WASTE WATER TREATMENT PLANTS:
THE FINANCING MECHANISMS ASSOCIATED WITH ACHIEVING GREEN DROP RATING

Report to the
Water Research Commission

by

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Executive summary

Background

The *Water for Growth and Development Report* (Department of Water Affairs, 2009c) notes with concern that poor water quality is a threat to the growth of the South African economy. Malfunctioning wastewater treatment works (WWTW) is a major cause of the deteriorating water quality in the country and it may be expected to threaten neighbouring countries in the river basins which South Africa shares with its neighbours.

In an effort to reverse the trend of deteriorating water quality in the country, the Department of Water Affairs has introduced the Green Drop programme. This programme aims to improve the performance of WWTWs through providing an incentive to the works in the form of a scoring system which rates the aspects of WWTW performance. Those WWTWs which were performing properly were awarded Green Drop status.

The first Green Drop assessment was conducted in 2009. A total of 449 WWTWs out of 853 municipal WWTWs were assessed in this first round. Thirty two of the WWTWs assessed were awarded Green Drop Status, but a number of these achieved very low scores (see Chapter 2).

It was against this backdrop that this project set out to achieve the objectives as described in the following section.

Objectives

The objectives of this project were as follows:

1. To determine the challenges and their contribution to the cumulative risk rating (CRR) that various categories of wastewater treatment works (WWTW) are facing.
2. To determine what the financial cost implications are for improving the performance of WWTW.
3. To determine the high-level environmental, health and economic implications of not improving the performance of WWTW (where high-level refers to a strategic and economy-wide analysis as opposed to low-level that would imply a detailed analysis for an individual WWTW).
4. To determine a pricing and financing mechanism towards improving the performance and CRR of WWTW.

Findings

What would it take to improve the quality of service rendered by wastewater treatment works (WWTWs), and what is the risk of not doing so and how could this risk be mitigated? This study endeavoured to unpack these questions and to provide some suggestions as to what is required.

From analysing the Green Drop Ratings (GDR) of 416 WWTWs for 2009 and 2011, the following has been established:

- For WWTWs that achieved a substantial improvement in GDR from a mid to high range in 2009:
  - The criteria that showed the most consistent improvement in this group were **Effluent Quality Compliance,** and **Process Control;**
  - The **Change in Wastewater Facility Capacity** was improved in 10 WWTWs, while in others this criterion declined.
- WWTWs where the GDR showed a substantial improvement from a low base in 2009:
  - Showed an improvement in each of the criteria examined;
  - Although the improvement in **Effluent Quality Compliance** was less marked than in some of the other criteria, the weighting of 30% makes this the most important area for improvement. Some WWTWs showed large gains in **Operations (Process Control)**.
- WWTW where the GDR showed a substantial improvement from a 0 (zero) base in 2009:
  - Showed substantial improvement in each of the criteria examined.
  - Noticeably in this category is the improvement in **Effluent Quality Compliance** and **Operations (Process Control)** where the improvement shown across the range of WWTWs is more consistent.
  - Criteria which showed smaller improvements in this category are **Submission of Wastewater Quality Results** and **Wastewater Quality Failure Response.**
- WWTWs showing a substantial decrease in GDS from 2009 to 2011:
  - Criteria which showed consistently large decreases between 2009 and 2011 were **Submission of Wastewater Quality Results**, **Effluent Quality Compliance**, **Wastewater Monitoring Programme** and **Wastewater Sample Analysis (Credibility)**.

General observations from WWTWs which showed an increase in their GDS also showed:

- Improvements in the management of the WWTWs.
- That the most important categories in each case being **Effluent Quality Compliance** and **Operations (Process Control)**.

In the group of WWTWs which showed a decline in rating **Operations (Process Control)** being an area where an intervention would have strong positive outcomes.

Given this knowledge and background, this study explored what will it cost to improve the performance of WWTWs? This question was analysed using a multivariate linear regression model that was developed using data from KwaZulu-Natal WWTWs. The model found that the factors affecting the future GDR in KwaZulu-Natal most, i.e. the drivers of the GDR, were:

- skills availability,
- effluent treatment levels in relation to plant capacity,
- investment in refurbishment and improvements (R&I), and

- the risk category of the plant.

The model was then applied to the 19 ERWAT WWTWs in Gauteng and a number of baseline results were generated. Results were distinguished by drainage district, size class and technology class. It was found that the ERWAT sites are likely to benefit from improved investment in R&I as the necessary skills are, for the most part, already in place to manage this process. The study suggests that investments in R&I could result in positive improvements in the GDR of ERWAT WWTWs when compared with the expected 2015 levels. The above results clearly point to the need for future investment and hence the need to consider different pricing and financing mechanisms for achieving this investment.

While there is a range of conventional pricing and financing options available (see Annexures 1 and 2), they tend to be expensive options and difficult to access over the short-term. This dilemma is aggravated by an urgent need to improve and upgrade many of the WWTWs in South Africa. A range of innovative pricing and financing mechanisms for assisting in dealing with the implications of the rapid growth in urbanisation and economic development has recently emerged. Applying such options would also assist in reducing the pollution discharges and assist in achieving the much required environmental outcomes, while being efficient and cost-effective. It is, therefore, recommended that WWTWs strongly consider implementing such in addition to their on-going engineering solutions linked to R&I and expansion. These options include the consideration of Payments for Ecosystem Services, and/or the introduction of a pollution discharge trading system. With the consideration of these it would be possible to integrate both financial efficiency considerations as well as environmental objectives.

There is a substantial risk linked to the non-improvement in the performance of WWTWs. Not only is the current load on WWTWs too much already and hence their underperformance, adding additional loads that could logically be expected due to increases in both income and people, will only add to the already overburdened ecosystems in which the effluent are being discharge. This will add to the economic cost of such pollution (Graham et al., 2011:ix-xii). Not only is the economic cost a concern, but also the deteriorating ability of ecosystems to absorb/dilute the effluent loads. This places the entire water system in highly populated places such as Gauteng at high risk as the ecosystems are required to act as water purifier of last resort. A contaminated water system is akin to a contaminated socio-ecological and economic system as it affects each and every part of both economy and society.

While the upgrade and expansion of WWTWs are imperative, the difficulties WWTWs are being faced with is to source the required funds and skills to access such funds, and the time it takes to develop new financing mechanism, which requires that urgent action be taken to mitigate the risk. Attention should therefore be given to the introduction of technologies such as floating islands, which could be used either on-site (i.e. on the WWTWs oxidation or maturation ponds) or off-site (i.e. in the river system). The introduction of these technologies could coincide with implementing Payments for Ecosystem Services, such as for the reduction of nutrient loads using wetlands, and pollution discharge trading systems. The conjunctive use of WWTWs and floating wetlands, as an example of one form of biotechnology, has proven to be the most cost-effective way to improve water quality and to mitigate the risk of ecosystem collapse, with its ensuing socio-economic, political and ecological consequences.

Conclusion

The current precarious state of wastewater treatment works in South Africa is a matter of grave concern. It has a detrimental impact not only the health of both people and ecosystems; it negatively affects the moral fibre of society leading to social unrests and even deaths. This is a matter that requires urgent and immediate attention. This study identified the drivers for change and/or improvement, irrespective of the size of the plant, to be skills and the cost of improving WWTWs through refurbishment and improvements. This implies the need to improve the skill base of the workforce and to invest in the refurbishment of the plants. As conventional financing mechanisms tend to be expensive, the range of innovative and environmental benign funding options that have recently emerged should be explored. Failure to improve the quality of the country's wastewater treatment works will require the riparian systems to provide waste dilution services, increasingly so and in a compounded way. This will place undue pressure on the already stressed systems. Decision-makers would therefore be well-advised to engage in mitigating such risk by investing in in-stream biotechnologies as a risk mitigating measure concurrent to investing in the refurbishment of wastewater treatment works.

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Abbreviations

CAPEX	Capital Expenditure
CBA	Cost-benefit Analysis
CEA	Cost-effectiveness Analysis
CRR	Cumulative Risk Rating
DD	Drainage District
DWA	Department of Water Affairs
ERWAT	East Rand Water Care company
FW	Floating Wetlands
GDR	Green Drop Rating
KZN	KwaZulu-Natal
MIG	Municipal Infrastructure Grants
MLR	Multivariate Linear Regression
NPV	Net Present Value
OPEX	Operational Expenditure
PPP	Public-Private Partnership
R&I	Refurbishments & Improvements
RRS	Risk Rating Score
RWQO	Resource Water Quality Objectives
WSA	Water Services Authority
WTP	Willingness-to-pay
WWDCS	Wastewater Discharge Charge System
WWTW	Wastewater treatment work

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Chapter 1 Introduction

Waste water is the FIRST BARRIER in a multi barrier system of ensuring safe drinking water quality (Van der Merwe-Botha & Manus, 2011:1).

South Africa is an arid country and water resources are very unevenly distributed based on geographic factors and climatic patterns. The distribution of the population, however, is largely dictated by the presence of mineral wealth rather than water and this has resulted in the largest conurbation in the country being situated on the continental divide away from major water sources. Recognition that the water scarcity implied that water needed to be re-used in one way or another led to the Water Act of 1956 which requires all effluent to be purified and returned to its stream of origin. These return flows were recognised as a component of the national water budget and so needed to be managed.

During the mid-1980s it was noted that the water quality in many parts of South Africa was deteriorating and that water *quality* may, in future, become a more important factor than *quantity* in determining the availability of water in some areas (DWA, 1986). The response to this challenge has been to develop world-leading wastewater treatment technologies. These technologies have served the country well but are proving to be inadequate to handle the rapidly increasing load due to urbanisation and, consequently, to avoid environmental deterioration (i.e. the deterioration of the ecosystems, riparian zones and water courses – the very source of our water supply). This decline in water quality led to the comment in the *Water for Growth and Development Framework* (DWA, 2009c:4) that "[t]he Department is extremely concerned about the status of the quality of the country's water resources". During the 1980s and 1990s there were also on-going efforts to improve the capacity of the process controllers operating the wastewater treatment works (Ernst & Greef, 1992; Ernst, 1994). In spite of this, the water quality continued to decline. One very clear-cut case being that of the Jukskei River, feeding the Hartbeespoort Dam, and the associated eutrophication thereof (Ashton et al., 1985; Keto, 2013).

The importance of well-functioning wastewater treatment works (WWTWs) is embedded within the fact that they are the last barrier and final interface between untreated/polluted/used water and a healthy and functioning ecosystem, and hence the health of the population.

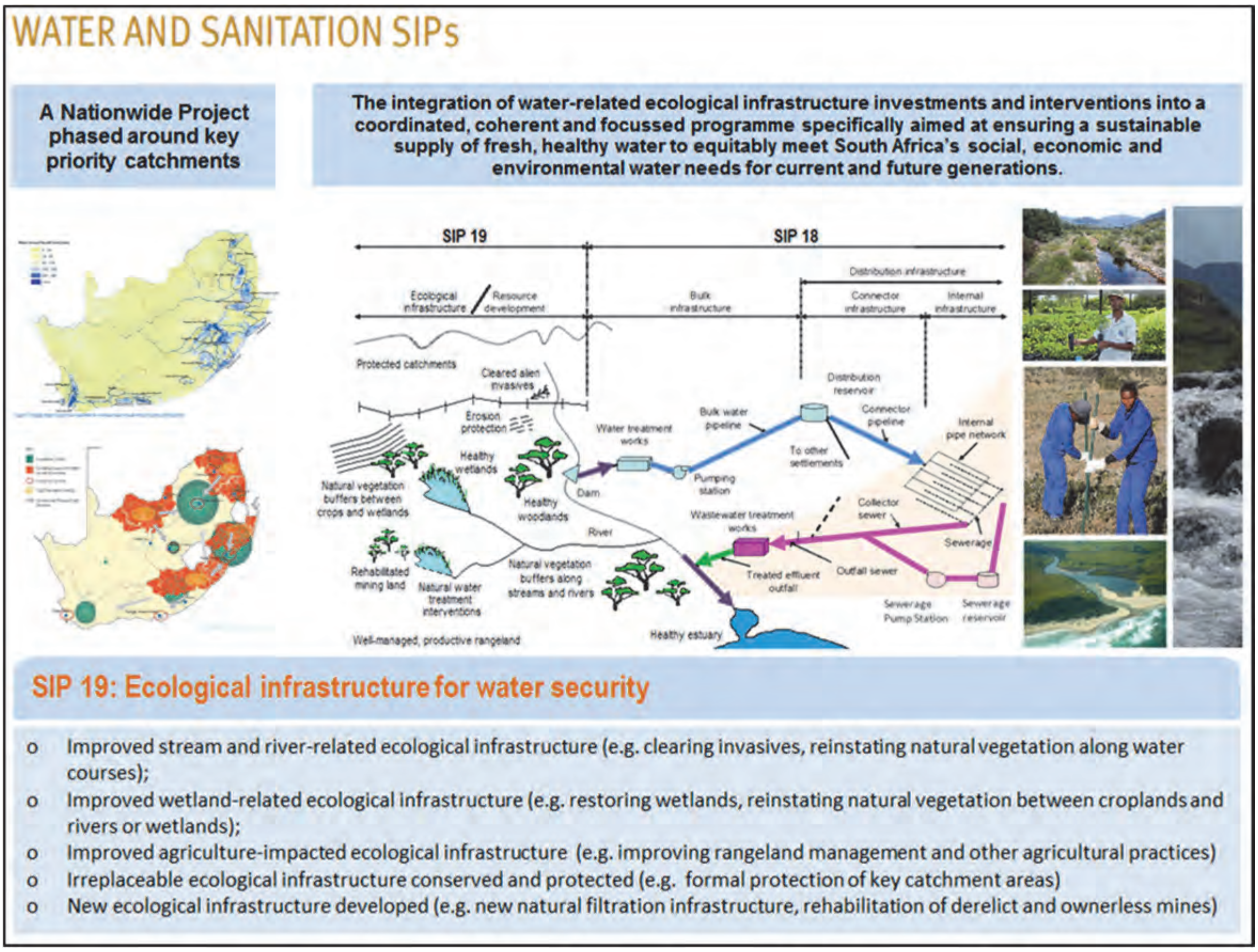


Figure 1.1 Diagrammatic representation of the passage of water through the natural and built environments

Source: SIP 19 (2014:5)

The key function of wastewater treatment works (shown in Figure 1.1) is to treat water polluted through urban and industrial use and return water of acceptable quality to the environment. *SIP 19* (2014:8) recognises that "[w]ater is a critical strategic natural resource. It is essential for growth and development, the environment, as well as the health and well-being of the people of South Africa". With respect to the *Strategic Integrated Project 19*, the focus is specifically on the ecological infrastructure that underpins water-related ecosystem services commonly known as watershed services. Ecological infrastructure that underpins healthy river ecosystems (providing 'watershed services'):

> *...does much the same work as a water treatment plant and other built water quality infrastructure, but without the expensive equipment and with added benefits like protection of wildlife habitats and carbon sequestration. Watershed-related ecological infrastructure can filter out water pollution, regulate stream flows, recharge aquifers, and absorb flooding. These benefits are collectively known as "watershed services," and society can't do without them*[1] (SIP 19, 2014:9).

SIP 19 recognises the importance of the ecological infrastructure in providing the ecosystem services necessary for the support of the growth and development required by South Africa. The

[1] See more at: http://www.watershedconnect.com/pages/primer#sthash.yRPHOWB7.dpuf

change of government in South Africa in 1994 led to a number of changes. Two of these changes relevant to the wastewater industry are the following:

- The general increase in the affluence of the population, resulting in an improved quality of life and also an increasing use of resources (see Figure 1.2).
- The roll-out of on-site and water-borne sanitation.

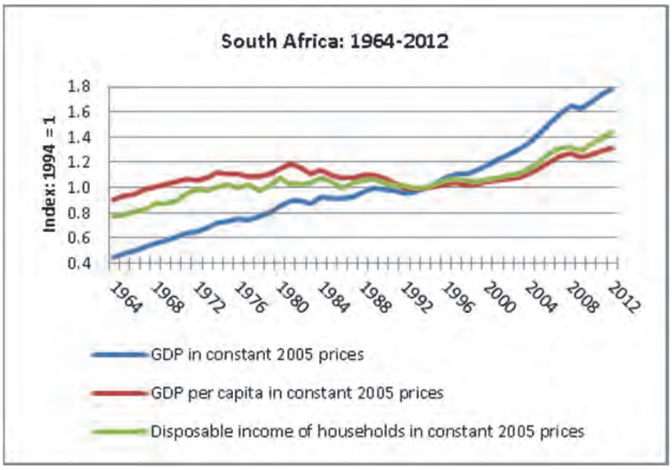


Figure 1.2 Selection of key macro-economic statistics

Source: South African Reserve Bank. Quarterly bulletin (Various issues)

The first of these two changes resulted in a higher level of consumption, increasing the per capita waste load generation while the second changes mentioned increased the direct load on wastewater collection and treatment infrastructure substantially. The focus on service provision was not supported by a similar focus on infrastructure provision to treat the wastewater generated as a result of these changes.

The quality of wastewater treatment affects all people in the society as well as the economy in a number of ways. The discharge of poorly-treated or untreated wastewater into the environment reduces the ability of the environment to provide the benefits on which society depends, negatively affecting the availability of clean water for urban, agricultural and industrial use. Pathogens carried by improperly treated wastewater lead to infant mortality or morbidity as well as increased absenteeism from the work force, decreasing national productivity. Van Vuuren (2010) and the national press noted that poor water quality threatens the export market for irrigated produce. The example cited is the Groblersdal irrigation scheme which generates exports to the value of R50-R100 million per annum and provides approximately 30 000 jobs. Farmers from this irrigation scheme have been warned by the EU Regulator to attend to water quality or risk losing these export opportunities supporting this economy. Thus, there are social and economic reasons, in addition to the regulatory requirements, to improve the performance of wastewater treatment works.

It became apparent that the level of wastewater treatment in South Africa was inadequate to control the eutrophication of the inland waters, particularly obvious in the impoundments on rivers draining the Gauteng region. The strong focus on service provision post-1994 without the equivalent emphasis on upgrading the facilities to treat the additional waste was but one factor contributing to further deterioration of the general level of treatment of water being discharged into the environment. Clearly, the purely regulatory approach to managing the quality of effluent treatment adopted by the Department of Water Affairs (DWA) was not achieving the desired results.

The National Water Act (DWA, 1998: Chapter 1 paragraph 3. (1)) states the following:

> *As the public trustee of the nation's water resources the National Government, acting through the Minister, must ensure that water is protected, used, developed, conserved, managed and controlled in a sustainable and equitable manner, for the benefit of all persons and in accordance with its constitutional mandate*.

The poor performance of wastewater treatment works (WWTWs) in protecting the health of the water resource has necessitated that the DWA take action to rectify the situation. The DWA has adopted a two-tiered approach (i.e. Green Drop and Blue Drop certifications) which is best described in the words of the *Green Drop Report* (DWA, 2009b:1) as follows:

> *Fundamental to addressing the gaps and raising the performance of municipal waste water service providers, has been the introduction of the Green Drop Certification process. In addition, to this* ***incentive*** *driven initiative, the Department of Water Affairs has also commenced with a corrective process, where* ***punitive*** *measures could be applied when all avenues have been exhausted to rectify situations of continued non-compliance. This process is driven by* ***strengthening the regulatory approach****, whilst at the same time refocusing the Local Government Support model in a manner that is more responsive to regulatory imperatives*.

The Green Drop certification is part of a wider process aimed at ensuring compliance with the DWA's responsibility in terms of its constitutional mandate. The Blue Drop and Green Drop certification processes are incentive-based initiatives aimed at raising the performance of municipal wastewater service providers. This study focuses on the Green Drop process.

The Green Drop process addresses the treatment of wastewater and has adopted a risk-based approach through the presentation of tangible targets for municipalities to reduce risk within acceptable time frames. The DWA-targeted approach to regulatory enactment of the Enforcement Protocol uses an action research methodology aimed at problem solving. The DWA expects acceptable plans for remedying the situation from all water services authorities responsible for works which did not perform at acceptable levels to ensure a definitive turn-around of the South African wastewater treatment services.

As a first step in considering the costs of achieving the desired turn-around in the performance of the wastewater treatment in the country, we need to address the question: **'Why do we treat wastewater?'** This question urges us look beyond the wastewater treatment works to the environment into which the treated wastewater is discharged and to subsequent users downstream of the discharge; also to view the socio-ecological system as a whole in all its complexity, rather than simplifying it to make it easier to understand. If we draw an analogy between the socio-ecological system and the human body, the water resource (rivers) may be compared with the circulatory system. The blood stream sustains the body's metabolism and removes the waste products for removal from the system via the kidneys. Impurities in the blood which are not removed by the kidneys are removed by the liver. The figure below illustrates the human circulatory system, with the arteries (red) carrying fresh blood to the various parts of the body and the veins (blue) returning the blood to the heart after some of it passing through the kidneys and liver.

If the kidneys or liver fail, the person will become ill and in advanced cases this may cause death. It is possible to clean the blood through the process of kidney dialysis. If the liver becomes overloaded by, for instance, excessive alcohol intake then its capacity to perform the function of cleaning or polishing the blood is diminished, possibly permanently in extreme cases.

In our analogy we may compare water treatment works (both water purification for potable purposes and wastewater treatment) to the kidneys of the socio-ecological system, although we do not have the option of dialysis if the treatment works do not perform as they should. The function of the WWTW is to treat the water after it is used in the socio-economy and restore it to a point where it is fit for discharge back into the water resource for re-use as and where required.

Furthermore, we may compare the regulating ecosystem service of water purification and detoxification of wastes (i.e. water purification and waste treatment: retention, recovery, and removal of excess nutrients and other pollutants (MEA, 2005:2)) to the function of the human liver as the ecosystem can cope with the purification of a certain amount of waste. But we need to note that as the load on the ecosystem is increased so the capacity of the ecosystem to cope with increasing loads decreases until the resilience of the system is lowered to a point that it is unable to cope with an increased load and there is a change of state. In some cases this state change may be irreversible within the structure of the current socio-ecological system.

In the same way that the human body ceases to function as it should when the kidneys or liver malfunction, so the social-ecological system ceases to function as it should when the components of the water resource management system do not function properly.

Below are four excerpts from the South African national press (the most recent first) which illustrate the impact of malfunctioning infrastructure on the socio-economic system. These few examples illustrate the 'acute' symptoms of system malfunction which often lead to angry protests from users.

Box 1: Beeld: Dinsdag 21 Januarie 2014

Standerton. – Dié dorp kan ’n volgende Brits word, het ’n inwoner van die township Sakhile gewaarsku oor die stink, bruin water in hul krane.

Ben Shongwe (42) het gesê van Donderdag kom bruin water wat “soos vis ruik” uit hul krane.

Daar is reeds van middel verlede jaar ’n gesukkel met die voorsiening van water.

Protesoptrede oor watervoorsiening in die woonbuurte Mothutlung en Damonsville by Brits het die dood van vier mense gekos.

Shongwe, ’n pa van drie, het gesê die gemeenskap is moedeloos. Nie ’n enkele druppel water kom uit sy krane nie. Die Lekwa-munisipaliteit lewer op ’n sporadiese basis water aan die gemeenskap, maar dit is nie genoeg nie, meen hy.

“Dit wat in Brits gebeur het, gaan ook hier gebeur. Ons gaan ook baklei oor water. Hier gaan ook mense doodgaan. Hier sal seker tien mense doodgaan.”

Intussen het Hester Grint, ’n gemeenskapsleier, ’n petisie opgestel wat sy aan die munisipaliteit wil oorhandig.

Sy het reeds 4 200 handtekeninge en soek nog 800 voor sy dit aan die munisipaliteit gee.

Haar water is “bruin en modderig”, het Grint gesê.

“Van die water het tot wurms in. Dit is nie drinkbaar nie. Ek kan nie kos maak nie.”

Nóg ’n inwoner, Fikile Nkambule, het gesê sy koop soms gebottelde water, maar kan dit nie meer bekostig nie.

“Dan het ek nie ’n ander keuse as om die vuil water te drink nie.”

Johannes van der Wath, DA-raadslid, het gesê die probleem lê by die suiweringswerke wat te klein is om in die dorp se behoeftes te voorsien.

“Dit kan 27 megaliter water voorsien, maar die dorp se aanvraag is 33 ML per dag.”

Volgens hom het die munisipaliteit vir die afgelope 20 jaar geen onderhoud aan die suiweringswerke gedoen nie.

Sipho Mkwanazi, woordvoerder van die Lekwa-munisipaliteit, het om verskoning gevra vir die situasie.

“Die munisipaliteit prioritiseer water en elektrisiteit. Die geld wat ons sou gebruik om paaie in stand te hou, gaan ons eerder gebruik om die water- en elektrisiteitsdiens te verbeter.”

Die oorsaak van die “lae kwaliteit water” – hy wou nie vuil water sê nie – is volgens hom die vuil waterpype en die opgaartenks. Daarby is die reuk as gevolg van alge wat in die tenks gegroei het ná die baie reën.

Hy het toegegee dat die suiweringswerke nie op standaard is om in die dorp se behoefte te voorsien nie en dat sekere dele van die gemeenskap nie altyd water in hul krane het nie.

“Die munisipaliteit het ’n studie oor die probleem gedoen. ’n Langtermynplan is in plek gestel om die watersuiweringstelsel teen 2030 te verbeter.” Dit sal R36 miljoen kos.

Die munisipaliteit sal op kort termyn die waterpype en waterstelsel skoonmaak om die watergehalte te verbeter.

Hy wou nie ’n datum gee wanneer inwoners weer ’n beter gehalte water sal kry nie.

Source: http://www.beeld.com/nuus/2014-01-21-daars-wurms-in-ons-water

see also http://www.youtube.com/watch?feature=player_embedded&v=AFkvDMmoYnA

Box 2:

Fourth person dies after water protests

January 20 2014 at 10:16am

Comment on this story

Related Stories

- Corrupt officials blamed for fatal protests
- 'Cops are killing us'
- Water restored in Mothutlung
- Politician attacked at Mothutlung memorial
- N West water pumps fixed: minister

Residents of Mothutlung, outside Brits, burnt tyres and barricaded roads after a fatal protest demanding water. File photo: Dumisani Sibeko

Johannesburg - A fourth person has died following violent clashes near Brits over access to water, Jacarandafm News reported on Monday.

Damonsville community leader Paul Hendricks said the man died early on Monday.

"He was shot in the head with live ammunition and taken to Ga-Rankuwa hospital where the bullet was removed," he was quoted as saying.

The man was in a coma and later died.

According to SABC radio news, the 36-year-old man spent seven days in the intensive care unit of hospital. He was injured during clashes last week. His family confirmed the death.

SABC also reported that he had died, quoting his brother.

Three others who were killed during the service delivery protest in Mothutlung were buried at the weekend.

Two protesters were shot dead, allegedly by police.

Another man died after falling out of a moving police vehicle in a bid to escape, according to police. - Sapa

Source: http://www.iol.co.za/news/south-africa/mpumalanga/judge-says-carolina-s-water-tainted-1.1350185

Box 3:

Malema takes up Brits water fight

January 14 2014 at 06:07pm
By Karabo Ngoepe
Related Stories

Comment on this story

- Premier, minister to visit Brits families
- Casac outraged at Brits protester killings
- Police minister visits Brits after shooting
- Brits protester killings condemned
- Probe Brits protest deaths, says DA
- Mthethwa calls for calm in Brits
- Two protesters killed in Brits

EFF leader Julius Malema. File photo

Brits - EFF leader Julius Malema on Tuesday promised to fight side by side with Mothutlung residents, near Brits, until they got water.

"We must arrange a proper march to Madibeng municipality and I will be there," he told locals at a sports field following violent protests in the township for water.

Two people were killed during a service delivery protest on Monday.

Roads in the township have been barricaded with rocks and tree stumps. Police were patrolling the area.

Malema told residents he had heard their plea.

"We have heard your concerns... we were in Natal (KwaZulu-Natal) and saw our people being shot.

"Their innocent request (of water) was met with brutal murder. This is what this current government has become known for," he said.

Malema said the African National Congress-led government was no different from the apartheid regime.

He said it was the community's right to have water and he blamed the situation on poor administration.

"While the water was still under Magalies, there were no such problems," he said.

Residents took the opportunity to complain about their ward councillor. They claimed they were confronted at gunpoint on Sunday when they went to ask him for help. Malema urged them not to be afraid of the councillor and to fight for what they believed in.

"We will make sure the person who was pointed with a gun opens a case so that he (the councillor) can be locked up."

He said it was not the community's fault that the councillor did not have toys while growing up. The crowd erupted with laughter and applause.

He reminded the people that they had the power to change their situation.

"Only you have the power to change this nonsense. You can't live like this."

North West premier Thandi Modise visited one of the families who had a relative killed during the protest. In a statement sent from her office, she appealed for calm and expressed her condolences to the families.

She appealed to those with information about the clash between the protesters and police and the shooting to help the Independent Police Investigative Directorate with its investigation.

"Our hard-won democracy guarantees people the right to peaceful protest," she said.

"While we sympathise with the need for our communities to voice their frustrations and dissatisfaction with service delivery, we wish to appeal that such protests be in accordance with the Public Gatherings Act to avoid unnecessary confrontations and loss of lives," she said.

Sapa

Source: http://www.iol.co.za/news/crime-courts/malema-takes-up-brits-water-fight-1.1631628#.Ut9-0tL8Low

Box 4:

Judge says Carolina's water tainted

July 26 2012 at 08:15pm
By SAPA

Comment on this story

Pretoria - The water in the Mpumalanga town of Carolina still presents a health risk, a High Court Judge said in Pretoria on Thursday.

The water in the Mpumalanga town of Carolina still presents a health risk, a High Court Judge said in Pretoria.

Judge Moses Mavundla said the contention of the Gert Sibanda district municipality that his court order about Carolina's water supply was "un-enforceable" was unacceptable.

He ordered it to immediately comply with his July 10 order, despite granting leave to appeal his ruling to a full bench of the high court.

He also granted a cost order against the district and local municipalities.

Earlier this month, Mavundla gave the district municipality 72 hours to provide temporary drinkable water, in line with compulsory national standards, to residents of Silobela, Caropark and Carolina town.

He also ordered it to speak to the national government to ensure drinkable water could once again be supplied through the town's water system.

The water was declared unsafe earlier this year because of pollution caused by local coal mines.

Granting leave to appeal would ordinarily have suspended the court's ruling, but Mavundla said residents stood to suffer more harm, in the form of a health risk, than the municipality.

"I must incline towards protection of the rights of the community and uplift the suspension of the operation of the order, pending finalisation of an appeal and exhaustion of any possible appeal to the Supreme Court of Appeal or the Constitutional Court," he said.

The judge said it was unlikely another court would come to a different conclusion, but granted leave to appeal to avoid a lengthy and costly petition and appeal process.

The district municipality insisted it was not accredited as a water service provider and could therefore not comply with the order. Mavundla said this attitude was tantamount to dereliction on technical grounds of the statutory duties placed on local and district municipalities.

He said both municipalities were organs of state, established in terms of the Constitution. They were tasked with co-operative governance, within the broad mandate of providing basic necessities such as water. They needed to be innovative if necessary to provide basic services.

Mavundla said it was common cause that the water in the area still presented a health risk.

It was also clear that the district municipality was not complying with the court order and that the water supply was still not adequate.

"The quality of water provided must be hygienic. In my view, there is no room for half-measures in providing water.

"The respondents contended that there are no people dying and that the situation is exaggerated for political gain by the applicants, but the water is (not) fit for human consumption." - Sapa

Source: http://www.iol.co.za/news/south-africa/mpumalanga/judge-says-carolina-s-water-tainted-1.1350185

The health and livelihoods of downstream users (be they rural communities, urban, agricultural or industrial) depends on the quality of the treated wastewater. Poorly treated wastewater is likely to spread disease, cause eutrophication and increase treatment costs for downstream users. In some cases it may even cause agricultural produce to be rejected (see Van Vuuren, 2010 as quoted above). In well-watered countries sufficient dilution capacity exists to reduce the impact of wastewater discharges. In an arid environment, particularly in cases where the volume of wastewater discharged makes up a substantial proportion of the total river flow, there is inadequate capacity for dilution and the impact of wastewater discharge negatively impacts the environment.

Management of the wastewater cycle is fragmented. For instance, the siting of industries is influenced by factors other than the waste streams that will be generated, such as income into the municipal fiscus through rates from the industry and its employees, for example. Regulation of on-site waste generation falls under the ambit of municipal by-laws and such technologies as cleaner production. Regulation of WWTWs is the responsibility of water service authorities but under national legislation of the Department of Water Affairs and the regulation of the quality of the environment falls under national legislation of both the Departments of Environmental Affairs and Water Affairs. When these are not integrated, the overall quality of treated wastewater returned to the environment becomes difficult to manage.

While the Green Drop initiative seeks to promote incentive-based regulation and acknowledge excellence in wastewater quality management, it neither reflects on the financial cost and resources required for achieving this, nor on the economic costs and implications of not achieving the desired turn around in wastewater management and the improvement in the performance of the WWTW. This is an important gap in planning for remedial action and one taken up in the research project as outlined in this report.

1.1 Structure of the report

This project addressed, at least in part, this gap by addressing the following aims:

1. To determine the challenges and their contribution to the cumulative risk rating (CRR) that various categories of WWTW are facing (see Chapter 2).
2. To determine what the financial cost implications are for improving the performance of WWTW (see Chapter 3).
3. To determine the high-level environmental, health and economic implications of not improving the performance of WWTW (Chapter 4 but addressed in detail by Graham et al. (2011)).
4. To determine a pricing and financing mechanism towards improving the performance and CRR of WWTW (see Chapter 4).

Aim 3 has been addressed in detail by Graham et al. (2011). It became apparent, during the course of the study, that there was a place for the use of high rate biotechnologies downstream of the WWTW to polish the water in the environment (to perform the function of the human liver in our analogy to the human body). A biotechnology which has been tested elsewhere in the world is that of floating wetlands, and the use of floating wetlands has been tested/modelled for use in conjunction with WWTWs (see Annexure 3).

Chapter 2 Green Drop Scores: An assessment

2.1 Introduction

Chapter 1 noted the poor compliance of many WWTWs. There are a number of reasons for this poor compliance and in Chapter 2 we determine which are the most prevalent. This will enable investment in the remediation of the reasons for non-compliance to be directed to the most appropriate interventions (the subject matter of Chapters 3 and 4). This analysis is based on the information that was available was in the Green Drop reports of 2009 and 2011.

2.2 Method

2.2.1 Selection of WWTWs to be included in the analysis

The initial assessment of WWTW performance was based on those which were assessed in 2009 and could be positively matched to the WWTWs which were also assessed in 2011. A total of 449 WWTWs were assessed in 2009 while a much larger number was assessed in 2011. It was not possible in all cases to match the WWTWs assessed in 2009 to those assessed in 2011. For example, in 2009 Knysna was assessed while in 2011 Knysna 1 and Knysna 2 were assessed. After the elimination of these uncertainties, a total of 416 WWTWs remained and the database for analysis was complied.

Furthermore, the criteria against which WWTWs were assessed differed slightly between 2009 and 2011. Only those criteria which were used in both assessments were used (see Table 2.1 for the set of criteria used). Each of the major requirements is made up of one or more sub-requirements, but the sub-requirements are not detailed in Table 2.1. Should these be needed they may be obtained from the *2011 Green Drop report* (DWA, 2011:5-8).

Table 2.1 The criteria selected for in-depth assessment of change in performance of WWTWs between 2009 and 2011

Green Drop criteria	Requirements	Sub-requirements
Green Drop Rating	An agglomeration of the factors listed below combined with some other factors	
Operations (Process Control), Maintenance and Management Skill *Primary weight 10*	• A copy (certified) of Registration Certificate of Works displaying Classification (R2834)	1 sub-requirement
	• Copies (certified) of Registration Certificates of Process Controllers and Supervisors	4 sub-requirements
	• Proof of Maintenance Team used for general maintenance work at the plant (both mechanical & electrical)	4 sub-requirements
	• Proof of a 'site-specific' Operation & Maintenance Manual	2 sub requirements
	BONUS – Proof of Process controller staff being subjected to relevant training the past 12 months	
Wastewater Monitoring Programme *Primary weight 10*	• Details of sampling sites; determinants and frequencies of Operational Monitoring	2 sub-requirements
	• Details of sampling sites; determinants and frequencies of Compliance Monitoring	3 sub-requirements
Wastewater Sample Analysis (credibility) *Primary weight 5*	• Provide proof and the name of the Laboratory used	1 sub-requirement
	• Certificate of Accreditation for applicable methods OR Z-scores results (–2 ≥ z-score ≥ 2 are unacceptable) in a recognised Proficiency Testing Scheme. OR proof of Intra- and Inter-laboratory proficiency (quality assurance as prescribed in Standard Methods)	2 sub-requirements
	• Explanation on how monitoring results are used to amend / improve process controlling	1 sub-requirement
	BONUS: Monitoring at an acceptable frequency and for the required determinants	

Green Drop criteria	Requirements	Sub-requirements
Submission of Wastewater Quality Results *Primary weight 5*	Proof of data submission to DWA (12 months)	3 sub-requirements
Effluent Quality Compliance *Primary weight 30*	• Copy of effluent quality limits or standards used to calculate compliance (e.g. effluent limits or standards as per license, General Authorisation, or Permit)	1 sub-requirement
	• Effluent Quality CATEGORIES: 90% Microbiological compliance; 90% Chemical compliance & 90% Physical compliance	2 sub-requirements
	BONUS: 2 sub-requirements	
	PENALTY: 1 sub-requirement	
Wastewater Quality Failure-Response Management *Primary weight 10*	• Proof of a documented wastewater Incident Management Protocol	2 sub-requirements
	• Provide evidence of implementation of Protocol	1 sub-requirement
Wastewater Treatment Facility Capacity *Primary weight 10*	• Documented design capacity (hydraulic and organic) of the wastewater treatment facility. Documented daily receiving flows over the 12 months of assessed period (ideally < than design capacity)	3 sub-requirements
	• Medium to long term planning to ensure sufficient capacity for treatment system and to ensure effluent quality compliance	1 sub-requirement
	• Medium to long term planning to ensure sufficient capacity for collecting system	1 sub-requirement

2.2.2 Analysis

A database was constructed (in Excel) of all the WWTWs for which data exists in both the 2009 and 2011 reports and the following criteria from both the Green Drop reports were entered for each of the 416 WWTWs to be analysed:

1. Green Drop Rating
2. Operations (Process Control), Maintenance and Management Skill
3. Wastewater Monitoring Programme
4. Wastewater Sample Analysis (credibility)

5. Submission of Wastewater Quality Results
6. Effluent Quality Compliance
7. Wastewater Quality Failure-Response Management
8. Wastewater Treatment Facility Capacity

The 2009 report used letters while the 2011 report used percentages. Therefore, the letters were converted to percentages following the table given in the 2009 Green Drop report (DWA, 2009b:9-10) in order to work with comparable data. To reduce the number of classes from which the selection for further analysis was made, percentages were changed to deciles (see Table 2.2).

Table 2.2 The scores for each of the criteria assessed were given as percentages which were converted to deciles

PERCENTAGE	DECILE
0	0
1-10	1
11-20	2
21-30	3
31-40	4
41-50	5
51-60	6
61-70	7
71-80	8
81-90	9
91-100	10

The change in decile between 2011 and 2009 for each criterion for each WWTW was then calculated. The initial selection of WWTWs for further investigation was made based on the change in the Green Drop Rating (GDR) between 2009 and 2011 (see Figure 2.1). While a number of plants showed a substantial increase in their GDR, some plants showed a big decrease while other plants showed no or little change.

Green Drop Rating (2009 – decile)	Increase (— = decrease) in Green Drop Rating between 2009 and 2011 (0 = no change)																	
	-8	**-6**	**-5**	**-4**	**-3**	**-2**	**-1**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Grand Total**
0								3	3	2	2	3	2	1	11	1		28
1								1	8	25	6	2	4	6	4	1	1	58
2							3	1	2	6	3	10		1	4			30
3							3		3	5	5	7	5	2				30
4					1		4	7	1	4	7	5	3	1				33
5						1	4	7	4	11	15	2	1					45
6				1	1	2	14	11	12	11	8	2						62
7		1	5	3	3	3	5	2	6	10	2							40
8			2	2		2	2	8	21	13								50
9	2					1	1	4	5									13
10					1	1	15	10										27
Grand Total	**2**	**1**	**7**	**6**	**6**	**10**	**51**	**54**	**65**	**87**	**48**	**31**	**15**	**11**	**19**	**2**	**1**	**416**

Key:

large decrease (16 plants)
Increase from 0 rating (18 plants)
Increase from low rating (20 plants)
Increase from high rating (23 Plants)

Figure 2.1 The overall changes in Green Drop Rating between 2009 and 2011, showing the four groups selected for further analysis.

Based on this initial analysis, four groups were selected for further investigation into the reasons for the observed changes. These four groups were the following:

1. WWTWs showing an increase from between 45 and 90 to >91 in Green Drop Rating from 2009 to 2011 (see Section 2.3.1)
2. WWTWs showing a large increase in Green Drop Rating from between 3 and 33 from 2009 to 2011 (see Section 2.3.2)
3. WWTWs showing a large increase from 0 (zero) in Green Drop Rating from 2009 to 2011 (see Section 2.3.3)
4. WWTWs showing a substantial decrease in Green Drop Rating from 2009 to 2011 (see Section 2.3.4)

The differences in the scores for each of the WWTWs selected for each of the criteria 2-8 as given in Table 2.1 were plotted on graphs. These graphs are presented in Sections 2.3.1-2.3.4. The initial assessment of the areas in which the changes have occurred is based on these graphs.

The next step was to obtain more information from DWA on the areas of maximum change identified in this preliminary analysis. This made it possible to see what the important criteria are and to estimate costs of remediation of WWTWs.

2.3 Results

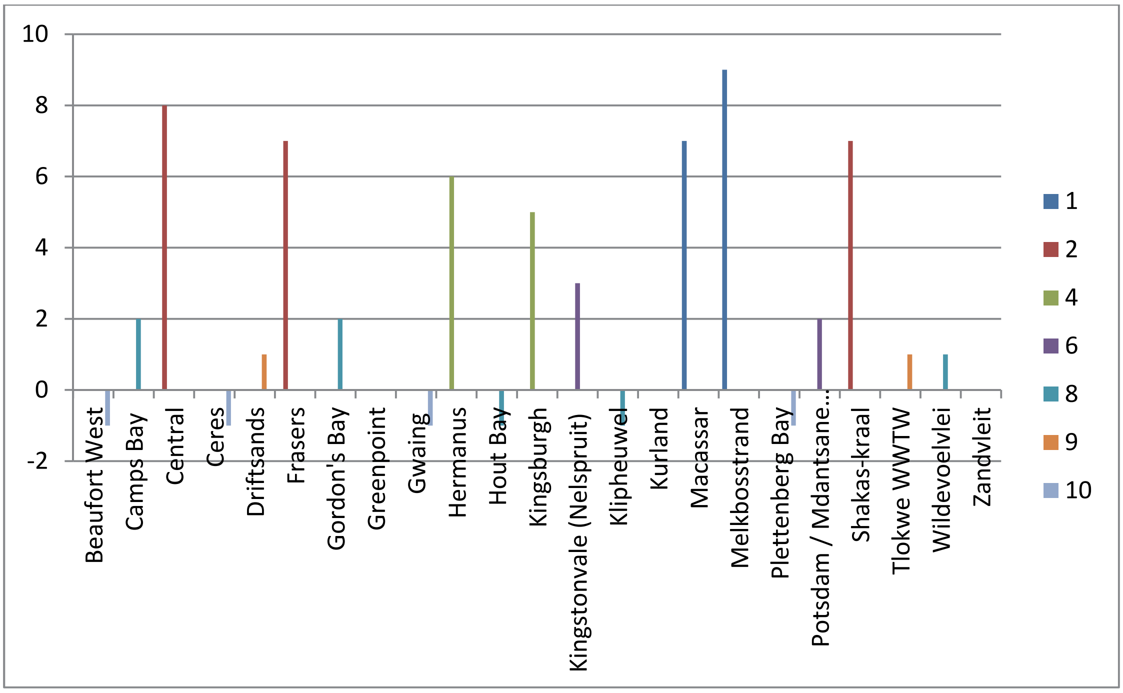
The overall distribution of change in GDR is illustrated in Figure 2.1. From this distribution of performance, the four groups listed above were selected for further analysis using the 8 criteria listed in Table 2.1.

2.3.1 *WWTWs showing an increase from between 45 and 90 to >91 in Green Drop Rating from 2009 to 2011*

The WWTWs in this group are those which were already performing well or reasonable well, but where the performance improved to a GDR of >90 between 2009 and 2011.

Change in Operations (Process Control), Maintenance and Management Skill from 2009 to 2011 (Weighting – 10%)

The majority of WWTWs in this group showed an increase in score on this criterion, with a number showing a substantial increase from a low base (Figure 2.2). Some WWTWs which had scored over 90% in 2009 dropped to between 80 and 90% in 2011.

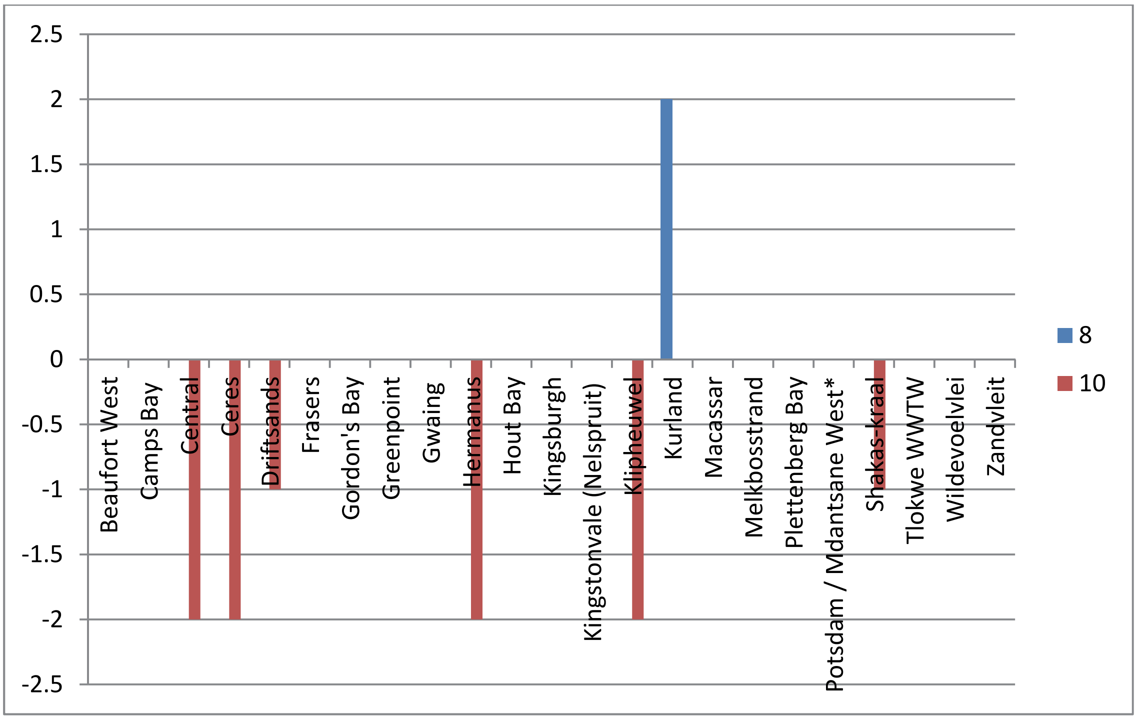


Key: The colour of the bars (legend on the right-hand side) indicate the decile of Operations (Process Control), Maintenance and Management Skill in 2009.

Figure 2.2 Change in Operations (Process Control), Maintenance and Management Skill from 2009 to 2011 (Weighting – 10%)

Change in Wastewater Monitoring Programme from 2009 to 2011 (Weighting – 10%)

The majority of WWTWs in this group showed no change in their performance on this criterion (Figure 2.3). While some WWTWs showed a decrease from over 90%, only one plant showed an increase in its performance.

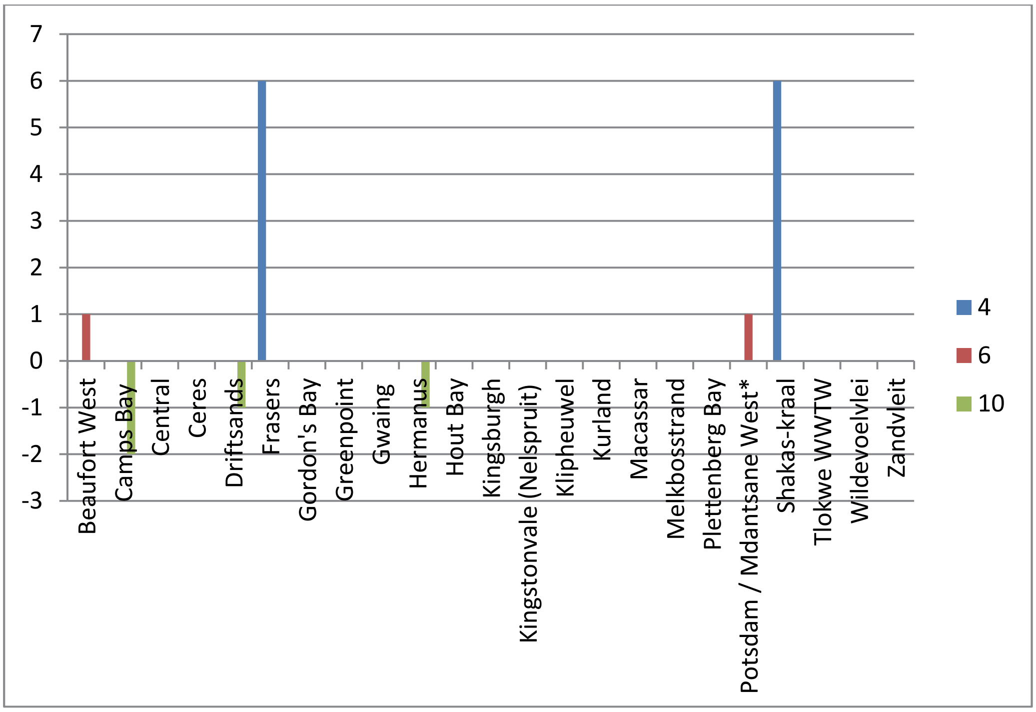


Key: The colour of the bars (legend on the right-hand side) indicates the decile of wastewater monitoring in 2009.

Figure 2.3 Change in Wastewater Monitoring Programme from 2009 to 2011 (Weighting – 10%)

Change in Wastewater Sample Analysis (credibility) from 2009 to 2011 (Weighting – 5%)

The majority of WWTWs showed no change (Figure 2.4). Two WWTWs showed a substantial increase in the score on this criterion while a small number showed slight change either up or down.

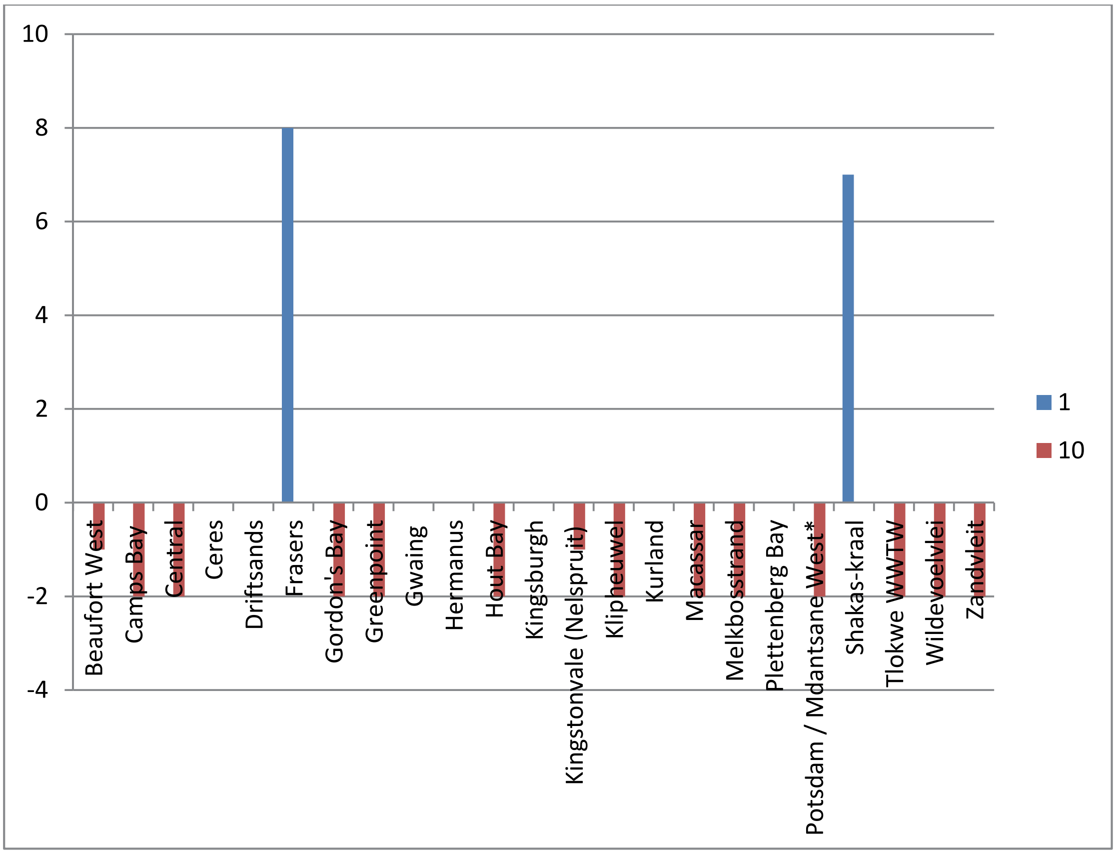


Key: The colour of the bars (legend on the right-hand side) indicates the decile of wastewater sample analysis in 2009.

Figure 2.4 **Change in Wastewater Sample Analysis (credibility) from 2009 to 2011 (Weighting – 5%).**

Change in Submission of Wastewater Quality Results from 2009 to 2011 (Weighting – 5%)

Over 50% of the WWTWs in this group showed a slight decrease in their performance on this criterion with only two showed a substantial increase (Figure 2.5).

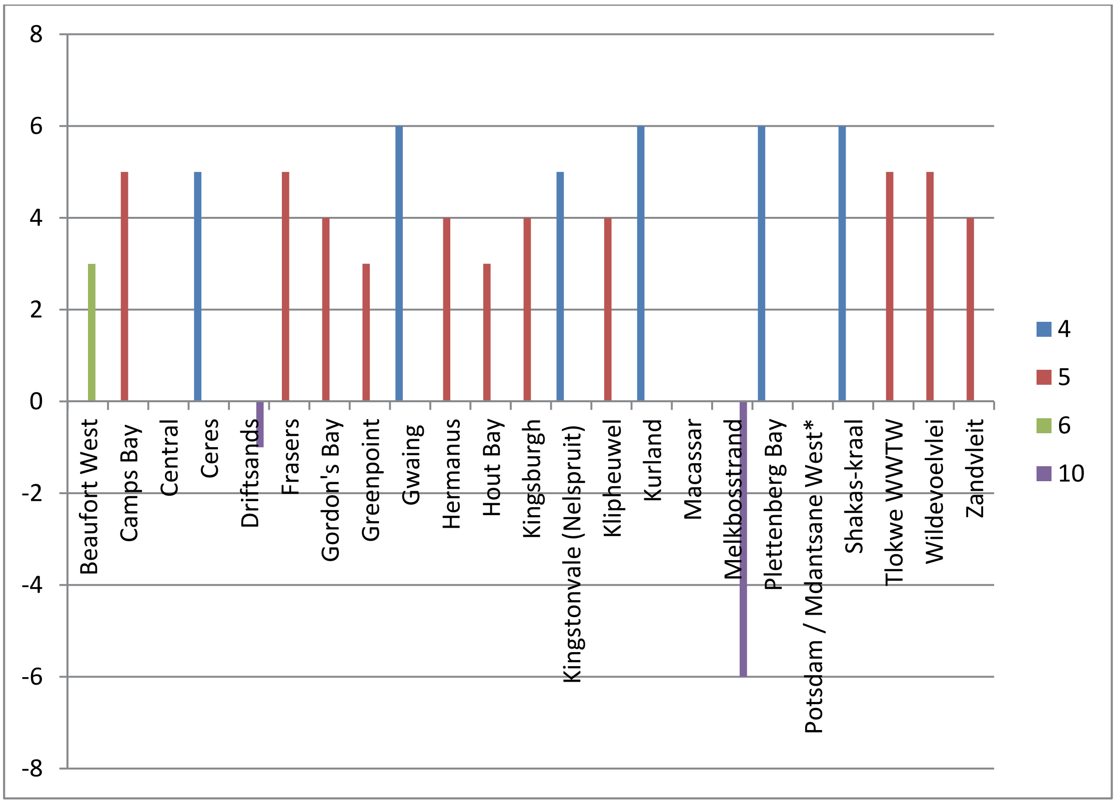


Key: The colour of the bars (legend on the right-hand side) indicates the decile of submission of wastewater quality results in 2009.

Figure 2.5 **Change in Submission of Wastewater Quality Results from 2009 to 2011 (Weighting – 5%)**

Change in Effluent Quality Compliance results from 2009 to 2011 (Weighting – 30%)

This is the most heavily weighted of the criteria considered in this analysis, and most of the WWTWs showed a substantial increase in score (Figure 2.6). Only one, Melkbosstrand, showed a large decrease in score on this metric.

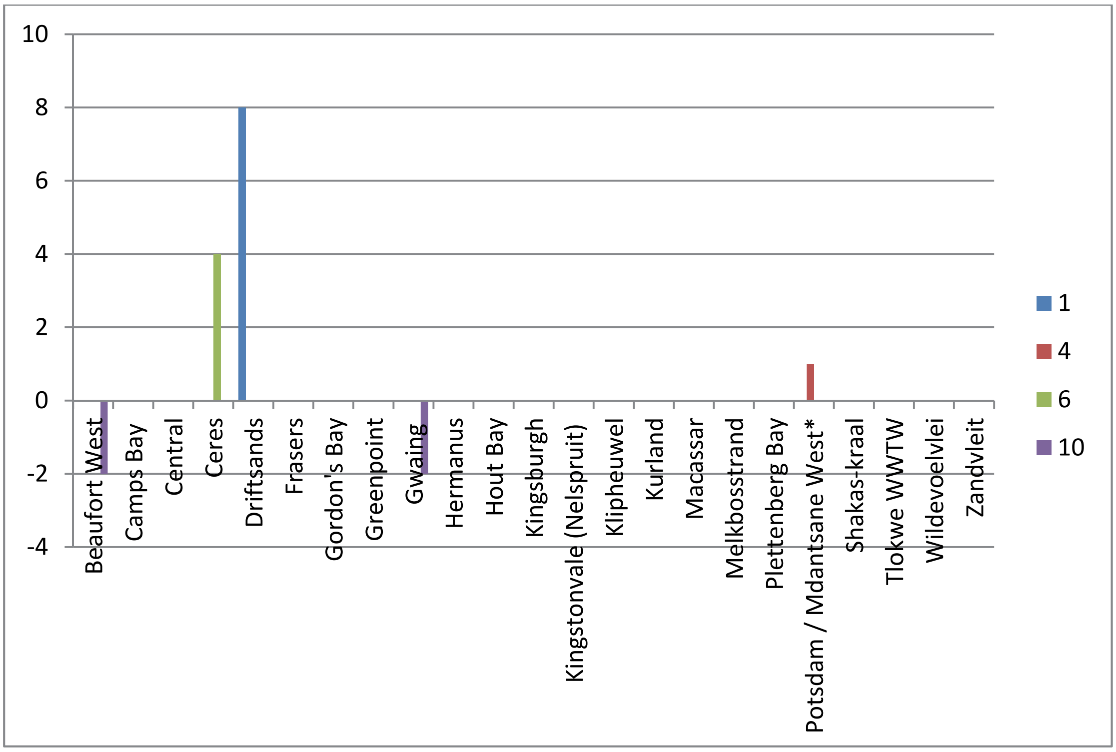


Key: The colour of the bars (legend on the right-hand side) indicates the decile of effluent quality compliance in 2009.

Figure 2.6 **Change in Effluent Quality Compliance results from 2009 to 2011 (Weighting – 30%)**

Change in Wastewater Quality Failure-Response Management results from 2009 to 2011 (Weighting – 10%)

Most of the WWTWs showed no change in this metric, with only Driftsands and Ceres showing substantial increases in performance (Figure 2.7).

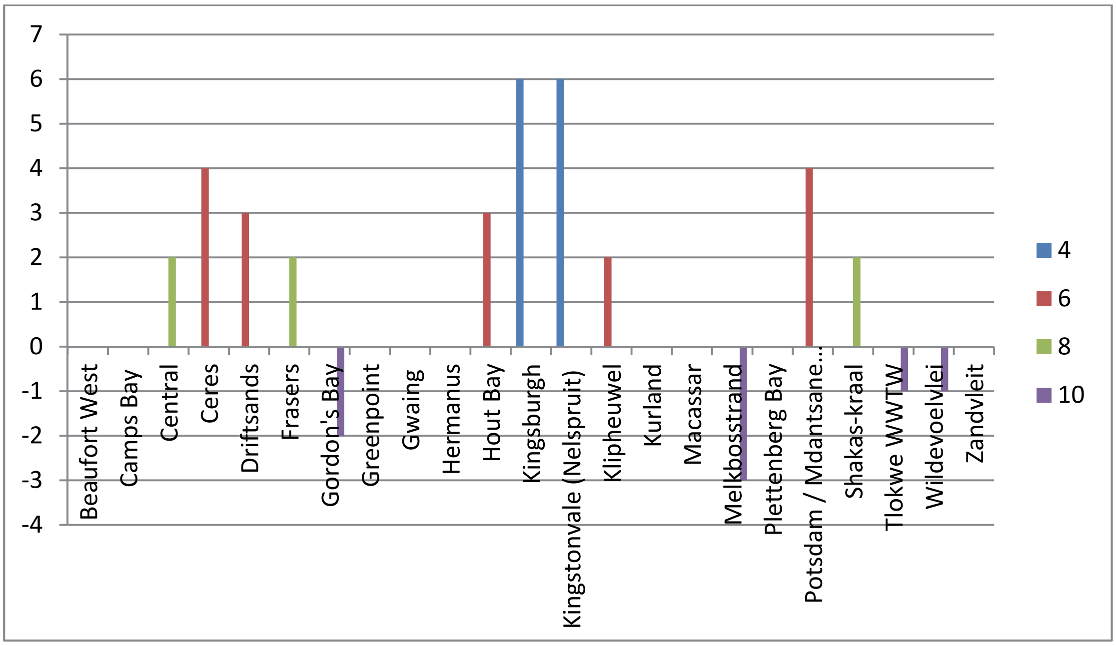


Key: The colour of the bars (legend on the right-hand side) indicates the decile of wastewater quality: failure response management in 2009.

Figure 2.7 Change in Wastewater Quality: Failure-Response Management results from 2009 to 2011 (Weighting – 10%)

Change in Wastewater Treatment Facility Capacity: capacity results from 2009 to 2011 (Weighting – 10%)

Two thirds of the WWTWs in this group showed either no change or an improvement (some a substantial improvement) in the performance of this metric with the remainder recording a decrease in score (Figure 2.8).



Key: The colour of the bars (legend on the right-hand side) indicates the decile of wastewater treatment facility capacity in 2009.

Figure 2.8 **Change in Wastewater Treatment Facility Capacity: capacity results from 2009 to 2011 (Weighting – 10%)**

2.3.2 *WWTWs showing a large increase in Green Drop Rating from between 3 and 33 from 2009 to 2011*

The twenty WWTWs in this group registered generally low scores in the 2009 assessment but were able to improve their GDR substantially in the 2011 assessments.

Change in Operations (Process Control), Maintenance and Management Skill from 2009 to 2011 (Weighting – 10%)

Most of the WWTWs in this group showed a substantial improvement in the performance of this criterion (Figure 2.9).

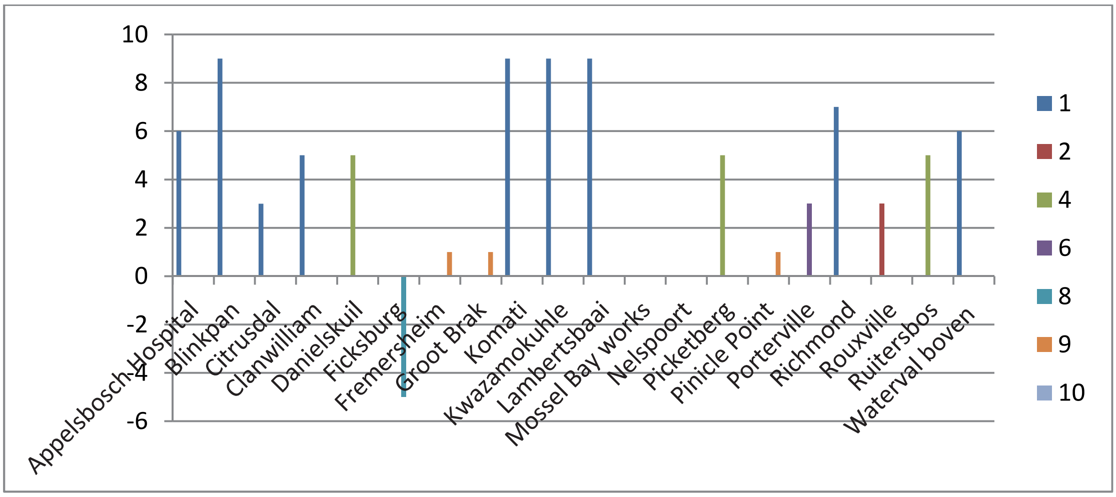


Figure 2.9 **Change in Operations (Process Control), Maintenance and Management Skill from 2009 to 2011 (Weighting – 10%)**

Change in Wastewater Monitoring Programme from 2009 to 2011 (Weighting – 10%)

With only one exception all the WWTWs in this group showed a substantial increase in this criterion (Figure 2.10).

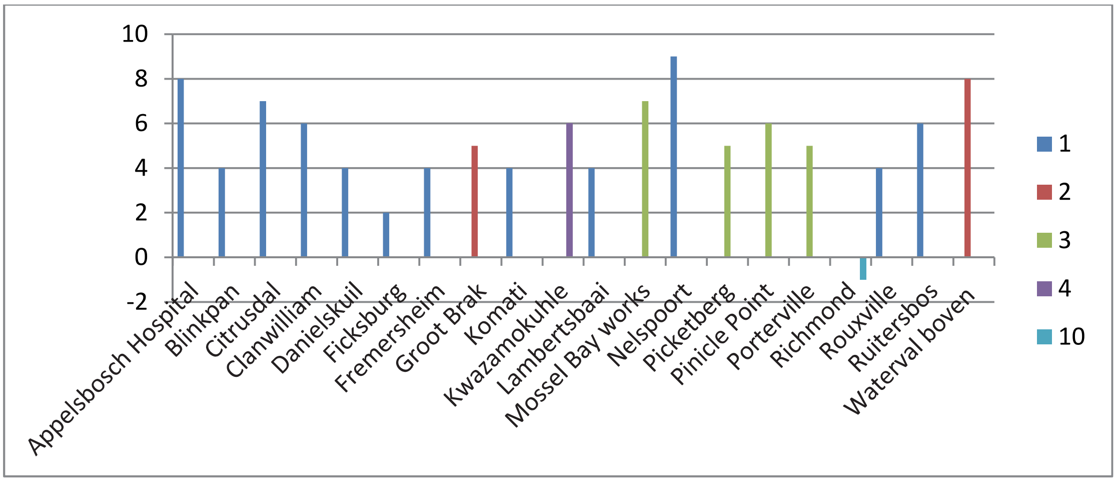


Figure 2.10 **Change in Wastewater Monitoring Programme from 2009 to 2011 (Weighting – 10%)**

Change in Wastewater Sample Analysis (credibility) from 2009 to 2011 (Weighting – 5%)

Seventeen of the 20 WWTWs in this group showed an improvement of 30% or more in their performance of this criterion (Figure 2.11).

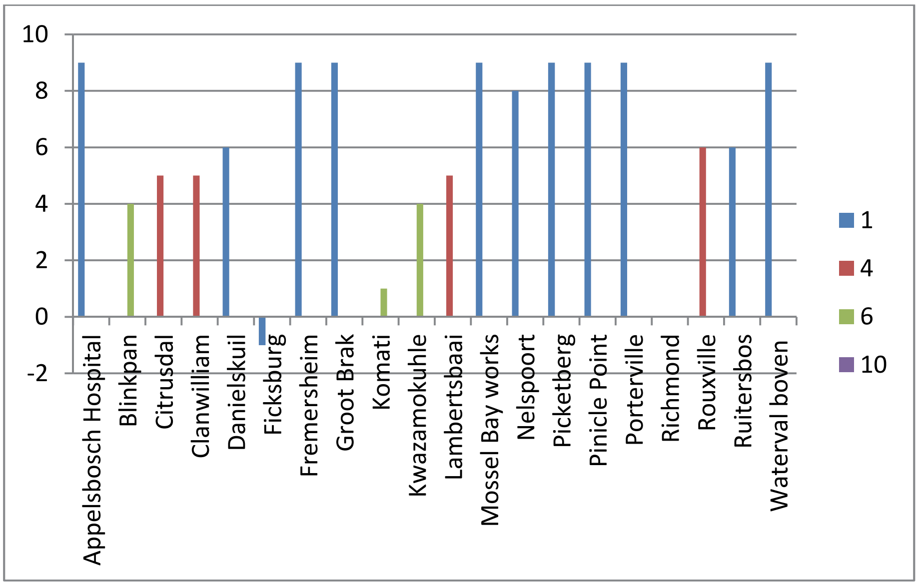


Figure 2.11 **Change in Wastewater Sample Analysis (credibility) from 2009 to 2011 (Weighting – 5%)**

Change in Submission of Wastewater Quality Results from 2009 to 2011 (Weighting – 5%)

Most of the WWTWs in this group registered a substantial improvement in their performance of this metric (Figure 2.12).

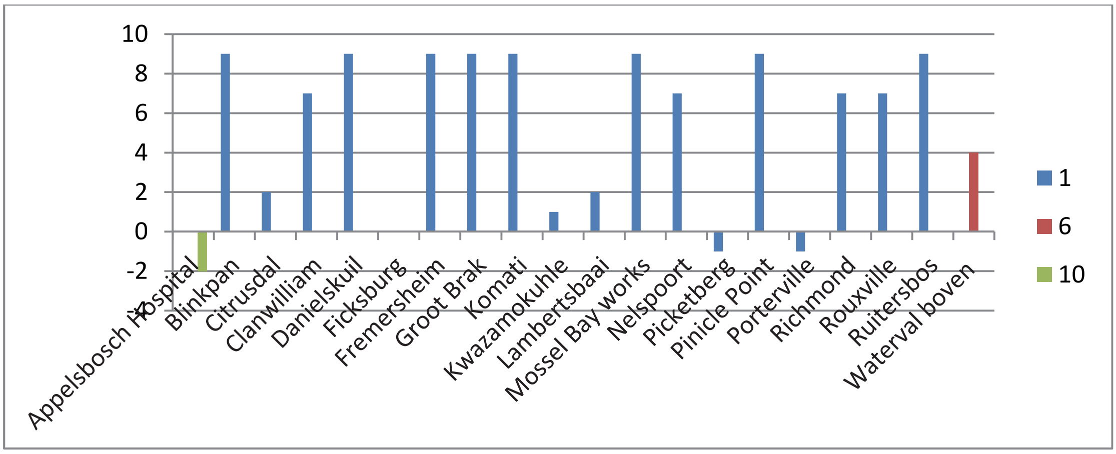


Figure 2.12 Change in Submission of Wastewater Quality Results from 2009 to 2011 (Weighting – 5%)

Change in Effluent Quality Compliance results from 2009 to 2011 (Weighting – 30%)

Only one WWTW, Komati, registered a small decrease in its compliance (Figure 2.13). All the other WWTWs registered an increase, many of them a substantial increase.

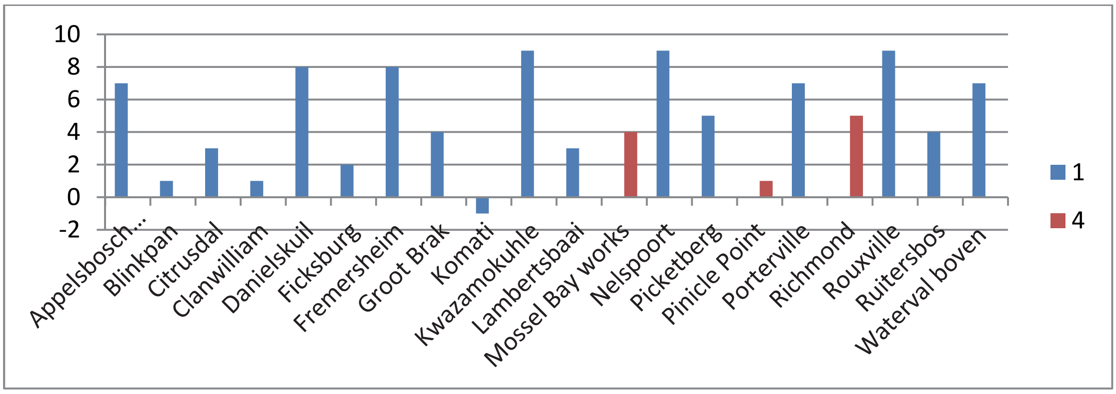


Figure 2.13 Change in Effluent Quality Compliance results from 2009 to 2011 (Weighting – 30%)

Change in Wastewater Quality Failure-Response Management results from 2009 to 2011 (Weighting – 10%)

With the exception of two WWTWs which registered a slight decrease, all the WWTWs in this group showed an increase with 16 of the 20 WWTWs showing an increase of 60% or more between 2009 and 2011 (Figure 2.14).

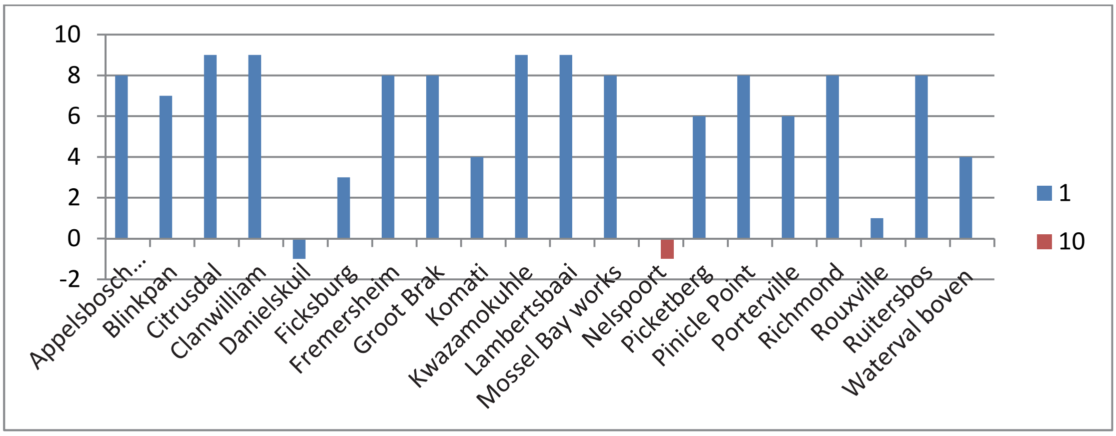


Figure 2.14 Change in Wastewater Quality Failure-Response Management results from 2009 to 2011 (Weighting – 10%)

Change in Wastewater Treatment Facility Capacity results from 2009 to 2011 (Weighting – 10%)

Following the pattern of this group, most of the WWTWs registered a substantial increase in the score achieved (Figure 2.15).

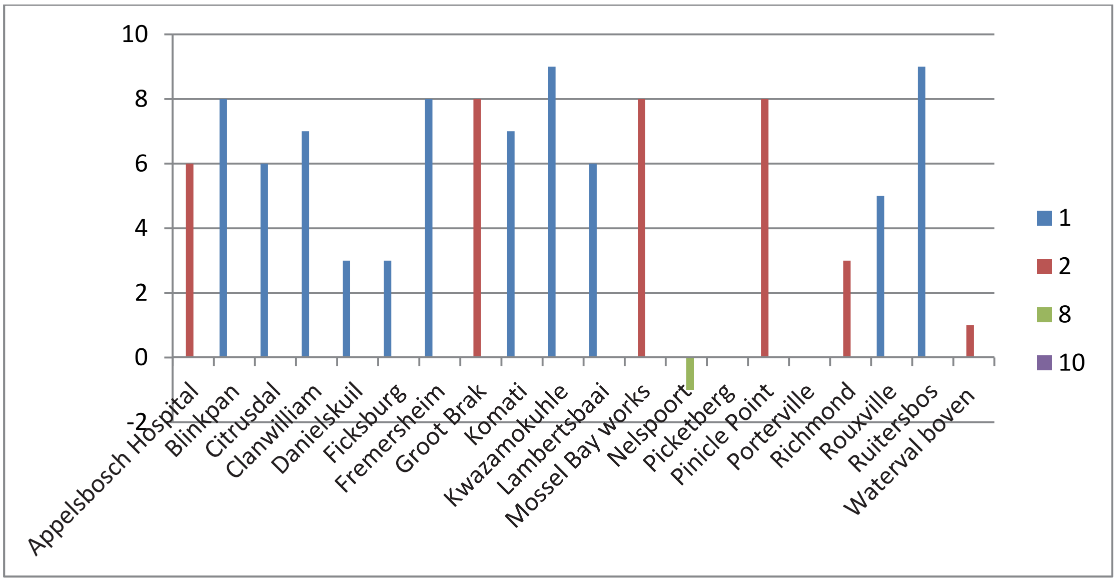


Figure 2.15 Change in Wastewater Treatment Facility Capacity results from 2009 to 2011 (Weighting – 10%)

2.3.3 WWTWs showing a large increase from 0 (zero) in Green Drop Rating from 2009 to 2011

The 18 WWTWs in this group failed to achieve a rating higher than G (0% or no information) in the 2009 assessment. They did, however, improve their performance substantially in the period between the assessments and managed to score between 30% and 76% in the 2011 assessment.

Change in Operations (Process Control), Maintenance and Management Skill from 2009 to 2011 (Weighting – 10%)

All WWTWs in this group improved their performance in this metric, with 14 of the 18 WWTWs registering an improvement of greater than 30%, some as much as 70% (Figure 2.16).

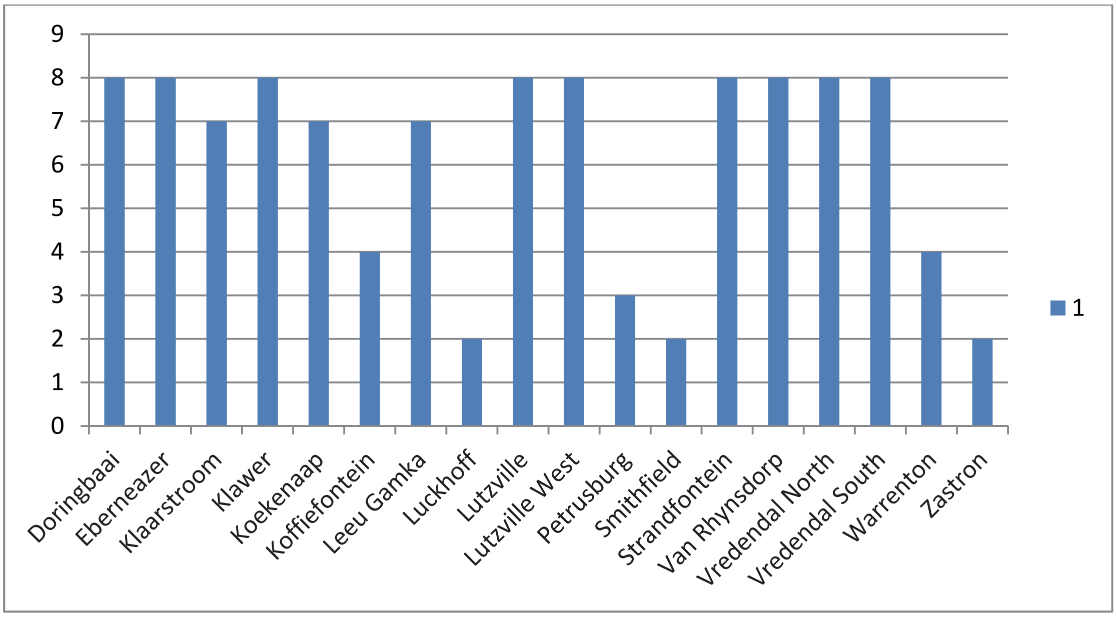


Figure 2.16 Change in Operations (Process Control), Maintenance and Management Skill from 2009 to 2011 (Weighting – 10%)

Change in Wastewater Monitoring Programme from 2009 to 2011 (Weighting – 10%)

All WWTWs in this group registered an improvement in this measure, with 16 of the 18 WWTWs showing an improvement of 30% or more (Figure 2.17).

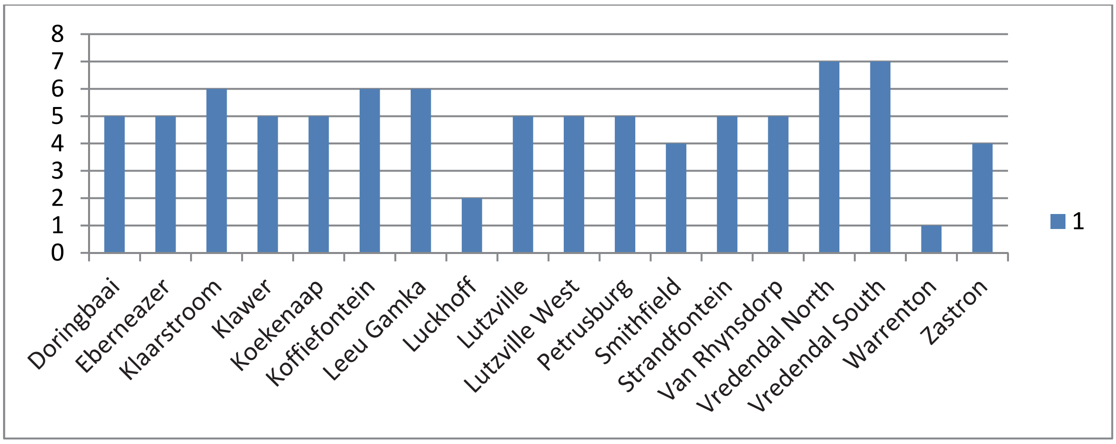


Figure 2.17 Change in Wastewater Monitoring Programme from 2009 to 2011 (Weighting – 10%)

Change in Wastewater Sample Analysis (credibility) from 2009 to 2011 (Weighting – 5%)

Seventeen of the 18 WWTWs in this group registered an improvement of greater than 50% for this metric (Figure 2.18).

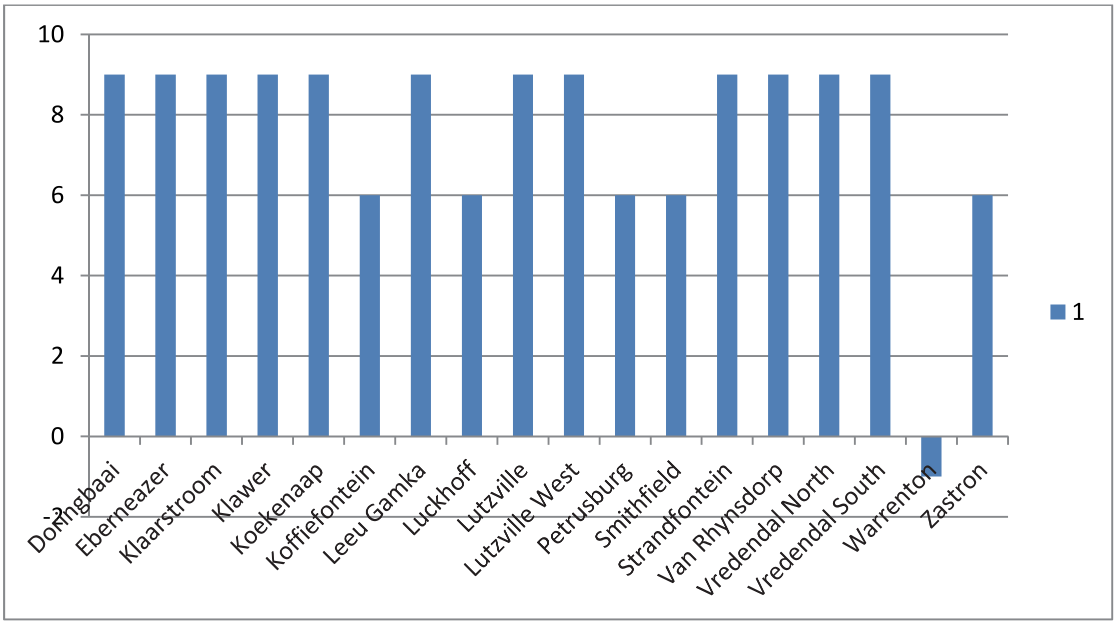


Figure 2.18 Change in Wastewater Sample Analysis (credibility) from 2009 to 2011 (Weighting – 5%)

Change in Submission of Wastewater Quality Results from 2009 to 2011 (Weighting – 5%)

While some of the WWTWs registered a substantial increase in the achievement of this metric, the majority registered a relatively minor increase (Figure 2.19).

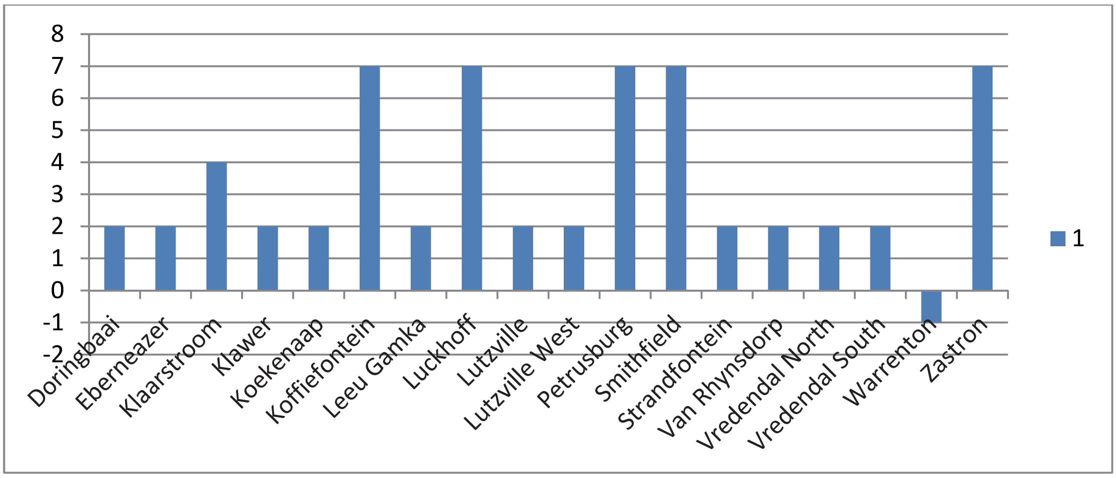


Figure 2.19 **Change in Submission of Wastewater Quality Results from 2009 to 2011 (Weighting – 5%)**

Change in Effluent Quality Compliance results from 2009 to 2011 (Weighting – 30%)

Twelve of the 18 WWTWs registered and increase of 50% or greater between 2009 and 2011 (Figure 2.20).

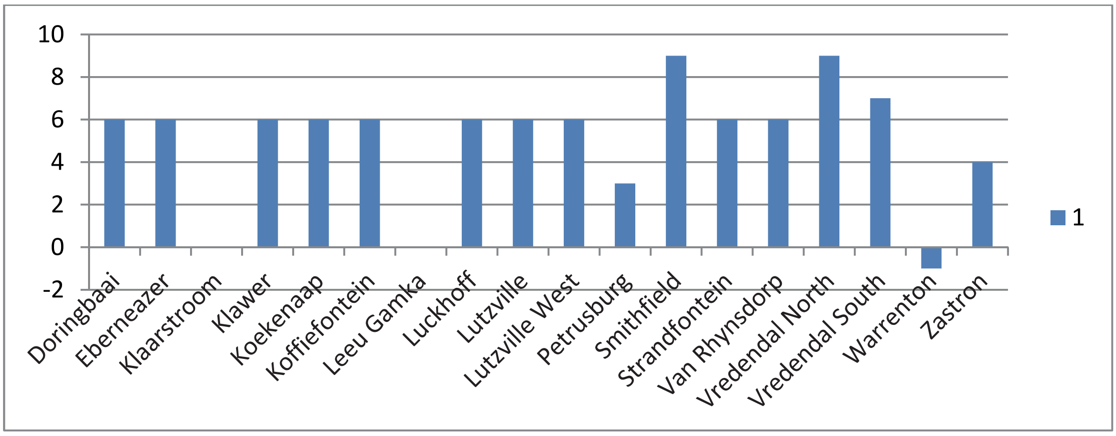


Figure 2.20 **Change in Effluent Quality Compliance results from 2009 to 2011 (Weighting – 30%)**

Change in Wastewater Quality Failure-Response Management results from 2009 to 2011 (Weighting – 10%)

Three of the WWTWs in the group registered a decrease in score, but most registered a slight increase (Figure 2.21).

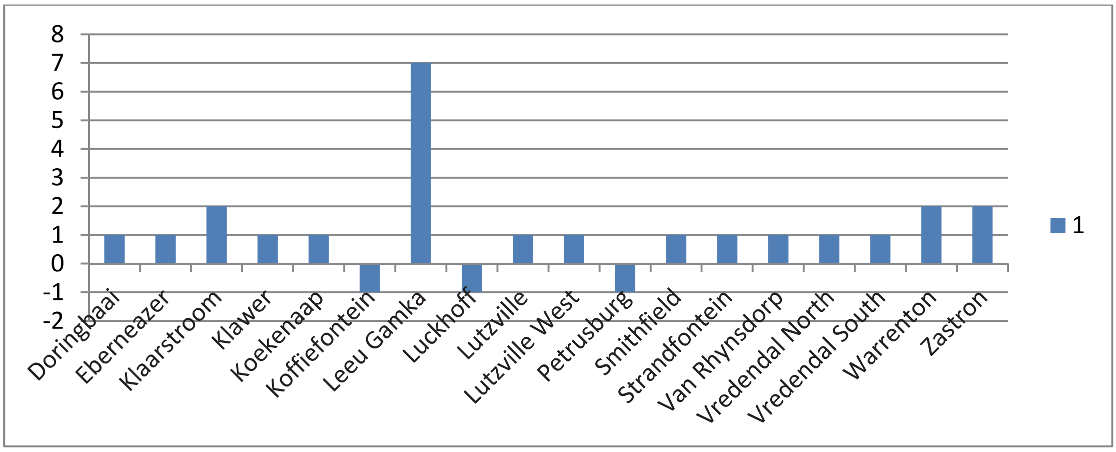


Figure 2.21 **Change in Wastewater Quality: Failure-Response Management results from 2009 to 2011 (Weighting – 10%)**

Change in Wastewater Treatment Facility Capacity results from 2009 to 2011 (Weighting – 10%)

Twelve of the 18 WWTWs registered an increase of 50% or greater in their score on this metric (Figure 2.22).

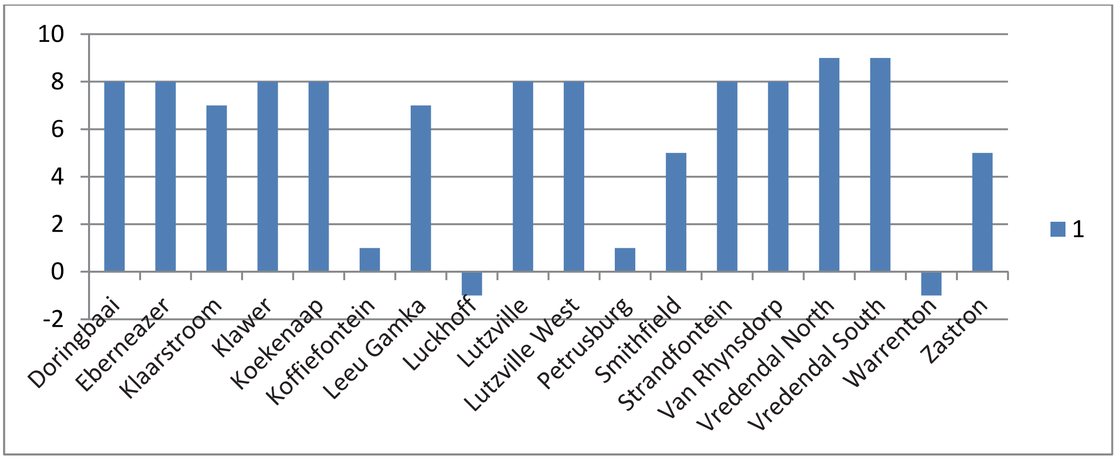


Figure 2.22 **Change in Wastewater Treatment Facility Capacity results from 2009 to 2011 (Weighting – 10%)**

2.3.4 WWTWs showing a substantial decrease in Green Drop Rating from 2009 to 2011

While a number of WWTWs showed a decline in their performance between 2009 and 2011, 16 of these registered an overall decrease of 30% or greater in their GDRs. These have been analysed to see if a reason can be identified for this drastic decline.

Change in Operations (Process Control), Maintenance and Management Skill from 2009 to 2011 (Weighting – 10%)

While 50% of the WWTWs in this group showed a decline in score, the remainder, with the exception of Garies which showed no change, showed an improvement in score (Figure 2.23).

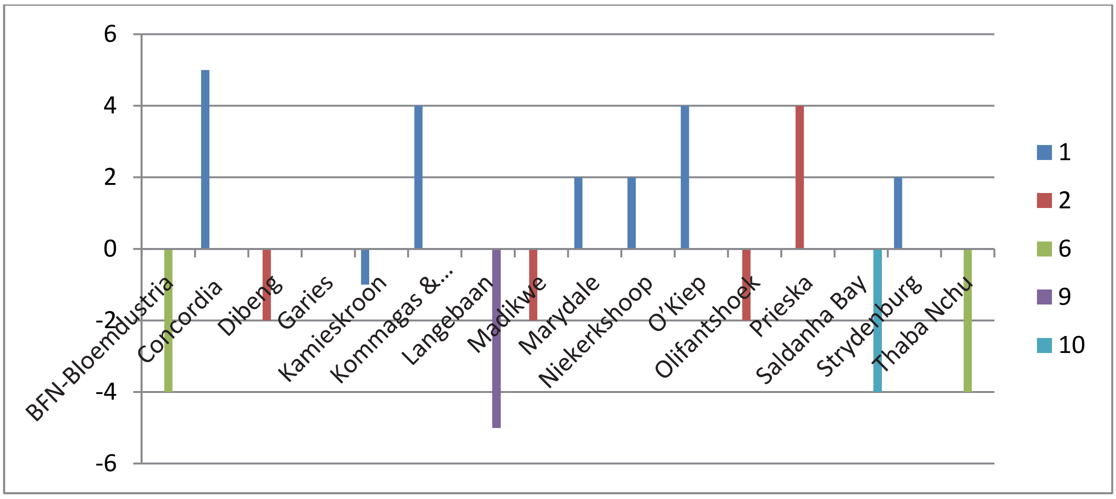


Figure 2.23 Change in Operations (Process Control), Maintenance and Management Skill from 2009 to 2011 (Weighting – 10%)

Change in Wastewater Monitoring Programme from 2009 to 2011 (Weighting – 10%)

All the WWTWs registered a decline in this metric, with seven WWTWs declining by more than 90% (Figure 2.24).

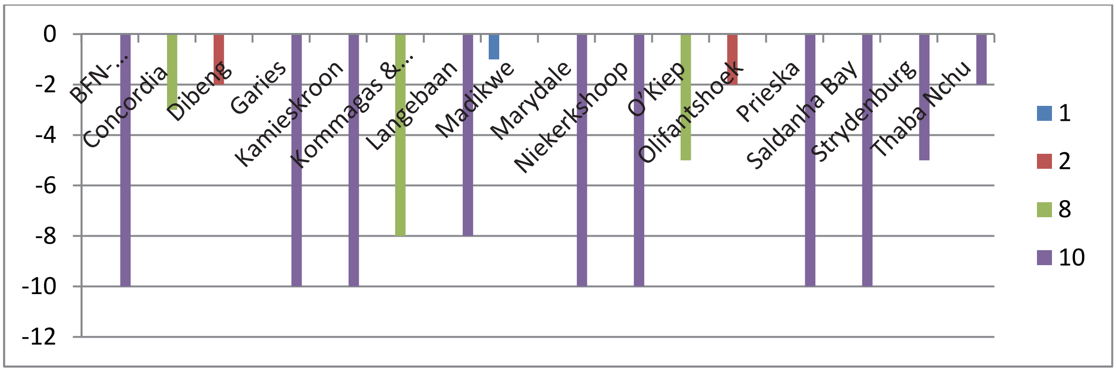


Figure 2.24 **Change in Wastewater Monitoring Programme from 2009 to 2011 (Weighting – 10%)**

Change in Wastewater Sample Analysis (credibility) from 2009 to 2011 (Weighting – 5%)

Except for one WWTW, all the WWTWs registered a decrease with eight of the 16 WWTWs registering a decrease of more than 90% (Figure 2.25).

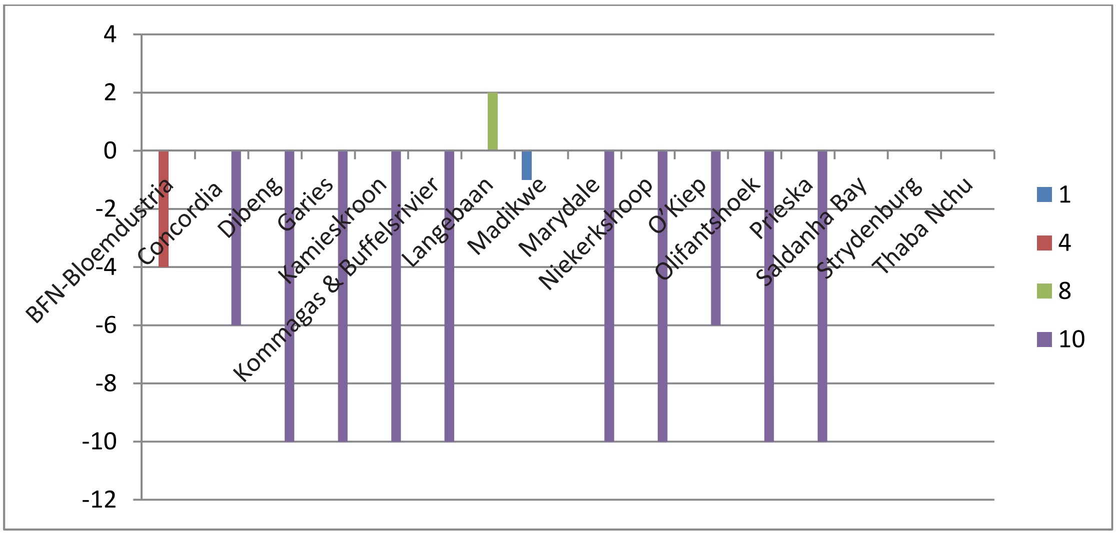


Figure 2.25 **Change in Wastewater Sample Analysis (credibility) from 2009 to 2011 (Weighting – 5%)**

Change in Submission of Wastewater Quality Results from 2009 to 2011 (Weighting – 5%)

Without exception all the WWTWs registered a decrease on this point, with 13 of the 16 WWTWs registering a decrease of greater than 90% (Figure 2.26).

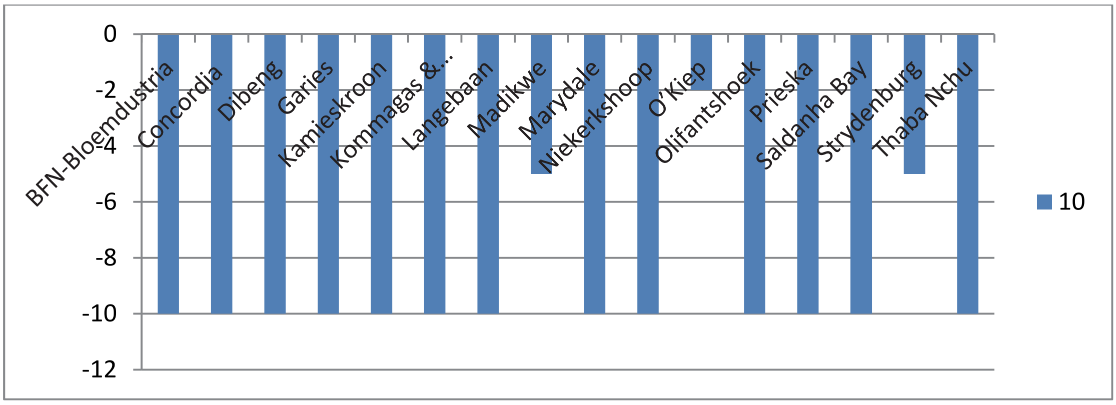


Figure 2.26 **Change in Submission of Wastewater Quality Results from 2009 to 2011 (Weighting – 5%)**

Change in Effluent Quality Compliance results from 2009 to 2011 (Weighting – 30%)

Seventy five per cent of the WWTWs registered a decrease in score of greater than 90% for this metric, with the remaining four registering lesser reductions in score (Figure 2.27).

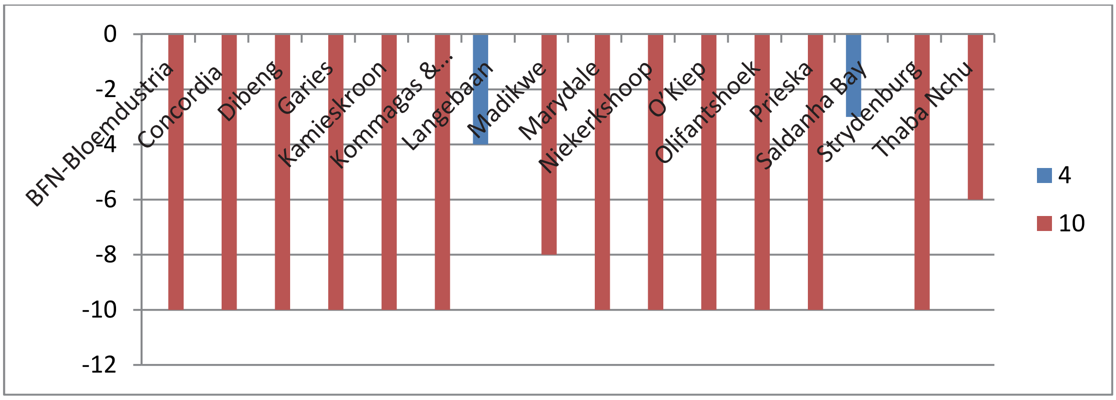


Figure 2.27 **Change in Effluent Quality Compliance results from 2009 to 2011 (Weighting – 30%)**

Change in Wastewater Quality Failure-Response Management results from 2009 to 2011 (Weighting – 10%)

Four WWTWs registered a small improvement while the remainder showed a decrease with four WWTWs showing a decrease of greater than 90% (Figure 2.28).

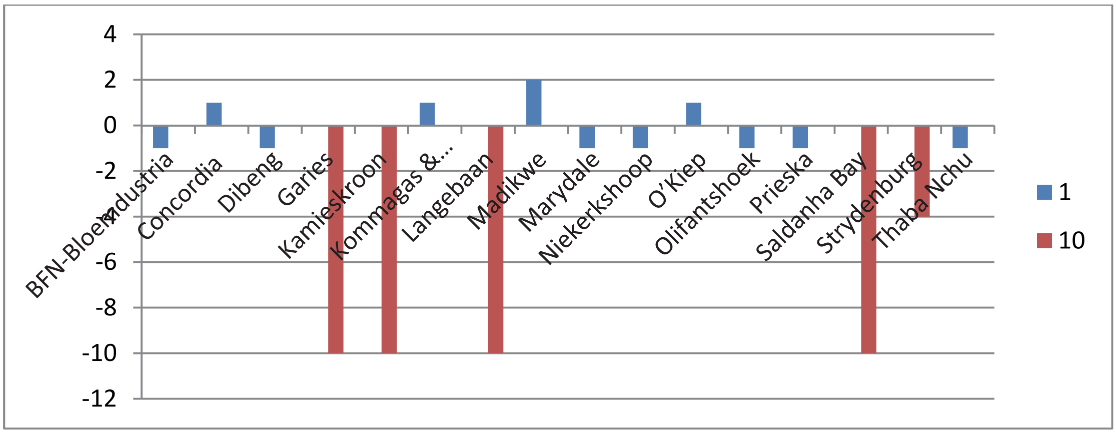


Figure 2.28 Change in Wastewater Quality: Failure-Response Management results from 2009 to 2011 (Weighting – 10%)

Change in Wastewater Treatment Facility Capacity results from 2009 to 2011 (Weighting – 10%)

Three of the WWTWs in the group showed an increase of 30% or greater, but the others all showed a decrease in score (Figure 2.29).

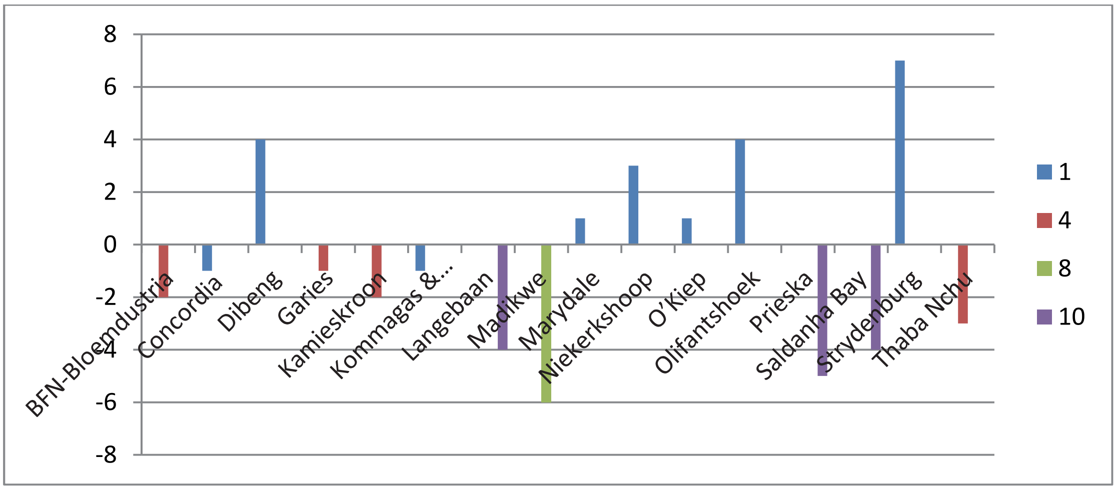


Figure 2.29 Change in Wastewater Treatment Facility Capacity results from 2009 to 2011 (Weighting – 10%)

2.4 Salient/emerging facts

From the above analysis the following key salient facts have emerged:

- While the GDR assesses the operation of the WWTWs through 10 indicators, most of these indicators are underlain by a number of criteria which are separately assessed and then accrued to give the score for the category.
- These categories provided clear insights into the management of the WWTWs, but it became apparent early on in the process that the WWTWs may achieve similar scores for different performance in different criteria. These differences, however, could not be teased out from the data as presented in the Green Drop report.
- For this reason it is necessary to analyse the data underlying each of the categories in the report to ascertain which of the criteria exert a critical influence on overall WWTW performance.

WWTWs that achieved a substantial improvement from a mid-range GDR in 2009 (Section 2.3.1)

- The criteria that showed the most consistent improvement in this group were **Effluent Quality Compliance** (Figure 2.6) and **Process Control** (Figure 2.2).
- The **Change in Wastewater Facility Capacity** (Figure 2.8) was improved in 10 WWTWs, while in others this criterion declined. The other criteria tested showed no patterns.

WWTW where the GDR showed a substantial improvement from a low base in 2009 (Section 2.3.2)

- WWTWs in this category showed an improvement in each of the criteria examined.
- Although the improvement in **Effluent Quality Compliance** (Figure 2.13) was less marked than in some of the other criteria, the weighting of 30% makes this the most important area of improvement. Some WWTWs showed large gains in **Operations (Process Control)** (Figure 2.9) while others did not.

WWTW where the GDR showed a substantial improvement from a 0 (zero) base in 2009 (Section 2.3.3)

- WWTWs in this category showed substantial improvement in each of the criteria examined.
- Noticeably in this category is the improvement in **Effluent Quality Compliance** (Figure 2.20) and **Operations (Process Control)** (Figure 2.16) where the improvement shown across the range of WWTWs is more consistent.
- Criteria which showed smaller improvements in this category are **Submission of Wastewater Quality Results** (Figure 2.19) and **Wastewater Quality Failure Response** (Figure 2.21).

WWTWs showing a substantial decrease in Green Drop Rating from 2009 to 2011 (Section 2.3.4)

- Criteria which showed consistently large decreases between 2009 and 2011 were **Submission of Wastewater Quality Results** (Figure 2.26), **Effluent Quality Compliance** (Figure 2.27), **Wastewater Monitoring Programme** (Figure 2.24) and **Wastewater Sample Analysis (Credibility)** (Figure 2.25).
- Other criteria showed a mix of increases and decreases. **Operations (Process Control)** (Figure 2.23) showed no consistent pattern, with some WWTWs registering a decline in score while others registered gains.

The following are observations from these categories above which showed increases:

- The management of the WWTWs improved generally.
- The WWTWs which showed large improvements, improvements were in all criteria.
- The most important category of improvement in each case was **Effluent Quality Compliance**.
- **Operations (Process Control)** was also a category which showed consistent improvement.

The following are observations in the group of WWTWs which showed a large decline in rating:

- The **Operations (Process Control)** showed less consistency than other metrics, with there being roughly equal numbers of WWTWs showing gains and declines.
- It would appear from these results that this is an area where an intervention would have positive outcomes.

General observations:

- What is apparent, as discussed above, is that each of the criteria tested is an agglomeration of a number of requirements, each with one or more sub-requirements, and so it is not possible to make further assumptions on the reasons for success or failure without interrogating the underlying data.
- An economic model was therefore developed to delve deeper into the cost structures of WWTWs, in order to assess what financial interventions would be required to facilitate improvements to WWTWs. This is discussed in the Chapter 3.
- A constraint identified is the procurement process required for municipalities by the Public Finance Management Act. It can take several months to comply with the required process in order to address an emergency.

2.5 Conclusion

The criteria that were measured may be broadly divided into two categories, those that involved the control of the on-plant processes and those that involved administrative decisions. In the former category the criteria **Effluent Quality Compliance and Operations (Process Control)** showed consistent improvement among the WWTWs that improved their performance between 2009 and 2011. In the latter category, approximately 20% of the WWTWs assessed in 2009 scored a GDR of below 10. Among these the criteria which showed a substantial improvement were **Submission of Wastewater Quality Results**, **Wastewater Monitoring Programme** and **Wastewater Sample Analysis (Credibility)**. It is possible that these requirements were not being addressed before the Green Drop programme was initiated.

The consistent small decrease in the scores of **Submission of Wastewater Quality Results** and **Wastewater Monitoring Programme** among the WWTWs that had performed well would appear to be an artefact of the assessment procedure as the requirements against which the assessment was made changed slightly.

Chapter 3 The costs of treating wastewater

3.1 Introduction

Earlier we indicated that while South Africa has developed some of the leading WWTWs and technologies, these have proven unsuccessful in stemming the tide of environmental degradation due to increased population growth, growth in income and resource use. Government's response to this has been to develop the Green Drop Rating (GDR) system. The higher the Green Drop Rating, the better the performance of the wastewater treatment works in terms of a number of predefined criteria. These include the design capacity, water quality and skills levels. Chapter 2 analysed some of the trends in the Green Drop Rating of different wastewater treatment works, along with some of the key drivers.

This chapter discusses the results of an economic model that was developed to further understand the drivers affecting the GD rating. It differs from Chapter 2 in the following two respects:

- The focus is on the financial drivers of changes in the GDR. In other words, what was the impact of changes in operational and capital expenditure on the GDR?
- A new measure, introduced by the Department of Water Affairs (DWA), called the Risk Rating Score (RRS) is used. The RRS assesses the deviation of the Cumulative Risk Rating (CRR) of a wastewater treatment work (WWTW) from its maximum value. The closer the value is to 100, the worse the WWTW is performing. It is therefore the inverse of the Green Drop Rating (GDR). A further elaboration of how this indicator is developed is provided in Section 3.2.

The objective of this chapter is to discuss the mechanics of a model that was developed to assess the factors affecting the RRS of WWTWs by considering:

- the cost of improving the wastewater treatment works performance; and
- assessing the impact of investments in refurbishments and improvements (R&I) on the RRS.

Supporting variables feeding into the model included some of the important variables that comprise the GDR, such as: the capacity of the plant (in kl), the capacity utilisation (%), the type of technology, the capital budget, the operational budget, the number of members of staff, and the years' of experience of the senior management of the plant. This made it possible to:

- identify which variables were the ones to impact the most on the RRS, and
- which variables needed to be improved and by how much in order to improve the RRS.

The model made this possible by enabling the interrogation of the model using "what if" type scenarios. The model was initially developed for KwaZulu-Natal, since data was available for both capital (CAPEX) and operating (OPEX) costs, and then applied to the ERWAT sites in Gauteng.

3.2 Methods

3.2.1 Model structure

The economic model was constructed in the form of a series of multivariate linear regression (MLR) equations of the form:

$y_i = \alpha + \beta_1 x_{1i} + \beta_2 x_{2i} + \beta_3 x_{3i} + \ldots + \beta_j x_{ji} + \varepsilon_i$

for i = 1 to n

where:

y_i = The dependent, or response variable

α = the intercept

x_{ki} = the independent variable k (for each of the j independent variables in the model)

β_k = the coefficient of the independent variable k (k=1,…,j)

ε_i = the error term, or residual of the model

n = the number of observations, which in this case is the number of wastewater treatment works in the sample

MLR equations are useful for identifying which variables are the ones that impacts most on the RRS (in other words, addressing point 1 in this chapter's introduction). The MLR approach is the standard form for analysing cross-sectional data. A limitation of MLR is that the direction of causality between the independent variables and the dependent variable needs to be known *a priori* and is unidirectional. In other words, the independent variables "influence" the dependent variable and not vice versa. For multidirectional and complex systems, the system dynamics modelling approach is a preferred technique for modelling (see e.g. Crookes & De Wit, 2014). In this case, given the nature of dependent variable and its construction, it has to be assumed that the present direction of causality is correct.

There are three main types of data used in regression equations, namely, time series (or longitudinal) data, cross-sectional data and panel data. Time series data is variables that change over time, cross-sectional data contains variables for a single point in time, and panel data contains both time series and cross-sectional data. This study uses cross-sectional data. The regression model includes the population of WWTWs in KZN, applied to the ERWAT sites, at a particular moment in time.

The characteristics of cross-sectional data differentiating it from standard time series analysis include the following (Cameron & Trivedi, 2005):

1. The standard regression model assumes that the data is derived from random sampling. Quite often this is not the case with cross-sectional data. Sometimes other sampling techniques are employed. The implication for the regression model is that the data is independent but not identically distributed (the standard regression assumption is that the data is independent and identically distributed).

2. The model is correctly specified and there are no omitted variables (this assumption also applies to time series data).

3. The independent variables may be stochastic, which is the case when survey data rather than experimental data is used.

4. There is no endogeneity in the model. In other words, the independent variables are not correlated with the error term. This is quite a common feature of cross-sectional data and the solution is usually to use instrumental variable regression, assuming an appropriate instrument can be found.

5. Quite often the error terms in cross-sectional models are heteroskedastic, which means that the variances of the error terms are unequal. This is not regarded as too problematic, and may be corrected, for example by estimation robust (also sometimes called White) standard errors.

6. R-squared values for cross-sectional models are often quite low, but this is also not regarded as too problematic. Some studies with large datasets even have R-squared values as low as 0.1, without rendering the model invalid. Most common ranges for R-squared values in cross-sectional models are between 0.1 and 0.4 (Norwood, 2008).

Economic models are constructed both on aggregate levels (for all WWTWs) and based on plant size, class and technology, where data are available. In Section 3.2.2 a description is given of how the dependent variable is constructed and in Section 3.2.3 the independent variables in the model are described.

Multivariate Linear Regression

A Multivariate Linear Regression model is a powerful tool that is used by most of the sciences to explore relationships between data. It comprises two components: 1) the dependent variable, which is on the left-hand side of the equality sign, and 2) the independent variables, on the right-hand side of the equality sign. The independent variables are also called explanatory variables, since they 'explain' the variation in the dependent variable.

3.2.2 Dependent variable

The dependent variable is based on the change in the deviation of the cumulative risk rating (% CRR deviation) of a WWTW from 2008 to 2012 and forms the basis of the construction and assessment of the RRS for each WWTW. In order to understand this measure it is necessary to see 1) how the CRR is derived, 2) how the % CRR deviation is derived, and 3) how the change in % CRR deviation is calculated. This % CRR deviation is referred to as the RRS (see Section 3.1).

3.2.2.1 Cumulative risk rating (E)

The CRR of a particular WWTW measures the performance of the WWTW against a number of criteria, including design capacity (A), the capacity exceedance rating (B), the effluent failure rating (C) and the technical skills rating (D).

The cumulative risk rating (E) as defined by the DWA is:

E = A * B + C + D

Each of the individual components (A, B, C and D) is calculated as follows:

Design capacity (A)

Design capacity rating (A) gives the size of the WWTW based on the volume of effluent flow that it is designed to treat. A assumes a value from 1 to 7, depending on the volume of flow, as follows:

Design Capacity (Ml/d)		Score
Design Capacity Rating	> 400	7
	201-400	6
	101-200	5
	51-100	4
	21-50	3
	5-20	2
	<5	1

The capacity exceedance rating (B)

The capacity exceedance rating (B) measures the degree to which the actual effluent flow exceeds or is less than the design capacity (A) of the plant. The formula for calculating B is as follows:

$A_{dev} = A_{real}/A * 100$

Where A_{dev} = deviation of flow from design

A_{real} = Actual flow at WWTW

Capacity Exceedance (Ml/d)		Score
Capacity Exceedance Rating	> 150	5
	101-150	4
	51-100	3
	11-50	2
	1-10	1
	<= 0	0

Effluent failure rating (C)

The effluent failure rating (C) measures the number of non-compliant trends for the various parameters, and assumes a value from 1 to 9. The non-compliant parameters fall into three categories: microbiological, chemical and physical, as follows:

Microbiological Determinants

Escherichia coli

Faecal Coliforms

Chemical Determinants

COD

Ammonia Nitrogen

Nitrate Nitrogen

Ortho-phosphates

Physical Determinants

pH

Suspended Solids

Electrical Conductivity

A non-compliant parameter occurs where that parameter has a monthly compliance of less than 90% based on a comparison of compliant samples expressed as a percentage of total number of samples reported in the year of assessment (DWA, undated).

Technical skills rating (D)

The technical skills rating (D) assesses the extent to which a WWTW complies with the requirements of staff employment. This variable assumes a value from 1 to 4, based on the following criteria:

Weighting Factor (WF) for the various priorities:		Score
Technical Skills Rating	Superintendent & Process Controllers & Maintenance Team in place	1
	Superintendent + Maintenance Team & No Process Controllers	2
	Process Controllers + Maintenance Team & No Superintendent	
	Process Controllers + Superintendent & No Maintenance Team	
	Superintendent & No Maintenance Team & No Process Controllers	3
	Process Controllers & No Maintenance Team & No Superintendent	
	Maintenance Team & No Superintendent & No Process Controllers	
	No superintendent & No Process Controllers	4

In the next section, the RRS is calculated, based on the cumulative risk rating (E) derived in this section.

3.2.2.2 Risk Rating Score (F)

The RRS is the % CRR deviation, which is the risk measure used in the Green Drop report to estimate compliance of the plant with Green Drop criteria. The RRS is calculated as follows:

Risk Rating Score (F) = E/E_{max}

Where E_{max} is the maximum CRR value that a WWTW can assume subject to its design capacity. The formula for E_{max} is similar to that of E:

$E_{max} = A*B_{max}+C_{max}+D_{max}$

In order to derive E_{max}, the values for B, C and D assume their maximum values, which are 5 (B), 9 (C) and 4 (D) respectively.

The RRS is rated as follows (based on how close the CRR is to its maximum values): low risk (green), medium risk (yellow), high risk (amber), and critical risk (red). The ranges of these values are given in the following table:

Risk Rating score:

90 – 100% Critical risk WWTPs	
70 - <90% High Risk WWTPs	
50-<70% Medium risk WWTPs	
<50% Low Risk WWTPs	

In the next section the dependent variable for the regression models is derived, namely the change in RRS.

3.2.2.3 Change in RRS (G)

Given the nature of the independent variables used in the model it is not possible to simply use the RRS as dependent variable in the model. Furthermore, we are interested in the factors that cause a *change* in the RRS over time. As a result, the dependent variable in the model measures the change in RRS over a four-year period (G). The costing data that we use is from KwaZulu-Natal for the year 2008. We used the 2012 Green Drop report to obtain estimates of RRS for 2012 (F_{2012}). The change in RRS is then:

$G=F_{2012} / F_{2008} * 100$

A value for G of greater than 100 suggests that the 2012 RRS of the WWTW has worsened since 2008, while a value for G of less than 100 suggests that the RRS has improved since 2008. A value of 100 implies that the RRS remains unchanged.

3.2.3 Independent variables

The independent variables seek to identify what potential factors could explain the change in the RRS (whether it improved or worsened) or why it stayed the same. Given the paucity of data available, the independent variables are based, among others, on a range of criteria used to construct the cumulative risk rating (E). Therefore it is not very informative to use the RRS (or % CRR deviation) (F) as the dependent variable in the model. The dependent variable that is used, ΔRRS (G), measures the change in RRS over time and is therefore not a static measure. The change in RRS over time is used to predict the RRS over a four-year period, and is used in the simulation modelling to determine what the expected future RRS will be based on a range of criteria as input variables.

3.2.3.1 The capacity of the plant

The capacity of the plant measures the amount of effluent (measured in Ml/d) that a WWTW is able to treat. The plant capacity was used to construct two size class measures:

- A size class measure that divided the capacity of the plant into five equal quintiles. Unfortunately, in using this measure, 95 percent of the available data fell into size class 1.
- A size class measure that is based on the design capacity rating (see Section 3.2.2.1.a). This approach uses a 7-size class weighting. Even though this approach is weighted towards the

lower end of the sample, the majority of the KwaZulu-Natal WWTWs for which cost data was available fell within size class 1 and 2 (see Figure 3.1).

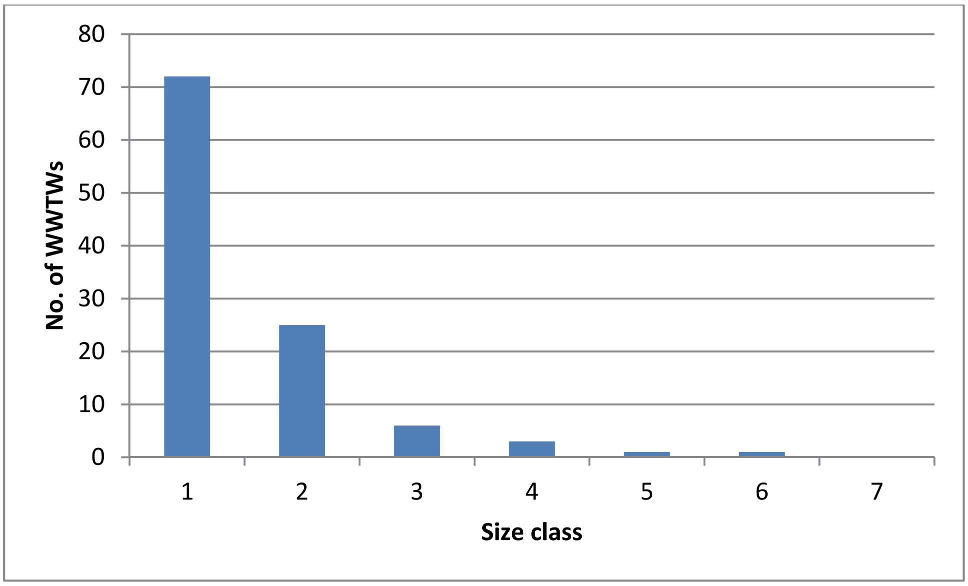


Figure 3.1 Size classes of WWTWs in KwaZulu-Natal

Multivariate regressions were run for all WWTWs in the sample using both the 5-size class measure and the 7-size class measure, and in none of the models was plant capacity shown to be a contributing factor that explained an improvement or a decline in the RRS. Separate multivariate regressions were run, however, for size classes 1 and 2, and these results are discussed in Sections 3.3.2 and 3.3.3.

3.2.3.2 The capacity utilisation (%)

Capacity utilisation measures by how much actual effluent flows deviate from capacity. This is the same measure as used in 3.2.2.1.b, except that actual deviations are used rather than the rating score.

3.2.3.3 The type of technology

A range of technologies are used at the different WWTWs, including oxidisation ponds, trickling filters, activated sludge and nutrient removal activated sludge. The KwaZulu-Natal data uses a two-tier classification, namely low-end technology and high-end technology, and this was the data used for the regression models. Although, for the results discussed in Section 3.3 it was possible to use a three-tier technology classification.

As for the class sizes, type of technology was included as an independent variable in the aggregate WWTW multivariate model, and was not found to be a significant contributor to the RRS on an aggregate level. Technology was, however, modelled in the disaggregated models for size classes 1 and 2, and also modelled as separate classes: a low-end technology regression (Section 3.3.2) and high-end technology regression (Section 3.3.3).

3.2.3.4 *The capital and operational budget*

Although not available for all WWTWs, data on the potential capital (CAPEX) and operational (OPEX) expenditure of the future infrastructure outlays of KwaZulu-Natal WWTWs for the year 2008 were available for a number of plants. Usually, CAPEX is incurred at the start of a project, while OPEX persists over the lifespan of the project. In the absence of other data it is assumed that the investment cycle of the plant runs over a 20-year period and continues into perpetuity (although the latter assumption is not required for the running of the model). The Net Present Value (NPV) approach is used to estimate the total costs of infrastructure outlays over the lifespan of the project. The formula for NPV used in this study is as follows:

$$NPV_i(rate, N) = CAPEX + \sum_{t=1}^{N} \frac{R_t}{(1+rate)^t}$$

Where

$NPV_i(rate, N)$ = The Net Present Value for WWTW i for discount (rate) and N periods

and R_t = is the OPEX in time period t

The split between the NPV of OPEX and CAPEX is roughly 60:40.

Two independent variables were constructed based on NPV:

- The first used the actual value of NPV in the model
- The second used a three-tier rating depending on the size of the cost:
    - 1 for all NPVs less than R5m
    - 2 for all NPVs between R5m and R10m
    - 3 for all NPVs greater than or equal to R10m

None of the regression models produced satisfactory results for the first measure (actual cost data used), so only the results of the second measure (NPV tier rating) are reported on in Section 3.3.

3.2.3.5 *Staff numbers and years of experience of senior management*

No data was available for either number of staff members or years of experience of senior management. It was therefore necessary to resort to the technical skills rating reported on in Section 3.2.2.1.d. This data uses a four-tier system, with 1 indicating the highest levels of staff technical ability and 4 indicating the lowest levels.

3.2.3.6 *Risk rating*

One final independent variable that was included in the model was the risk rating. This variable assumes one of three values dependent on the risk category of the RRS (see Section 3.2.2.2.):

- A value of 1 implies a high risk RRS
- A value of 2 implies a medium risk RRS
- A value of 3 implies a low risk RRS

The risk category independent variable is included to assess the effect of risk rating on the change in RRS. It has a similar effect as a lagged dependent variable in the model. In other words, it attempts to answer the question whether a historically high risk RRS is a contributing factor to future decreases in the RRS. Or, otherwise put, does the poor performance of WWTW prompt management to invest in measures to improve the RRS?

In the next section, the results of the KwaZulu-Natal model are presented, and then applied to Gauteng (the so-called ERWAT sites).

3.3 Results

3.3.1 KZN WWTWs – Aggregate model

Multivariate linear regression models (MLR) for KwaZulu-Natal were estimated for the aggregate model. Only those models that provided the highest overall model significance (as measured by the F-statistic) in each section were retained. In this section we discuss outputs from the aggregate model, as well as change in RRS by size class and technology, and by technology only. The results from the aggregate model indicate that the most significant contributors to changes in the RRS at KwaZulu-Natal WWTWs between 2008 and 2012 were the capital exceedance ratio, skills level and infrastructure cost.

3.3.1.1 Capacity exceedance ratio

The results indicate that a 1% increase in the capacity exceedance ratio results in a decrease in the RRS between 2008 and 2012 of 0.12%. This indicates that a high capacity exceedance rating does not play a major role in decisions affecting the lowering of the RRS. In other words, a high capacity exceedance does not in itself provide a strong incentive to reduce the RRS, although it does provide a slight incentive.

3.3.1.2 Infrastructure cost

There is a stronger relationship between an increase in the Refurbishment and Improvement (R&I) costs of WWTWs and the RRS. The cost coefficient in the regression equation indicates that if the R&I expenditure is less than R5m (NPV), then the RRS will decrease by 7.61%, if the R&I expenditure is between R5 and R10 million, then the RRS will decrease by 15.22% and if the R&I expenditure exceeds R10 million, then the RRS will decrease by 22.83%. These results indicate that there is a greater incentive for WWTWs to invest more in R&I, as this results in a greater reduction in RRS.

3.3.1.3 Skills level

Skills level was by far the highest contributor to changes in the RRS over time, but is also the hardest to interpret as the results at first glance appear counterintuitive. WWTWs with the lowest skills levels (in other words, the highest skills score) make the greatest contribution to reducing the RRS. It would appear that those WWTWs with low skills levels in 2008 are most likely to invest in capacity development, and this had the greatest impact on improving the overall RRS amongst KwaZulu-Natal WWTWs by 2012.

3.3.2 KZN WWTWs – Low-end technology models

The results from low-end technology models generated similar results. Therefore, they are discussed together. In all cases, only risk was found to be a contributing variable. As with the skills level variable discussed in the previous section, a somewhat counterintuitive outcome is that a *lower* risk score (in other words, a higher Green Drop rating) has a greater effect on changes in the RRS. From this we can deduce that the RRS of low-end technologies (ponds, lagoons) is more likely to improve in those WWTWs that have a higher Green Drop rating (i.e. a lower risk score). However, further analysis is required to understand the drivers that cause this.

The risk categorisation has a lesser impact on changes in the RRS at larger WWTWs – class size 2 compared with class size 1 (compare coefficients on equation 4 versus equation 2). In other words, larger WWTWs that have a higher RRS (i.e. have a lower risk score) experience a lower decrease in their RRS compared with smaller WWTWs that have the same high RRS (low risk score). This MLR model does not provide sufficient information to identify what the other drivers are for changes in RRS by class. All that can be said is that plant size does play a role.

3.3.3 KZN WWTWs – High-end technology models

For the high-end technology models, the skills level and the R&I cost rating had the greatest effects on lowering the RRS. This was in accordance with expectations as we anticipated that a greater investment in R&I would be associated with higher-end technologies, and consequently would have a greater effect on lowering the overall RRS. Significantly, R&I in size class 1 (coefficient = -22.19) had the greatest effect on lowering the RRS compared with high-end technology WWTWs in general (coefficient = -10.00) and R&I in the aggregate model (coefficient = -7.61). Skills level also played an important role in high-end technology WWTWs, since it is likely that those WWTWs that invest in high-end technologies would also have to invest in skills development.

A strength of the multivariate model is that, once developed, it may be used in a variety of contexts, provided the assumptions underlying the model is comparable. For example, MLR functions are often transferred from one country to another in order to estimate the value of benefits derived from environmental amenities and services, in what is known in the literature as benefits transfer estimation (e.g. Garrod & Willis, 1999). In the next section we discuss results from the baseline model that was developed for KZN WWTWs and applied to the ERWAT sites in Gauteng.

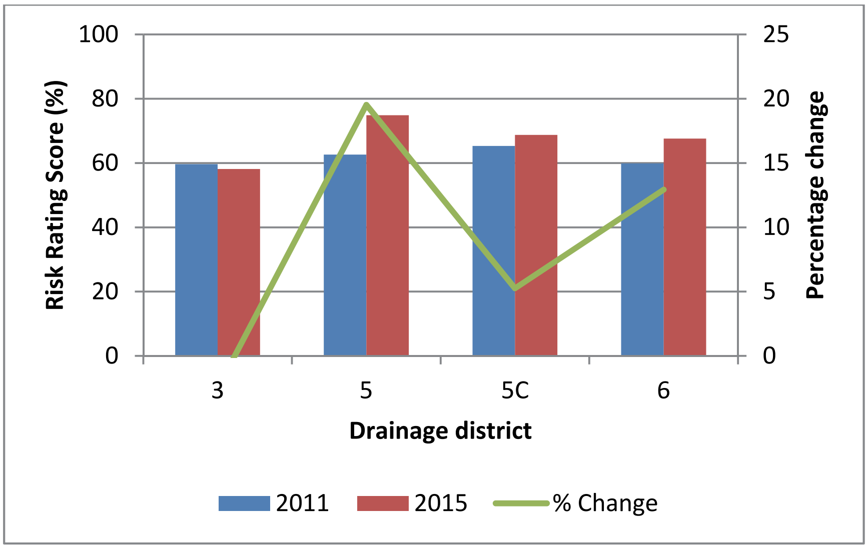
3.3.4 ERWAT WWTWs – Baseline model

3.3.4.1 WWTW level results

The KwaZulu-Natal model worked on a period of 4 years. With 2011 data available for the ERWAT sites, this implies that the forecast values of the RRS are applicable to the year 2015. Given the nature of the analysis conducted in the subsequent sections, only results based on the aggregate data are used. The datasets do, however, indicate that the majority of ERWAT WWTWs were performing well in 2011. The technical skill rating indicates that most WWTWs have the necessary technical staff for the management of the plants. Most of the WWTWs' current operational levels are below the plant capacity. Furthermore, there are no WWTWs with a RRS that is critical (in other words, a % CRR deviation of over 90%). The model developed in Section 3.2 does, however, indicate that it is those WWTWs that are currently performing well that may be most at risk of a decline in RRS by 2015. The reason for this is that, while there is little room for improvement in the RRS among those WWTWs that are already performing well, it is likely that WSAs will likely neglect these and rather invest in those WWTWs that are not performing well to improve their RRS. This is evident from the ERWAT data, where there was generally low levels of investment seen at the ERWAT plants based on the 2011 data, which suggests that, with growing populations in Gauteng, increasing pressures will come to bear on WWTWs and that plants will need to increase investment in R&I in order to increase design capacity and ensure that incidents of non-compliance do not occur. The next section provides results for the ERWAT baseline model distinguished by drainage district, size class and technology class.

3.3.4.2 Drainage districts

According to model predictions for the ERWAT site, the RRS for most drainage districts is expected to increase (i.e. worsen) between 2011 and 2015 (Figure 3.2). The greatest expected increase is in drainage district 5 (DD5), where the RRS is expected to increase by almost 20%. The only exception is drainage district 3 (DD3) where the RRS is expected to decrease marginally. Again, it should be emphasised that this trend is not based on current performance but expected future performance at these WWTWs based on existing levels of investment. All ERWAT WWTWs across all four drainage districts are currently performing well based on the 2011 RRS (Figure 3.2).

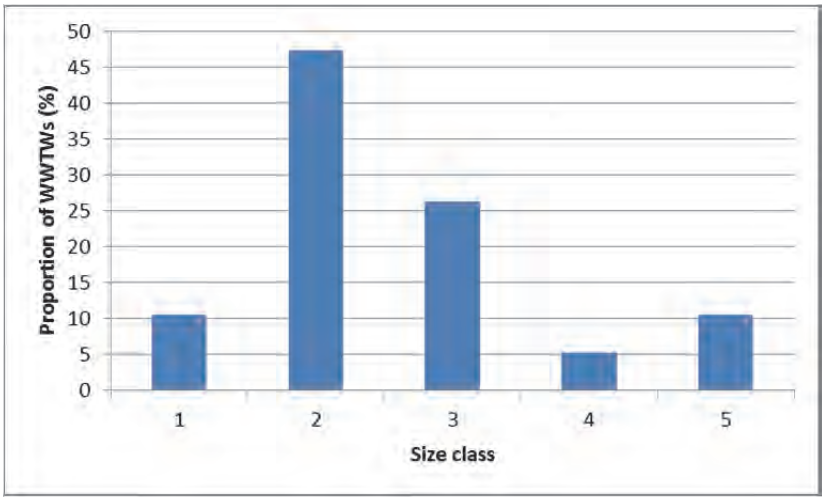


Key: DD3 = Northern drainage district; DD5 = Blesbokspruit drainage district (Ekurhuleni metro); DD5C = Blesbokspruit drainage district (Sedibeng district); DD6 = Rietspruit drainage district

Figure 3.2 Change in RRS by drainage district

3.3.4.3 Size Class

A notable feature of the ERWAT plants is the larger size classes of the plants compared with KwaZulu-Natal. Whereas in KZN the vast majority of WWTWs are in size class 1 (see Figure 3.1), most ERWAT plants are in size class 2 and 3 (Figure 3.3).



Key: Size Class: 1 = <5Ml/d; 2 = 5-20Ml/d; 3 = 21-50Ml/d; 4 = 51-100Ml/d; 5 = 101-200Ml/d

Figure 3.3 Size classes of ERWAT WWTWs

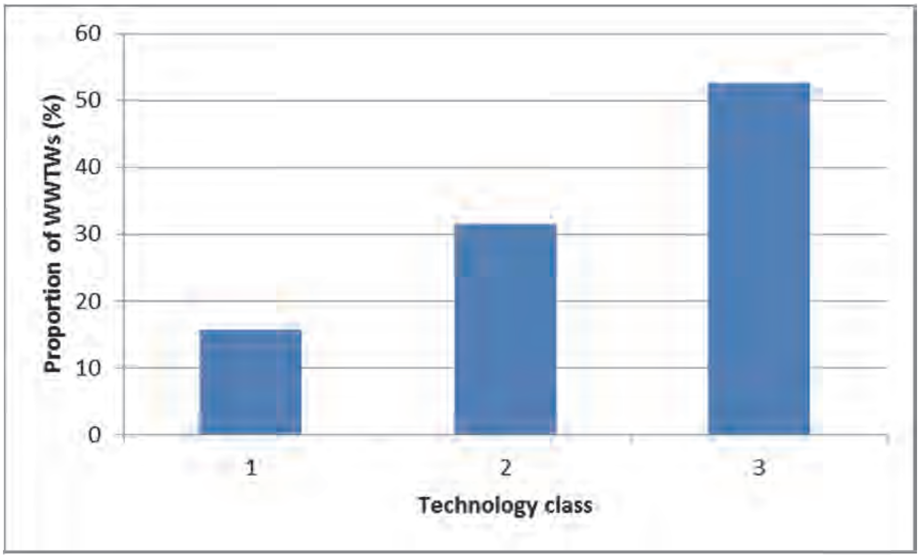
For all size classes at ERWAT plants the RRS is expected to increase between 2011 and 2015 (Figure 3.4). The greatest increase is expected in size class 2, followed by size class 3. Size class 1 shows the lowest expected increase in RRS from 2011 to 2015.

Key: Size Class: 1 = <5Ml/d; 2 = 5-20Ml/d; 3 = 21-50Ml/d; 4 = 51-100Ml/d; 5 = 101-200Ml/d

Figure 3.4 Change in RRS by size class

3.3.4.4 Technology Class

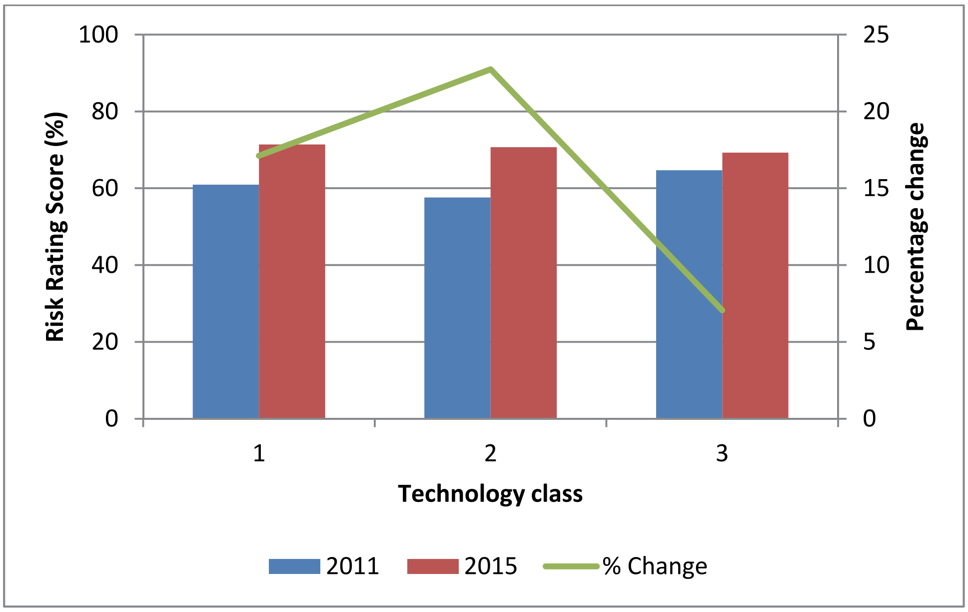
The majority (more than 50%) of ERWAT WWTWs use high-end technology (technology class 3, activated sludge), followed by technology class 2, trickling filters (Figure 3.5). Very few WWTWs use technology class 1, the lagoon and pond technology.



Key: 1 = Ponds & lagoons, 2 = trickling filters, 3 = activated sludge

Figure 3.5 Technology classes of ERWAT WWTWs

The greatest increase in RRS (thus worsening) is expected for technology class 2, followed by technology class 1 (Figure 3.6). This is in accordance with expectations, as technology class 2 is older wastewater treatment technology, coupled with low investment in R&I, potentially resulting in adverse consequences for the performance of WWTWs (as measured by the RRS) down the line. Technology class 3 requires the lowest levels of investment and consequently results in the lowest changes in the RRS over time.



Key: 1 = Ponds & lagoons, 2 = trickling filters, 3 = activated sludge

Figure 3.6 Change in RRS by technology class

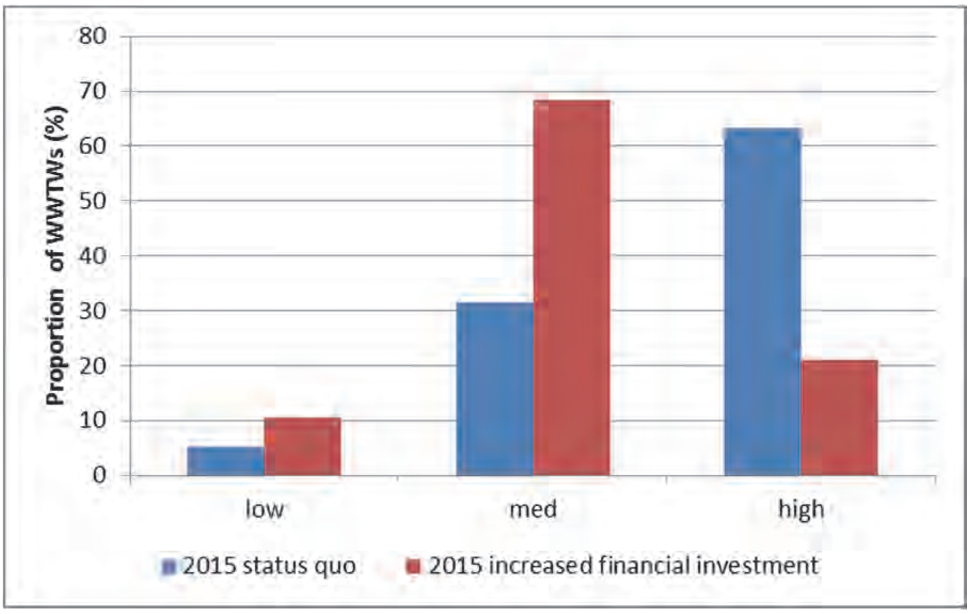
3.3.5 ERWAT WWTWs – Scenario: Increase in plant investment

3.3.5.1 Overview

In the previous section it was noted that although ERWAT WWTWs plants are generally performing well, there are low levels of investment in R&I. In this scenario, we model an across-the-board increase in the NPV of expenditure on R&I to at least R10 million (equivalent to the maximum NPV tier of 3 in the model). In this section, results are compared by drainage district, size class and technology class, as well as comparing the baseline 2015 simulation (status quo) with a 2015 scenario based on the higher investment expenditure. In the next section results are also compared by risk category.

3.3.5.2 Risk category

The first comparison between the baseline and increased investment scenarios is undertaken using the same risk categories as in Section 2.2. Figure 3.7 indicates that the proportion of WWTWs in the high risk category decreases while those in the medium and low categories increases under the increased investment scenarios. Significantly, those WWTWs in the high risk category decrease from more than 60% to approximately 20% under the increased investment scenario (Figure 3.7).

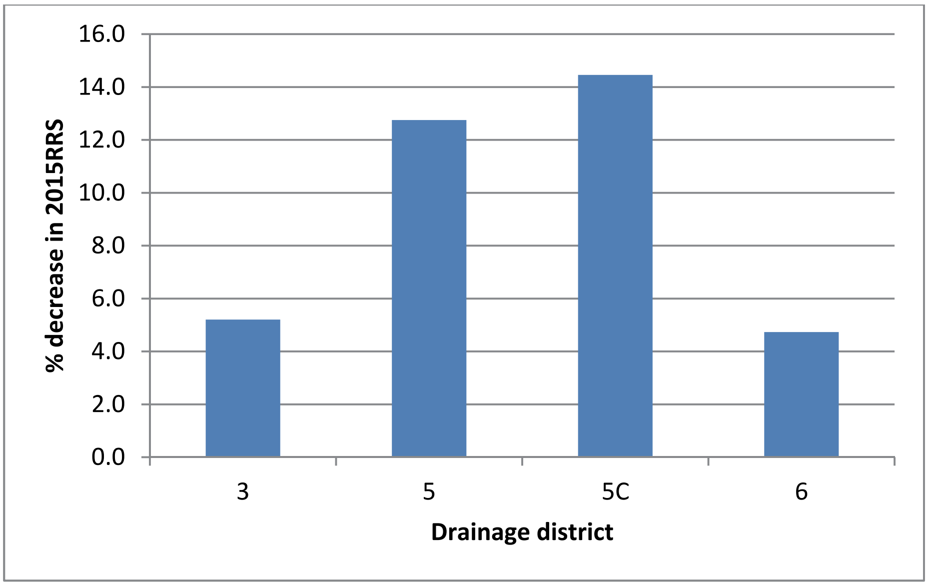


Key: risk category based on how close the risk rating score is to the maximum cumulative risk rating: low=<50%; medium=50-70%; high=70-90% (see Section 2.2 for elaboration)

Figure 3.7 Change in Risk Rating Score by risk category

3.3.5.3 Drainage district

Greater investment in R&I is likely to have the greatest benefit to WWTWs in DD5C, followed by DD5 (Figure 3.8). In both of these drainage districts, the RRS is expected to decline by more than 12%.

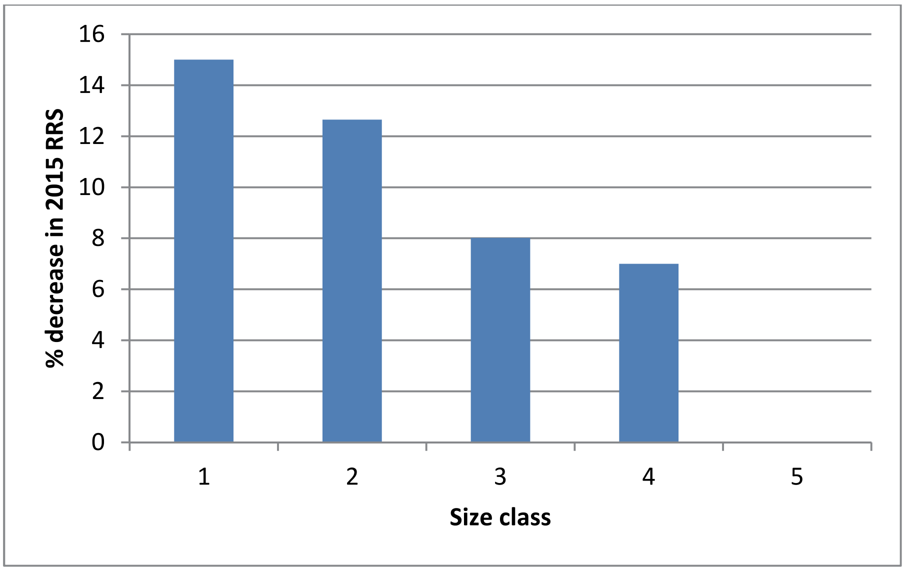


Key: DD3 = Northern drainage district; DD5 = Blesbokspruit drainage district (Ekhurhuleni metro); DD5C = Blesbokspruit drainage district (Sedibeng district); DD6 = Rietspruit drainage district

Figure 3.8 Change in Risk Rating Score by drainage district

3.3.5.4 Size class

The results suggest that improved financial investment will have a greater proportional benefit for smaller WWTWs. The RRS decreases by 15% for size class 1 WWTWs, followed by 13% for size class 2 (Figure 3.9). The decrease in RRS is generally less as size class increases.

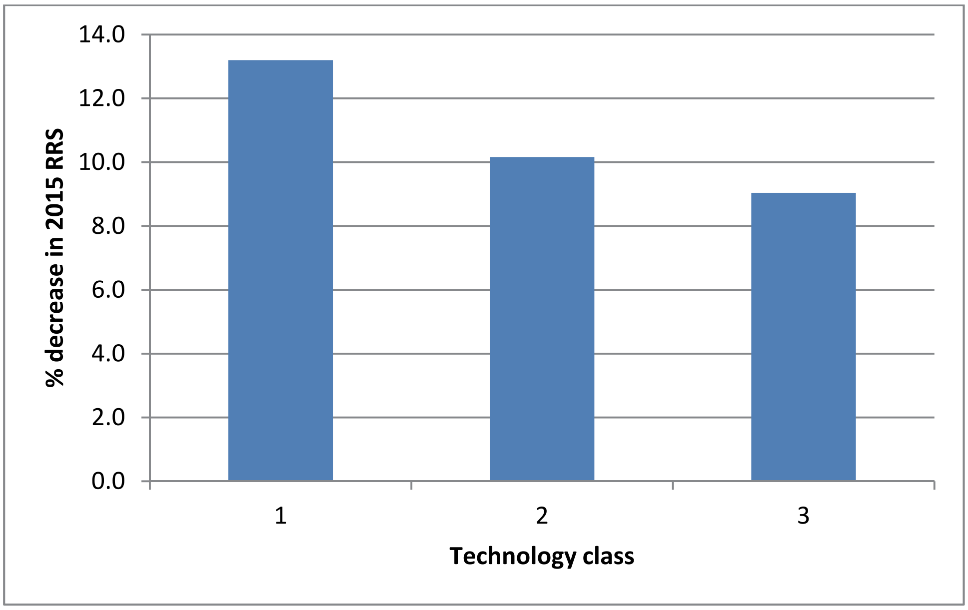


Key: Size Class: 1 = <5Ml/d; 2 = 5-20Ml/d; 3 = 21-50Ml/d; 4 = 51-100Ml/d; 5 = 101-200Ml/d

Figure 3.9 Change in Risk Rating Score by size class

3.3.5.5 Technology class

As with size class, those WWTWs that employ low-end technology benefit more from financial investment compared with those plants that use high-end technologies. WWTWs without treatment plants or those using ponds experience an increase in RRS of 13% under the financial investment scenario (Figure 3.10). WWTWs using high-end technologies still experience a sizeable 9% decrease in RRS compared with the status quo estimation.



Key: 1 = Ponds & lagoons, 2 = trickling filters, 3 = activated sludge

Figure 3.10 Change in Risk Rating Score by technology class

3.4 Salient/emerging facts

The following key facts emerged from the analysis above:

- This chapter discussed a multivariate linear regression model that was developed using data from KwaZulu-Natal WWTWs. The model found that the factors most affecting the future Green Drop Rating (GDR) in KwaZulu-Natal were:
  - skills availability,
  - effluent treatment levels in relation to plant capacity,
  - investment in R&I and
  - the risk category of the plant.
- Results were presented using the Risk Rating Score, which is the inverse of the Green Drop Score. Here we summarise the findings by once again making reference to the Green Drop Rating as this is more intuitively understood:
  - An overall evaluation of the model suggests that it is useful for scenario analysis and policy simulation, but is crude and inflexible and therefore cannot be applied to all WSAs throughout South Africa.

        - However, since the Green Drop initiative is relatively new, an important objective of the model was achieved, namely to identify critical drivers affecting the GDR. The model also highlighted areas requiring future work.
        - The KZN data indicated that those WWTWs that were performing poorly in 2008 were most likely to experience significant improvements in their GDR over time, but this was only a factor in low-end technology models and further work is required to understand what the other drivers for this were.
    - The model was then applied to the 19 ERWAT WWTWs in Gauteng and a number of baseline results were generated. Results were distinguished by drainage district, size class and technology class.
        - The ERWAT sites generally performed well in 2011 but were characterised by low investment in R&I.
    - The model was then used to simulate the cost to maintain and/or improve the functioning of ERWAT WWTWs, namely to identify which variables have to be improved by how much to improve the GDR using "what if" type scenarios.
        - Only one scenario to assess the financial implications of improving the performance of WWTWs was possible, namely an increase in cost to an NPV of at least R10m over a 20-year period (tier rating 3). The crudeness of the model implies that it is not possible provide an indication of how much additional investment is required to get the GDR to an acceptable standard, only to measure the implications of raising the NPV to tier rating 3.
        - This study ran the increased investment simulation described above and found significant potential improvements in the GDR over time for those WWTWs.
        - These improvements were then distinguished by size and technology class of the WWTWs.
        - The ERWAT sites in particular are likely to benefit from improved investment in R&I as the necessary skills are, for the most part, already in place to manage this process
    - The study suggests that investments in R&I could result in positive improvements in the GDR of ERWAT WWTWs when compared to the expected 2015 levels.
    - It should be noted, however, that these improvements are on the back of an expected worsening of GDR over time for many WWTWs between 2011 and 2015 under the status quo.

The above analysis clearly points to the need for future investment and hence Chapter 4 considers different pricing and financing mechanisms for achieving this investment.

3.5 Conclusion

This chapter has analysed the main drivers affecting the Green Drop Rating (GDR). The drivers hypothesised included: the capacity of the wastewater treatment plant, the capacity utilisation, the type of technology, the capital budget, the operational budget, the number of members of staff, the years' of experience of the senior management of the plant, variables incorporating risk and various size and technology class variables. A range of potential drivers were analysed in a series of multivariate linear regression (MLR) models: i) an aggregate model; ii) models distinguished by the size class of the plant and iii) models distinguished on the basis of technology class. The MLR model enables the establishment of those variables that make a statistically significant contribution to the GDR. In other words, a driver is identified as a variable that is significantly different from zero in the model. The results were as follows:

- In the aggregate model, skills, the capacity exceedance ratio and cost were the main drivers affecting changes in the Green Drop Rating.
- For low-end technology models, the risk rating score was found to be significant, irrespective of the size class of the wastewater treatment work.
- For high-end technology models, skills and the cost of improving WWTWs were the main drivers. Again, this was irrespective of the size of the plant.

The model therefore demonstrated statistically that capacity constraints, budgets and skills levels pose the major challenges to WWTWs wishing to improve their GDR. These are not new findings, but emphasise the urgent need to give attention to these issues.

Chapter 4 Pricing and financing mechanisms

4.1 Introduction

Improvements in WWTWs are accomplished through the interaction between pricing and financing options, where:

- Pricing options include instruments used to raise finance such as taxes, subsidies and charges.
- Financing options indicate sources or methods applied from which capital is derived and disbursed to upgrade WWTWs. These include bonds, loans and public-private partnerships (PPPs).

Annexure 1 provides a comprehensive list of these pricing and financing mechanisms, as well as the advantages, disadvantages and examples of applications. Some of the most noteworthy options are the following:

- Pricing options:
    - Taxes: These are charges, usually levied by central government on individuals and businesses, with the specific purpose of raising funds for the activities of the state and parastatal organisations.
    - Fees/Charges: A fee or a charge is a levy charged by government. Ideally, money raised from these mechanisms should be earmarked for green investments.
    - Wastewater discharge charge system (WWDCS): A targeted measure based on the polluter pays principle aimed at promoting waste reduction and water conservation. It forms part of the Pricing Strategy and is established under the National Water Act (Act 36 of 1998).
    - Development charges: Used mostly for new developments whereby the developer gets the right to operate a service at a charge, but the capital cost of the service delivery cost is made part of the initial development cost.
    - User pay: Make use of user charges to pay for the services delivered, i.e. directly requited payments linked to a specific quality and level of service delivered.
- Financing options:
    - Public-Private Partnerships (PPPs): Long-term contractual agreements between a private operator/company and a public entity, under which a service is provided, generally with related investments.
    - Bonds: The issue of bonds directly related to green infrastructure development.
    - Ecosystem-based and/or environmental financing mechanisms, e.g. carbon finance: The use of carbon-related instruments such as carbon markets to raise revenue for green investment.
    - Loans or capital access programmes: Borrowing money from the private sector or national government.

  - Grant/donor financing: Contributions made by the civil society and/or major international donor agencies.

Important factors that determine which pricing and financing options to select include the following:

- The costs, both to the implementing entity as well as the recipient, of the pricing or financing option.
- The ease with which these measures can be implemented and enforced.
- Whether or not the implementing entity has the capacity to implement and enforce such a pricing and financing mechanism.
- How well the money raised can be earmarked for the specific improvements in the WWTW (some instruments such as taxes are more broad-based than specific targeted interventions such as the WWDCS).
- The riskiness of the financing option (e.g. the issuance of shares and other forms of private sector funding are higher risk and more volatile than longer-term sources of funding such as bonds and donor/grant funding).
- Whether or not repayment of the disbursement is required. This also adds to the riskiness of financing option.
- How pricing influences short- and long-term polluting behaviour.
- Whether pricing provides an impetus for switching to less polluting technological alternatives.
- Whether the higher costs of operations is balanced by lower damage costs to the environment and human health.
- Which organisations are responsible for paying higher prices and who receives the benefits of lower pollution.
- The popularity of such an intervention with the general public (for example, taxation may be less popular than subsidies, there may be a public outcry over excessive State indebtedness).
- Loan repayment conditions, for example interest and/or other conditions.

The purpose here is not to select the definitive option and/or combination, but to provide an overview of the options. For any option, decision-makers will first have to consider the implications of investing in any form of WWTW improvement, expansion or new development, and then they have to consider the best combination bearing in mind that such combination might involve the deployment of new and emerging pricing and financing options.

4.2 Implications of investing in WWTW or not

The South African government has embarked on an R844bn infrastructure investment programme for the country, motivated by its key role in enabling socio-economic development, economic growth and job creation (DBSA, 2012; Department of Economic Development, 2010). R75bn or 8.9% of this investment is earmarked for the water and sanitation sector.

DWA (2009a) performed a high-level costing analysis and estimated that capital investments of R16bn is needed for the period July 2009-June 2016 to refurbish and extend the immediate needs of South Africa's WWTW. An additional R1bn per annum operational and maintenance expenditure was needed in the existing budgets of Water Service Authorities at that time. These figures must be seen in context of the size of the wastewater management industry in the country. According to the first Green Drop report released in 2009, the industry survey comprises of 852 municipal bulk treatment plants, pipe networks and pump stations treating 7 589Ml of wastewater on a daily basis (DWA, 2009b). According to DBSA (2012) there are approximately 2 000 WWTW in the country. The estimated capital replacement value of the WWTW is >R23bn and estimated OPEX >R3.5bn per annum (DWA, 2009b). The sector operates at 80% of its design capacity, with the 20% 'surplus capacity' not readily available due to inadequate maintenance and operational deficiencies. DBSA (2012) estimates that the total investment in sanitation infrastructure is R73bn, with WWTWs accounting for 26% and sanitation accounting for 47% thereof. A further 11% goes to the sanitation refurbishment budget and 16% to bulk sanitation infrastructure. It is clear from these high-level costs that a considerable proportion of the wastewater infrastructure is due for refurbishment and a substantial increase in operational costs is required.

From the poor state of the country's wastewater infrastructure and the large requirement for refurbishment, it should not be surprising that water resource pollution is recognised as one of the top ten water sector challenges (DBSA, 2012). Wastewater treatment is already included in the country's infrastructure spending plan, but the question remains whether these resources are sufficient to deal with the problem and how to achieve the most with the available resources. The rehabilitation of sewerage infrastructure, specifically WWTW, is seen as a crucial intervention in reducing pollution of the environment, improving the quality of water resources and reducing the risk to humans. The main rationale for investing in WWTW is the impact of untreated water on ecosystems, human health and the socio-economic welfare of the country in general.

The consequences of the impacts on ecosystems and human health carry economic costs to society and need to be included in any economic analysis of investment and financing options. Figure 4.1 provides one typology of such economic costs, including for degradation of ecosystem services, health-related costs, impacts on economic activities such as agriculture (decrease agricultural fruit and crop yields and quality), industrial production, tourism, increased water treatment costs, and reduced property values (Palaniappan et al., 2010:33).

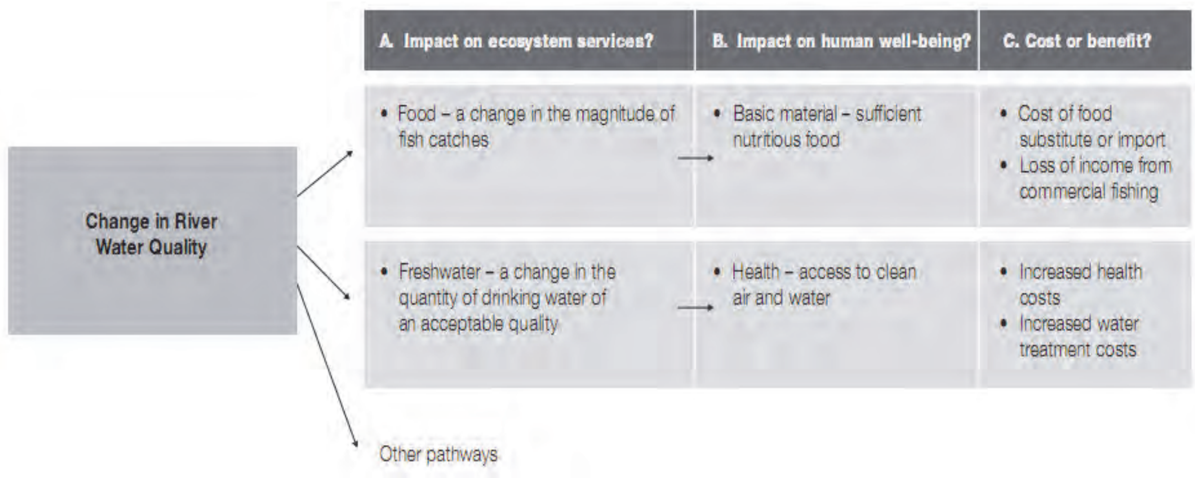


Figure 4.1 Possible impact pathway for a change in river water quality including potential economic costs

Source: Pintér et al. (2007)

One example of the South African context is documented in Roux et al. (2010) who performed a study in the Crocodile-West Marico water management area and found that pollution reduces the quality and, therefore, the economic value of the available water in the area in question. Technology needs to be updated based on the worsened quality of intake water, and the cost of such technology upgrades is one indicator of the financial impact of pollution in the Crocodile-West Marico water management area.

The consensus in the South African literature to date is that the impact of eutrophication on property prices is not really discernible, although its impact on property prices could not be ruled out (Sibande, 2011; Mostert, 2009; De Villiers, 2009). It has been established that eutrophication does have an economic impact on agriculture and water treatment (Sibande, 2011). However, these studies are all limited to the outcomes from statistical regression analysis and would benefit from a more dynamic treatment. Despite the limitations of these studies, Graham et al. (2011:ix-xii) (based on aforementioned studies) conclude the following:

1. The estimated relationship between **agricultural costs** and eutrophication was relatively weak. However, it was shown that eutrophication did contribute to total agricultural costs. Furthermore, it is likely that this relationship was actually underestimated as a result of data and model limitations.
2. From the **water supply services treatment cost model**, the estimated relationship between water treatment costs and eutrophication (nitrogen and phosphorus levels) was statistically significant and showed that a 10% increase in nitrogen present in the water would result in an increase in water treatment costs of 3.2c/kl. A similar increase in phosphorus present in the water would lead to a 5.0c/kl increase in water treatment costs.
3. The investigation into the **relationship between raw water quality and the chemical costs of producing potable** water identified the main drivers of chemical water treatment cost for the Zuikerbosch treatment plant to be both the combined effect of the levels of chlorophyll, pH and nitrate loadings in raw water, and the combined effect of water hardness, calcium, magnesium and sodium. From the model results, a 1% increase in raw water nitrate, *ceteris paribus*, would result in an increase of R207 841.95 per annum (i.e. R0.285*1 998ML*365 days) in chemical water treatment costs provided that Zuikerbosch treats water at a daily average of 1 998ML per day. Total hardness, calcium and turbidity were identified as the main drivers of chemical costs of water treatment at Balkfontein. An increase of 1% in raw water turbidity, *ceteris paribus*, could raise chemical water treatment costs by R249 003.00 per annum (i.e. R1.895*360ML*365days), provided that Balkfontein treats water at its full capacity (i.e. 360ML per day).
4. The study of the **impact of algae blooms on water treatment costs** indicated that algal blooms can be expected to increase water treatment costs by as much as five to 10 times.
5. The **property price** models showed that increased levels of ammonia present in the water would lead to a reduction in the price of property for all three study areas. The estimated coefficients for the chlorophyll 'a' and nitrite/nitrate variables were generally not statistically significant.
6. The costs to **recreation** associated with eutrophication were described using estimated willingness to pay (WTP) values for improved water quality by visitors to the three dams. Visitors to the Bloemhof Dam would be willing to pay between R25 and R47 (per person per night's stay) for water quality improvements, visitors to the Vaal Dam would be willing

to pay between R37 and R69 and the WTP values for Grootdraai Dam were between R46 and R86. Furthermore, many of the respondents to the Vaal (68%) and Grootdraai (45%) Dam surveys indicated concern for the water quality of these two dams.

7. In terms of the **integrated model**, the relationship between eutrophication and the various sectors (property, agriculture and water treatment) affected by eutrophication was difficult to establish. However, it was possible to determine functional relationships between eutrophication and economic costs, especially linked to years in which the average eutrophication level exceeded the stated Resource Water Quality Objectives (RWQO). The estimated costs vary from relatively low to as much as R2 900/ha/year for agriculture, R1.44/kl for water treatment and R18 800/m^2 with respect to residential property prices.
8. The various analyses within this study show that eutrophication has an economic impact on the sectors of agriculture, property, recreation and water treatment and in a number of instances these impacts are significant. For example, algal blooms can be expected to increase water treatment costs by as much as five to 10 times. In addition, several of these analyses underestimated the relationship between eutrophication and the particular economic sector and it can be expected that the costs of eutrophication presented in this study are even higher in reality. Furthermore, ecosystem costs of eutrophication and costs associated with the control and monitoring of eutrophication as well as costs linked to eutrophication policy and strategy development are yet to be determined.
9. The application of both the integrated model (in calculating the costs if exceeding RWQOs) and the water treatment cost model developed by Gebremedhin (2009) demonstrate that the research undertaken in this study can be practically applied and used to inform policy and strategy development.

Despite the tentative evidence on the actual economic costs of declining water quality, partially driven by failing wastewater treatment, investment decisions need to be informed as well as possible. One option is to select those investments that have the least impacts on ecosystems and human health and to select those financing options where costs can be easily recouped. Therefore, the substantial investments required and the broader implications of failing WWTW on ecosystems and human health raises further questions on the nature and timing of wastewater infrastructure investment, such as the following:

- Over the timeframe of re-investment in the sector, what would be the appropriate investments leading to the least impact on ecosystems and human health at the lowest cost?
- What are the options for financing such investments and mechanisms to recoup the costs of such investments through various pricing options?

Traditional engineering solutions to WWTW is one option, although these are often capital intensive. Solutions also need to be sought for improving the operational efficiency of wastewater treatment infrastructure as well as other aspects such as investing in ecosystems to increase the ability to absorb the increased levels of nutrients when wastewater treatment fails. The type of intervention will have implications for the financing options. Standard engineering solutions can be financed like any other infrastructure. Investments in biological treatment or broader river ecosystems may, however, open up possibilities on green infrastructure financing such as green bonds and payments for enhanced ecosystem services. An evaluation of the costs and benefits of alternative intervention options over time is needed to inform the choice of options and the timing of such options.

Not all additional investments in WWTWs are economically feasible though. With budget constraints, the choice where to invest and how much to invest in improved WWTW remains very relevant. WWTWs also do not operate in isolation and there are several other polluters in most river systems, including industries, power generators and agriculture, who are also responsible and share the burden of improving river quality. One way to achieve a fairer distribution of investment is to create the right incentives to take action. The incentive for investing in WWTWs, for example, might come from stricter enforced legislation, raising the costs of pollution through higher discharge charges, placing a price on nutrients and phosphates by introducing a cap on the amount that may be discharged in any given water system and give all polluters the right to buy and sell permits, or a combination of these. The World Resources Institute (WRI) performed a study on the last-mentioned option and concluded that the trading of a nutrient is an economically feasible approach to reduce the costs of meeting water quality goals in the Gulf of Mexico (Perez et al., 2013). Such options must be researched in more detail for South African situations with rapidly deteriorating water quality, multiple polluters, serious budget constraints and, by implication, constraints on the type and scale of technology that can be employed.

4.3 Finding new ways to finance WWTW: Some suggestions

4.3.1 Technologies

The process of wastewater treatment comprises a number of stages which may be broadly divided into preliminary treatment, primary treatment, secondary treatment, tertiary treatment and sludge treatment. There is a selection of technologies which may be employed in each of these stages and the technology employed is a matter of choice. As a result, no two plants (necessarily) employ the same sequence of technologies in the various stages of the process.

Van der Merwe-Botha and Quilling (2012, Table 4.1) generated a 'simplistic table' for the various types of treatment technologies found on the WWTWs that they surveyed. The treatment technologies are graded as "low", "medium" or "high" based on their expected effluent quality results and the level of capital and operational costs, power consumption and maintenance requirements. The technologies described are classified by their place in the treatment process (preliminary, primary, secondary, tertiary and sludge treatment). The full table of technology options is available in the above publication, but for the purpose of this review we selected technologies from the primary and secondary and certain technologies from the tertiary and sludge treatment stages (see Table 4.1). Those technologies not recommended have been omitted.

Table 4.1 Technology type and summative level of technology

TECHNOLOGY TYPE	SUMMATIVE / GENERAL COMMENT ON TECHNOLOGY
PRIMARY TREATMENT	
Primary settling	Low to medium
Flow balancing	Low to medium
SECONDARY TREATMENT	
Trickling filter	Low to medium

TECHNOLOGY TYPE	SUMMATIVE / GENERAL COMMENT ON TECHNOLOGY
Rotating biological filter	Medium
Pasveer ditch	Medium
Oxidation ponds	Low to medium
Wetlands	Low to medium
Extended aeration	Medium to high
Biological nutrient removal / activated sludge (AS)	High
Surface aeration (for AS)	Medium to high
Fine bubble aeration (for AS)	Medium to high
Sludge fermentation	Medium to high
Clarification	Low to medium
TERTIARY TREATMENT	
Chlorine gas disinfection	Medium
Maturation pond	Low
SLUDGE TREATMENT	
Gravity thickening	Medium
Thickening by dissolved air flotation	Medium to high
Aerobic digestion	Medium to high
Anaerobic digestion	Medium
Belt press dewatering	Medium
Solar drying beds	Low
Centrifuge dewatering	Medium to high
Composting	Low to medium
Pelletisation	High
Disposal to land	Low

Source: Modified from Van der Merwe-Botha and Quilling (2012).

The above are all technologies which are in use, in general. While Table 4.1 is not meant to be comprehensive, one notable omission that could be of interest within a South African context is a biotechnology which has been tested internationally (although not locally yet) namely that of floating islands. We will discuss this biotechnology in more detail in Chapter 5.

4.3.2 Financing

The above suggests the need to think afresh with respect to the way in which the financing and pricing needs are addressed with respect to WWTW infrastructure development.

New financing options that have come to the fore in recent years with respect to green infrastructure include aspects such as Payments for Ecosystem Services and Green Bonds. These have rarely been applied to investment related to and/or in WWTWs. In considering these, one has to ask what is the purpose, the rationale, of WWTWs. Here it is assumed to be the treatment of wastewater to an acceptable level or standard; to reduce the level of nutrients, chemicals and other water-borne pollutants in the wastewater to levels acceptable to society and the environment before discharging the effluent water into the ecosystem.

It should be noted that South Africa is an ever-developing and expanding economy. This implies that, in addition to the increase in the number of users of water and hence the producers of wastewater, there is a very high likelihood of the increase of the economic use and hence associated contamination of water. To meet the objective of reducing the level of pollution to acceptable levels, the following can be considered:

- The introduction of new capital infrastructure.
- The use of ecological engineering, either on- or off-site.
- The improvement of the existing wastewater infrastructure either through improved maintenance of capital equipment, or through improved skills and the number of experienced managerial personnel.

It is within this context that special attention should be made to the application of eco-friendly and/or related biotechnologies, whether or not within the context of Payments for Ecosystem Services or Green Bonds, for example.

The challenge of water resource protection is linked to the variability of water quantity as well as the human impacts and poor management of the resource. The protection of water resources is necessary for securing ecosystem services for economic development, growth and protection of human and animal health (NWRS2, 2012).

Eco-friendly biotechnologies and the application of Payments for Ecosystem Services

Payments for Ecosystem Services have been made famous, most notably, by the advance of the carbon market. In close pursuit, however, is the development of water markets and markets for renewable energy, such as hydro-electricity generation, whereby land users are compensated to manage the land in such a way as to improve the land cover – thereby reducing siltation leading to the extension of the power plant's operational life. Much less well-developed, however, is the contribution Payments for Ecosystem Services can play with respect to water treatment. Within this context it is important to distinguish between the technology use, compliance issues and the payment mechanism.

Green Bonds

Green Bonds are financial debt instruments applied to green infrastructure and yielding positive socio-ecological externalities. Although these positive socio-ecological externalities are often not valued or quantified, they do exist, for example renewable energy having multiple benefit streams. The environmental and social benefits are additional to the financial returns a project is rendering.
In the short-term, Green Bonds could change the market conditions for environmental-related enterprises. Such an option is depicted in Figure 4.2, which provides an example of how Green Bonds enable this change in the energy sector. The high cost of capital and lack of financial mechanism mean that renewable energy production will not be market-viable for a long time. Given the immediate need for renewable energy (from both an environmental and competitiveness perspective), Green Bonds could provide governments with a solution to raise capital.

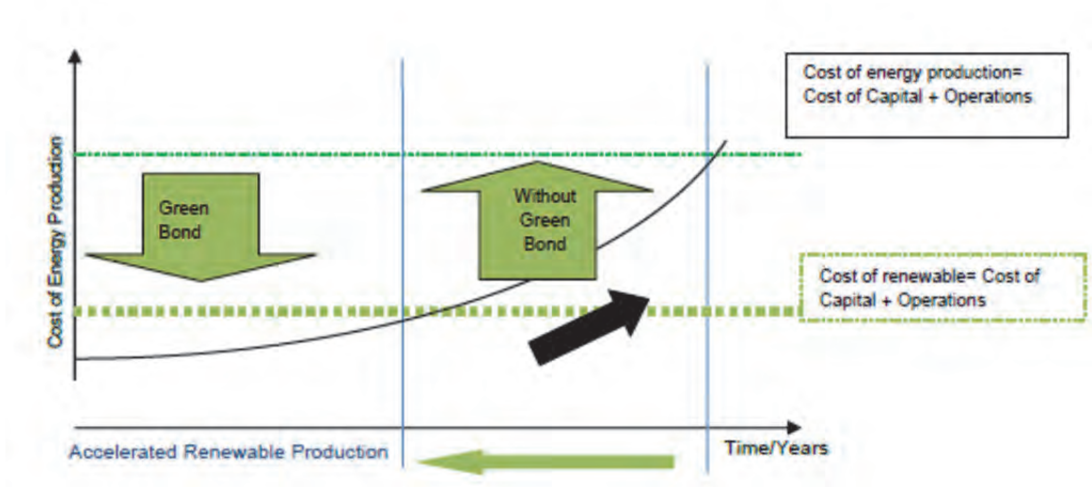


Figure 4.2 Cost of energy production with and without Green Bonds
Source: Fine et al. (2009)

As more capital gets invested in renewable energy technologies, there would be excess grid energy available for consumers and that would lower the price of energy. Government-backed Green Bonds could accelerate countries' ability to attain their sustainable development objectives by raising capital for green infrastructure and reducing the risk for capital investment. In Figure 4.2, Green Bonds demonstrate the potential to reduce the total cost of producing renewable energy today, ensuring that renewable energy generation becomes price competitive in the near future. The lowered cost of debt capital lowers the cost of renewable energy production such that it competes with fossil-based sources in the near future.

Applied to WWTWs, this implies that the Green Bond would reduce the cost of capital, and accelerate the introduction of new technologies. This is largely because of the reduced risk in the investment and the added benefits such an investment will bring to society.

4.3.3 Markets for nutrients

A development over the past two decades that has much potential yet without any applications in South Africa is an emissions or effluent "cap-and-trade" programme. Internationally, however, there are various examples of such programs (see Annexure 2) in the water quality sector. A "cap-and-trade" programme is an emissions or effluent/nutrient trading system with the aim to reduce pollution discharges in the most efficient way possible.

An authority, often related to the government, will exogenously determine a limit (or cap) of the permissible pollution. This cap is either sold or allocated (also called grandfathered) to polluting firms and essentially represents a pollution permit as it represents the right to discharge a specific volume of a pre-specified pollutant. At the end of an accounting period, often a year, an audit is conducted to confirm that the discharge of the pollutant is either less than or equal to the firm's number of permits. In the event that the firm has more permits than its actual pollution, it may sell those surplus permits to a firm that requires, or has a shortage of, permits. A firm might also decide to bank the surplus permits either for selling them when the price is higher or for their own use later. The transfer of the permits is the "trade" component under the "cap-and-trade" system.

A firm that has a shortage of permits, therefore, buys permits and is pays a charge for polluting. The seller, on the other hand, is rewarded for having discharge levels below its set "cap". Those firms that can reduce pollution discharges cheaply will do so and benefit from selling permits. Those for whom it is difficult and expensive to reduce its discharges, will find that buying permits might be cheaper, i.e. more efficient. Overall, however, a reduction has been achieved by meeting a cap. If a buyer is unable to buy enough permits, there might be high and punitive penalties.

Determining the cap is an important regulatory process and the cap might be revised periodically (e.g. every five years) to achieve new environmental targets or industry norms. The system's efficiency lies in the fact that there is a strong financial incentive for reducing pollution discharges in the most cost-effective way possible. Its disadvantage is that highly localised pollution, such as mercury, has to be traded among firms in the same geographic area and/or catchment if the impact thereof is to be reduced at a local level. In other words, to reduce the nutrient levels of a particular river, the WWTWs in that specific catchment will have to trade within the river's catchment area.

4.4 Synthesis and salient facts

A range of pricing and financing options to assist WWTWs to improve their respective Green Drop scores were considered. As there is an urgent need to improve and upgrade many of the WWTWs in South Africa, alternative options that could be considered, that have not yet received much attention, were discussed.

These options include Payments for Ecosystem Services, and/or the introduction of a pollution discharge system. With the consideration of these it would be possible to integrate both financial efficiency considerations as well as environmental objectives.

Attention should also be given to the introduction of biotechnologies such as floating islands, which could be used either on-site (i.e. on the WWTWs oxidation or maturation ponds) or off-site (i.e. in the river system). The introduction of these biotechnologies could coincide with implementing Payments for Ecosystem Services, such as for the reduction of nutrient loads using wetlands, and pollution discharge trading systems.

A range of innovative pricing and financing mechanisms for assisting in dealing with the implications of the rapid growth in urbanisation and economic development has recently emerged. Applying such options would also assist in reducing the pollution discharges and assist in achieving the much required environmental outcomes. It is, therefore, recommended that WWTWs strongly consider implementing such in addition to their on-going engineering solutions linked to R&I and expansion.

4.5 Eco-friendly biotechnologies

South Africa does not have the dilution capacity to cope with the effluent from large WWTWs. This combined with the fact that the population centre in Gauteng is sited on the continental divide has resulted in the rivers draining the conurbation being highly polluted, leading to a deterioration in environmental health with concomitant decline in the provision of ecosystem services on which the socio-economy relies (DWA, 2009c; MEA, 2005). The water quality deterioration resulting from this pollution causes a substantial cost to the economy (Graham et al., 2011). The situation is exacerbated by the fact that a number of the WWTWs are not performing as they should, in part as a result of infrastructure that is in need of refurbishment.

Ecological infrastructure, a concept which is gaining increasing recognition, may be employed as part of the arsenal to address the gap in treatment capacity currently plaguing the national inability to meet the required water quality in the environment.

There is a need for the development of new high-rate biotechnologies to improve the capacity to polish or treat waste streams. For some time wetlands have been used as a treatment biotechnology for small works or a polish for the effluent from larger works. This biotechnology has constraints in that the land-based wetlands are low rate, so require a large land area. Land is expensive in the vicinity of urbanised areas, and sufficient land which is flat enough to accommodate the required area of wetland may not be conveniently available. In the same way that the bacterial processes which mineralise urban wastes have been developed to become high rate in the activated sludge biotechnology, so have wetlands been developed to become high rate in the Biohaven® Floating Island biotechnology.

The employment of this technology in tandem with conventional activated sludge or biofilter biotechnologies has been investigated in this study and is reported in detail in Annexure 3.

Chapter 5 Conclusion

This study's aims were to understand the following:

1. What is needed to improve the quality of service rendered by wastewater treatment works (WWTWs)?;
2. What is the risk of not doing so?; and
3. How could this risk be mitigated?

There are many reasons for improving the performance of wastewater treatment works. Firstly, to ensure that there is sufficient water, in both quantitative and qualitative terms, to support South Africa's path of growth and development. Secondly, to ensure that a sustainable supply of water is achieved to meet basic human needs as well as other uses of water, so that every person in South Africa may have access to potable water. This basic right to water is enshrined in the Constitution. Thirdly, wastewater is treated to preserve the ecological integrity of the river system as a whole. Fourthly, the health and livelihoods of downstream users be they rural communities, urban, agricultural or industrial, depends on the quality of the treated wastewater. Poorly treated wastewater is likely to spread disease, cause eutrophication and increase treatment costs for downstream users.

The method used to achieve the first stated aim of this study focused mainly (although not exclusively) on the Green Drop certification system of wastewater treatment works. The Green Drop certification process is an incentive-based approach aimed at raising the performance of municipal wastewater service providers. It is therefore a critical means of understanding how to improve the quality of service rendered. A detailed analysis of Green Drop reports were therefore undertaken, as well as an analysis of DWA priority (risk-based) matrices for Kwazulu-Natal and Gauteng ERWAT WSAs and their WWTWs. An important facet of the work was then to make recommendations on how to implement improvements in service quality rendered by WWTWs.

The second aim of this project included an assessment of the risks linked to the non-improvement in the performance of WWTWs. Most of this was addressed in detail in another WRC report (Graham et al., 2011) and is therefore only briefly mentioned here. Pollution loads in many overpopulated areas such as Gauteng are not only currently high, but are also expected to increase due to increases in both income and people. This is expected to add to the economic cost of such pollution, as well as affect the ability of ecosystems to absorb/dilute the effluent loads. In the absence of investment, in the long-term this would likely negatively affect the ability of WWTWs to provide a service, increasing the risk of service delivery protests and undermine economic development.

The third aim of this study was addressed through a cost-effectiveness analysis for the Jukskei river catchment, where the status quo of continued investment in wastewater treatment works technology was compared with a risk mitigation option of investing in an appropriate high rate biotechnology.

Further to the conclusion one should take note of the fact that the management of water resources is extremely important in South Africa, a semi-arid country heavily reliant on rainfall. The government already recognised these issues more than 5 years ago. In a report in 2008 entitled 'Water for Growth and Development in South Africa', where the issue of water scarcity was raised:

> *Water scarcity has been identified in the major urban centres. These major urban areas anchor the country's economy, and the Department has reached a point where it knows that it must invest heavily in the diversification of its water mix to avert serious water shortages that could impact adversely on our economy. In addition to the traditional augmentation schemes, there are two major ways that water supplies can be augmented. These are the treatment of effluent and the desalination of sea water for productive use, thereby rendering primary water sources for the domestic use* (DWA, 2008: i)

The treatment of effluent is therefore crucial in the amelioration of water scarcity, all the more so for landlocked provinces. The main focus of the study was therefore the Wastewater Treatment Works themselves. The study by DWA (2008) indicates that:

> *A major source of water loss is ageing infrastructure exacerbated by poor operations and maintenance at a municipal level and analysis shows that this state of affairs is a multi-faceted problem including a lack of managerial and technical skills and funding. The Department will strengthen its efforts to support this sector in a bid to reverse this dire situation; it becomes an even more crucial intervention when one factors in the pollution of water sources due to faulty wastewater treatment works* (DWA, 2008: i).

This study found that the problems highlighted in the 2008 report by DWA still apply: the availability of skills as well as compliance with effluent standards are still critical factors affecting WWTWs. This reinforced the importance of investing in both skills development and ensuring that the necessary human capital as well as infrastructure was in place to treat effluent. Again, this was raised in the 2008 DWA report and is still an urgent intervention issue for WWTWs:

> *Presently, many water and wastewater works have reached their design capacities, are in a poor state and not properly functioning, hence resulting in major wastewater spillages and related environmental and health impacts. Bulk infrastructure development, asset management as well as water quality management are priority intervention areas* (DWA, 2008: 7)

Our study concluded that unless something was done, Green Drop Scores would decline over the next five years. Although it was not possible to identify exactly how much investment would be required to facilitate improvements in the Green Drop Score, this was likely to be substantial, and required both capital and operational expenditure. Although local government has other sources of funds that it can access from National Treasury, such as municipal infrastructure grants (MIGs), operating grants for free basic services (equitable share subsidy), and capacity building grants to improve performance, these are not likely to be enough. A number of innovative pricing and financing options were therefore presented, drawing from both established investment mechanisms (such as the issuance of green bonds) to more novel approaches (e.g. the pollution discharge charge system). Again, these measures are only possible where the necessary skills are in place to source these funds, as well as to ensure that they are used for the purposes of infrastructure development.

Finally, the study concluded by looking beyond Wastewater Treatment Works themselves to the water system as a whole, and asked the question, 'why do we treat wastewater'? Firstly, "to ensure that there is sufficient water, in both quantitative and qualitative terms, to support South Africa's path of growth and development" (DWA, 2008: i). Secondly, to ensure that a sustainable supply of water is achieved to meet basic human needs as well as other uses of water: "every person in South Africa must have access to potable water" (DWA, 2008: i). Thirdly, wastewater is treated to preserve the ecological integrity of the river system as a whole. A major problem in that regard is eutrophication. A number of innovative options that focus on catchment level management of water resources were therefore presented. The conclusion from that is that WWTWs, although important, should not be used as standalone mechanisms for achieving water quality and supply, but used in conjunction with appropriate catchment wide management interventions.

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Annexure 1 List of pricing and financing options

Category	Description	Strengths	Weaknesses	General Examples/ Applications	WWTW application
A. Pricing options					
Taxes	Taxes are charges, usually levied by central government, on individuals and businesses with the specific purpose of raising funds for the activities of the state and parastatal organisations	Relatively easy to implement; usually fairly broad based; relatively low cost	Resistance by vested interest groups to internalising the costs of scarce resources	Carbon tax	An effluent tax is one form of incentive that is used in many countries, ranging from France, Germany and The Netherlands to China and Mexico. It can be applied to any dischargers, cities or industries, with two benefits; it induces waste reduction and applied to any treatment and can provide a source of revenue for financing wastewater treatment investments
Tax incremental financing	Introducing higher taxes on other potential sources of finance, such as property rates, to repay the capital cost of the infrastructure	Relatively easy to implement; usually fairly broad based; relatively low cost	Resistance by vested interest groups to internalising the costs of scarce resources	Property rates	Costs should be assigned to different levels according to the benefits accruing at the different levels. E.g. The residents of a city collectively pay the additional cost incurred in collecting the wastes from blocks and transporting these to the boundary of the city (or of treating the city wastes)
Fees / Charges	A fee or a charge is a levy charged by government. Ideally, money raised from these mechanisms should be earmarked for green investments	Provides a means to internalize external environmental costs and to send the correct signals of the scarcity of resources such as electricity, water, landfill space for waste and sanitation (EWWS) services	Obstacles to implementation include a vague policy and legislative context; a weak understanding by governments on the cost of infrastructure provision and mechanisms to capture revenues from such charges	Levy raised applied to municipal park capital works	In many communities in the USA, households and commercial organisations pay for sewer connections through a sewer levy charged to all property owners along the streets served, and secondary sewers and major collectors and interceptors are often financed by improvement levies on all property owners in the serviced areas
Wastewater discharge charge system (WWDCS)	tier 4 of the water pricing structure (NWA 1998 and DWAF 2004)	Targeted mechanism that is based on the polluter pays principle	Limited capacity within the Department of Water Affairs, especially within regional offices, to enforce compliance with the license conditions	Draft National Water Resource Strategy 2 (NWRS-2)	WDCS as proposed by the DWA comprises two charges: (1) Incentive Charge and (2) Mitigation Charge. The Incentive Charge seeks to change discharge behaviour by providing an incentive to reduce waste load at source. The Mitigation Charge is intended to cover the costs of mitigation measures undertaken in the water resource where this is more economically efficient than reducing discharge at the source.

Development charges	Used mostly for new developments whereby the developer gets the right to operate a service at a charge, but the capital cost of the service delivery cost is made part of the initial development cost	May provide a small but potentially important contribution to municipal revenues, especially if earmarked for green investment	Obstacles to implementation include a vague policy and legislative context; a weak understanding by governments on the cost of infrastructure provision and mechanisms to capture revenues from such charges	Charge on property rates	In the City of Toronto, a range of projects are eligible for funding from development charges, including all projects providing for the upgrading, improvement and/or expansion of wastewater treatment facilities.
User pay	Make use of user charges to pay for the services delivered, i.e. directly requited payments linked to a specific quality and level of service delivered	Targets specific entities that generate externalities; polluter pays principle	May have adverse impacts on industries such as resources sector and utilities that could have adverse economy-wide impacts	Payment for services rendered	Stakeholders collectively assess the value of different levels of water quality within a basin and decide on the level of quality they wish to pay for, and on the distribution of responsibility for paying for the necessary treatment and water quality management activities.
Subsidies	Either in full or in part from either municipal or national sources	Provides a 'carrot' mechanism for compliance rather than a 'stick' approach	Has cost implications for government and may impact on ability to spend in other areas	Subsidy on renewable energy developments	The City of Kumasi, Ghana is a large city with many pockets of poverty. The Kumasi Strategic Sanitation Plan provides an example of a differentiated plan matching housing types, income levels and user preference. Willingness to pay studies were used to help define differentiated financing options, with explicit subsidies targeting the city's low-income population.

B. Financing options					
Public-Private Partnerships (PPPs)	Long term contractual agreements between a private operator/company and a public entity, under which a service is provided, generally with related investments	Provides a means of co-funding investment that reduces the reliance on one source of funding	• Global contracts may imply that selected operator not always best one for every step of the project • Long-term agreements may suggest that competition is reduced, technology and level of demand is more uncertain • Complex projects may suggest incomplete contracts • Higher risks increase costs • Payments are spread over long term	Buy-Build-Operate; Buy-Own-Operate	The Ruhrverband in Germany, which is a self-governing public body that manages water in the Ruhr basin. Ruhrverband itself is responsible for the "trunk infrastructure" (the design, construction and operation of reservoirs and waste treatment facilities), while communities are responsible for the "feeder infrastructure" (the collection of wastewater)
Bonds	The issue of bonds directly related to green infrastructure development	Provides a means in which the general public may participate in green investment	Green bonds are most promising when cities and national governments cooperate to offer lower risks to investors. This may prove to be a significant obstacle in the South African context	Nedbank's Green bonds	In Maine an Act was passed that would authorize the State to issue bonds of $7,925,000 to raise funds for drinking water and wastewater treatment programs. This would enable the State to secure matching federal grants for the amount of $39,625,000.
Ecosystem-based and/or environmental financing mechanism, e.g. Carbon finance	The use of carbon related instruments such as carbon markets to raise revenue for green investment	Market mechanisms by which polluters can mitigate the effects of carbon emissions	• Limited autonomy of urban authorities to directly regulate greenhouse gas emissions; • Limited budgets and access to start-up capital; • Limited institutional and technical capacity; • Difficulties in measuring the effects of urban mitigation projects with existing methodologies and lack of standardised methodologies (e.g. for greenhouse gas inventories at the urban level); • Small scale of municipal-level greenhouse gas reduction initiatives (e.g. improving the efficiency of street lights) that do	Clean Development Mechanism (CDM), voluntary carbon markets, or domestic carbon offsets	The Roxol Bio-Energy Corporation is located in La Carlota City, Philippians. The project involves the construction and operation of an Ethanol Plant and Support Facilities for the production of fuel grade ethanol and the treatment of wastewater in collaboration with the World Bank. The project includes a carbon finance transaction that involves the creation and eventual purchase by the Bank of the carbon emission reduction generated from the wastewater treatment system of the ethanol plant.

			not warrant the transaction costs of pursuing carbon finance; • Lack of support from national governments		
Loans or capital access programmes	Borrowing money from the private sector or national government	Ready access to funds for infrastructure or green projects	Usually involve sizeable interest obligations which can add to the capital cost of the project	Loan for development of floating wetlands	The Sewerage Treatment Group of the Far North District Council of New Zealand were involved in a number of upgrade projects, including the upgrade of the floating wetland at Kaitaia sewerage treatment plant. The total funding for all activities (including the upgrades) for the 2011/12 period amounted to NZ$12 million, of which just over half (NZ$6.6 million) was funded through loan finance.
Trust funds	Earmarked capital development public funds	No repayment obligations	Usually come with strict requirements in terms of the use of funds; accountable to trustees for proper use of money		The Zimbabwe Multi-Donor Trust Fund (ZimFund's) Urgent Water Supply and Sanitation Rehabilitation Project (UWSSRP) will increase the reliability, quality and availability of water, restore wastewater treatment capacity and reduce the incidence of cholera and other water related diseases. This project, valued at USD 9.04 million, is the first to be implemented under the Fund's overall USD 29.65 million UWSSRP, which will also see developments in the municipalities of Chegutu, Chitungwiza, Harare, Kwekwe and Masvingo.
Revolving loan fund	A fund dedicated to the delivery of a specific service whereby the repayment thereof is being re-invested in the sector elsewhere	Flexible terms that enable replenishment of initial funds	Risk of excessive debt obligation as the loan amount is not fixed and requires constant monitoring	Useful for intermediate size loans	The Nebraska Clean Water State Revolving Loan Fund (CWSRF) program provides low interest loans and small community matching grants to municipalities for construction of wastewater treatment facilities and sanitary sewer collection systems to alleviate public health and environmental problems. The loan principal repayments go into new loans and interest earnings on the Fund is used 1) to pay off the state match bond issues and 2) to make new loans.

Grant/donor financing	Contributions made by the civil society and/or major international donor agencies	No repayment obligations	Usually come with strict requirements in terms of the use of funds; accountable to donor agencies for proper use of money	Funding from the World Bank Global Environment Facility (GEF)	The World Bank, in collaboration with the Brazilian Government, has financed the PROSANEAR project, in which around US$ 100 million of investments are providing water and sanitation infrastructure to about 800,000 favela residents in 11 cities
Offset investments	Care should be taken how best to finance such, as the issuing of bonds could be the cheapest option pending the entity's credit rating;	Means by which public and private sector entities can generate goodwill by contributing to environmental improvements; Benefits are tailored to the local environment	Limited institutional and technical capacity to implement	Vele coal mine; King Shaka International Airport	The concept of 'Water Neutrality' aims at reducing water consumption and pollution and by compensating for the negative impacts of remaining water consumption and pollution through investing in water offset projects that promote the sustainable and equitable use of water in the environments and communities that are affected. Travellers to Southern Africa can utilise an individual water neutral offset calculator to determine the impact of their water use & pollution and to offset potentially adverse effects.
Private sector funding	Contributions in full by the owner/operator of the system Issuance of shares/equities	• Provides a means in which private owners can contribute to green investments through corporate social responsibility • Investors willing to take more risk than other financing instruments (e.g. bonds)	• Usually confined to projects that would provide the most leverage in terms of public support • Most expensive means of raising revenues	• Sasol's contribution of Rm to reduce non-revenue water loss in Sebokeng and Evaton by fixing pipes, leaks, etc. • Money raised from special share issues used towards environmental projects	More often than not, private sector funding of WWTWs is through private-public-partnerships. One example where the private sector may get involved is through a grant to buy down the capital costs of an expansion project and increase its affordability for the government, as was the case for the As-Samra Waterwater Treatment Plant in Jordan.

Annexure 2 List of selected water quality cap-and-trade operations globally

Nr	Source / Author	Year	Location / State	Pollutants traded	Parties in the system	How the system works	Who and how is the system monitored / governed
1	Harbans Lal	2009	Long Island Sound (LIS) of Connecticut and New York	nitrogen	Connecticut Department of Environmental Protection	The NCE program provides incentive to facilities that complete nitrogen treatment projects, while allowing other facilities to remain in compliance with the general permit (GP) by purchasing nitrogen credits from other facilities that have surpassed their basic requirement. For each participating facility, the GL also establishes an “equalization factor” that accounts for each facility’s geographic location in relation to the most impacted site of the Sound.	Con-DEP established a Nitrogen Credit Exchange (NCE) overseen by a Nitrogen Credit Advisory Board, and authorized issuance of a Nitrogen General Permit. This permit establishes annual limits for each facility based on the expectation that the cumulative amount of nitrogen discharged from all of Connecticut’s public owned STPs will decrease annually as nitrogen treatment projects are completed.
2	Harbans Lal	2009	States of Maryland, Virginia, and Pennsylvania	nitrogen, phosphorus, and sediments	Pennsylvania Department of Environmental Protection (Penn-DEP); trading in Pennsylvania can take place between any combination of eligible entities- point sources, non-point sources, and third party sources.	Trading in Pennsylvania can take place between any combination of eligible entities- point sources, non-point sources, and third party sources. However, each entity must meet applicable criteria established by the Penn-DEP before being eligible to participate in the program. For example, a point source should be able to demonstrate that it is implementing treatment beyond the required limits. On the other hand, non-point sources should first ensure that they are meeting minimum “threshold requirements” before they become eligible for generating the tradable credits.	The Penn-DEP has a procedure of credit certification for entities interested in participating in the program. The department has a listing of credit generating BMPs, which can be submitted to the Penn-DEP for review. The department analyses these applications against the procedures outlined in the trading of nutrient and sediment reduction credits and policies and guidelines (PADEP, 2006) to determine their eligibility. The applicant can also use NutrientNet, a nutrient trading tool created by the World Resources Institute to calculate and post credits for sale on their website.
3	Harbans Lal	2009	Great Miami River Watershed Water Quality Trading Program	phosphorus and nitrogen	Permitted dischargers; The conservation district staff works with agricultural producers to identify practices that accomplish the desired nutrient reduction	Water quality credits only originate from an activity undertaken voluntarily (i.e. not otherwise required by local, state, or federal law). Water quality credits may be purchased by permitted dischargers who become eligible buyers for the purpose of complying with regulations related to the particular nutrient for which the credit is generated. The management practices that generate credit are proposed by the county. The conservation district staff works with agricultural producers to identify practices that accomplish the desired nutrient reduction	The reduction is verified through inspection and by conducting water quality monitoring at the project site. The continuous monitoring over the project life span since 2005 has shown much lower nutrient discharge from agricultural activities than previously predicted by Ohio Department of Natural Resources (Ohio DNR) and USEPA. The program utilizes a Load Reduction Spreadsheet (v1.2) to calculate nutrient discharge reductions for specified agricultural practices. This spreadsheet is available online through the Ohio Department of Natural Resources (Ohio DNR) website.

4	Harbans Lal	2009	Willamette Basin in Oregon	temperature, bacteria, and mercury	Oregon Department of Environmental Quality (OR-DEQ)	The Oregon Department of Environmental Quality (OR-DEQ) is encouraging point sources needing upgrades to comply with the NPSES permits to consider water quality trading. In this system, a point source could pursue buying credits in lieu of installing expensive refrigeration equipment to reduce its temperature impacts. These credits could be generated by agricultural producers by installing BMPs that augment the water flow or accelerate restoration of riparian vegetation. These practices are direct and less expensive ways to cool the flowing water than refrigeration. In addition, they do not require significant amounts of electricity and provide several additional environmental benefits	In addition, the Willamette Partnership, a local coalition of leaders and non-profit organizations, is developing the Willamette Ecosystem Marketplace to further improve ecosystem functions in the basin. In this approach, the regulated industries, developers, and other investors can pay land managers to implement conservation practices that can protect and enhance ecosystem services, such as clean abundant water, healthy population of fish and wildlife, and a stable climate. This effort is funded through the "Target Watershed Grant" from the US EPA. Under the terms of the grant, the marketplace must first target transactions to achieve temperature reductions for the Willamette River, which are consistent with the Willamette Basin TMDL objectives. In the marketplace, cities and industries that discharge hot water into rivers and streams will be able to purchase conservation credits offered by landowners who restore streamside shade, reconnect floodplains, or take other actions that cool water naturally. The experience gained in temperature trading will help develop approaches for other nutrients within the marketplace. This approach of thermal trading based upon riparian restoration could save Oregon taxpayers and utility rate payers millions of dollars in construction and operating costs for conventional water cooling facilities.
5	Cherry, Britney, Siegel, Muscari & Strauch	2007	Tar-Pamlico Nutrient Reduction Trading Program; North Carolina	phosphorus and nitrogen	North Carolina Agriculture Cost Share Program; the Association, the state, and the North Carolina Environmental Defense Fund (NCEDF); Partners involved in the effort were NCDWQ, Soil and Water Conservation Districts, North Carolina DSWC, North Carolina	Throughout Phase I, the association was able to meet the nutrient reduction goals collectively through improvements in operational efficiencies. During Phase II (1995 through 2004), the focus of the nutrient management strategy shifted to include NPSs based on the recognition that NPSs contribute the majority of nutrient loading to the watershed. The modelling completed by the Association in Phase I estimated that NPSs accounted for 92 per cent of the nutrient loads (Gannon, 2005b). A goal of 30 per cent reduction was set for both PSs and NPSs and the limit for discharge of phosphorus was set at 1991	PSs and NPSs are required to achieve environmental goals and provide sufficient information to document compliance. The NCEMC, NCDWQ, and Soil and Water are the key administrative bodies for the NSW management strategy. The government agencies retain the ability to take enforcement actions against PSs and NPSs in the event that they are not able to demonstrate compliance. The Agreement signed by the Association, NCEMC, NCDWQ, and Soil and Water is the primary mechanism used to assure accountability. The NPDES permits of the Association members do not contain

					Cooperative Extension, USDA's NRCS, North Carolina Department of Agriculture, North Carolina Farm Bureau, North Carolina State University, the Association, the agricultural community, and commodity groups. Fourteen dischargers equalling about 90 per cent of all PS flows to the river joined the Association	levels. An interim target of 60 per cent progress towards these goals by 1999 was set. If progress was inadequate, the NCDWQ and NCEMC would evaluate whether additional regulatory requirements were necessary (Kerr et al., 2000). When adequate progress had not been made, mandated rules on riparian buffers, fertilizer application, stormwater, and agriculture were adopted by the NCEMC and went into effect in 2000 and 2001 (Gannon, 2005b). The Phase II agreement reduced the price of NPS credits to $13 per pound. Throughout Phase II, the Association has maintained discharges well below the caps assigned without needing NPS offsets (Breetz et al., 2004). The Phase III agreement spans an additional 10 years (2005 through 2014), with an amendment after 2 years to address potential needs for improvements. The Phase III Agreement updates Association membership and maintains the nutrient caps established in Phase II. It also proposes actions over the first two years that will improve the offset rate, resolve related temporal issues (life span of offset credits), and evaluate alternative offset options. The offset credit life span, what happens after 10 years when the credits expire, and how to handle credits that have been banked by the Association, but not used within 10 years, are issues that participants in the Phase III agreement are currently working to resolve (Huisman, 2006). It also establishes 10-year estuary performance objectives and alternative management options. If water quality in the estuary worsens by 2008, a process to re-model the estuary and revise TMDLs will be initiated (Gannon, 2005b).	limits for nitrogen, which means that if they over-perform, they are not subject to the anti-backsliding requirements in the federal CWA (which would result in adjustments in permit limits if association members showed they could meet more stringent requirements). This would effectively penalize environmental performance. The NPDES permits do, however contain a "reopener" clause stating that if conditions in the agreement are violated, then permits would be revised to impose new discharge limits. The Association documents its nitrogen loading for the year in an annual report. Non-Association members (the remaining 10 per cent of the PS dischargers) are subject to slightly different rules. They are regulated by traditional PS permitting requirements. In addition, they are required to offset new nutrient loading by funding BMPs at an offset ratio of 1.1:1 (Kerr et al., 2000). The performance of NPSs on nutrient reduction goals is tracked using three methods: tracking activities, computer modelling, and sampling. Tracking Activities. The NCDWQ and EMS use annual reports submitted by LACs to verify progress of NPSs on BMP implementation plans developed by LACs. LACs were created to develop agriculture BMP implementation strategies. LACs are required to submit annual reports on progress. Modelling. Computer modelling efforts have included improving the Tar-Pamlico Estuarine Water Quality Model used to develop the basin-wide strategy. In addition to the NLEW and PLAT modelling tools developed for agriculture, an Excel-based model was developed to calculate nitrogen and phosphorus loading associated with stormwater runoff from new developments before and after BMP implementation. Monitoring. The Soil and Water Conservation Districts perform compliance monitoring on BMP implementation; they inspect 5 per cent of all contracts for cost share projects per year and all animal waste systems twice per year; and review all local programs every five

							years. The NLEW is also used to track progress.
6	Cherry, Britney, Siegel, Muscari & Strauch	2007	Neuse River Basin Nutrient Sensitive Waters Management Strategy; North Carolina	nitrogen	NCDWQ: issues NPDES permits to individual dischargers and a group NPDES permit to the NRCA; provides regulatory oversight for the group nitrogen allocation. NCEMC: responsible for developing and adopting the Neuse River Nutrient Management Strategies and associated rules. NRCA: association of PS dischargers, primarily large municipal WWTPs, with a common nutrient cap. Lower Neuse Basin Association (LNBA): a non-profit coalition of dischargers that conducts in-stream monitoring; preceded the NRCA by several years and served as the starting point for the development of the NRCA. Many LNBA members became NRCA members. Wetlands Restoration Fund (administered by the Ecosystem Enhancement Program [EEP]). USEPA, Region IV. Neuse River Foundation and Neuse Riverkeepers:	The system established for PS-NPS trades is similar to that of the Tar-Pamlico Nutrient Reduction Program and can best be described as an exceedance tax, rather than a traditional trading program. Potential trading parties include: members of the NRCA, any discharger holding an allocation, and landowners. Trades with NPSs are conducted indirectly through the North Carolina Wetlands Restoration Fund. Landowners receiving grants from the Wetlands Restoration Fund are indirect trading partners. As with the Tar-Pamlico Program, responsibility rests with the state for ensuring nutrient offset projects are implemented and successful. A fixed, per-pound price has been established for the purchase of TN offset credits. Credits may be purchased if new or expanding dischargers cannot secure nitrogen allocations from other PSs or if the NRCA exceeds its annual nitrogen allocation. In addition to the offset payments, the NRCA is subject to penalties and other enforcement action for any exceedance. In that event, the NRCA members are also subject to enforcement if they exceed their individual allocations as listed in the NRCA's permit. Non-members with TN limits are not required to make offset payments, but are subject to enforcement for any exceedance of their TN limits (15A NCAC 2B.0234). The Neuse NSW Strategy also created a mechanism for NPS-NPS trades. The Neuse NSW Stormwater Requirements (15A NCAC 2B.0235) set a nitrogen export standard for local governments identified within the regulation based on population and growth rate. Local governments subject to this regulation are required to develop stormwater management program plans and have them approved by the NCEMC. Local governments that do not submit stormwater management program plans or fail to implement them will be subject to NPDES	The NCDWQ, NCEMC, and EEP administer the Neuse NSW Strategy. As with the Tar-Pamlico, it is the responsibility of PSs and NPSs to demonstrate compliance with the Neuse Rules. The NPDES permits of PSs within the NRCA do not contain a discharge limit for TN; the TN limit for the NRCA is specified in the group compliance NPDES Permit. Each co-permittee has been assigned a TN allocation, but that is subject to change due to purchases, sales, trades, leases, and other transaction among the NRCA members. Furthermore, if the membership of the NRCA changes, the group TN allocation is changed in the group compliance NPDES permit accordingly. Members of the NRCA monitor discharges and report results to the NCDWQ, as specified in their NPDES permits, and to the NRCA. The NRCA compiles the co-permittee reports for its own reporting. As a group, the NRCA submits mid-year, year-end, and five-year reports. Offset payments are paid to the EEP and tracked by an "In-Lieu Fee Coordinator," a staff position created to administer the program. North Carolina State University and local governments assist the EEP in identifying potential projects. The offset BMP projects are located no farther from the estuary than the loading being offset. Offset BMP projects are awarded to an on-call EEP contractor pool. The contractors are responsible for design, construction, and one year of performance monitoring. There are currently numerous projects in design.

					environmental advocates.	permitting requirements. The plans are tailored to help the local government ensure nutrient reduction goals are met. A key component of the plans is review and approval of stormwater management plans of new developments to ensure they will comply with a nitrogen export standard of 3.6 pounds per acre per year. Developers have the option of installing stormwater BMPs to satisfy this standard or may choose to implement stormwater BMPs that will attain maximum allowable nitrogen export rates and purchase offsets for the remainder of the nitrogen export rate above the rate set for local governments. An initial focus on education is another aspect of Neuse NSW Strategy that is different than the Tar-Pamlico Program. At the outset of the 1997 strategy, the Neuse River Education Team (NRET) was created (and funded) with a mandate to educate NPSs of nutrients (agricultural producers, homeowners, and cities).	
7	EPA	2008 (programme started in 2001)	Middle-Snake River Demonstration Project; Idaho	phosphorus	Aquaculture and fish-processing facilities, municipalities, the State of Idaho, and EPA	Developed a trading program for buying and selling total phosphorus credits among dischargers. Under the trading arrangement, the City of Twin Falls' WWTP, fish-processing facilities, and aquaculture may generate phosphorus reduction credits that can be purchased by other aquaculture facilities in that same section of the Middle Snake River.	Not mentioned

8	Department of Environment and Conservation	2003/2006	Hunter River Salinity Trading Scheme; New South Wales	Salt (salinity)	NSW Government	There are a total of 1000 salt discharge credits in the scheme— different licence holders have different numbers of credits (see page 10 for a list of credit holders and the initial credit allocation). Licence holders can only discharge salt into a river block in proportion to the credits they hold—1 credit allows a discharge of 0.1% of the total allowed. Licence holders' need to discharge depends on highly variable operational conditions at each site. Credit trading gives each licence holder the flexibility to increase or decrease their allowable discharge from time to time while limiting the combined amount of salt discharged across the valley. The trading system is online, allowing licence holders to trade quickly and simply. The trades can be for one or many blocks (i.e. a single day or longer periods), and the terms of the trade are negotiated by the parties involved. A register ensures the information on credit holdings is publicly available at all times. Other information on the trading scheme is also available.	River monitoring, modelling and the river register are provided by the Services Coordinator at the Department of Infrastructure, Planning and Natural Resources (formerly Department of Land and Water Conservation). Administration of licensing and regulation, online credit register and exchange facility are provided by DEC. The Operations Committee considers issues in relation to the day-to-day operation of the scheme. The Hunter River Salinity Trading Scheme Operations Committee consists of: • a member nominated by the Hunter River Catchment Management Trust • four members to represent the interests of licence holders • a member to represent the interests of irrigators • a member to represent environmental interests • a member from an organisation concerned in the management of a river in the catchment • a member from the Department of Infrastructure, Planning and Natural Resources. The cost of administering the scheme is shared equally between credit holders and discharge licence holders. (In the future credits may be held by persons other than licensees).

9	KERR et al	2000	San Joaquin River; Central Valley of California	Selenium	Federal, state and local authorities, in conjunction with local farmers and environmental stakeholders	The trading program, called the “Tradable Loads Program,” builds upon the framework established in the bypass project. A regional cap on selenium discharges is a key component in the bypass project. That cap limits the combined discharges from seven separate drainage districts that have joined together forming a regional authority. The regional authority must pay “incentive fees” for any selenium discharges above that regional cap. Incentive fees are used to fund environmental improvements in the watershed that would otherwise not be funded. The trading program takes the incentive fees one step further. Each drainage district in the authority is allocated its share a “selenium load allocation” (SLA)–that dictates the quantity of selenium it can discharge, as well as how to pay its share of the incentive fee if the authority as a whole exceeds the regional cap. Instead of simply paying for discharges above their portion of the cap, districts have the option of purchasing SLAs from another district. That trading option provides incentives to districts to remain below their individual allocations.	A detailed monitoring system provides farmers, drainage districts, and the advisory committee with weekly updates on the progress in meeting monthly selenium load allocations. That quick turn-around time allows farmers to modify management and irrigation practices to remain below their allocations. The monitoring system provides a significant level of accountability for all stakeholders participating in the project and is considered a key component of the trading system. Multiparty permitting. The California Regional Water Quality Board issued the Waste Discharge Requirements Order to a regional legal entity, not to individual farmers. Permitting at that higher level provided an adequately enforceable framework and avoided the costs of an administratively complex program for regulating individual discharges.
10	EPRI	2010	Ohio River Basin Interstate Water Quality Trading Project; Ohio	phosphorus and nitrogen	Division of Soil & Water Resources Ohio Department of Natural Resources; Ohio Environmental Protection Agency;	1 Some states have adopted trading policies or rules to govern trading within their jurisdictions 2 To date, no states have come together to develop or implement an interstate trading program (i.e., where all states operate under the same rules and a water quality credit generated in one state can be applied in another). That is the primary purpose of this Project and Plan. All trades that occur as a result of this Project will be grounded in a scientifically-based justification. Water quality trading as a tool to improve water quality within the ORB is a priority for federal agencies, ORSANCO, 3 ORB states, and a diverse range of stakeholders. 4 This Pilot will support water quality pilot trading within the ORB on an interstate basis, but will not pre-empt any new, or supersede any existing water quality trading program agreements or initiatives at the state or local level.	Credit registration and tracking will be accomplished using a system that builds on the work of other, existing trading programs around the country, where similar systems have already been established. The system will be subject to approval by the participating states. The Pilot will be audited annually for environmental and economic effectiveness, as well as to ensure that the reports and data generated under this Pilot are complete and accurate. The participating ORB states will be authorized to participate in these audits. The results of the audits will be made available to the public and will serve as a basis for validating or amending the Plan in the future. All BMPs must be periodically monitored, inspected, and verified by the State Agency or an EPRI-approved third party. During the Pilot, verification will occur, at a minimum, annually. Verification will be based on visual monitoring and

							inspection, as well as a review of records provided by the landowner and/or SWCD.
11	Sovacool	2011	Fox River water permits in Wisconsin	The primary sources of pollution were paper mills and waste water treatment plants and the principal goal was to control biological oxygen demand	Administered by the state of Wisconsin; firms	Administered by the state of Wisconsin in accord with the Federal Water Pollution Control Act, firms were issued five-year permits that defined their waste-load allocation. Trading was influenced by location, with two points on the river classified as most sensitive to pollution; firms were divided into clusters so that trading would not increase biological oxygen demand at either of these points, with about six to seven firms in each cluster. Early studies projected that substantial savings on the order of $7million per year would result after implementation of the trading system. Compromises in program design, however, prevented the credit market from ever working effectively. Fearful that a water dis-charge permit system would enable shrewd facility managers to manipulate trades to their advantage, regulators in Wisconsin went too far in setting restrictions and conditions.	

Annexure 3 A futuristic perspective: The role of biotechnologies

Introduction

Ecological infrastructure is a concept which is coming to the fore although it has not received much attention locally. Initially it was greeted with a certain degree of suspicion but as we begin to understand it as the 'generator' of ecosystem services, there is growing acceptance (Mitchell et al., 2013:10). In the same way that built infrastructure provides the socio-economy with certain services on which society depends, so ecological infrastructure provides society with a range of (ecosystem) services which support society in various ways. The full extent of this support is seldom recognised because, unlike built infrastructure, ecological infrastructure is seldom traded on the open market. The result of this is that the ecological infrastructure tends to become degraded through lack of investment in its maintenance, resulting in a decline in its ability to provide the services on which society depends. Ecological infrastructure, as built infrastructure, requires investment to maintain it. When this investment is forthcoming the ecological infrastructure is able to deliver the services at a high level but where this is not forthcoming the level of service delivery is eroded.

When the interventions to maintain environmental water quality are integrated at a catchment scale, as proposed in Chapter 1, then the potential contributions from ecological infrastructure to the overall socio-ecological system becomes apparent. This is especially the case where the contribution from the WWTW to the total flow is high, such as is the case with the small rivers draining the large conurbations in Gauteng. In cases where the management of the WWTWs is sub-standard there are likely to be a number of effects on the downstream environment. But even in the case of the large WWTWs which are consistently well-managed and where the flow of treated effluent provides a substantial contribution to the total flow and the capacity for in-stream dilution is exceeded, some of the effects of waste discharge, such as eutrophication, will be cumulative. While cumulative environmental deterioration may happen relatively slowly, the danger of disease to downstream users from pathogens is immediate and sensitive users, such as infants or immune-compromised individuals, will be the first to become infected.

Wetlands provide a basket of ecosystem services which includes the sequestration of nutrients, pollutants and carbon as well as the attenuation of disease organisms. Such ecological infrastructure would be outside and usually downstream of the WWTW in a position where it would polish the river water quality. In developed catchments, however, space is at a premium so there is a place for high rate ecological infrastructure. One such biotechnology which has been tested internationally is the floating wetlands developed by Floating Islands International (http://www.floatingislandinternational.com) although other eco-friendly biotechnologies which may be used conjunctively with conventional WWTW will certainly become available.

The availability of quantitative data on the performance of these floating wetlands has enabled the costs of this biotechnology to be modelled as part of a hybrid wastewater treatment system to improve the quality of the Jukskei River, a tributary of the Crocodile West which drains northern Johannesburg, Gauteng.

Floating wetlands: a discussion

Restoration of the riparian zones and construction of floating wetlands is important at an ecosystem level. As part of ecological infrastructure they are important in ensuring the stability of the water cycle and its benefits to agriculture and households, the carbon cycle and its role in climate mitigation, soil fertility and its value to crop production, local microclimates for safe habitats, fisheries for proteins, and so on, which are all crucial elements of a green economy (UNEP, 2011).

But what does the floating wetland technology entail? According to Headley and Tanner (2006:9): "*constructed treatment wetlands are engineered systems designed to enhance the processes and interactions that occur in natural wetlands between water, plants, microorganisms, soils and the atmosphere in order to remove contaminants from polluted waters in a relatively passive and natural manner*". Wetland technology relies on the biological and mechanical filtering of excess nutrients and pollutants from the body of water as it flows slowly through shallow areas of dense vegetation. The primary methods of excess nutrient removal include microbial transformation and uptake, macrophyte assimilation as well as absorption into organic and inorganic substrate materials. Floating wetlands are an expansion on the more traditional method of using constructed wetlands in water treatment (Stewart et al., 2008).

Constructed wetlands, however, have certain drawbacks which floating wetlands are able to overcome (Stewart et al., 2008). One of the drawbacks of conventional wetlands, especially in the application to an area that has fluctuating water levels is that the system may become submerged which could damage the bottom-rooted plants. Floating wetlands do not have this problem as they rest on the surface and can adjust more readily to changes in the water level (Headley & Tanner, 2006).

Naturally occurring wetlands, which surface-flow constructed wetlands mimic, require large areas of land. Surface-flow wetlands perform best when the water level is stable at a depth of 30-50 cm and will die back if the water level exceeds this for extended periods. So in order to realise the same level of treatment a larger area will be required. Sub-surface flow constructed wetlands is a technology which to some extent may overcome the problem of a fluctuating water level as the water flows through a matrix of gravel, coarse sand or some other porous medium with the water level being controlled by a weir. This technology offers higher performance than the surface-flow technology but still requires land to be set aside for its construction. Among the advantages offered by the floating island technology are that floating islands do not require additional ground but are accommodated on existing water bodies. They also serve to reduce wind-induced turbulence thereby creating conditions more conducive to the settling of particulates, so removing the pollutants adsorbed to the particulates from the system at the same time. Floating islands provide additional surface area for the development of microbial biofilm which is active in the removal of nutrients and pollutants (Headley & Tanner, 2006, 2012; Reed & Brown, 1995). The Floating Island biotechnology has been shown to remove nutrients at a higher rate than natural wetland systems (even up to 100 times more) due to their location, the concentration of vegetative matter and the biofilm that grows on the mat matrix (Stewart et al., 2008). Therefore, floating wetlands contribute to the green economy by removing pollutants, such as nitrates, phosphorous, ammonia and some heavy metals, at a high rate by exposing water to natural microbial processes. This makes them an ideal biotechnology for cleaning dams, rivers, streams, wastewater ponds (such as oxidation and maturation ponds) and waterways affected by sewage, landfill effluent or other sources of pollution or excess nutrients. Floating wetlands have also been used for purposes such as water quality improvement, habitat enhancement and aesthetic purposes in ornamental ponds. With regards to water quality improvement, the main applications have been for the treatment of storm water, combined storm water-sewer overflow, water supply reservoirs, etc. (Kerr-Upal et al., 2000; Revitt et al., 1997; Garbutt, 2004 as cited in Headley & Tanner 2006:9).

With rivers in South Africa carrying high levels of nutrients and pollution (see, for instance, Bollmohr et al., 2008; Harding, 2010), it is apparent that there is a need for cutting edge, "green" technologies such as floating wetlands to solve water quality problems. Floating wetlands contribute to water quality improvement by providing treatment for agricultural-impacted waters, municipal wastewater, storm water and polishing of tertiary wastewater, as well as the restoration of riparian zones (Reinsel, 2012).

How effective a wetland is in drawing out excess nutrients depends, at least partially and specifically, on the surface area which is available for microbes to colonise as well as the exposure of this surface area to nutrient-rich waters. In terms of traditional constructed wetlands, the roots of plants delve deep into the soil and away from nutrient rich waters found near the surface of the body of water (see Figure 1A), a drawback addressed by the sub-surface flow wetland technology. Floating wetlands, on the other hand, grow hydroponically with their roots extending into moving water below which is rich in nutrients (Figure 1B). This ease-of-access to nutrients allows more nutrient-absorbing microbial biofilm to grow. Furthermore, the roots of floating wetlands provide additional substrate for nutrient-absorbing microbes to grow on, a substrate not available to microbes in surface flow wetlands (Figure 1). All in all, this extra surface area as well as extra access to nutrient-rich waters allows for higher efficiency from floating wetlands as compared to traditional constructed wetlands (Stewart et al., 2008). Certain proprietary designs of floating wetland also present a large area of substrate in addition to the roots of the macrophytes which provide additional area for the development of microbial biofilm, thus substantially enhancing the performance of this technology (Stewart et al., 2008)

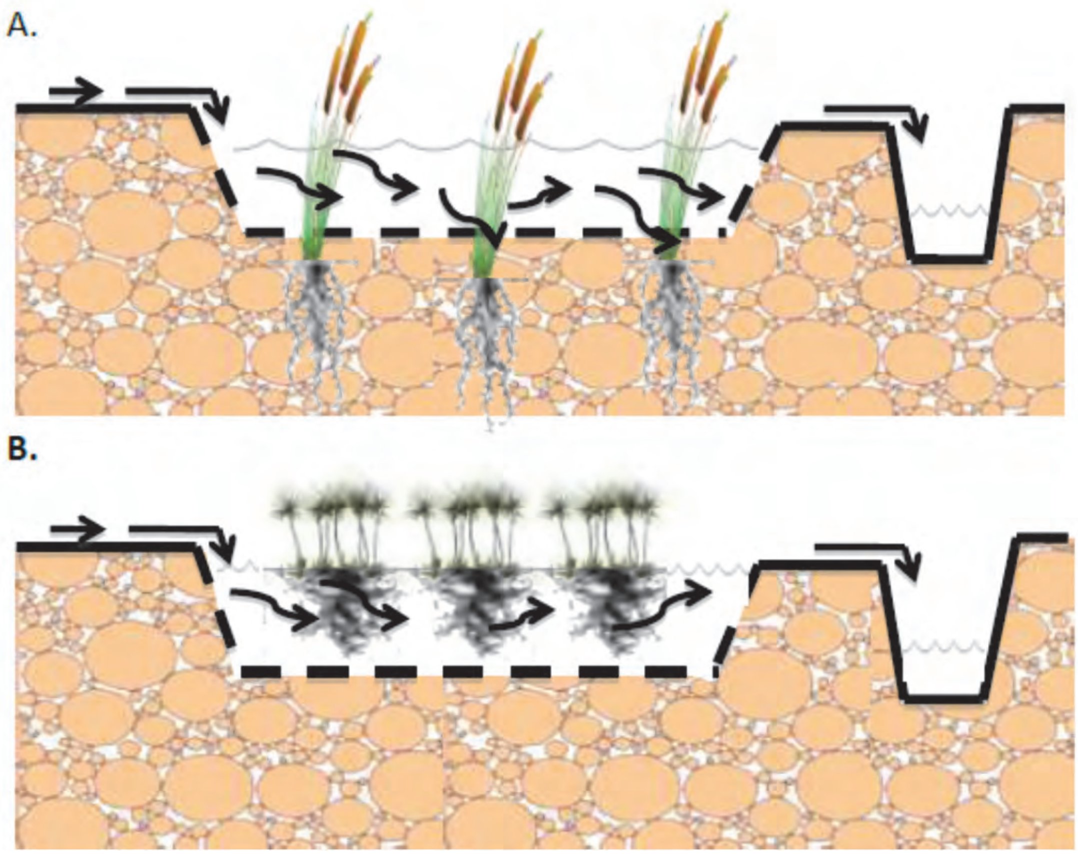

Figure 1 **The relative positions of the macrophyte roots in relation to the nutrient-rich water to be treated. Figure A is of a surface-flow wetland in which the macrophytes are rooted in soil. Figure B is of a floating wetland in which the roots of the macrophytes are in contact with the water.**

Why should floating wetlands be considered?

A particular example that may be of interest is the case of the Alexandra Township and its effects on the Jukskei River. Alexandra's population has grown more rapidly than the formal facilities designed to accommodate the size of the population, resulting in frequent contamination of the Jukskei River from sewage and urban runoff produced in the township. One particular problem is the fact that the nitrate and orthophosphate concentrations at points sampled downstream from the township were at least double those concentrations at points upstream from the township (Matowanyika, 2010).

Excess nutrients (nitrogen and phosphorous) are a threat to freshwater ecosystems. In particular, excess nutrients will cause eutrophication, a natural response of the ecosystem to excess nutrients. Excess nutrients will result in the dominance of phytoplankton within an aquatic ecosystem that is not dominated by rooted macrophytes. In the case of rivers and streams where residence time is shorter and wash out rates are higher, the effects may be less noticeable (Smith et al., 1999). Oligotrophic lakes are limited by phosphorous and may have excess nitrogen. As the phosphorous level increases the aquatic system will become more productive. Once nitrogen becomes limiting there is a shift from green to blue-green algae (Cyanobacteria) which are able to fix atmospheric nitrogen and so their growth is not limited in conditions of excess phosphorous

(Wetzel, 1983). High phosphorous (P) levels can result from the denitrification of domestic sewage as phosphorous is more difficult (and expensive) to remove.

Excess phosphorous will cause cyanobacterial blooms which can make water treatment for human consumption more expensive. These blooms may, under certain conditions, present taste and odour problems or become toxic. Harding and Paxton (2001) cite examples of patients on dialysis dying when inadequately treated water was used in the process. Also recorded is the poisoning of an entire dairy herd by cyanobacteria in South Africa. Such events may wreak havoc on local aquaculture with damages recorded in various locations all around the world. Such damages also inevitably translate into monetary damages and vary by location.

Floating wetlands offer a solution to the high concentrations of the nutrients found in the Jukskei River. In a series of controlled experiments it was found that the floating wetlands constructed by Floating Islands International can remove nitrates and phosphates from bodies of water. In some controlled environments they managed to remove as much as 100% of the nitrate content. Up to 80% of the effectiveness of nitrate removal stems from the bacteria found in the roots of the floating wetland itself. The remaining 20% is attributed to nitrate absorption by the plants directly into their roots (Biohaven, n.d.).

As the Jukskei River flows into the Hartbeespoort Dam, with the latter exhibiting a high degree of eutrophication, the potential benefit of floating wetlands as a means to reduce excess nutrients in the Jukskei River will have a significant positive impact on the Hartbeespoort Dam situation in addition to the benefit of cleaning up the river in its own right.

Any further rise in the concentration of nutrients will exacerbate the problem of eutrophication in the Hartbeespoort Dam, with one of the primary sources being sewage effluent (Steyn et al., 1975; Ashton et al., 1985; Harding, 2010; Keto, 2013). The Jukskei River, due in part to the Alexandra Township, is regularly contaminated by sewage effluent (Matowanyika, 2010) with the threats to human health that this entails.

The damages of further eutrophication of the dam are varied. Property prices have been found to be negatively affected in particular. In the cases of the Vaal Dam, housing prices decreased by 1% for every 1% increase in ammonia levels. Also, agricultural costs were found to be adversely affected, although the effect here is small, yet significant. Furthermore, treatment costs for water were found to have risen 0.2% for every 1% rise in the levels of nitrates occurring in the water according to data supplied by Rand Water. A rise of 10% in nitrogen and phosphorous levels would lead to an increase of 3.2c/kL and 5.0c/Kl, respectively (Graham et al., 2011).

Floating Island technology can be applied either on- or off-site. When applied on-site, Payments for Ecosystem Services could be considered once the works have complied with the set discharge standards, in other words for the additional improvement in water quality. With respect to off-site options, much will depend on the type of water use and beneficiaries thereof.

With respect to on-site options:

This entails the introduction of technologies such as floating wetlands on maturation or oxidation ponds to absorb nutrients, so decreasing the nutrient levels in the effluent.

With respect to off-site options:

This entails the introduction of technologies such as floating wetlands directly into the riparian zone and the ecosystem downstream from the WWTW's discharge into the ecosystem. Here attention should, however, also be given to other (especially non-point) sources of pollution entering the system.

With this in mind, the following is a case study assessing how floating wetlands might perform when employed conjunctively with WWTW on the Jukskei River. The quantitative data refers to the technology of Floating Island International.

CASE STUDY: The Jukskei River

Harding (2010) notes that all of the major impoundments in the economic heartland of the country are grossly impaired although the full extent of the problem is not known. It is also apparent that the performance of even well-managed WWTWs is not always sufficient to prevent eutrophication of reservoirs downstream from the Gauteng conurbations. Taking the Hartbeespoort Dam and its catchment as a case study, for instance, the impoundment receives 600ML of treated sewage per day from WWTWs in the catchment, with approximately 420ML/d^{-1} coming from the Johannesburg Metropolitan Municipality's Northern Works which discharges into the Jukskei River. Northern Works is a well-run WWTW with highly capable personnel and employs modern technologies, achieving a Green Drop Rating of 92.4 and receiving Green Drop Certification in 2011. The 600ML/d^{-1} of treated sewage delivers a load of 200 tonnes of ortho-phosphate per annum into the impoundment. The mean concentration of ortho-phosphate in the effluent discharged into the Hartbeespoort catchment, thus, is 0.913mg/ℓ$^{-1}$ and the mean daily load of ortho-phosphate discharged into Hartbeespoort Dam is 547.95kg. Geographically, the Hartbeespoort Dam is situated in the upper Crocodile (West) River catchment and with its major tributaries the Jukskei and Hennops Rivers, are all relatively small rivers. These rivers do not have the assimilative capacity to dilute the effluent from the WWTWs in the catchment (Harties Metsi-a-Me programme, 2011).

The Harties Metsi-a-Me programme is the most recent of a succession of programmes that has addressed the problem of eutrophication in the Hartbeespoort Dam. A number of recommendations are made by this programme, both to limit the quantity of ortho-phosphate entering the sewers and to increase the assimilative capacity of the catchment through the improvement or increase in the availability of in-stream habitat and wetlands (Harties Metsi-a-Me programme, 2011). The area through which these rivers flow is heavily populated and generally hilly so there is not much land available for interventions aimed at increasing the assimilative capacity of the catchment. One novel method of increasing the assimilative capacity of the system, however, is through the use of artificial floating wetlands.

In the following sections the floating wetland technology is examined and compared to natural and land-based constructed wetlands. Then the costs of the treatment of sewage using conventional technology and as a hybrid system of conventional technology combined with the floating wetland technology, is investigated.

Costs and benefits of floating wetlands – a review

According to a study done for the Bay of Plenty Regional Council in New Zealand (Hamill et al., 2010), the floating wetlands manufactured by Floating Islands International are by far the most effective of the different types of wetlands when it comes to nutrient removal per hectare. When adjusted for costs though, the floating wetlands seem to be more expensive for removing one kilogram of waste (see Table 1). The benefit of floating wetlands being less land (or space) intensive is illustrated by their superior extraction ability per hectare.

Table 1 Floating Wetlands versus Constructed Wetlands

Region	Constructed wetlands	Floating wetlands
TN (kg/ha) (Removal/ha/yr) TP (kg/ha) (Removal/ha/yr)	368 11	714 13
TN (USD/kg) (Cost for removal) TP (USD/kg) (Cost for removal)	63.55 2 038	351 19 523
TN (ZAR/kg) (Cost for removal) TP (ZAR/kg) (Cost for removal)	604 19 361	3 335 185 469

TN = Total Nitrates
TP = Total Phosphates
An exchange rate of R9.5 = 1$ was used
Source: Hamill et al. (2010)

It should be noted though that the cheapest option found pertained to the protection or reconstruction of existing natural wetlands as a means to water control. Whether or not the alternative wetlands prove to be cheaper in the case of the Jukskei River depends on local circumstances such as whether or not natural wetlands exist, with sufficient capacity, to be restored as a solution. There is a case for combining the various options to achieve the optimal results, as will be noted in Section 5.

Further processes exist for wastewater treatment beyond floating wetlands. One innovative way to deal with this is by the use of SHARON (Stable High Ammonia Removal Over Nitrate) systems. These constructed systems produce cost estimates of approximately 1.5 Euros per kilogram of nitrogen removed. These systems compare favourably with other similar industrial scale removal techniques in terms of costs (see Table 2). It should be noted however that the sizes of the SHARON systems tend to be very large, removing 400 to 5000kg of nitrogen per day at the plants currently in existence.

Table 2 Nitrate Removal Costs for Alternative Methods

Technique	**Energy requirements**	**Cost (USD/kg)**	**Cost (ZAR/kg)**
Air Stripping	Average	7.92	75.24
Steam Stripping	High	10.56	100.32
MAP/CAFR process	Low	6.92	65.74
Membrane Bioractor	High	3.7	35.15
Biofilm Airlift Reactor	Average	7.52	71.44
SHARON Process	Average	1.98	18.81

Source: Grontmij (n.d.)

An exchange rate of R 9.5 = 1$ was used.

Examples of floating wetlands

Floating wetlands are currently proposed as a solution for the Hartbeespoort Dam. The floating wetlands root systems provide an alternative ecosystem for plants and animals that require the shoreline vegetation to function. The use of floating wetlands in this particular case may even aid the restructuring of fish populations within the dam with wider benefits including the restructuring and rehabilitation of the entire food web. Strategic placement of floating wetlands can augment further support to local ecosystems if such wetlands are placed close to the traditional vegetation found on the banks of the dam. The advantages of floating wetlands, therefore, extend well beyond the treatment of water. These wetlands can also be introduced in both the dam and the river itself. Furthermore, as indicated previously, the dam suffers from algal blooms which are the source of many of the ecological problems in the area. Floating wetlands present themselves as a natural solution here.

One example abroad of the use of floating wetlands include their application at Heathrow Airport in the United Kingdom to prevent chemicals used in de-icing of the wings of planes from finding their way into the environment. Another example is found in Belgium where floating wetlands were applied to deal with occasional sewage overflow from occasional environmental conditions. A further success story is the treatment of sewage and swine wastewater in Australia (Auckland Regional Council, 2006). It should be noted that not all designs of floating wetlands offer the same efficiencies of nutrient and pollutant removal. The cost-efficiency depends on the material used, the design and the life span of the wetland. This should be investigated before the final decision is made.

The use of floating wetlands for water quality improvement: an economic study

Introduction

The review of floating wetlands as water treatment systems indicates that the technology has promise in improving the quality of the water flowing into the Hartbeespoort Dam. A study of the economics of the removal of nutrients from the inflowing rivers using a hybrid technology which combined floating islands with conventional WWTW, in comparison to conventional treatment alone, was conducted to investigate the relative cost-effectiveness of the technologies.

Eutrophication is associated with nitrate and phosphate enrichment, and results in increases in algal biomass (Smith et al., 1999). High levels of algal biomass have been observed in the Hartbeespoort Dam. Algal blooms and high levels of ammonia have a negative impact on water quality, resulting in increasing treatment costs of potable water treatment works, and also have negative effects on property prices, recreation, fish life and the environment (Graham et al., 2011). The major cause of algal build up in the Hartbeespoort Dam is the nutrients brought in by the Crocodile River, of which the Jukskei River is a major contributor (DWA, 2012). This case study therefore aims to investigate different management options for treating algal build up and high ammonia levels. A cost-effectiveness model is developed for different effluent treatment options, with the aim of identifying the least cost method for addressing eutrophication.

Study area

The study area is the Jukskei River catchment, which is situated in the A21C quaternary catchment. The catchment is approximately 760km^2, and is the second largest catchment draining into the Hartbeespoort Dam. The catchment is primarily urban, with a large portion of it falling within the City of Johannesburg (see Figure 2), and has a number of major polluting industries, including NCP and AECI, agricultural pollutants such as piggeries, and domestic pollution (urban run-off) from sources such as Alexandra Township (DWA, 2012). The largest wastewater treatment works in the catchment is the Northern WWTW, treating 420Ml of effluent per day. The Jukskei River is a major tributary of the Crocodile River. Major perennial rivers in this catchment include, Modderfonteinspruit, Upper Jukskei River, Sandspruit, Braamfonteinspruit, Little Jukskei River and Jukskei River.

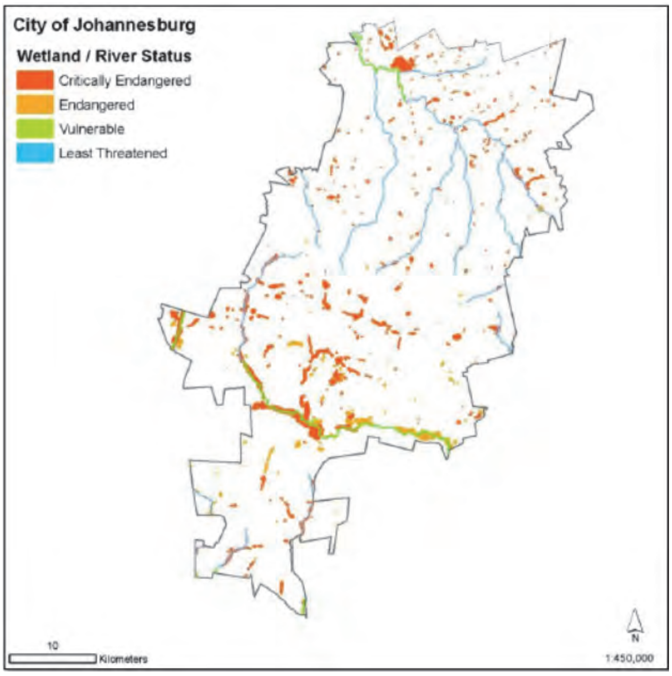

Figure 2 Map showing City of Johannesburg and rivers and wetlands
Source: City of Johannesburg (2011)

Data

The water quality data for the study is collected from DWAF water quality monitoring point 90189, which is the point at which the Jukskei River exits the A21C quaternary catchment, just upstream of its confluence with the Crocodile River (see Figure 3). Data from this monitoring point has been collected from 1971 until the present day, the latest available value used in this case study being 15/05/2013 (DWA, 2013).

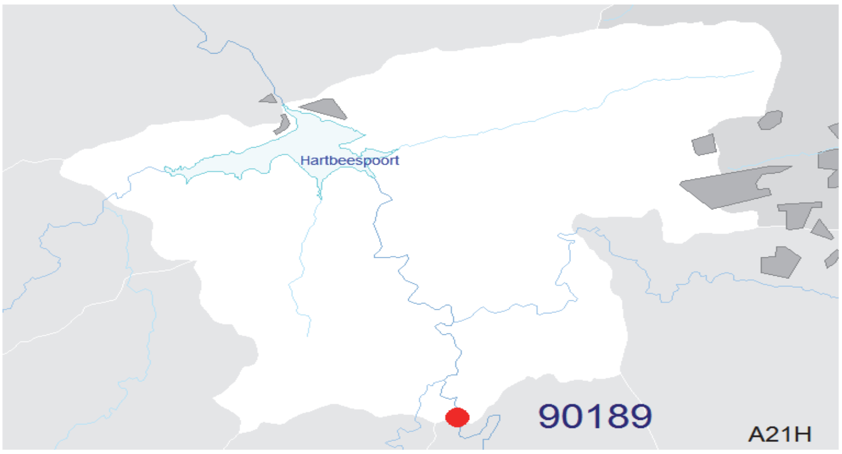

Figure 3 Location of water quality monitoring point 90189
Source: DWA (2013)

Most recent data from this water quality monitoring point (see Figure 4) indicates that nitrate pollution loads have remained fairly constant and even declined over the past decade while phosphate and ammonia levels have increased, with greatest increases being between 2012-2013. It is unclear what the reason for this dramatic increase is. Possibly it is a result of one or more of the industries, agriculture or residential sectors increasing effluent production, or possibly it is as a result of biological processes. Whatever the reason, these increases are a cause for concern.

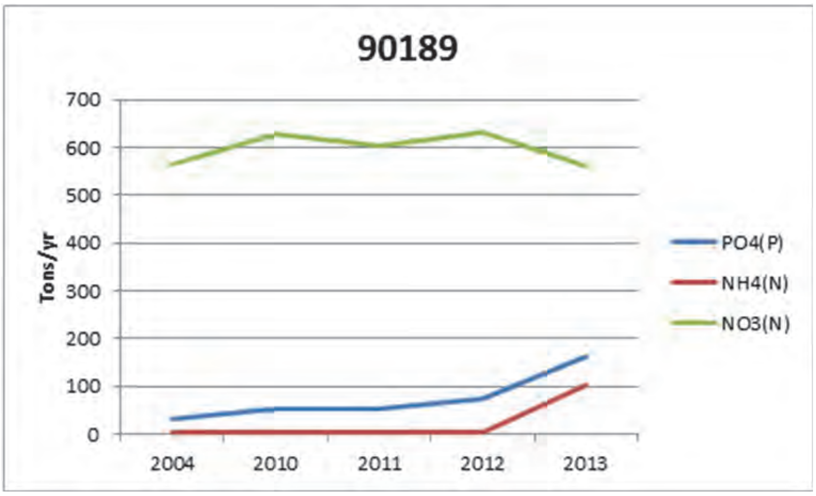

Figure 4 Changes in pollution loads, 2004-2013
Source: DWA (2013)

Any modelling effort therefore needs to take into consideration both scenarios of constant effluent loads, but also increasing effluent loads in the Jukskei River. In the next section, we will consider the methodology used to assess the different technologies that are available to solve the problem of eutrophication in the Jukskei River.

Methodology

The following cost-effectiveness analysis (CEA) compares three options:

1) A business-as-usual option based on existing WWTWs only

2) Utilising floating wetland technology exclusively
3) A hybrid option that considers a combination between WWTW and floating wetland technologies

Further particulars of these three scenarios are given below, but first it is necessary to explain the CEA methodology in more detail.

Cost-effectiveness analysis method

A CEA is similar to a cost-benefit analysis (CBA), except that only costs are included and not benefits. The literature indicates that a CEA is the preferred evaluation technique to CBA in situations where an environmental goal has already been set by the authorities, and the least cost means of achieving that goal needs to be evaluated (see e.g. Winpenny, 1995). Given the severe problems of eutrophication in the catchment, we believe that addressing this problem is an inevitable outcome, so a quantification of benefits is not undertaken. However, should this not be the case, then subsequent work would be needed to address the benefits of mitigation measures.

The cost effectiveness analysis estimates the Net Present Value (NPV) of cash flows, using the following formula:

$$\mathrm{NPV} = \sum_{i=1}^{n} \frac{values_i}{(1+rate)^i}$$

Where *n* is the number of periods, *values* are the cost cash flows, and *rate* is the discount rate. The period for the CEA is the assumed lifespan of the floating wetland or WWTW, whichever is the longest. According to Hamill et al. (2010), the lifespan of a floating wetland is 50 years, whereas in Chapter 3 a lifespan of a typical WWTW of 25 years was employed. Furthermore, Hamill et al. (2010) use a discount rate of 8% for their NPV calculations of different technologies, which seems a bit high in the current investment climate. We therefore employ a project lifespan of 50 years, and a range of discount rates, 4%, 6% and 8%.

We will now consider the assumptions associated with these three scenarios.

WWTW-only option

The Northern WWTW is operating at in excess of 90% of capacity, so this scenario models the construction of a new WWTW at water quality monitoring point 90189. The average flow at this point is 2.7m^3/s, thus the plant would need to have a capacity of 235Ml/d in order to treat the water. Two plants would be required over the 50-year period of the study, and total costs of treatment include both construction costs as well as operating costs over this period.

Two waste water treatment scenarios are employed:

- WWTW1 = pollution loads are kept constant. In other words, only plant construction and operating costs are included, as described above. It was difficult to source recent estimates of construction costs of a typical WWTW. The construction costs for the study are based on somewhat dated estimates from Hartbeestfontein WWTW, published in an EWISA report and extrapolated to 2014 values. Hartbeestfontein WWTW uses similar effluent technology as the

Northern WWTW, the major WWTW in the Jukskei River catchment, and is also in the Gauteng region so is probably indicative. The study uses a value of just over R8 million/(Ml/d) construction, which appears to be a reasonable estimate when compared with other estimates of WWTW construction in the literature. Operating costs are from DWA (2012), which state that a typical WWTW in 2011 cost between 56 and 82c/kl to run (activated sludge technology (without biological nutrient removal) for metro areas). Using average values, and extrapolating to 2014 values, gives a total operating cost of R811/Ml.

- WWTW2 = nutrient loads are assumed to increase. Under this scenario, not only construction and operating costs are included (as per WWTW1), but also changes in the cost of wastewater treatment as a result of increasing pollution loads. Data are derived from Graham et al. (2011), where a 1% increase in phosphate, ammonia, and nitrate loads results in an increase in operating costs of R0.007/kl, R0.001/kl, and R0.004/kl (2014 values), respectively. Multiplying this by the average annual change in effluent loads between 2004 and 2013 gives the unit cost increases (R/kl) that when multiplied by the total flow, indicates that the total treatment cost associated with increases in effluent loads is R20,8 million per annum (2014 values).

Floating wetlands only

The costs associated with floating wetland (FW) technology were difficult to arrive at. We attempted to source local cost estimates from a variety of sources, and for various reasons it was difficult to directly use estimates from these sources. In the end, we decided to base our costs on literature estimates from overseas studies. This is less than ideal, and further work would be needed to revise these estimates. We used estimates of unit costs of constructing and maintaining FW from a cost-effectiveness study conducted on different technologies from New Zealand (Hamill et al., 2010). We used standard benefits transfer techniques to convert these values to 2014 South African Rands, taking into consideration the exchange rate, purchasing power and differences in wealth. These values were ground-truthed with values from Floating Island International (FII), a company that has a local office in South Africa, and seem comparable. Construction costs equated to R1 360/m^2 and operating costs were R9/m^2 (2014 values). These estimates were then converted to R/tonne estimates based on FW removal rates for ammonia, phosphates and nitrates from Stewart et al. (2008), which is also based on the FII technology. These unit costs are then multiplied by individual effluent loads to get the total annual costs (maximum values are used and not the summation of effluent loads, as one FW will remove all three pollutants). As for the WWTW option, two scenarios were attempted. In the first scenario, effluent loads were held constant (as was the case with the WWTW1 scenario). In the second scenario, effluent loads were assumed to increase over time. However, this scenario reached carrying capacity constraints after 6 years (i.e. there is not enough space (ha) available in the catchment to consider this option, and was therefore abandoned in favour of a hybrid option.

Hybrid option

The hybrid option assumes that loads increase as per historical levels, taking into consideration carrying capacity limitations on the planting of floating wetlands. The Hartbeespoort Dam spans an area of approximately 2 034 ha (DWA, 1986); rivers and wetlands in the City of Johannesburg span an area of 5 006 ha (City of Johannesburg, 2011); while the rivers, floodpains, pans and wetland areas in the Jukskei River catchment seem closer to 68 ha (Fakir & Broomhall, 1999). These wide disparities make the estimation of a maximum area for floating wetlands difficult. We, therefore, assume a maximum feasible area for floating wetlands in the Jukskei River catchment and Hartbeespoort Dam of 125 ha, but test this by conducting a sensitivity analysis on the outcome. The hybrid option assumes that floating wetlands are added until the maximum feasible area is reached (as indicated above, this would be after 6 years), then WWTWs are constructed to take into consideration excess pollutant loads above this level. In other words, after carrying capacity constraints are reached with FWs, then the WWTW2 scenario becomes applicable, but at lower unit costs for treating additional pollutant loads than would have been likely had floating wetlands not been introduced.

Results

Net present values

Results from the CEA are presented in Table 3. The results indicate that the floating wetland technology (FW scenario) is very cost-effective under assumptions of constant effluent loads. The FW scenario generates a NPV of approximately R0.1 billion at an 8% discount rate, compared to the WWTW1 scenario (which also assumes a constant effluent load over time) of R3.1 billion. The two scenarios that assume an increasing effluent load for phosphates and ammonia are WWTW2 and the hybrid scenario, which is a combination of FW and WWTW technologies. (As indicated previously, FW under an increasing effluent load scenario is not plausible). Results indicate that the hybrid scenario is slightly better than the WWTW only option (R3.04 billion over 50 years, compared to R3.38 billion at 8% discount rate). These conclusions are not affected by changes in the discount rate.

Table 3 Net present values (R billion) of different eutrophication management technologies

	FW	**WWTW1**	**WWTW2**	**Hybrid**
	R bn	**R bn**	**R bn**	**R bn**
4%	0.11	4.18	4.64	4.51
6%	0.11	3.51	3.86	3.63
8%	0.10	3.10	3.38	3.04

Scenarios:

FW = floating wetland technology, no increase in effluent loads

WWTW1 = waste water treatment work technology, no increase in effluent loads

WWTW2 = waste water treatment works technology, increase in effluent loads over time

Hybrid = floating wetlands technology until carrying capacity, then waste water treatment work technology, increasing effluent loads over time

Annualised values

The annualised values indicate that FW could cost as little as R5 million per year to implement (assuming effluent loads remain constant). However, the more plausible hybrid option could cost between R210 and R250 million per year to implement. The cost of the WWTW-only options are higher, ranging between R254 million/yr (assuming no increases in pollution loads) to R276 million/yr (assuming increasing pollution loads over time). All estimates are in 2014 prices (see Table 4).

Table 4 Annualised values (2014 R million/yr) of different eutrophication management technologies

	FW	WWTW1	WWTW2	Hybrid
	2014 Rm/yr	**2014 Rm/yr**	**2014 Rm/yr**	**2014 Rm/yr**
4%	R 5	R 194	R 216	R 210
6%	R 7	R 223	R 245	R 230
8%	R 8	R 254	R 276	R 249

Scenarios:
FW = floating wetland technology, no increase in effluent loads
WWTW1 = waste water treatment work technology, no increase in effluent loads
WWTW2 = waste water treatment works technology, increase in effluent loads over time
Hybrid = floating wetlands technology until carrying capacity, then waste water treatment work technology, increasing effluent loads over time

Sensitivity analysis

The baseline simulation compares the NPV of different WWTW options against a modelled floating wetland area of 125 ha. But one other management option available to environmental engineers is to control the total area of potential floating wetlands. The question, therefore, is what the optimal floating wetland area in the Jukskei River catchment and Hartbeespoort Dam is that minimises cost? Figure 5 plots NPV under the hybrid option as a percentage of the WWTW2 NPV (scenario of increasing effluent loads) for different floating wetland areas. As indicated in Figure 5, the minimum cost scenario for the hybrid option occurs at a floating wetland area of between 60 and 80 ha. At this level, the NPV of the hybrid option is just less than 88% of the WWTW2 NPV.

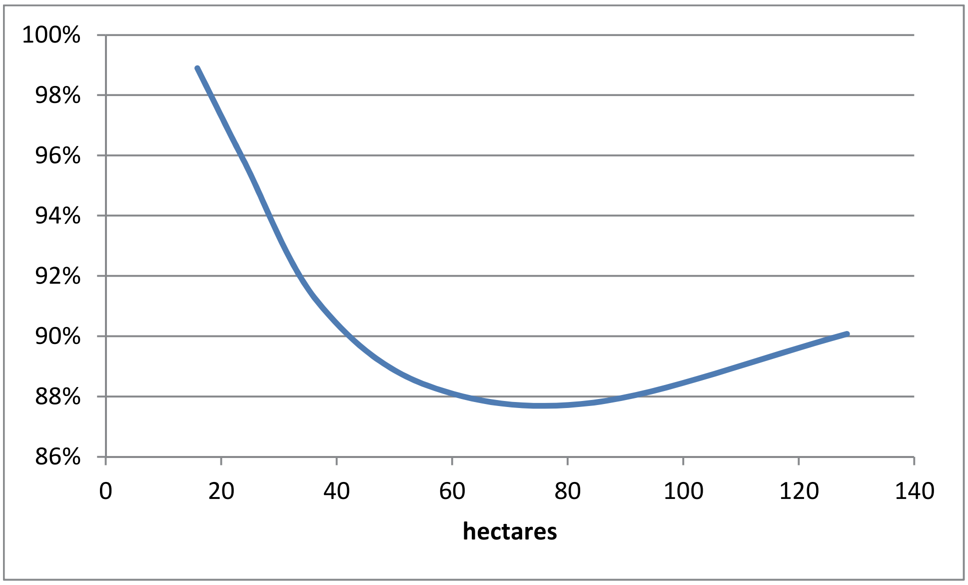

Figure 5 **NPV of the hybrid option as percentage of WWTW2 NPV, at different FW areas**

Conclusion

Eutrophication is a serious problem in the Jukskei River catchment, with pollutant loads for ammonia and phosphates increasing by more than 20% per year over the past decade. Eutrophication and associated increased ammonia levels have the effect of increasing algal blooms, emitting unpleasant odours and also causing environmental damage. This project considers two options: one option is the business-as-usual scenario, building new wastewater treatment works, and the other scenario is a hybrid option that combines new wastewater treatment works with the implementation of floating wetland technology. Floating wetland technology should not be considered as a standalone solution to increased eutrophication, not least because wastewater treatment works are able to treat a wider range of pollutants than is possible by floating wetlands only. The study also finds that a hybrid approach combining of floating wetlands with WWTWs is more cost-effective than WWTWs only. The reason of this is that floating wetlands can defer the cost of building new wastewater treatment works, and can reduce the treatment costs associated with increasing effluent loads.

Salient points

- Maintenance of water quality should be managed at the level of the catchment, with conventional wastewater treatment works being a part of the infrastructure to achieve the maintenance of the required water quality.
    - As far as possible, wastewater treatment may be managed on-site through appropriate municipal bylaws and cleaner production technologies.
    - Ecological infrastructure may be harnessed to provide supplementary treatment capacity.
    - In particular, high rate biotechnologies which are available, such as floating wetlands by Floating Island International, may be employed either on- or off-site to provide additional treatment capacity.

- The siting of the conurbations in Gauteng was determined by the distribution of minerals, not water availability.
    - The rivers draining the conurbations are generally small and cannot provide the dilution necessary to negate the eutrophication of downstream impoundments.
    - In the case of the Jukskei River, a tributary of the Crocodile River which runs into the Hartbeespoort Dam, the major contributor of effluent is the Northern Works. Northern Works has consistently achieved high Green Drop scores (Green Drop status in 2009 and a Green Drop Score of 92.4% in 2011). However, there are other sources of pollution which raise the nutrient levels of the river beyond the capacity of the river to dilute these.