper Reach	UR
Middle Segment	MS
Lower Reach	LR
River Bank	RB
Flood Plain (Within 1 in 50-year flood line)	FP
10 m Buffer Zone. That is 10 m further away from the stream than the 1 in 50-year flood line (No development is permitted in the area)	BZ

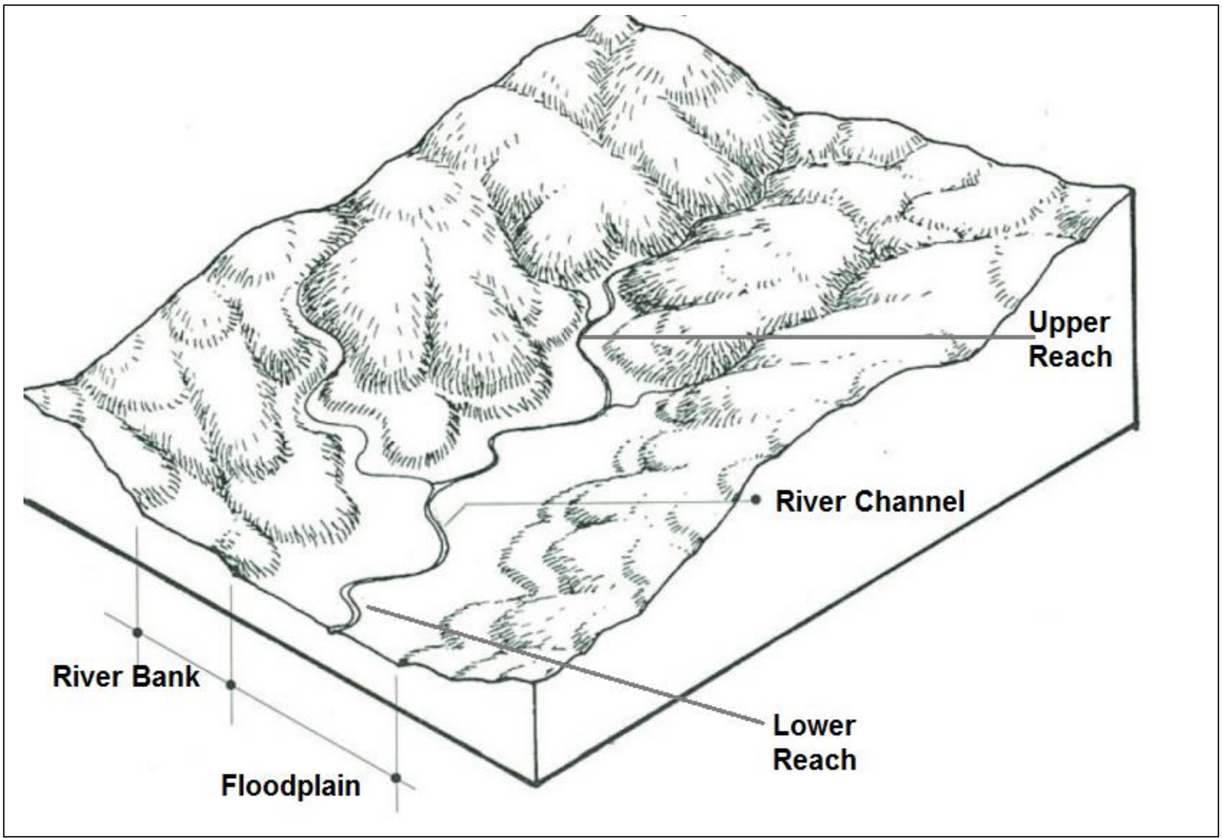

Figure 26: River channels showing areas that are usually affected by settlements. Adapted from UMCES, 2010

4.1.2 Nature of catchment area

Successful and suitable rehabilitation in an aquatic system has to suit the state of the natural environment or the prevailing catchment character. In an urban or peri-urban setting, the broad description of the catchment area is characterised by the land cover, established developments and infrastructure, coastal or inland, topography and other physical characteristics. The state and level of development in relation to the aquatic ecosystem can be placed into five categories. These are listed in Table 12 below:

Table 12: Settlement classifications in terms of level of development in catchment area

State and level of development in catchment area of a river in an urban setting	**Denotations**
Densely built-up city CBD with offices, high rise buildings, congested roads, transportation network centres	CBD
Densely populated regional town centre (RTC) or city with large volume of day visitors but relatively low levels of infrastructure	RTC
Low density (LD) or high income residential suburbs	LD
Medium density (MD) residential area with smaller stand suburbs	MD
High density (HD) residential townships	HD
Informal settlement (IS)	IS
Plots and commercial farms	PCF
Mining settlement	MS
Industrial areas	IA
Retail and shopping centres	RSC

The selection of a rehabilitation/resilience option should be in line with the forms of degradation that are characteristic of these areas or the river reach. Table 13 shows the components of the waterway where different forms of degradation within one waterway are experienced. Rehabilitation has to be responsive to these different structures on the waterway and other parts of the waterway.

The other dimension for dealing with rehabilitation has to do with communities' local characteristics. People in a locality usually share cultural, certain behavioural and religious traits. These characteristics affect how they interact with the waterway, the degradation they cause and rehabilitation option preferences. Observations made and discussed in a local radio forum concluded that certain communities tend to dispose of their waste along the road servitudes and waterways, especially in areas where these habits were reinforced over many years when residents were affected by an absence of formal solid waste management.

Development of resilience to degradation in an area is also affected by the nature and type of land cover. Consideration of land cover in rehabilitation of aquatic ecosystems includes accounting for the vegetation, woodland, crop plantation area, grazing area and forestry area. In terms of vegetation land cover, Figure 27 shows a map of South Africa's vegetation distribution. The classifications in the map can be used directly to determine the nature of land cover in the catchment area and its possible effect on the rehabilitation options to be applied.

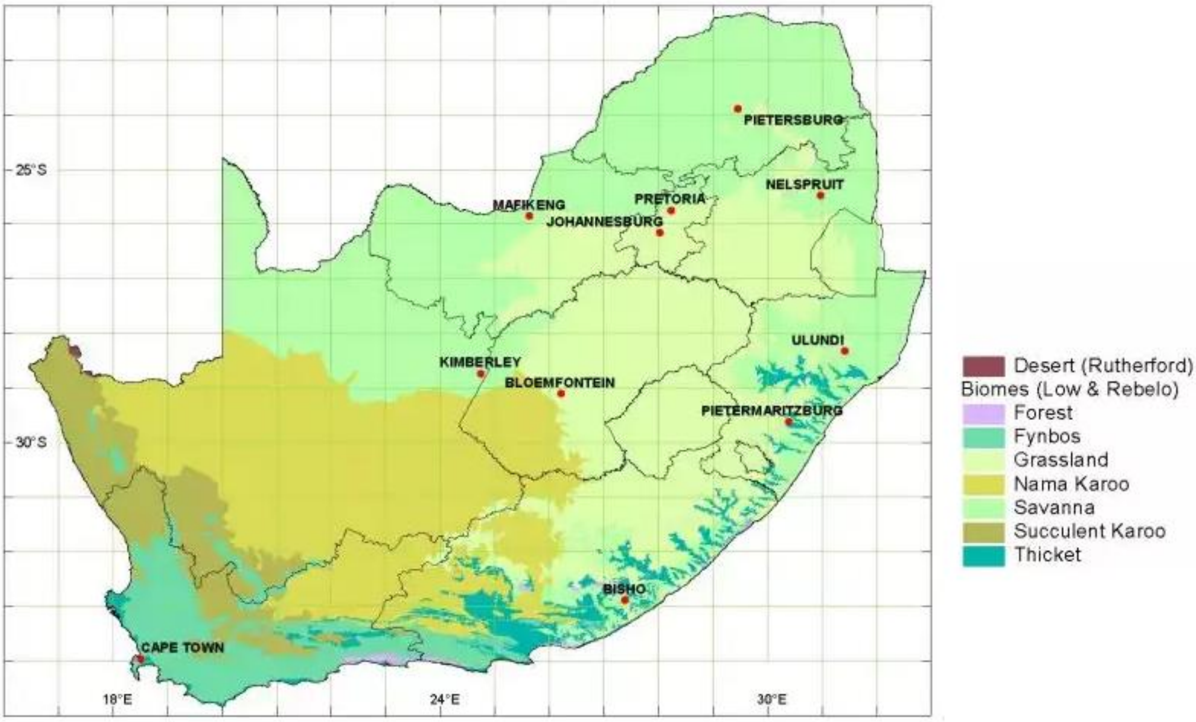

Figure 27: Vegetation and desert classification in South Africa (SANBI, 2011)

4.1.3 Type of degraded aquatic ecosystem

Table 13: Components of the aquatic ecosystem and how they are denoted in the rehabilitation framework

Type of aquatic ecosystem to be rehabilitated	Denotation
River	R
Wetland	W
Canal	C
Enclosed section of river (e.g. piped section)	E
Tunnel/Culvert	T/C
Dam	D

4.1.4 Culture and religious beliefs in aquatic ecosystem degradation

Religious and cultural beliefs play a role in some forms of degradation of aquatic ecosystems; hence, selection of rehabilitation and resilience options should take these into consideration. Some cultural practices can result in degradation of water ecosystems. As an example, some cultural and religious practices are practised close to or inside water bodies. The congregation in these cultural and religious gatherings bring various material including food and other items, which end up being disposed of in the riparian area or in the waterway. Some religious groups use open area-based facilities, usually under a large tree that is located next to a river. Sanitation facilities are rarely provided. In many of the gatherings for religious services the direct disposal of human waste in the open is highly probable. This is practised in most urban areas and it directly results in certain forms of general environmental degradation, including damage to aquatic ecosystems.

Establishing resilient aquatic systems should be influenced by an understanding of the cultural and religious practices of the communities in the area, especially to ensure that further degradation is not going to take place as a result of their activities. These forms of religious practices are usually associated with informal settlements where the communities do not have proper church facilities.

4.1.5 Legislation, policies, by-laws and regulations

There are existing environmental and water resource protection laws, policies and regulations that are used to protect the environment, especially water systems, from degradation. In dealing with degradation due to settlements and land uses on riparian areas, the legislative tools include the following:

- *Air Quality Management Act*, Act 39 of 2004. The legislation addresses the release of particulate matter into the atmosphere. Particulate matter often settles to the ground after a while and some of it settles in rivers as suspended solids, contributing to physical and chemical degradation. Some of this material falls back to the ground as part of rainfall.
  - *Local Government: Municipal Structures Act*, Act 117 of 1998
  - *Local Government: Municipal Systems Act*, Act 32 of 2000
  - *Mineral and Petroleum Resources and Development Act*, Act 28 of 2002
  - *National Water Act*, Act 36 of 1998
  - *National Environmental Management Act*, Act 107 of 1998
  - *Water Services Act*, Act 108 of 1997
  - Municipal by-laws for prevention and control of informal settlements
  - *Local Government Transition Act* of 1996, which seeks local government development that is based on the concept of "integrated development plans" that incorporate and extend the land development objectives as set out in the *Development Facilitation Act* and link them to local government budgets.
  - *Environmental Conservation Act*, Act 73 of 1989, which was enacted to guide national and provincial authorities and municipalities towards promoting the objectives of the General Environmental Policy and the principles of integrated environmental management.
  - *Development Facilitation Act,* Act 67 of 1995, which focused on infrastructure development taking place in such a way that apartheid patterns are not reinforced.
  - The *Abolition of Racially Based Land Measures Act,* Act 108 of 1991, which was promulgated in order to bring an end to apartheid era land acts.
  - The White Paper on Land Policy, 1997. This policy set the basis for land reform.
  - *Minerals Act*, Act 50 of 1991
  - *Mine Health and Safety Act*, Act 29 of 1996).

4.1.6 Institutional considerations

Aquatic ecosystem rehabilitation and resilience is led by several institutions, of which some of the main role players are DEA, DWS, the Department of Cooperative Governance and Traditional Affairs (CoGTA) and municipalities (Table 14). Currently, national institutions such as DWS, DEA and CoGTA are important structures that lay out the vision for the rehabilitation of waterways. In 2013, the DWA published the National Water Resource Strategy with the vision “sustainable, equitable, and secure water for a better life and environment for all”. The strategy outlines the importance of addressing and managing water resources effectively to prevent further pollution, unlawful abstraction and water wastage (DEA, 2013).

The DEA’s five-year strategic plan (2013-2018) addresses issues with environmental quality and protection, waste management, and the rehabilitation of rivers and wetlands (DEA, 2013). SANBI has highlighted the need to rehabilitate rivers and wetlands as a means of improving water services and environmental resilience in areas where rivers have been degraded.

At local government level, municipal structures have to set out their strategy and business plan for actively participating in stopping degrading activities and establishments as well as rehabilitating damage already caused. Strategies developed by national institutions provide the national direction and usually come short in leading to the development of rehabilitation and resilience activities in urban and peri-urban areas that are controlled by metropolitan councils and municipalities. To that end, the selection of rehabilitation/resilience options should take into consideration the incorporation of river rehabilitation into the business plan and programmes of local institutions that are charged with the upkeep of the water resources at local levels.

Table 14: Institutions responsible for river rehabilitation/resilience

Waterway rehabilitation/resilience	**Responsible institution and role players**
Pollution monitoring, prevention and policing	DEA, DWS, municipalities, environmental NGOs
Enforcement of ecological integrity of waterway and riparian areas	DEA, DWS, SANBI, municipalities, environmental NGOs
Solid and effluent waste management	DWS, DEA, municipalities
Water resource protection	DWS, DEA, municipalities
Wetland rehabilitation	DEA, SANBI, municipalities
Dam rehabilitation	DWS, water boards
Removal of riparian area settlements	DHS, Municipality, Human Rights NGOs
River basin and flood area management	Municipalities, disaster management units, DWS, DHS
Control of degradation from mining and mining effluent	DMR, DWS, Municipalities
Prevention and control of criminal environmental degradation activities	SAPS, Metro Police
Pathogen and disease control in aquatic ecosystems	Department of Health, Municipalities
Enforcement of green technologies	DoE, DMPR, DEA
Minimisation of pollution from government structures	Environmental NGOs, Community environmental support groups
Prevention of degradation from roads and vehicles	SANRAL, municipalities, Department of Transport

4.1.7 Resource availability

In identifying the best options for rehabilitation, the right resources should be identified and made available to ensure success. Two key resources that have to be considered are financial and human resources. Initial considerations have to deal with existing resources before deciding on further resources to be secured. Existing resources are accounted for in the planning while motivation for extra resources is submitted to the right institutions based on the prioritisation in the business plan. The availability of human resources has to be considered in terms of technical expertise, knowledge levels and the numbers of suitably qualified personnel to take through the identified resilience options from inception phase through implementation, commissioning and maintenance.

4.1.8 Cost-benefit analysis of rehabilitation/resilience options

Decisions reached on rehabilitation/resilience options should involve consideration of costs and returns. An important method for evaluating the returns is the cost-benefit analysis (CBA). This should take place prior to the implementation of selected options. The selected rehabilitation options have cost-benefit implications that need to be determined and presented as part of the option selection process.

Ideally, the criteria for evaluating the costs and benefits should include the following three:

(i) Net present values (NPV)

For a project to be accepted the net present value criterion must be positive; that is, the financial resources will be allocated to the project only if the analysis produces a positive net present value. The NPV entails obtaining the PVs of all the relevant cost and benefit flows after expressing these in monetary units and applying the selected discount rate. In considering NPV, it has to be noted that the positive NPV means that the project is profitable or beneficial. An important parameter in the NPV criterion is the discount rate to be used. Many water utilities around the world use a discount rate equal to the interest rate or the current cost of capital. At any one point this discount rate can be obtained from the national treasury.

(ii) The internal rate of return (IRR)

The selected project should be one where the value obtained for the IRR exceeds the social discount rate.

(iii) The discounted benefit-cost ratio (BCR)

The preferred option should be the one where the BCR is greater than one. Consideration has to be made to account for government grants in the evaluation of projects of this nature. The government contribution should be considered as a social component that gives such projects a head start. The rest of the financing has to be considered strictly on commercial terms and evaluated as such. If the project still fails to show good returns after utilising the government's contribution to reduce the municipal financial commitments, then it will add much value to look at other viable options.

4.1.9 Political will in rehabilitation

Politics is one of the biggest factors that affect the successful implementation of projects, especially any activity that tends to use municipal or government resources. Party politics in South Africa affects service delivery in municipal institutions and on a national scale (Pasquini & Shearing, 2014). One of the influential effects of politics on continuity of planned rehabilitation or resilience projects comes about when there is a change in the ruling party, as highlighted by Pasquini and Shearing (2014). The authors highlight that a change in the ruling party can result in the success or failure of a project. Frequent changes in ruling parties result in political instability in a region as political manifesto continue to change, and different projects are prioritised, leading to loss of continuation of long-term projects. Political parties can also aid the successful implementation of an environmental project if there are environmental champions within the party. It is therefore of importance to consider the willingness of political structures in a region during the selection of rehabilitation actions and approaches. In municipalities, rehabilitation of degraded aquatic ecosystems should be included in prioritised municipal IDP projects and the necessary networks should be fostered with environmental NGOs and national institutions. Budgeting for rehabilitation and resilience is necessary. Very often, the failure of a project is due to lack of prioritisation in institutional budgets resulting in a lack of allocation of funds.

4.1.10 Additional adverse or positive effects of a selected option

A rehabilitation option should not result in adverse effects on other ecosystem components or other reaches of the same river or an associated wetland. The option selected should create an ecosystem health balance that ensures all components of the aquatic and terrestrial systems, including riparian zones, benefit from it. Chances of selection of an option should be higher if it enhances the health of surrounding ecosystem components, in other words, the selected option should deliver additional benefits. It is important to note that some options will only address the degradation in the aquatic system without necessarily leading to any beneficial impacts on other components. This should not discourage the selection of these options.

4.1.11 Consideration of rehabilitation time frame

Rehabilitation should be carried out with a time frame in mind. For this study, the selected time frames are in line with the time frames for the implementation of municipal IDPs (Table 15). Short-term time frames are for five-year rehabilitation goals and carry a priority description of P1; mid-term time frames are for fifteen-year rehabilitation goals and carry a priority description of P2, while long-term time frames are longer than fifteen years and carry a priority description of P3. The timelines were adapted from municipal IDP documents as developed and applied in various municipalities.

Table 15: Priority selection criteria for rehabilitation and resilience options

Timescale	Period	Denotation
Short-term	Up to 5 years	P1
Mid-term	5 to 15 years	P2
Long-term	>15 years	P3

4.1.12 A new state of balance

In urban and peri-urban areas, the degradation of waterways and the nature of impacts are such that rehabilitation measures cannot successfully restore the pristine conditions of degraded rivers. The degradation is inherently linked to the development of urban areas and their continued existence. As such, rehabilitation can only improve the state of health of the degraded waterway and establish a new state of balance that can withstand already existing land uses and anthropogenic influences while maintaining the functionality of the waterway, and support for its biotic components.

In this light, it is important for decision makers who are in charge of river rehabilitation/resilience programmes to define achievable goals for the aquatic system they are focused on. These goals should be realistic and should first be aimed at achieving functionality and sustenance of aquatic life.

An example of such goals could be the re-introduction and maintenance of certain species of fish after initial clean-up activities have been completed. The use of fish as a measure of progress towards restoration of the health of waterways is one that is not only easy to achieve due to its measurability, but it also helps to integrate community members and institutions to work together in addressing river health. As a result, pollution activities are more likely to be minimised as citizens will aim to preserve the fish in the river for recreational purposes.

4.2 Aquatic ecosystem rehabilitation/resilience framework

4.2.1 Framework concept

The nature of urban and peri-urban settlements is such that they tend to congest or clog the natural process that has sustained the ecosystem from time immemorial. Rehabilitation aims to attain a balance between developments due to human settlements and natural processes. Through rehabilitation activities, the system's resilience can also be improved. However, most systems cannot be rehabilitated to a stage where pristine conditions are attained. Such is the nature of degradation afflicting local waterways that pass through or are located in urban and peri-urban areas of the country. Given this reality, the framework for aquatic ecosystem degradation was developed to assist users in understanding the waterway, identifying cases of degradation for specific locations, and accessing recommendations for rehabilitation before participating in prioritising these options on the basis of inputs to represent the constraints and enablers.

The ecosystem rehabilitation framework is conceptualised taking into account degradation sources, nature of impacts, resultant effects on ecosystem goods and services, location of impacts and degraded areas, as well as timing of solutions to degradation that has occurred over time or is responsive to solutions provided at a specific time. While the focus is on settlements on riparian areas, the investigations have revealed the combined effects of other land uses that cannot be left out if a sustainable and resilient waterway is to be attained. As such the framework allows for both instream and out of the river channel sources of degradation.

4.2.2 Ecosystem rehabilitation framework structure

4.2.2.1 Development of the Nxt2u waterway rehabilitation framework

The aquatic ecosystem rehabilitation framework is based on commonly used development software and the Google-based GIS platform that is most preferred within the environment of envisaged usage. Several GIS-based techniques were considered and ultimately a platform that utilises an open software approach was selected. The following guidelines were set in establishing the best possible framework approach:

- Standalone application where users do not need to load several applications.
- Ability to integrate qualitative inputs, quantitative inputs, geographical references, images from dispersed but known locations as well as the ability to define the waterway and its riparian area while keeping all components encapsulated into one seamless tool.
- Preference for tools where users do not need to pay high costs to secure the software or other associated software.
- Allowance for open source approaches that do not expose users to high maintenance or update costs.
- A framework that is appropriate to the level where decisions are made, but makes it possible to take into account inputs from local communities and institutions.
- Available programming expertise.
- Cost-effective methods that can stand the test of time, i.e. the software should run for at least ten years and without losing functionality when operating systems change. This entails avoiding unique specialist objects and data libraries in the code but rather opting for those trusted classic approaches.
- The framework structure allows for easy update of data to change how the waterway is modelled or to represent other waterways. (The framework comes with data for the case study area as applied in the development and testing stages. As the structure is built to give a generic framework, inputs for other areas in the country can be easily used to update the analysis and presentation.)

- The selected approach for developing the framework was based on a new software tool that was developed from original concepts as provided in the study inception phase. Delphi language was used in the development as well as an open source GIS platform accompanied by a full relational database. The best attribute of this development is that the use of the expensive ESRI GIS tools was excluded while taking advantage of the readily available Google open source platform. As such, the users will not need to pay software licences to utilise this tool.

4.2.2.2 Use of objects: Waterway instream objects

The framework consists of objects to describe the instream features or components of the waterway. In Figure 29, a typical framework object, a dam, is illustrated. The coordinates are captured and translated to define the location in the framework. The waterway objects are added to the framework by selecting the relevant associated tool from the toolbox and then adding the properties using parameters from the data and information available for the represented instream water feature. Forms, such as the dam description input form in Figure 28 below, are used to capture the inputs. When capturing, the properties of the representative positions are also captured for the schematic display such that the object is added to the waterway scheme.

4.2.2.3 The framework operational system

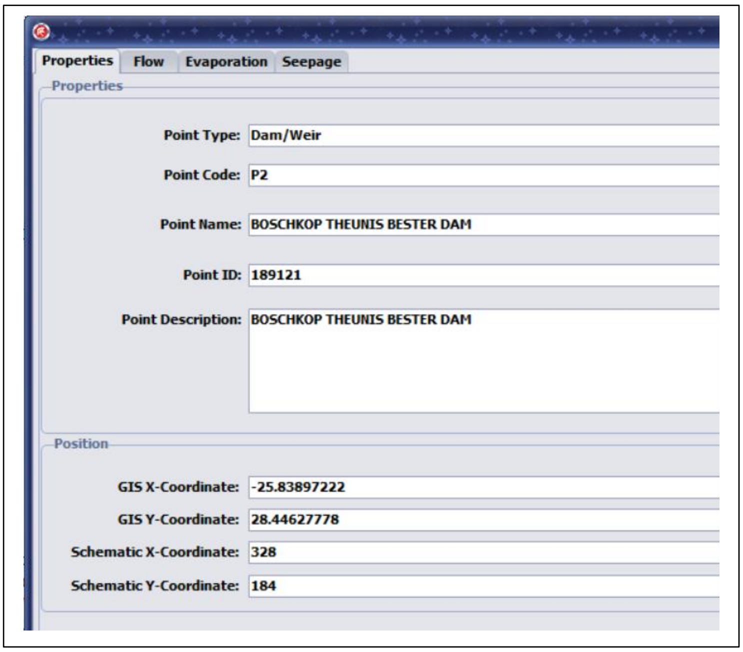

Figure 28: Instream object input form to define dam characteristics

The dam object is accompanied by data to show the historical daily flow data, water quality, changes in the flow and storage. The object in the example is a dam on the Pienaars River. The instream objects are the features that constitute the waterway. These features are represented as points that include wetlands, confluence of streams, bridges, waterfalls, abstraction points, discharge points, dumping sites, a sand abstraction point, and alluvial mining area. Figure 29 shows the points in the waterway as updated in the framework for the Upper Pienaars River, upstream of Roodeplaat Dam.

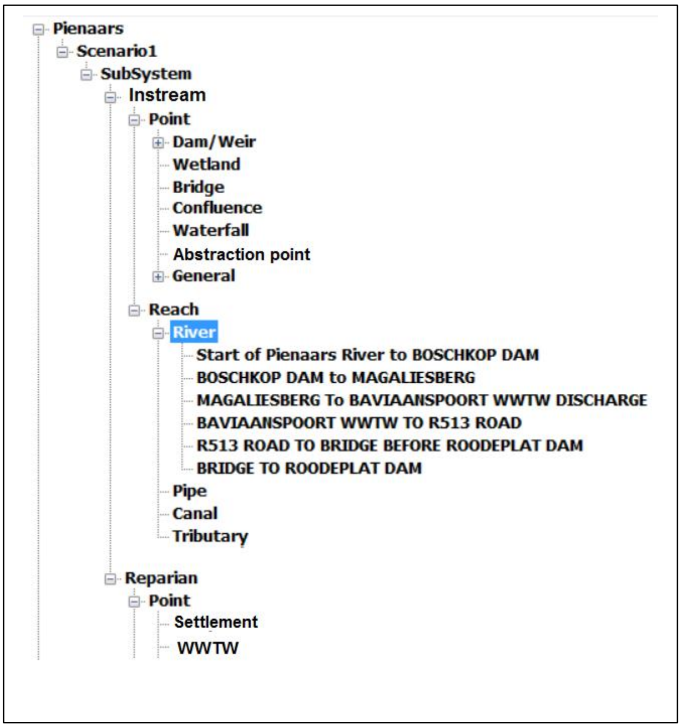

Figure 29: Structure of waterway description in the framework

4.2.2.4 Riparian area objects

In the framework, settlements are considered to be located on the riparian area rather than instream. This also applies to agricultural activities, industry, mining, WWTWs, some river dams, slime dams, malls and shopping centres. Land uses and other degrading processes that are located on the riparian area are represented as points in the framework and modelled using an object with properties to define key functions and characteristics. A river reach is also defined to connect these riparian points to the main waterway channel. In Figure 30 below, the schematic illustration showing the main waterway and one riparian object outside of the channel is shown. The user can click on the points in the schematisation to access and update the associated fixed and variable properties including the data.

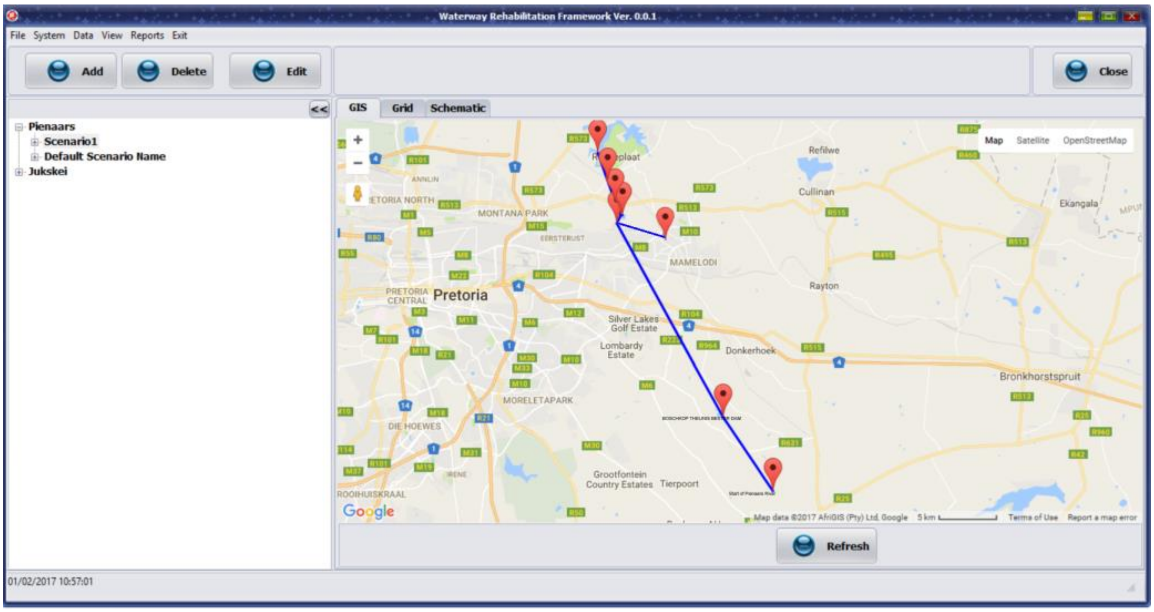

Figure 30: Schematic illustration of the waterway instream objects and a riparian point P4

4.2.2.5 The reach in the waterway

The waterway is divided into reaches. These are sections of the waterway from one point to another point where the nature of degradation and possible rehabilitation options are considered to be similar. The reaches or sections of the waterway are considered as stretches that start at a point and end at another point, which are both defined. Ideally, the section captured as one reach is characterised by a similar state and nature of degradation for which similar rehabilitation options are considered. The water quality data and reach properties are captured in the reach objects as shown in Figure 31.

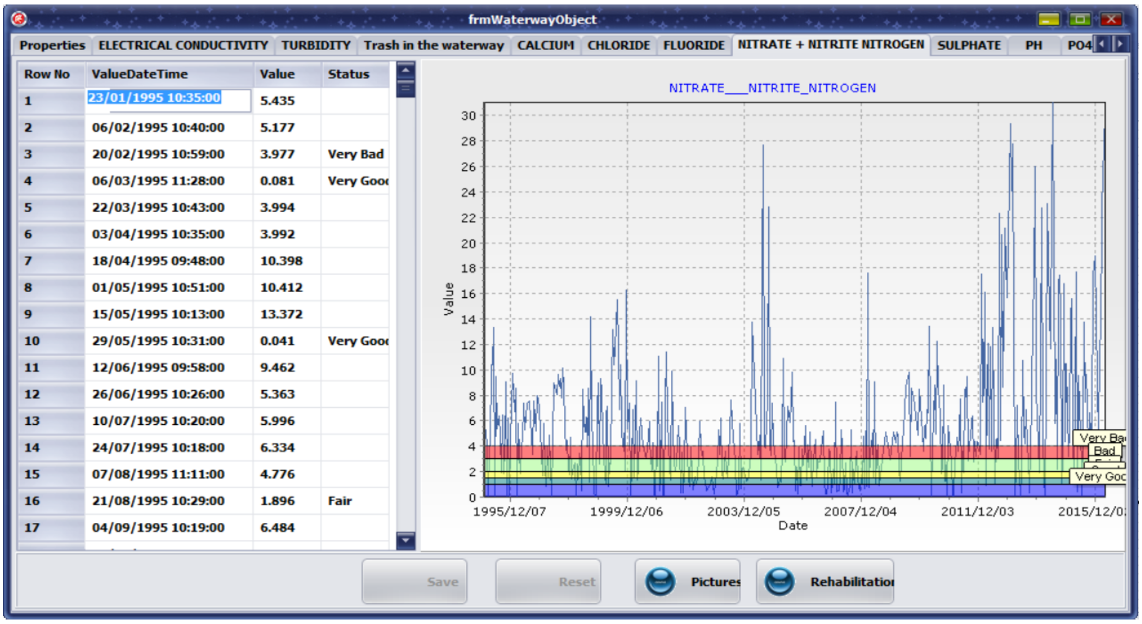

Figure 31: The reach showing one of the water quality variables recorded over a long period

The data entered in the reaches is immediately analysed to show whether the water quality indicator reached levels that are considered bad or very bad, as illustrated in the graph presentation, with colour coding for the different data statuses. Depending on the nature of the water quality degradation, the framework presents possible rehabilitation options. The selection for rehabilitation will present a long list of possible rehabilitation options for the state of water quality being considered.

4.2.2.6 Capturing riparian degradation in the framework

In the riparian area, the impacts are selected from a list of possible impact options, which was compiled during the study from observed degradation in case study areas and literature of local waterways. To identify the observed degradation, the user clicks the point where degradation is taking place. In the following window, the user is assisted to assess the degradation through images that are captured against the locations. This information on observed degradation is also uploaded to the framework through the waterway rehabilitation application (NXT2U App). The short list of possible degradation for riparian areas is shown in Table 16 below and a longer list is provided in Appendix 1 as impacts. The user will then identify the degradation observed or identified.

Table 16: List of riparian impacts considered in the rehabilitation framework

1	Impacts due to clearing of riparian area (grass, trees, reeds or even soil, rocks and sand are removed)
2	Impacts due to converting riparian area to road or paved surfaces. This also comes with compaction of riparian area soil
3	Established temporary and public toilets on riparian areas and open defecation
4	Lack of sanitation in shack dwellings leading to direct disposal of sewage into aquatic systems
5	Degradation from formal and informal polluting industry or business venture located on riparian area
6	Waterway channel converted to pipe, culvert, tunnel
7	Flow changed by effluent inflows, dam, urban storm
8	Dam, bridge or other structure in the waterway
9	Agricultural activities on riparian area
10	Water abstraction and streamflow
11	Mining in waterway and riparian area

4.2.2.7 Use of the Waterway Rehabilitation App in capturing degradation

The process of capturing degradation allows for the participation of communities and other stakeholders. The app connects stakeholders to a dedicated server. The user goes through the user registration or log-in processes to allow other users and the administrator to be assured that they are sharing information with an identifiable person (Figure 32). The user of the app is guided to capture and send information on degradation. The app captures the coordinates, which are also sent to the online data server. The user has access to all other information captured by other users that will show (i) the nature of degradation identified by other stakeholders, (ii) the response by the municipality to show that they have been made aware of the problem, and (iii) that the responsible authorities are working on it. Once the degradation problem is receiving attention or has been resolved, the details of progress on the problem are also captured to the online database so that the connected community members are aware of this status in real time. It is possible for another connected community member to reload the same problem if he/she observes that it is not resolved or if the water degrading activity or event arises again. Figure 33 shows the capturing forms used in the field. The app is set to become freely available after the project team has addressed contractual copyright expectations with the client.

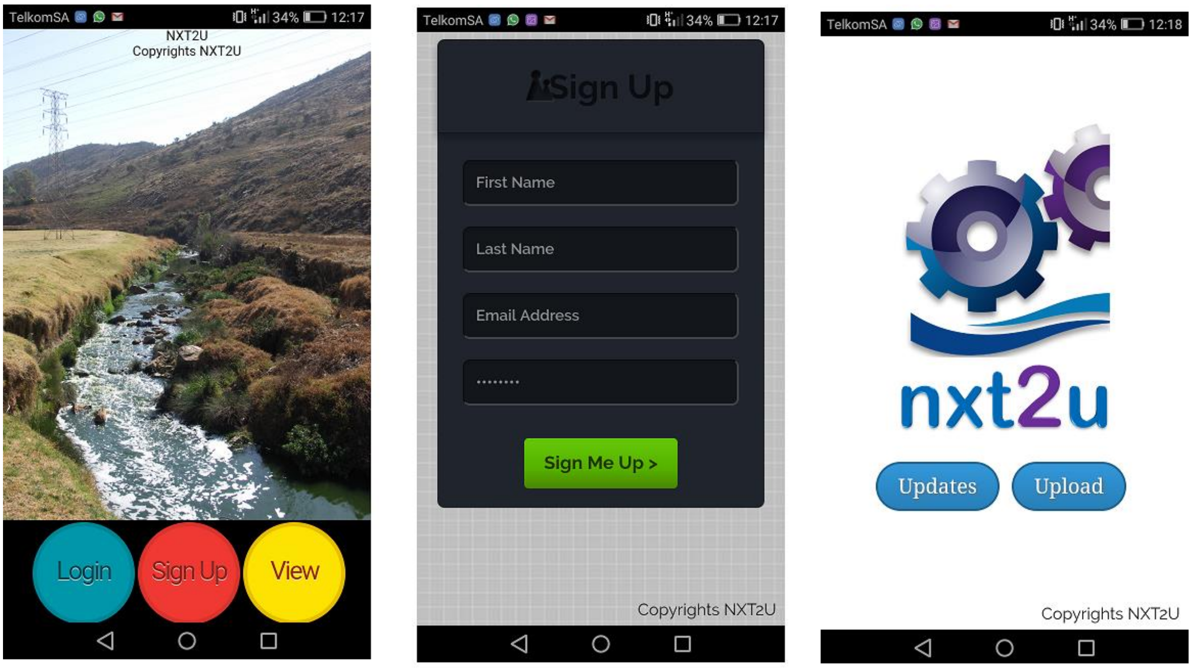

Figure 32: Nxt2U waterway rehabilitation cell phone app forms showing log-in and update input interfaces

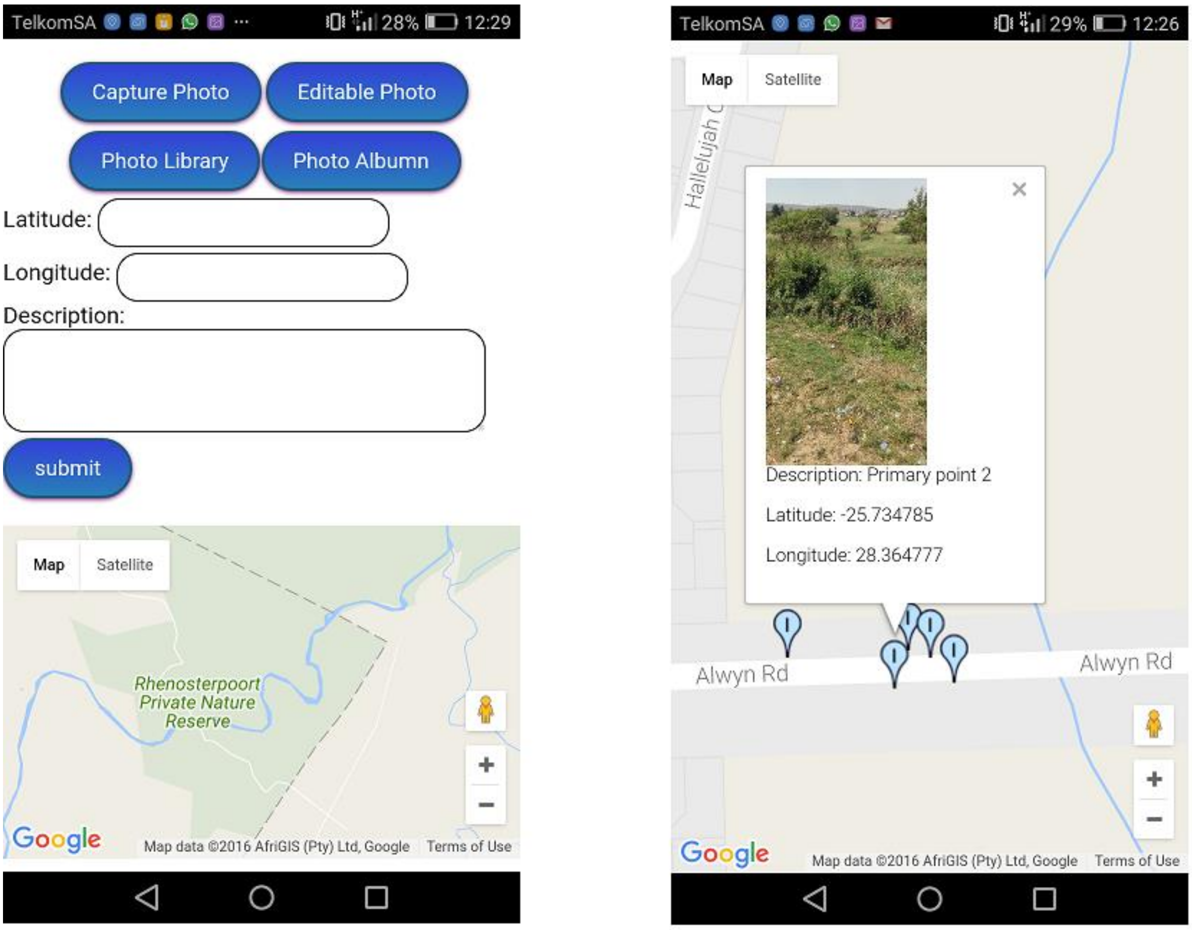

Figure 33: Nxt2U waterway rehabilitation cell phone app forms for capturing field observations and presenting visuals as captured by a user

4.2.3 Identification and selection of rehabilitation/resilience options

4.2.3.1 Input of already considered options

Determination of the potential performance of rehabilitation options depends on various variables. However, the objective sought in the performance of rehabilitation options is such that there are variables (constraints and enablers) that do not significantly affect the final outcome such that even when they are left out of the analysis the same decision will be derived. In other words, the solution to be attained when all variables are applied in selecting the best option is highly sensitive to some variables and hardly sensitive to others. There is no need to include variables that do not improve or change the decision-making process. To exclude those variables which exhibit very low sensitivity or no sensitivity in correspondence analysis against the outcome, the Principal Component Analysis (PCA) method was applied (Abdi & Williams, 2010). This method involved reducing the dimensionality of the data set, such that after starting with as many as 30 variables, one could end up with only two or three that will efficiently meet the performance objectives in determining the best performing options in the case of the different rehabilitation options. The variables (enablers and constraints) considered to be making a significant contribution to the prioritisation of rehabilitation and resilience options are listed in Table 17 below.

Table 17: Variables used to evaluate and score the performance of rehabilitation options in the rehabilitation framework

A	Budget	Projects with an approved budget have the best chance of being implemented. The state of affairs in terms of budget also affects what will be preferred.
B	Time required to complete	Projects that take many years are not usually preferred. The preference is usually to work on projects that can be completed and generate positive performance evaluation.
C	Available human capital	Rehabilitation options requiring human resources that are not available are not preferred.
D	Legislation and enforcement	Enabling legislation and its enforcement, such as strict legislation to stop pollution will see the institution addressing the problem. Here the legislation is for the enforcement of measures to stop the degradation.
E	Institution level and capacity	The nature of the institution involved in implementation affects the rehabilitation option. The larger the institution or the better resourced, the more able it is to implement any measure.
F	Strategy and planning	Projects that are already in the planning stages are most likely to be preferred.
G	New technology	Selection of a technology tends to be influenced by past positive feedback. The nature of feedback from assessments made on the use of a rehabilitation technology elsewhere affects future decisions.
H	Required human capital	Cases where the rehabilitation option does not require human resources once it is in place are better than cases where further resources are required throughout the life of its use.
I	Ecological river classification	Natural rivers are highly endangered; hence they carry the highest priority during rehabilitation and resilience activities. The priority for rehabilitation is lowest in systems where goods and services have already been lost, i.e. aquaculture, domestic use, irrigation, livestock watering, recreational use.

A list of enablers and constraints is used to prioritise options in the framework (Figure 34). The enablers and constraints are discussed in more detail in Appendix 3 of this report.

4.2.3.2 *Input of values to define constraints and enablers*

Selection of the most suitable options for rehabilitation in the framework is based on an understanding of the prevailing environment in the institution responsible for rehabilitation as well as external factors defined in terms of how easy or how difficult it is to take each option through. Once the user has determined the nature of impacts and selected the option to list the available rehabilitation options, the best performing options can be obtained by using the prioritisation module of the framework. The prioritisation module seeks to arrange the identified rehabilitation options in order of which ones should be prioritised for implementation at the top and those that could be left for later consideration at the bottom. The priorities are analysed based on the input selected or updated in the framework to provide measures against nine variables: the enablers and constraints. Figure 34 shows the list of enablers and constraints with the associated scores that are applied to determine the best performing rehabilitation option.

4.2.3.3 *Presentation of outputs – GIS*

	Scores	1	2	3	4	5
A	Budget	Not budgeted for	In the 10+ Years budget	In the 5-10 Year budget	in 5 Year budget	In the approved budget
B	Time required to complete	>15 Years	10 to 15 Years	5 to 10 Years	3 to 5 Years	0 to 3 Years
C	Available human capital	None with no chance of obtaining resources	None but can be obtained with ease	Low number of resources	Fair number of resources	Suitable resources are available
D	Legislation and enforcement	There is no legislation	There is legislation but no enforcement	There are plans to penalise	The institution has been warned	Penalties are already being applied
E	Institution level and capacity	Local Municipality	Other Centre / Town	District Centre	Other Major City	Metropolitan City
F	Strategy +Planning	No plans	Greater than 10 Year plans	5 to 10 Year plans	In 5 Year plans	In current annual plans
G	New technology	No history of evaluation and use	Positive theoretical evaluations only	Successful theoretical and practical tests	Limited positive feedback from past users	Used with good feedback in similar institutions
H	Required human capital	Required for installation and over the long term	Required for long term and not at installation	Required for installation only	Can be obtained easily when required	Not required
I	Ecological river classification	Critically modified	Largely modified	Moderately modified	Largely natural with few modifications	Natural

Figure 34: Input of constraints and enablers to set rehabilitation priorities

Prioritisation of rehabilitation options is based on decisions made against variables used to define the performance of each option. In the framework, these variables are called "enablers and constraints" Simply, the "enablers" are variables that make the implementation of the option more favourable to accomplish, while the "constraints" are the variables that make it more difficult or less worthwhile to accomplish the rehabilitation option. The different enablers and constraints differ in relevance to the final outcome of the prioritisation process. This implies that the rehabilitation options do not have the same sensitivity to the different enablers and constraints. Weights have been used in the framework to address these differences. As an example, if the rehabilitation option is to refurbish a WWTW and the score for the “budget” is 5, that is to say, this project is already budgeted for, while for the same option the score for the “institution level and capacity” variable is 1, this rehabilitation option will still proceed. However, if the scores are reversed with “budget” scoring 1 and the “institution level and capacity” scoring 5, this option will not proceed. This example explains that the decision is less sensitive to institutional level and capacity. To reflect this reduced sensitivity, a lower weight is applied to the variable “institution level and capacity”. Default weights are provided against the different enablers and constraints. However, the user can change these weights if it is determined that the weights do not correctly reflect a specific scenario that is under consideration. Further description of the enablers and constraints is provided in Appendix 3 of this report.

4.2.3.4 Calculation of weighted decisions in rehabilitation

The value of each weight (w_i) is assigned within the range 1 to 10. The indicator value after weighting is given by equation 1:

$$\boldsymbol{x_{ji} = z_i \times w_i} \qquad \text{Equation 1}$$

Where:

x_{ji} is weighted indicator value

z_i *is* indicator value (without weighting)

w_i *is weight assigned to indicator i*

In the framework the weights are factored to give $\sum_{i=1}^{n} w_i = 10$

In the framework, the weights will be aggregated and factored proportionately to give the total of weights of one unit for the eight variables (enablers and constraints) considered.

4.2.3.5 Calculation of performance of each option based on the variables (constraints and enablers)

The performance of each rehabilitation option (p) is based on the aggregate of the weighted values selected for each of the variables.

$$p_j = \sum_{i=1}^{n} [w_i(x_{ji})] \qquad \text{Equation 9}$$

Where:

p_j is the performance index at location j where indicators are agregated

$n\ is\ total\ number\ of\ variables\ being\ considered\ for\ each\ option$

$x_{ji}\ is\ the\ indicator\ at\ j^{th}\ location\ as\ upadted\ by\ the\ framework\ user$ and

$w_i\ is\ the\ assigned\ weight\ to\ indicator\ i, where\ each\ value\ w_i\ is\ between\ 1\ and\ 10$

After the weights are applied to the entered variable score values, the determination of a prioritised list of rehabilitation options is determined as shown in Figure 35 below.

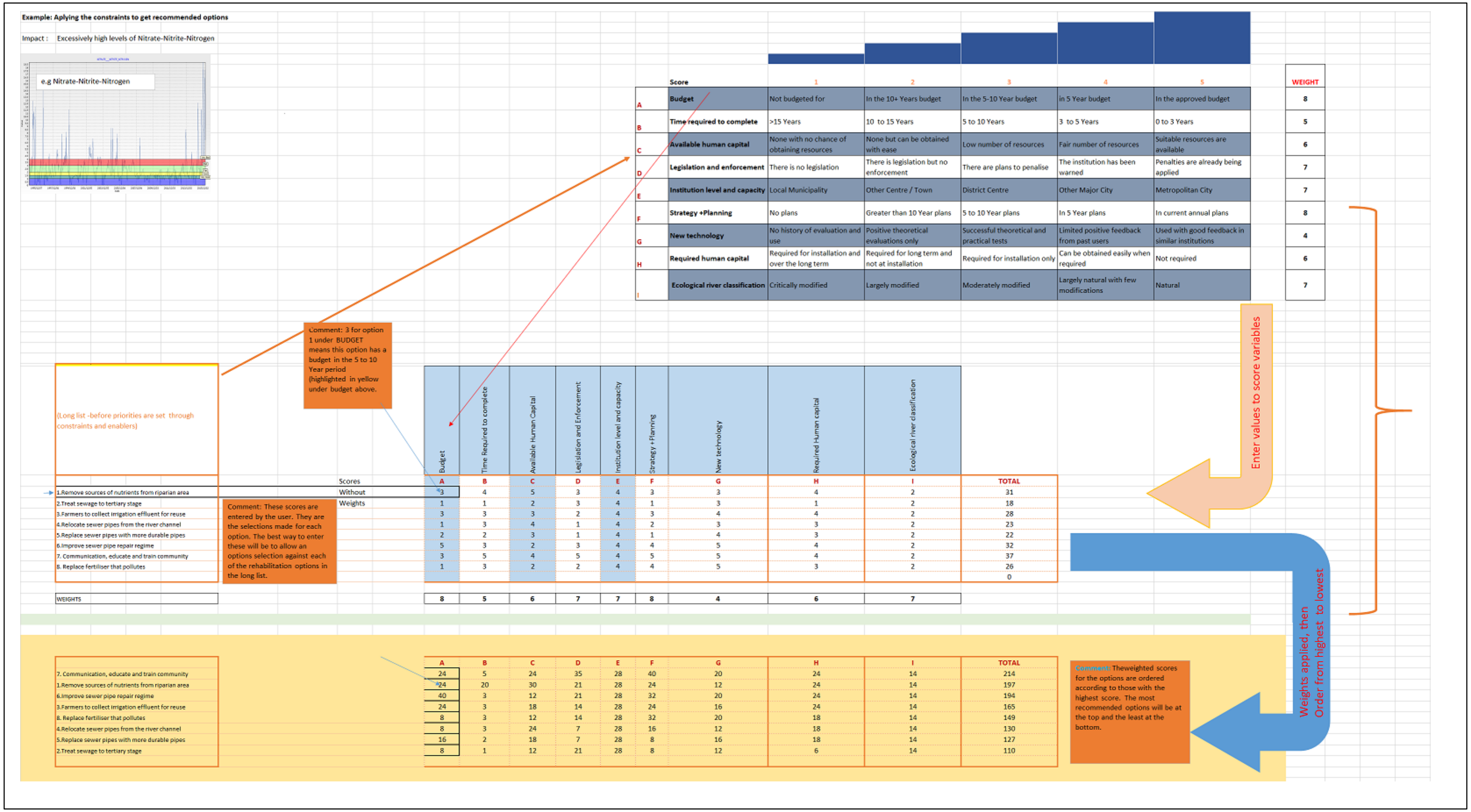

Figure 35: Illustration of methodology for determining priorities based on variable scores and weights

5 Conclusions

The human-induced degradation of aquatic ecosystems in South Africa has a long history, starting three and half centuries ago when settlements with large concentrations of inhabitants were established, starting with the first Dutch settlements around Cape Town. These settlements, unlike those established by the indigenous people, relied heavily on rivers and intensive irrigation-fed farming practices (EWISA, 2009). In the decades that followed, mills and other forms of water-powered factories were also established along the rivers causing even more degradation to the aquatic systems. In the nineteenth century, large scale settlements were established all over the country following the discovery of minerals, especially gold, diamonds and coal. The establishment of these early settlements was characterised by a lack of appreciation for the role of the ecosystem, which was worsened by the lack of suitable legislation to guide settlement patterns as well as maintain ecosystem health.

In the latter half of the twentieth century, the understanding of degradation and accompanying legislative framework have developed at a fast pace but the application of this knowledge to maintain healthy aquatic ecosystems has lagged behind. In the waterways investigated in this study, it was evident that there are still no clear plans to turn around the poor state of aquatic ecosystems. New urban developments are aligned to enhancing economic development. This entails building more houses, establishing new factories, construction of retail and service centres, building new roads, installation of infrastructure for local and inter-basin water transfers, as well as the setting up of new power generation facilities. A number of developments in urban areas also take place in wetlands, riparian areas and other areas within flood lines.

Degradation of the aquatic ecosystem is a result of all the degrading activities that are taking place in the whole catchment area. In the study, this was especially visible in the Kuils River, where there are fewer settlements and land uses on riparian areas and yet the aquatic system is in just as degraded a state as observed in both the Pienaars and Jukskei Rivers. The main problem is that the damage in the waterway is mainly affecting water quality and sources of this damage are mostly located outside the riparian areas. In the Kuils River this includes effluent pumped and diverted to the river from other catchment areas. Dealing with the riparian area settlements alone will not resolve the aquatic ecosystem damage in all the urban and peri-urban rivers investigated.

There are occasional programmes that seek enhancement of ecosystem integrity. However, these initiatives are very inadequate when compared to the current state of the aquatic ecosystem and ongoing degradation. While all the planned developments are taking place, more informal settlements and other informal livelihoods are sprouting in previously unimagined ecologically sensitive open spaces. In the case study areas in both Tshwane and Johannesburg North, the research team observed that there were planned urban renewal projects at various levels of development taking place. However, there were also new informal settlements being established in the riparian areas and within the river flood lines. These parallel developments where informal activities continue to take root at the same time as planned projects undermine possible gains of urban renewal projects.

The investigations showed that communities, institutions and the government lack the commitment to ensure that aquatic ecosystem degradation is stopped and the damage rehabilitated or even reversed. In both the Jukskei and Pienaars Rivers' riparian areas, the research team observed that there were new illegal dumping sites in the river channels and on river banks, which were established during the course of the study. Investigations showed that the recent establishment of dumping sites was due to the closure of formal dumping sites by the municipalities as well as the general lack of foresight in environmental health by the communities. In addition, the municipality was also responsible for the poor state of the WWTW that was resulting in the ongoing illegal sewage spillages into the rivers. As recently as November of 2016 certain municipal-controlled wastewater treatment facilities were releasing raw sewage into rivers. Records from very large WWTWs in the case study areas, in Tshwane, Johannesburg and Cape Town, showed frequent cases of sewage spills with a recent confirmed case at Northern Works in Johannesburg in the week ending 13 November 2016. This raw sewage spillage kills many aquatic organisms that are never accounted for. In most cases involving sewage spillage, the damage is communicated in terms of fish deaths only. The case of fish death in the Crocodile catchment on 12 November 2016 is a typical example where much degradation of the system took place and yet the media reduced the whole disaster to a limited narrative that tended to show that the degradation only caused the death of fish.

The research revealed that the general consensus is that South Africa's laws on settlements and water ecosystem health are adequate, although they will need to be updated, as always, as our understanding and circumstances change. Although there is concern about the complex proliferation and fragmentation of environmental law, the real problem is believed to lie in implementation. Reasons put forward for this include lack of capacity, inadequate resources in government departments, complexity of the systems being installed and their nature as resource intensive, thereby causing paralysis. Some scholars would argue that the problem is much deeper than the challenges mentioned above and requires a philosophical and legal paradigm shift away from the modernist, neo-liberal, market-driven mindset that dominates our relationships with each other and with the natural world (Watson, 2009; Cullinan, 2011; Swilling & Annecke, 2012).

The consultations carried out in township communities as part of this study showed that the communities find the rivers threatening to their otherwise peaceful existence. In spite of their contribution to the water quality degradation in the rivers, community members felt that they would be better off if those rivers were not there. They gave accounts of crime, flooding, health risks and lost land due to the waterways. Continued degradation of the waterways over the years has meant that people cannot associate the rivers with the services and goods that they can derive from them. Institutions that should be responsible for the health of aquatic ecosystems also add to the concerns. Faced with other competing needs, they tend to argue that these aquatic ecosystems are sources of their management and infrastructure development problems, including that they stand in the way of economic land uses. Observed and documented perceptions from the study show that rehabilitation and development of resilience in aquatic ecosystems can be achieved when all the stakeholders have a common goal and platform to contribute and take shared responsibility and ownership. These goals and the process to reach them could be shared in commonly used tools such as cell phone-based applications. The NXT2U App developed as part of this project is set to bring together all stakeholders, including the community, towards shared aquatic ecosystem health goals.

The poor levels of service delivered by the responsible authorities, especially DWS and municipalities, play a major role in the degradation that is taking place in waterways. As an example, available records kept by DWS show that the WWTW on the Roodeplaat Dam results in at least 70% of the Roodeplaat Dam’s annual phosphate load. If the problem of eutrophication is to be addressed at this dam, the sewage plants have to purify the water to a level that does not cause further degradation of the water body. In addition, the availability of information on degradation and records of the ongoing state of water quality in rivers and other natural water bodies is decreasing rapidly. The investigations in the case study areas also showed that the task of collecting records of water quality and pollution in rivers in urban areas was now becoming the responsibility of the municipalities. This makes monitoring and enforcement difficult as all institutions and individuals requiring this data have to rely on the municipality. The data collected by municipalities is hardily available to other institutions; hence the municipalities are often left with the freedom to pollute without being made accountable until there is a major spill that causes noticeable disasters such as fish death in the downstream water bodies. Lack of accountability is rampant on issues concerning wastewater services and the state of urban waterways. In spite of the many cases of sewage spillage into waterways, there are still no cases where the concerned municipal and government officers have been charged and sentenced for these violations.

There is an influx of settlements and land uses in urban and peri-urban areas for which the responsible authorities do not seem to have plans. Apart from informal settlements that are usually located in sensitive ecosystems, formal settlements are also being located in wetlands, river banks and riparian areas due to poor governance and other limitations in responsible institutions, especially municipalities. The case study areas suffered from the presence of numerous poorly located settlements that cause further damage to already compromised aquatic ecosystems. The role of informal settlements in the degradation of aquatic ecosystems is evident, but it cannot be isolated from the degradation due to land uses that are taking place in the whole catchment area.

The state of degradation in urban aquatic ecosystems, as observed in the rivers investigated, is such that the water systems in urban areas cannot be rehabilitated to pristine conditions. The aquatic ecosystem has suffered long-term damage and in most instances the degradation is permanent. In the investigated waterways, it was observed that the catchment systems that define the character and state of health of the aquatic ecosystems were no longer providing the same support to the waterways. It was also observed that there were no records of what these pristine conditions could have been, except some informed guesses for specific characteristics such as seasonal river flow regimes. The limited knowledge on the original state of the waterways fails to provide guidance on how to deal with the full complexity of the aquatic ecosystems. It was also noted that once the system is disrupted to the extent that most life forms are lost in aquatic systems, the billions of organisms in these systems will never be able to interact in the same balanced way if they were to be replaced. As such, there is no way that the pristine conditions can be fully comprehended and achieved in rehabilitation.

The understanding of government and municipal roles in aquatic ecosystem health has been investigated and documented in the recent past. As such, municipal structures and other national government departments have the tools to determine the state of aquatic ecosystems and identify the issues to address. However, this available guidance is theoretical and lacks defined systems of how the expectations on ecosystem health can be achieved. These approaches lack incentives to draw full participation of stakeholders. The rapidly changing world and local interests are not captured in the available approaches for dealing with ecosystem damage.

6 Recommendations

- **Define clear rehabilitation targets**

After more than a hundred years of degradation, the pristine conditions for aquatic ecosystems are now unknown and impractical to set as objectives for rehabilitation. Decision makers should decide on waterway health objectives that will make sense to both the person in the street and ecosystem health managers. Rehabilitation objectives should not seek to achieve pristine conditions but rather to establish a feasible but ambitious balance that is sustainable, healthy and based on prevailing environmental health requirements, legal considerations and societal expectations. The best form of objective is to target a certain visible condition that, if achieved, the general health of the whole system will also have been achieved. Past rehabilitation initiatives where fish were used as rehabilitation objectives have generated noticeable success. The recommended target for rehabilitation objectives for each of the three waterways investigated is to attain a state where a specific native fish endemic to the region flourishes. Suggestions on the fish species are: the yellowfish and blue kurper for the Jukskei and the Pienaars River, and the Cape galaxias (Galaxias zebratus) for the Kuils River. These fish are indigenous to the regions; they also have an additional value as a dependable food source if the ecosystem is maintained in a healthy state. The envisaged state will be the condition where these fish and other indigenous fish original to the area can breed freely and sustainably to the extent that people can fish and consume them without being exposed to health issues. Thornton and McMillan (1989) also suggest water ecosystem health measures involving water transparency, chlorophyll (balanced algae/plant growth) and nutrients. The use of these variables, which tend to have the same meaning to stakeholders and water managers, have the potential to close the gap for common water quality-based river health objectives. The water quality-based measure of river health could be used in conjunction with ecosystem health indicators such as fish-based targets.

- **WWTWs should treat the sewage to tertiary stage**

The WWTW and drainage from settlements in the catchment area are major contributors to water flows in the urban rivers investigated in the study. At the peak of the dry season, they contribute all the flows such that there is no dilution as envisaged when the water quality standards for WWTW effluent were set. In addition, these waterways are already degraded to a very poor state where any additional degradation cannot be naturally reversed. Considerations of the waterways investigated and the associated sources of degradation reveal that one of the main municipal ecosystem improvement programmes should focus on upgrading existing WWTWs to tertiary stage and if new ones are built, they must also include tertiary stage purification. The benefits will be achieved if these wastewater works are also adequately maintained to be robust enough to handle design peak flood flows and also manned by officers who are adequately trained. Other areas to work on will be to ensure accountability of responsible personnel through effective methods such as bonuses and remuneration.

- **Rebuild and rehabilitate other systems that affect the aquatic ecosystem**

In addition to rehabilitation of the waterway, rehabilitation programmes will be successfully sustained if all sources of degradation are eradicated. Eradication of degrading factors will include the removal of all land uses on sensitive ecosystems such as riparian areas, wetlands and within the flood line. In addition to addressing degradation due to land uses on sensitive ecosystems, sources of degradation within the catchment have to be stopped. Sewage and storm water conveyance systems have to be in a sound state and well maintained to avoid malfunction and unintended spillage. The misuse of storm water and sewage conveyance systems has to be addressed. This entails identifying and correcting all cases where sewage conveyance pipes are connected to storm water and vice-versa.

- **Enforce green technologies in aquatic infrastructure**

In spite of all the ecosystem degradation that has taken place, there are no clearly enforceable specifications to direct new developments, as well as other projects such as rehabilitation of aquatic ecosystem infrastructure, to use green or ecologically friendly methods and technology. The selection criteria for aquatic ecosystem rehabilitation projects should include favourable consideration of green and ecologically friendly technologies.

- **Legislate and enforce the installation of trash capture technologies**

A lot of solid waste that ends up in the waterway can be trapped before it becomes part of the aquatic ecosystem. Suitable guidance should be availed to designers and planners in urban and peri-urban areas. The techniques to be applied should be included in water ecosystem management guidelines. These include:

    - Installing screens at storm drain inlets, the entry points to the storm water system

    - Install in-line trash capture systems, within the tunnels and pipes or at the outlet of the storm water systems
    - Install trash capture on open water, such as a floating boom in the receiving water body
    - Install screens and debris isolation structures in the waterways including sediment traps
- **Treat storm water and other return flows from land uses before releasing it into the waterway**

The practice of releasing compromised water into the environment was viable in the past when the water released was usually a small percentage of the normal river flows. In urban and peri-urban areas, the effluent from various land uses and storm water constitutes a large percentage of the affected river flows. Over time any water quality variable that is worse than that in the river will result in a huge net effect on the health of the affected river. With the foresight generated from past experiences, it is only advisable that any water released into an urban or peri-urban river is of the same quality as what is expected to be in the river in the long term. Rehabilitation efforts will be compromised if polluted storm water and effluent is still discharged into the river.

- **Run education, communication and awareness programmes**

Programmes for rehabilitation and halting any further degradation are now complicated, expensive, and require the inclusion of all stakeholders. Both communities and formal institutions have to be involved. A process of rehabilitating rivers should also seek to rehabilitate the relationship between people and the neighbouring rivers. This can be achieved through targeted education and awareness programmes. These programmes should also build the perception of the envisaged river health goals.

- **Strengthen enforcement**

Enforce the application of supporting legislation and ensure that those responsible for the enforcement are accountable for the performance of enforcement programmes. Increased ability to enforce can be developed through separating policing and enforcement from regular service provision. The green scorpions are better off as a separate entity than as a small directorate in DWS. DWS and its partners are some of the main polluters and violators of the legal provisions on river health. In the current framework of enforcement, cases where a

WWTW releases raw sewage to rivers are never prosecuted. These facilities belong to the municipalities and in some cases to the DWS. The application of the legislation is compromised by the structural relationships between the organisations that seek enforcement of legislation and those that own and operate these facilities. In cases of settlements in riparian areas, there are no legally enforceable legal instruments. The recent case of floods in the Jukskei catchment in November 2016 showed that even when the communities are in danger of being killed in floods because of their location on riparian areas and within the flood line, the municipality and the relevant national government departments fail to intervene and they are not penalised for the failure. In addition, enforcement agents have to be equipped with adequate resources to carry out their mandate. The nature of resources and the number of agents should correspond with the numbers of violations and the complexity of the problems to be encountered.

- **Participation of community members in aquatic ecosystem rehabilitation**

The recently developed NXT2U App and software on aquatic ecosystem health monitoring and rehabilitation that accompanies this report is recommended as an additional tool that will enable communities to effectively participate in developing and maintaining waterway health. These tools, which can be provided freely to communities, will allow them to monitor and report cases of degradation in their neighbourhood, share river health data and follow up on the provision of rehabilitation solutions.

- **Waterway health budget and resources**

Degradation of aquatic ecosystems has taken decades and in some instances hundreds of years. The establishment of a healthy waterway is complex and requires time and financial and other resources. Rehabilitation programmes should be developed to be sustained over long periods before any benefits can be attained. A typical three-year municipal project will not suffice. In addition, post-project evaluation and monitoring are also required. This evaluation and monitoring stage also requires further resources to address any shortcomings and strengthen the gains of the rehabilitation programmes.

- **Strengthen the legislation through the enactment of a Clean Water Act**

The *Water Act* of 1998 and the *Water Services Act* of 1997 are very limiting when it comes to dealing with the degradation of aquatic ecosystems. A Clean Water Act should be developed, debated and passed to provide the most appropriate platform for addressing water ecosystem degradation. The degradation of the aquatic ecosystem is resulting in the depreciation of our livelihoods. We fail to adequately comprehend this due to the timeline involved from a pristine aquatic ecosystem to a dysfunctional dead body of slime.

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Appendix A: General rehabilitation and resilience options

List of tables for general rehabilitation and resilience options that can be considered for the case studies and other catchments

Table number	Description
A1	*Rehabilitation and resilience actions and approaches for impacts due to clearing or paving the riparian area*
A2	*Rehabilitation and resilience actions and approaches for impacts due to poor sanitation and settlements on riparian area*
A3	*Rehabilitation and resilience actions and approaches to address impacts due to informal activities performed on riparian areas*
A4	*Rehabilitation and resilience actions and approaches for addressing structures erected in riparian areas*
A5	*Rehabilitation and resilience actions and approaches to address impacts due to WWTW and sewer conveyance located in riparian area*
A6	*Rehabilitation and resilience actions and approaches to address impacts due to waterway modifications and diversions*
A7	*Rehabilitation and resilience actions and approaches to address degradation caused by obstructions in the waterway or converting waterway to a dam or weir*
A8	*Rehabilitation and resilience actions and approaches for degradation due to dumping of solid waste on riparian area*
A9	*Rehabilitation and resilience actions and approaches for degradation due to effluent and storm water releases into the waterway*
A10	*Rehabilitation and resilience actions and approaches for impacts due to land preparation for agricultural purposes*
A11	*Rehabilitation and resilience actions and approaches for impacts due to water abstraction and stream flow reduction by riparian plants*
A12	*Rehabilitation and resilience actions and approaches for agricultural land use effects on riparian areas*

A1: General rehabilitation and resilience options for land uses and activities on riparian zones and in aquatic ecosystems

Table A1: Rehabilitation and resilience actions and approaches for impacts due to clearing or paving the riparian area

Impact	• **Clearing of riparian area (grass, trees, reeds or even soil and sand are removed)** • **Converting riparian area to road or paved surfaces, compaction of riparian area soil**				
Goods and services affected	Aquatic ecosystem's value to tourism is lost when riparian area is cleared as these subjects the river to extensive degradation and reduces its overall resilience.	Absence of natural riparian vegetation that could remove sediments and dirt from the runoff result in ecosystem bio-diversity loss.	Increased sedimentation and solid waste on riparian area means that the water quality in the waterway is compromised. Thus, its potential to serve communities is reduced.	After clearing, waterway becomes fast flowing and turbidity is higher. This results in increased BOD. When oxygen is lost from the water body, water-based organisms, including food sources, die out.	Continuous land use of area as a result of road construction or paved walkways next to river results in environmental destabilisation and reduction of air quality.
Rehabilitation/ resilience	Replanting of original vegetation on riparian area.	Physical removal of excess sediments from rivers, especially where river channels have been paved. Re-introduction of riparian vegetation to reduce sediment loading of river.	Penalise unnecessary clearing and illegal dumping of wastes, especially in informal settlements.	Education and training of communities on the importance of riparian zones. Creation of boundary markers to inform communities of riparian zones and to prevent clearing.	Relocate road to an area further away from the riparian area or waterway. Create alternative routes farther from riparian areas that can be used by travellers.
Timeline	P1	P1/P2	P1	P1/P2	P2/P3

Applicable regulations/By-Laws/Legislation	*National Water Act* 36 of 1998; *Environmental Conservation Act* 73 of 1989 *Conservation of Agricultural Resources Act* 43 of 1983; *NEMA Biodiversity Act* 10 of 2004	*Environmental Conservation Act* 73 of 1989	*Environmental Conservation Act* 73 of 1989	*Environmental Conservation Act* 73 of 1989	*Environmental Conservation Act* 73 of 1989
Criteria for selection based on location: 1. Regional location 2. Location within the waterway	**Regional location**: *UA, *PA **Rainfall seasonality**: All applicable depending on type of natural riparian vegetation **Type of aquatic system**: R, W **Location within waterway**: RB, FP, BZ	**Regional location**: PA, *OCA **Type of aquatic ecosystem**: R, W **Location of damage in waterway**: All applicable	**Regional location**: UA, PA **Type of aquatic system**: R, W **Location of damage in waterway**: All applicable	**Regional location**: All locations **Type of aquatic system**: R, W, C, E **Location of damage in waterway**: All applicable	**Regional location**: PA, UA **Type of aquatic system**: R, W **Location of damage in waterway**: All applicable
Institutional considerations	DEA, SANBI, Environmental NGOs, Municipalities	DEA, DWS, SANBI, Environmental NGOs, Municipalities	DEA, Municipalities, SAPS and Metro Police	DEA, DWS, SANBI, Municipalities	DoT, SANRAL, Municipality

*UA= Urban Area, PUA= Peri-Urban Area, OCA= Other Catchment Area

Table A2: Rehabilitation and resilience actions and approaches for impacts due to poor sanitation and settlements on riparian area

Impact	**Established temporary public toilets lined along riparian area** **Lack of sanitation in shack dwellings leading to direct disposal of sewage into rivers**				
Goods and services affected	Aquatic ecosystem value to tourism and recreation is reduced when there are ablution facilities on riparian area.	Direct sewage flows in area and into waterway making area unsuitable for recreation or sport.	Increased pollution from the ablution area causes disease and negatively affects fauna.	Fish from the aquatic ecosystem can be negatively affected either through bio-accumulation or death as a result of disease-transmitting pathogens.	Increasing populations in informal settlements directly result in increases in pollutant load. Water use is diminished if there are pathogens in the water.
Rehabilitation/resilience	Remove toilets from riparian zones and relocate to areas much farther from the riparian area. Increase the number of mobile toilets in correlation with the population of the settlement.	Formalise informal settlements by improving sanitation availability and installing more effective sanitation facilities.	Improve service delivery for collection of waste. Apply penalties for disposal of sewage into aquatic systems.	Education and training of community members on health issues and values associated with a healthy and sustainable aquatic ecosystem.	Supply alternative water of good quality to communities.
Timeline	P1	P1/P2	P1	P1/P2	P3
Applicable regulations/ by-laws/legislation	*Environmental Conservation Act* 73 of 1989.	NEMA *Waste Management Act* 59 of 2008; *Waste Amendment Act* 26 of 2014	NEMA *Waste Management Act* 59 of 2008; *Waste Amendment Act* 26 of 2014.	-	*Environmental Conservation Act* 73 of 1989 *Prevention of Illegal Eviction Act* 19 of 1998 should be revised

Criteria for selection based on location: 1. Regional location 2. Location within the waterway	**Regional location**: All locations with prolific informal settlements. **Type of aquatic system:** R, W, C,	**Regional location**: All locations with informal settlements **Type of aquatic system**: R, W, C	**Regional location**: All locations **Type of system**: All aquatic systems	**Regional location**: All informal settlements.	**Regional location**: All informal settlements, especially shacks.
Institutional Considerations	Human Rights NGOs and activists. DWS, DEA, Municipalities	DHS, Municipalities	Municipalities, DWS, DEA, SAPS,	DWS, Municipalities, NDMC	DHS, Municipalities

Table A3: Rehabilitation and resilience actions and approaches to address impacts due to informal activities performed on riparian areas

Impact	**Riparian area converted for use as an informal drinking spot or by vagrants for temporary shelter** **Riparian area is used as a venue for cultural or church gathering**				
Goods and services affected	The value of the area and waterway in the vicinity of these activities is lost. Intrinsic and future value is lost. Instead of an area that is known for good natural diversity the area exists in bad light in community members' memories.	Area that could be used for recreation, bird watching becomes inaccessible and crime ridden.	Direct contamination of waterway from trash, beer bottles and human waste. Water and surrounding area is associated with diseases and foul smells.	Leisure walks and bird watching activities are no longer viable. Loss of habitat for birds and other wild animals.	Frequent fires in the area due to drinking community in area and other associated social delinquencies make area unsuitable as a source of value and good aesthetics.

Rehabilitation/resilience	Area is cleared of vagrants and polluters. Formal recreational facilities and accommodation are developed elsewhere according to municipal plans.	Stakeholder awareness and community clean-up operations to stop practices that degrade the ecosystem. Control and criminalise criminal activities.	Community awareness programmes and organised regular clean-up operations. Municipal response line to stop pollution and misuse of environment.	Area is restored to natural state or close to pristine condition.	By-laws are applied to rid the place of criminals and polluters.
Timeline	P1, P2	P1, P2	P1, P2	P2, P3	P1
Applicable legislation	*Environmental Conservation Act* 73 of 1989, the *Abolition of Racially Based Land Measures Act* 108 of 1991	*Environmental Conservation Act* 73 of 1989. *Development Facilitation Act* 67, 1995, ***Criminal Procedure Act* 51 of 1977	*Environmental Conservation Act* 73 of 1989, ***Criminal Procedure Act* 51 of 1977	*Environmental Conservation Act* 73 of 1989. *Development Facilitation Act* 67, 1995	*Environmental Conservation Act* 73 of 1989. ***Criminal Procedure Act* 51 of 1977
Applicable selection criteria 1. Regional location 2. Location within the waterway	All locations; all aquatic systems; all locations of damage	All locations; all aquatic systems; all locations of damage	All locations; all aquatic systems; all locations of damage	All locations; all aquatic systems; all locations of damage	All locations; all aquatic systems; all locations of damage
Institutional considerations	Municipalities, DHS, DEA, DoH	Municipalities, DEA, DWS, SAPS	Municipalities, SAPS, Metro Police	DEA SANBI, Water boards, Department of Tourism	DEA, DWS, Municipalities

***Criminal Procedure Act,* Act 51 of 1977 read together with 77 *Criminal Procedure Amendment Acts* and Associated Amendment Bills.

Table A4: Rehabilitation and resilience actions and approaches for addressing structures erected on riparian areas

Impact	Erecting informal structures on the riparian area (housing shacks, tuckshops, informal businesses, informal abattoirs) Erecting formal structures on riparian area (houses, factories and other structures based on plans that are not aligned to the upkeep of aquatic ecosystem health)				
Goods and services affected	Area loses aesthetic and intrinsic value.	Water becomes unusable for domestic purposes.	The functionality of the riparian zone as a buffer/filter between terrestrial and aquatic ecosystems is lost.	The habitat for wild animals and other living organisms is lost.	Area is no longer associated with leisure activities such as bird watching but rather the survival of poor communities.
Rehabilitation/resilience	Allocate suitable land for settlements especially for low-cost housing.	Provision of water services to communities irrespective of where they are settled.	Revision of urban plans and relocation of poorly located houses, formal infrastructure including malls, factories, housing complexes and other business facilities.	Environmental rehabilitation and replanting of suitable land cover to produce a resilient environment.	Education and awareness in communities to ensure that they do not contribute to degradation.
Timeline	P1, P2	P1	P2, P3	P1, P2	P1
Applicable legislation	The *Abolition of Racially Based Land Measures Act* 108 of 1991, *Development Facilitation Act* 67, 1995.	*Environmental Conservation Act* 73 of 1989, *National Water Act* of 1997.	*Environmental Conservation Act* 73 of 1989 *Development Facilitation Act* 67, 1995.	*Environmental Conservation Act* 73 of 1989, *National Environmental Management Act* 107 of 1998	*Environmental Conservation Act* 73 of 1989
Applicable selection criteria	Regions with informal settlement problems; all types	Regions with informal settlements.	Regions with formal and informal settlements	Regions where settlements have	All locations and systems apply.

1. Regional location 2. Location within the waterway	of systems; all classes of location damage.		including highly populated areas.	altered riparian zones.	
Institutional considerations	DHS in conjunction with DEA and DWS, Municipalities	DWS, DEA, Municipalities	DHS, Department of Human Settlements, Municipalities	DEA, SANBI, Municipalities	Municipalities, DEA, DWS, DoH,

Table A5: Rehabilitation and resilience actions and approaches to address impacts due to WWTW and sewer conveyance located on riparian area

Impact	• **Effluent producing plants on riparian area (sewage plant, feedlot, industry and shopping malls)** • **Sewer conveyance pipes established on riparian area and even over the waterway**				
Goods and services affected	General loss in most goods and services due to high levels of pollutants associated with these facilities. Sewage plants and feedlots cause the most damage in very short periods.	The water resource becomes less useful or less available for domestic and other uses due to the higher price tag for purification.	High nutrient loads that result in oxygen depletion and enhance eutrophication processes. Takes away the water body's natural ability to support life.	Sewer conveyance pipes suffer frequent bursts and spillage directly into the waterway. Polluted water becomes unsuitable for use.	Unsightly and smelly aquatic ecosystems are usually the product of sewage plants, feedlots and sewer pipes established in riparian areas. Water body loses aesthetic value.
Rehabilitation/resilience	Relocate sewage plants and other highly polluting facilities out of urban or peri-urban areas. New locations to be easy to	Exercise total compliance to pollution standards including stricter compliance guidelines for facilities that are	Water from facilities should not be released with excessive pollutants. Regular monitoring and penalties applied	Strict monitoring and enforcement of by-laws for ensuring separate conveyance of grey water and urban runoff/storm water.	Change legislation and by-laws for enforcing water purification to tertiary stage. Legislation to improve sewer

	monitor and enforce water quality standards.	located in strained ecosystems.	and implemented for violations. Upgrade sewage treatment plants to enable complete removal of nutrients present in wastewater after conventional treatment.	Reduce sewage conveyance distances to reduce chances of bursts and outflows into aquatic systems before sewage reaches treatment plant.	conveyance without spills and using only buried pipes.
Timeline	P2, P3	All time periods	P1, P2	P1, P2	P2, P3
Applicable legislation	*Water Services Act* 108 of 1997; *Environmental Conservation Act* 73 of 1989; *National Water Act* 36 of 1998.	*National Water Act* 36 of 1998; *Environmental Conservation Act* 73 of 1989.	*Water Services Act* 108 of 1997; NEMA polluter pays principle; *NEMA: Waste Act* 59 of 2008; *National Water Act* 36 of 1998	*Water Services Act* 108 of 1997; NEMA polluter pays principle; *NEMA: Waste Act* 59 of 2008; *National Water Act* 36 of 1998.	*Environmental Conservation Act* 73 of 1989; *Water Services Act* 108 of 1997
Applicable selection criteria 1. Regional location 2. Location within the waterway	All regions with currently poor-performing WWTW, especially densely populated areas	All regions with currently poor-performing WWTW, especially densely populated areas	All regions with currently poor-performing WWTW, especially densely populated areas	All regions with currently poor-performing WWTW, especially densely populated areas	All regions with currently poor-performing WWTW
Institutional considerations	DWS, DEA, Municipalities	DEA, DWS, Environmental NGOs, DoH.	Environmental NGOs, Municipalities, DWS, DoH.	DEA, Environmental NGOs. Municipalities, DWS.	DEA, DWS, Municipalities

Table A6: Rehabilitation and resilience actions and approaches to address impacts due to waterway modifications and diversions

Impact	• **Converting waterway to an unnatural channel, canal, pipe, culvert or bank stabilisation** • **Diverting waterway to a new water course**				
Goods and services affected	Aquatic organism habitat is lost, no fishing is possible after water is piped or conveyed in other manmade conduit.	New water course means that most of the flora and fauna in the old water course are also lost. Fish, crabs, wood, reeds are lost.	Flow hydraulics including speed and pollutant-carrying capacity is altered. Further degradation of channel will take place with time.	Riparian area functions are lost. Stabilised and paved banks or riparian area will not perform the same functions as the natural riparian area in retarding flow and trapping sediments.	Cultural, recreational, tourism and religious uses are lost when the natural waterway is replaced or removed.
Rehabilitation/resilience	Establish a natural channel. This may involve relocating some earlier developments that now occupy the original water course.	Re-establishing the aquatic life to new defined goals. Including ecosystem goals in the strategies and business plans of relevant institutions.	Finding a balance between the development plans and the need for ecosystem health.	Using green technologies and other ecosystem-friendly designs to carry out the same goals for the infrastructure developments.	Balance the required changes to the waterway with the uses of the waterway to come out with sustainable alternatives.
Timeline for rehabilitation	P3, to start in P2	P2	P1	P1 for planning P2 for implementation	P1, P2, P3
Applicable legislation	*National Water Act* 36 of 1998.	*NEMA Biodiversity Act* 10 of 2004; *Environmental Conservation Act* 73 of 1989.	NEMA, NWA. *Development Facilitation Act* 67, 1995, *Abolition of Racially Based Land Measures Act* 108 of 1991.	*Environmental Conservation Act* 73 of 1989. *Development Facilitation Act* 67, 1995	*Environmental Conservation Act* 73 of 1989. *Development Facilitation Act* 67, 1995

Applicable selection criteria 1. Regional location **2.** Location within the waterway	All rivers with hydrological degradation.	All diverted rivers where biotic components have been affected.	All aquatic ecosystems and associated components apply in all locations.	All locations where riparian area functions have been lost.	All waterways where natural channel system has been physically modified.
Institutional considerations	SANBI, DEA	SANBI, DEA, Municipalities	DEA in conjunction with DHS	Municipalities, CoGTA	DEA

Table A7: Rehabilitation and resilience actions and approaches degradation caused by obstructions in the waterway or converting waterway to a dam or weir.

Impact	**Damming the waterway and flood control levees** **Storage of water off river** **Bridges, piers and other structures inside waterway**				
Goods and services affected	Dams in polluted urban and peri-urban waters usually end up as sinks for sediments and other pollutants. Nutrient accumulation results in eutrophic state. Balance of aquatic life is distorted.	The dam separates the flow of aquatic life between upstream and downstream habitats.	Dams on urban rivers have a tendency to accumulate sewage spills and urban storm water that is also polluted with bacteria. In time, this water is unsuitable for sport, recreation and leisure activities.	Levees and structures in waterway create barriers for ecosystem's natural processes to thrive. Vegetation and soil structure are also lost in the process. Area becomes unnatural and not suitable for services.	Off river storage creates stagnant water that does not drain. Conducive for bacteria and other disease vector breeding. Waterway becomes a health hazard to both people and animals.
Rehabilitation/resilience	Dams in urban areas that are already in a bad state need to be dredged, sediments removed and	Fish ladders and other ecosystem-friendly developments can be installed.	Purification of water already in the dams. Bio-engineering of the dam to eradicate diseases. Bacteria-	Find alternative solutions and remove structures in the waterway. Rehabilitate area to be close to natural	Remove off river storage and rehabilitate land to ensure more natural landscapes or parks

	remaining water purified.		eating fish could also be introduced.	and yet useable while still protecting residents from flood breaches.	for recreation and leisure walks.
Timeline	Draining should start in the short term (P1) with final phases of sediment removal taking place in medium term (P2).	Medium term (P2). Designs and approvals in short term (P1).	P2	P2	P2 to P3
Applicable legislation	*Water Services Act* 108 of 1997; *National Water Act* 36 of 1998.	*NEMA: Biodiversity Act* 10 of 2004	*Water Services Act* 108 of 1997; *National Water Act* 36 of 1998.	*Disaster Management Act* 52 of 2002; *Environmental Conservation Act* 73 of 1989.	*Environmental Management Act* 73 of 1989; *NEMA Act* 107 of 1998.
Applicable selection criteria 1. Regional location 2. Location within the waterway	All waterways with built dams or weirs.	All areas with dams or other developments that may have affected species distribution with the aquatic ecosystem.	All areas with dams.	All aquatic ecosystems and locations apply.	All locations where aquatic ecosystems have been enclosed.
Institutional considerations	DWS, Water boards	DWS, DEA, SANBI	DWS, Water boards, Municipalities	NDMC, Environmental NGOs, Municipalities	DEA, Municipalities

Table A8: Rehabilitation and resilience actions and approaches for degradation due to dumping of solid waste on riparian area

Impact	**Solid waste, logs, concrete, plastics and other debris blocking the waterway** **Using riparian area or waterway as a semi-commercial solid waste dumping site**				
Goods and services affected	Area becomes unsightly and unsuitable for tourism, recreation and leisure activities.	Toxic chemicals leach from solid waste and poison the water in the waterway and surrounding soils. In sandy soils, such disposal far from the water way will result in toxicants leaching to the waterway.	The whole waterway is covered with floating and unsightly waste. The BOD and COD rises to levels that will result in mass extinction of living organisms.	Water can no longer be used for domestic uses. It also becomes a source of diseases.	Polluted area will attract scavengers and vultures rather than original bird and insect life.
Rehabilitation/resilience	Awareness, education and training of community members to ensure that they assist in the maintenance of a good quality ecosystem in their neighbourhoods.	Relocate the waste dump and clear the area of the solid waste. Avoid the practice of most municipalities where the waste is covered with soil but left in the same riparian area.	Formal organised and informal clearing of pollution. To involve the communities to ensure that they are part of sustained regular clean-up operations. Add clean-up tasks to operations of a designated team.	Extend clean-up operations to areas upstream and downstream to ensure that solutions are catchment-wide rather than local.	Rehabilitate the area after clearing all the waste to re-establish the natural land cover in the riparian area and more natural water way morphology.
Timeline	All timelines apply	P1	All timelines apply	P1 and P2	P1, P2 and P3
Applicable legislation	*Environmental Conservation Act* 73 of 1989.	*NEMA: Waste Management Act* 59 of 2008.	*Environmental Conservation Act* 73 of 1989; *NEMA: Waste Management*	*Environmental Conservation Act* 73 of 1989; *National*	*Environmental Conservation Act* 73 of 1989; *NEMA* 107 of 1998.

			Act 59 of 2008; *NEMA* 107 of 1998.	*Water Act* 36 of 1998.	
Applicable selection criteria	All apply	All areas where dumping sites are located on riparian zones or within buffer zone of rivers or wetlands.	All areas where solid wastes have been disposed of on the riparian zones and inside the aquatic system.	All areas where solid wastes have been disposed of on the riparian zones and inside the aquatic system.	All apply
Institutional considerations	DEA, Municipalities, DoH, Department of Education (Primary and High)	DHS, DEA, DWS, Municipalities	Municipalities, DWS, schools	Municipalities, DWS	Municipalities, DWS, Community institutions (e.g. churches, cooperatives and clubs)

Table A9: Rehabilitation and resilience actions and approaches for degradation due to effluent and storm water releases into the waterway

Impact	• **Connecting storm water pipes and culverts to the waterway and release of effluent into the waterway**				
Goods and services affected	Piped storm water comes with high sediment and waste load, which exceed the waterway's self-cleansing ability.	Flood attenuation capacity is reduced or lost as waterway is already running full.	Altered flow regimes; pollutants from various sources in the catchment pollutes the water way and cause unnatural flow systems thus disrupting aquatic life.	Waste in the waterway creates abreeding ground for disease. This makes the waterway unsuitable for sport, leisure or games.	Excessive pollution due to effluent from facilities that are located far from the waterway. Remote location allows conditions for dissociating effluent with the source and thus difficult to police. This results in loss of aquatic organisms' habitat.

Rehabilitation/resilience	Purification of storm water in separate facilities or extending of WWTW to include a section to deal with storm water.	Sustainable volumes to be released to waterways with the rest purified and conveyed to dams.	Only suitable water volumes released into the waterway. The rest is purified and conveyed to dams or for re-use.	Develop mechanisms to trap waste and separate it from the waterway.	Water quality monitoring and enforcement of regulations at all plants and other potential pollutant sources in catchment area.
Timeline	P2 to P3	P2 and P3	P1 and P2	P2 and P3	All timelines apply
Applicable legislation	*National Water Act* 36 of 1998; *Water Services Act* 108 of 1997; Storm water Management By-laws. Update ECA and NEMA.	*National Water Act* 36 of 1998; *Water Services Act* 108 of 1997.	*National Water Act* 36 of 1998; *Water Services Act* 108 of 1997.	*National Water Act* 36 of 1998; *Water Services Act* 108 of 1997.	*National Water Act* 36 of 1998; *Water Services Act* 108 of 1997.
Criteria for selection based on location: 1. Regional location 2. Location within the waterway	All apply, especially in regions with high rainfall durations and intensity.	All regions apply	All apply	All apply, especially in formal settlements with CBDs that are often highly polluted with solid wastes.	All apply
Institutional considerations	Municipalities, DWS	Municipalities, DWS	Municipalities, DWS	Municipalities, DWS	Municipalities, DWS, Environmental NGOs

A2: Rehabilitation actions for impacts that result from agricultural land use

Table A10: Rehabilitation and resilience actions and approaches for impacts due to land preparation for agricultural purposes

Impact	**Ploughing, land tillage, irrigation and establishing other agricultural activities on riparian area** **Feedlots and livestock habitats (e.g. kraal for cattle) established on riparian area** **Gardening, livestock grazing, fish farming**				
Goods and services affected	Natural habitat where wild animals thrive on riparian area is lost. Tourism potential is lost.	Introduction of agricultural chemicals disturbs the healthy balance in waterway. Results in loss of goods from the waterway.	Chemicals and high loads of organic contamination from feedlots, agriculture and fish farming.	The soil texture and land cover is changed to an unnatural state. Loss of the value associated with the natural environment. Loss of habitat for wild life.	Communities lose the sources of wood, thatching grass and clean water sources.
Rehabilitation/resilience	Eradicate all agricultural activities that are degrading the riparian areas. Rehabilitate the area to colonise it with the original vegetation or land cover.	Stop riparian farming and encourage non-polluting green farming techniques in the catchment area. Stop fertiliser use to use organic farming methods that will not poison the environment.	Polluted effluent from highly damaging practices such as feedlots has to be purified on site before discharge to waterway or to the environment. Penalties should always include making right the damage caused.	Stop activities that change the natural land cover and increase erosion such as tilling and ploughing of riparian areas.	Educate community to build ecosystem sustainability knowledge and extend their minds to alternatives that are not degrading to the environment.
Timeline	P1	P1	P1, P2, P3	P1, P2, P3	P1, P2
Applicable legislation	*NEMA 107* of 1998; *Environmental*	*Environmental Conservation Act* 73	*Environmental Conservation Act* 73	*Environmental Conservation Act* 73	*Environmental Conservation Act* 73

	Conservation Act 73 of 1989, *Municipal Systems Act* No. 32 of 2000	of 1989, *Municipal Systems Act* No. 32 of 2000	of 1989, *Municipal Systems Act* No. 32 of 2000	of 1989; *NEMA 107* of 1998	of 1989, *Municipal Systems Act* No. 32 of 2000
Criteria for selection based on location: 1. Regional location **2.** Location within the waterway	All regions with prolific agricultural activities.	All regions with prolific agricultural activities.	All regions with prolific agricultural activities.	All regions with prolific agricultural activities.	All regions with prolific agricultural activities.
Institutional considerations	DEA, SANBI, DAFF, Municipalities	DEA, SANBI, DAFF	DEA, DWS, SANBI, DAFF, Municipalities	DAFF, SANBI, DEA	Municipalities, Department of Higher and Lower Education

Table A11: Rehabilitation and resilience actions and approaches for impacts due to water abstraction and stream flow reduction by riparian plants

Impact	**Water abstraction from waterway for agricultural purposes. Water diversion for flood irrigation. Streamflow reduction, e.g. by planting alien vegetation that has high water use rates. Water draining into mines.**				
Goods and services affected	The body of water in waterway and associated services are also lost.	Altered waterway water availability and flow patterns. Unsustainable habitat for aquatic organisms to thrive.	The riparian area dries up as water is no longer reaching the sensitive ecosystem.	Water that is lost into the ground is polluted and becomes inaccessible for uses.	The value of the aquatic and riparian area in recreation, leisure, wild life habitat and watering point for wild animals is lost.
Rehabilitation/resilience	Establishment of a monitored, controlled abstraction programme that	Clear the riparian area and catchment of alien vegetation that is responsible	Ensure adequate water flows by managing all upstream flow patterns.	Opening into disused mines to be closed, water access points into the ground	Generate awareness and educate stakeholders on the need to maintain the ecosystem health

	leaves adequate water for the environment.	for the high-water usage.		should be rebuilt to manage pollution.	and protect the water and riparian areas for now and into the future.
Timeline	P1 to P2	P1 to P2	P1	P1 to P2	P2 to P3
Applicable legislation	*National Water Act* 36 of 1998; *Water Services Act* 108 of 1997; *NEMA 107* of 1998	*Environmental Conservation Act* 73 of 1989	*National Water Act* 36 of 1998; *Water Services Act* 108 of 1997	NEMA: *Waste Act 59* of 2008; NEMA: EIA regulations (2010); *NEMA* 107 of 1998	*Environmental Conservation Act* 73 of 1989
Criteria for selection based on location: 1. Regional location 2. Location within the waterway	All areas where unmonitored abstraction of water for agriculture and other purposes is common.	All regions	All regions	All areas with abandoned mines that have not been properly decommissioned and currently operative mines with leaching problems.	All regions
Institutional considerations	DWS, DAFF	DEA, SANBI	DWS, Municipalities	DMPR, DEA, DWS	Municipalities

A3: Rehabilitation/resilience actions and approaches for impacts that result from industry and mining land uses

Table A12: Rehabilitation and resilience actions and approaches for agricultural land use effects on riparian areas

Impact	**Industry/tannery/power station, mineral processing plant on riparian area** **Mining in waterway and riparian area (mine, quarry, alluvial sand, gold panning)**				
Goods and services affected	Various chemical pollutants, foul odour and colouration from mining activities will devastate the aquatic environment. Life in the waterway is devastated.	Thousands of tonnes of NO2 and SO2 are released from coal-powered plants. This causes acid rain or intoxicates the soil and water. Environment becomes inhabitable by all organisms and surrounding air becomes toxic.	Effluent from highly polluting industries such as tanneries is both organic and chemical with a range of toxic chemicals released including several heavy metals. Will wipe out the flora and fauna to produce a wasteland.	Industry and mining in alluvial conditions or just next to the river create permanently mucky waters with colloids and floating debris. The channel is also altered. The function of waterway and riparian area is lost.	Industries generate several chemicals some of which are new and not accounted for in the regulations. These cause the water body to lose the character required to support life. The ecosystem value is lost.
Rehabilitation/resilience	Mining activities have to be developed to maintain sustainability in the affected aquatic environment. Environmental management plans to be available including what will be done at decommissioning stages.	Replace polluting power plants with clean technologies such as solar, wind turbines and even zero emission coal powered plants.	Industrial effluent should not be released into the aquatic environment. Full purification of effluent on site has to be applied and only fresh potable water released.	The licences and permits for these activities should include thoroughly investigated and tested environmental management and rehabilitation programmes.	Consistently updating the legal provisions and enforcing these to stop pollution and to support ecosystem resilience.

Timeline	P1	P2 to P3	P1 to P2	P1 to P2	All terms. A continuous activity.
Applicable regulations/ by-laws/legislation	*Environmental Conservation Act* 73 of 1989; *NEMA 107* of 1998; *NEMA: Waste Management Act* 59 0f 2008; *National Water Act* 36 of 1998, *Minerals Act*, 1991 (Act 50 of 1991), *Mine Health and Safety Act*, 1996 (Act No 29 of 1996)	*Air Quality Act* 39 of 2004; *NEMA 107* of 1998; *Mineral and Petroleum Resources Development Act* 28 of 2002	*National Water Act* 36 of 1998; *NEMA: Waste Management Act* 59 0f 2008	*Mineral and Petroleum Resources Development Act* 28 of 2002	*Environmental Conservation Act* 73 of 1989
Criteria for selection based on location: 1. Regional location 2. Location within the waterway	All mining regions	All mining and industrial regions	All mining regions	All mining and industrial regions	All mining and industrial regions
Institutional considerations	DMPR, DEA, DWS, Municipality, Environmental NGOs	DEA, DoE, DMPR	DWS, Environmental NGOs, Municipalities	DMPR, Municipalities	DMPR, DEA, DWS

Appendix B: Rehabilitation/resilience actions and approaches for degradation in case studies

List of Appendix B Tables

Appendix B1: Jukskei River

Table B1: Recommendations for planned projects that result in degradation in the Jukskei River

Project (s) description	The City of Johannesburg is busy with development of a huge up-market shopping complex at the Bruma Node. This place used to be a lake on the Jukskei River. There is a high possibility that the effluent from the activities in this area will drain into the Jukskei River and contribute significantly to physical and chemical degradation.			
Impacts on goods and services	Further loss of aesthetic appeal of the river Further loss of functionality in terms of support of biotic components Loss of recreational uses			
Rehabilitation/resilience options	All water effluent from this centre, including storm water flows that are currently planned to be directed into the Jukskei River, should be purified to tertiary level before discharge.	The river should not be piped or sent through a tunnel at the site as this will cause further degradation and affect species distribution.	The hydrology of the river should not be affected by the planned activities in order to ensure its functionality in the sustenance of aquatic organisms.	Any canalisation that may result from this project should be such that the river channel is still maintained and the natural features of the river are imitated to aid the functionality of the canalised section of the river.
Timeline for implementation	P1 – Planning and implementation strategies should be concluded before the commencement of the project	P1 – to be included in the plans for the project	P1 – to be included in the plans for the project	P2
Applicable legislation, by-laws or regulations	*National Water Act* 36 of 1998; *Environmental Conservation Act* 73 of 1989;	*Environmental Conservation Act* 73 of 1989	*Environmental Conservation Act* 73 0f 1989	*National Water Act* 36 of 1998; *Environmental Conservation Act* 73 of 1989

	NEMA Waste Management Act 59 of 2008			
Responsible institutions and authorities	The Ekurhuleni Metropolitan Municipality The Edenvale River Watch The City of Johannesburg DWS The project contractor and waste management authority	The Ekurhuleni Metropolitan Municipality The Edenvale River Watch The City of Johannesburg DWS Department of Regional Planning Project contractor	The Ekurhuleni Metropolitan Municipality The Edenvale River Watch The City of Johannesburg DWS Department of Regional Planning Project contractor	The Ekurhuleni Metropolitan Municipality The Edenvale River Watch The City of Johannesburg DWS Environmental NGOs and citizen forums

Table B2: Proposed recommendations for current problems in surrounding settlements that result in degradation in the Jukskei River

Problem description	There is a lack of functional landfill sites in the Sandton/Alexandra region of the Jukskei catchment. The only functional landfill site was at Linbro Park and is currently being rehabilitated. This has resulted in increased dumping of waste in areas that are not designated for such activities. As a result, there is physical land degradation that resultantly affects aquatic ecosystems.			
Impacts on goods and services	Presence of physical elements of degradation on the river results in a loss of aesthetic appeal. The river cannot be used for domestic or recreational uses or even aquaculture as an increase in organic matter results in a depletion of oxygen. River is unable to support aquatic life due to lack of sufficient oxygen. Loss of river functionality as biotic processes are impeded.			
Rehabilitation/resilience options	Establishment of more than one landfill site to enable easy reach for residents in the area. Penalisation of residents who do not dispose of waste appropriately.	Improvement of waste collection services from homes to ensure proper disposal at designated sites.	Upgrading of existing landfill site should take possible leaching of waste streams into consideration and measures should be put in place to completely avoid such occurrences.	Use of air traps within the rivers to aid the survival of organisms while rehabilitation or restoration processes are underway.

Timeline for implementation	P1 for planning and implementation P2 for completion	P1	P1	P1
Responsible institutions within the catchment area	The Ekurhuleni Metropolitan Municipality The City of Johannesburg DWS	The Ekurhuleni Metropolitan Municipality The City of Johannesburg DWS	The Ekurhuleni Metropolitan Municipality NGOs such as the Edenvale River Watch The City of Johannesburg DWS	The Ekurhuleni Metropolitan Municipality The Edenvale River Watch The City of Johannesburg DWS
Guiding legislation/By-laws	*Environmental Conservation Act* 73 of 1989; *NEMA Waste Management Act* 59 of 2008; NEMA Polluter pays principle.	*NEMA Waste Management Act* 59 of 2008; *Waste Amendment Act* 26 of 2014.	*NEMA Waste Management Act* 59 of 2008; *Waste Amendment Act* 26 of 2014; *Environmental Conservation Act* 73 of 1989; *National Water Act* 36 of 1998.	*National Water Act* 36 of 1998; *Environmental Conservation Act* 73 of 1989; *NEMA: Biodiversity Act* 10 of 2004.

Table B3: Proposed recommendations for current problems in surrounding settlements that result in degradation in the Jukskei

Problem(s)	Lack of proper measures at storm water inlets, especially in townships such as Dowerglen Ext 10, Edenburg Bryanston Ext 7 have resulted in the influx of litter into the rivers contributing to the degradation of the Jukskei and its tributaries. Sewerage outbursts and flows due to high population densities in some informal settlements such as Stjtwela and Alexandra. Illegal connections of sewerage pipes to storm water pipes.
Impacts on goods and services	High loading of pollutants and litter through storm water inlets at the river reduces river functionality and ability to support biotic life. Sewage outflows from informal settlements result in high bacterial loads, some of which may develop recalcitrance to current treatment techniques and become carcinogenic. Loss of domestic, aquaculture, and agricultural uses.

Recommendations	Establishment of low to middle income housing to reduce the population in some of the informal settlements. Upgrading of derelict high rise buildings in the city to provide low-cost housing to the residents of informal settlements, especially those located on the river flood plain, riparian area and the buffer zone.	Monitoring of storm water inlets to determine any illegal sewerage connections. Use of citizen science to prevent illegal connections through extensive education and awareness programmes and establishing a relationship between residents and the river.	Use of litter traps at storm water inlets to reduce the loading of physical elements of degradation.	
Timeline	P1 for planning P2 for implementation	P1	P1	
Responsible institutions within the catchment area	Department of Housing and Settlements, The Ekurhuleni Metropolitan Municipality, The City of Johannesburg	The Ekurhuleni Metropolitan Municipality, The Edenvale River Watch, The City of Johannesburg DWS	The Ekurhuleni Metropolitan Municipality The City of Johannesburg DWS	
Guiding legislation/by-laws	Municipal by-laws and regulations that address informal settlements	*NEMA Waste Management Act* 59 of 2008; *Waste Amendment Act* 26 of 2014; *Environmental Conservation Act* 73 0f 1989.	*NEMA Waste Management Act* 59 of 2008; *Waste Amendment Act* 26 of 2014; *Environmental Conservation Act* 73 0f 1989; *National Water Act* 36 of 1998.	

Appendix B2: Kuils River

Table B4: Proposed recommendations for planned projects that may affect the Kuils River

Project(s) description	Housing projects are key for the City of Cape Town; hence there are many projects planned to provide additional affordable housing to the city's residents. Some of these projects are planned in areas that will affect the Eerste River catchment, hence indirectly affect the Kuils River. The city also plans to upgrade the Khayelitsha CBD.			
Impacts on goods and services	Increased housing will no doubt result in an increase in population density in certain areas. As a result, there will be an increase in physical degradation due to generation of more solid waste from human settlements. In addition, existing WWTWs will be affected in terms of the quantity of waste received.			
Recommendations	Extend existing WWTW, taking into consideration the planned increase in population in these areas, in addition to projected population increases.	Establish mid-way treatment points between settlements and WWTW to reduce distance over which sewage and wastewater travels. This means the water is partially treated at a plant that aids the removal of certain components. This reduces chances of pollution of rivers should pipes burst.	Use of litter traps at the storm water inlets associated with new settlements to prevent the loading of rivers with solid wastes.	Establish efficient service delivery networks for new settlements to prevent uncontrolled pollution. Waste management and sanitation structures in the new settlements should be in place prior to occupation by residents. Penalties should be enforced for illegal dumping in the area.
Timeline	P1	P1 for planning P2 for implementation	P1	P1
Responsible institutions	City of Cape Town DWS	City of Cape Town DWS	City of Cape Town	City of Cape Town
Applicable legislation, by-laws and regulations	*National Water Act* 36 of 1998; *Environmental Conservation Act* 73 of 1989; *NEMA Waste*	NEMA *Waste Management Act* 59 of 2008; *Waste Amendment Act* 26 of 2014.	*NEMA Waste Management Act* 59 of 2008; *Waste Amendment Act* 26 of 2014; *Environmental*	*National Water Act* 36 of 1998; *Environmental Conservation Act* 73 of 1989.

	Management Act 59 of 2008.		*Conservation Act* 73 0f 1989.	

Table B5: Proposed recommendations for current problems that affect the quality of the Kuils River

Problem description	Sewage outflows are common at some of the WWTW in the Greater Cape Town area, especially those associated with the Kuils River, i.e. the Bellville WWTW and the Zandvliet WWTW, both of which discharge into the Kuils River. This results in nutrient loading of the Kuils River (nitrates, nitrites, phosphates), as well as bacterial loading, most commonly in the form of E.coli. Landfills in the area are full and some are in a disused state. Solid waste disposal on riparian areas and in the river channel by vagrants, temporary dwellers and informal settlers.			
Impacts on goods and services	Loss of functionality of the river. At the beginning of the Kuils River, there are fish for a few metres. However, afterwards, there are no fish or other visible biotic components. The river has lost its ability to support its biotic components throughout; hence, there is a loss of functionality. The absence of fish can also be attributed to reduced oxygen availability due to organic matter in solid wastes and nutrient loads from the discharge points of the WWTW associated with the river.			
Recommendations	Upgrade WWTW to treat water to tertiary level so as to reduce the nutrient loading of the river and prevent further bacterial loading.	Penalisation of loiterers and vagrants. Temporary dwellers are often those who are employed to do work in the area. The company they are employed by should take responsibility for ensuring they are not dwelling on riparian areas.	Use of litter traps at storm water inlets to prevent loading of solid wastes in the river. Penalties should apply to those who dispose of their waste on sensitive components of the aquatic ecosystem	Rehabilitation of sewage conveyance pipelines to reduce the occurrence of outflows. Rehabilitation of full and disused landfill sites to address leaching problems and pollution of rivers due to waste streams.
Timeline	P1	P1	P1	P1
Responsible institutions	City of Cape Town DWS	City of Cape Town	City of Cape Town	City of Cape Town DWS

Applicable legislation, by-laws and regulations	*NEMA: Waste Management Act* 59 of 2008; *National Water Act* 36 of 1998; *Environmental Conservation Act* 73 of 1989.	NEMA polluter pays principle; *Environmental Conservation Act* 73 of 1989.	*Environmental Conservation Act* 73 of 1989; *NEMA: Waste Management Act* 59 of 2008.	*NEMA: Waste Management Act* 59 of 2008; *Environmental Conservation Act* 73 of 1989.

Appendix B3: Pienaars River

Table B6: Proposed recommendations for planned and considered projects relating to human settlements that may affect the quality of the Pienaars River

Project(s)	The CoT is considering higher housing density for the Menlyn Maine, Menlyn shopping centre node and surrounding areas. Higher density residential developments are being considered for the vicinity of Mamelodi, and plans are in place to develop Eerste Fabriek as the urban core of the Mamelodi/Nellmapius node. There are already community residential units (CRU) in Mamelodi planned for rental purposes.			
Impacts on goods and services	The increase in housing developments will increase the population in the area. This will have an impact on the treatment of wastewater and sewage as the currently existing plants in the area were designed for a specific population. An increase in population will subject sewerage conveyance systems to more bursts and outflows, and this will directly affect the quality of the Pienaars River			
Recommendations	Upgrading of the WWTW in the area to accommodate the planned increase in population.	Establishment of a new wastewater treatment plant to reduce the flow to existing treatment plants and prevent bursts of sewage and wastewater into the Pienaars River.	Reduce distance from the new residential units to the WWTW to prevent increased occurrences of bursts and outflows of sewage.	Monitoring of residents in new residential units to ensure that establishment of back room dwellings and illegal connections of sewerage pipes are prevented, and

				penalisation of any such occurrence.
Timeline	P1	P1 for planning P2 for implementation	P1 for planning and implementation	P1
Responsible institutions	DWS City of Tshwane	DWS City of Tshwane	DWS City of Tshwane	City of Tshwane Environmental NGOs DHS
Applicable legislation, by-laws and regulations	*Environmental Conservation Act* 73 of 1989; *National Water Act* 36 of 1998.	*Environmental Conservation Act* 73 of 1989; *National Water Act* 36 of 1998.	*Environmental Conservation Act* 73 of 1989; *National Water Act* 36 of 1998; *Waste Management Act* 59 of 2008	Municipal by-laws and regulations that address informal settlements; NEMA polluter pays principle.

Table B7: Proposed recommendations for currently existing problems that affect the quality of the Pienaars River

Problem description	The Gartskloof landfill site has reached its capacity and has become a site of overspills. In addition, it has become an attraction for vagrants in the area, resulting in increased crime rates. Leaching from this landfill site can be carried in runoff into the Pienaars River and other surrounding rivers creating problems that affect chemical quality.
Impacts on goods and services	Chemical degradation of the Pienaars River will further affect its ability to support the required biotic components, and may enhance its hypertrophic state. This will affect the Roodeplaat Dam, which currently receives its inflows from the Pienaars River, the Moreleta Spruit and the Edendale Spruit.

Recommendations	Complete closure of the landfill site. Leaching from the site should be assessed on a continuous basis after closure, and measures should be in place to address any such occurrence.	Establishment of new landfill sites as opposed to a single landfill site to prevent the quick fill up of the sites.	Plans for the new landfill sites should take leaching into consideration, as well as the current population of the region and proposed population.	Discourage continuous disposal of waste at the Gartskloof site by educating and informing residents of new sites. Penalisation of those who continue to dump wastes at the site and contribute to environmental hazards.
Timeline	P1	P1 for planning P2 for implementation	P1	P1
Responsible institutions	DWS City of Tshwane	DWS City of Tshwane	DWS City of Tshwane	City of Tshwane Environmental NGOs DHS
Applicable legislation, by-laws and regulations	*Environmental Conservation Act* 73 of 1989; *National Water Act* 36 of 1998; NEMA: *Waste Management Act* 59 of 2008	*Environmental Conservation Act* 73 of 1989; *National Water Act* 36 of 1998; *Development Facilitation Act* 67 of 1995	*Environmental Conservation Act* 73 of 1989; *National Water Act* 36 of 1998; *Waste Management Act* 59 of 2008	*Environmental Conservation Act* 73 of 1989 NEMA Polluter pays principle

Table B8: Proposed recommendations for factors of urbanisation that may affect the quality of the Pienaars River and surrounding systems

Project Problem description	The region is faced with many issues surrounding road construction and storm water management. There is a planned upgrade for the Bavianspoort Road and a planned K16 road to connect some of the outlying areas in the region. Flooding in areas such as the Mahube Valley and Mamelodi Ext 8 is rather common due to lack of adequate storm water infrastructure.

Impacts on goods and services	Informal settlements in flood plains are affected by storm water during seasons of high rainfall duration and intensity. The presence of these settlements on the river channel affects the hydrology of the river and its functionality. Road constructions in the area, especially around Bavianspoort, could directly impact the quality of the Pienaars River through the deposition of physical and chemical elements of degradation.			
Recommendations	Construction of storm water management infrastructure necessary to address flooding and runoff.	Proper management of waste generated during construction activities and proper disposal measures should be put in place prior to commencement of construction.	Removal of informal settlements that are located directly on the river channel, on the flood plain or the buffer zones to reduce the occurrence of flooding and re-establish the river channel.	
Timeline	P1 for planning P2 for implementation	P1	P1	
Responsible institutions	DWS City of Tshwane Department of Regional planning	DWS City of Tshwane Construction contractor	DWS City of Tshwane DHS	
Applicable legislation, by-laws and regulations	*Environmental Conservation Act* 73 of 1989; *Disaster Management Act* 52 of 2002	*Environmental Conservation Act* 73 of 1989; *National Water Act* 36 of 1998; *NEMA: Waste Management Act* 59 of 2008.	*Disaster Management Act* 52 of 2002; Municipal by-laws and regulations that address informal settlements.	

Appendix C: Other considerations made in the selection of rehabilitation and resilience options in the framework

STAGE 1: IDENTIFICATION AND CONSIDERATION OF RELEVANT REHABILITATION/RESILIENCE MULTI-CRITERIA VARIABLES TO PURSUE

(Refer to Appendix A)

STAGE 2: INITIAL SELECTION OF REHABILITATION/RESILIENCE OPTION

At this stage all the possible rehabilitation/resilience options have been identified.

The extent of the degradation and the effects on goods and services are considered. The affected waterway and how it is prioritised as set out in Table C1 are considered.

Table C1: DWS classifications for nature of river degradation and goods and services affected (Kleynhans et al., 1999)

River class denotations	DWS ecological classification	Goods and services affected
A	Natural	None (rivers in this class are considered to be highly endangered, hence they should carry the highest priority during rehabilitation and resilience activities.)
B	Largely natural with few modifications	Mostly, none depending on the type of modifications. However, domestic use and livestock watering may be affected (rivers in this class are considered to be highly endangered, hence they should carry the highest priority during rehabilitation and resilience activities.)
C	Moderately modified	Domestic use, livestock watering, recreational use
D	Largely modified	Aquaculture, domestic use, irrigation, livestock watering, recreational use

E	Seriously modified	All goods and services lost
F	Critically modified	All goods and services lost

Other considerations in this stage include:

- Initial assessment of consideration of time frames for implementation: Short-Term/Medium-Term/Long-Term (medium and long-term options need no further evaluation).
- The rehabilitation/resilience option is applied in the waterway or in the riparian area – Refer to section 4.1.2.
- The rehabilitation/resilience option should meet the legal/regulatory provisions, standards and limits of pollutant load. Options that cause violation of legislation should not be considered further.

STAGE 3: FINAL SELECTION OF REHABILITATION/RESILIENCE OPTION

This stage entails the following:

- Financial performance of selected option is evaluated – use IRR or NPV (refer to section 4.1.9).
- Are there adequate financial resources?
- Are the other resources available: human, expertise, dams, area to construct solution?
- This rehabilitation option is suitable for which area? Maps could be used (urban/peri-urban; climate zone; sandy soils or grasslands (refer to sections 4.1.2 and 4.1.3).
- Will the option comply with the legislation? Check compliance with the following legal tools.
- Is this an acceptable solution/option? (To check against political acceptance/community interests/decision maker's strategy and plans).

- Other benefits generated to be included in the IRR and opportunity costs considerations (refer to sections 4.1.9 and 4.1.10).
- Secondary adverse effects to be quantified and used to reduce the NPV and IRR (refer to section 4.1.9).

STAGE 4: PRIORITIES AND TIME FRAME FOR IMPLEMENTATION OF REHABILITATION/RESILIENCE OPTIONS

- Is the continued degradation a violation of legislation or regulations? If yes, it is prioritised for early redress.
- Is the degradation affecting a high priority area, e.g. a pristine waterway considered threatened environments/degraded waterway (waterway classification)? If <20% of ecosystem type is in natural/near-natural condition – critically endangered
- Evaluate against strategy and business plan. (Is the budget already allocated? If not, the solution is added to the business plan for the term applicable.)
- Are there emergencies that have been prioritised over the implementation of the planned rehabilitation/resilience option?