DEMONSTRATION OF HOW HEALTHY ECOLOGICAL INFRASTRUCTURE CAN BE UTILIZED TO SECURE WATER FOR THE BENEFIT OF SOCIETY AND THE GREEN ECONOMY THROUGH A PROGRAMMATIC RESEARCH APPROACH BASED ON SELECTED LANDSCAPES

Deliverable 12: Report based on the tested evidence demonstrating how intact ecological infrastructure could have alleviated the costs resulting from degraded ecosystems

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By the:

Centre for Water Resources Research
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Project K5/2354
Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>CBA</td>
<td>Cost Benefit Analysis</td>
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<td>CEA</td>
<td>Cost-effectiveness analysis</td>
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<tr>
<td>CSIR</td>
<td>Council for Scientific and Industrial Research</td>
</tr>
<tr>
<td>CWRR</td>
<td>Centre for Water Resources Research</td>
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<tr>
<td>DUCT</td>
<td>Duzi-uMgeni Conservation Trust</td>
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<tr>
<td>DWAF</td>
<td>Department of Water Affairs</td>
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<td>DWS</td>
<td>Department of Water and Sanitation</td>
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<tr>
<td>EbA</td>
<td>Ecosystem-based Adaptation</td>
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<tr>
<td>EI</td>
<td>Ecological Infrastructure</td>
</tr>
<tr>
<td>EPWP</td>
<td>Expanded Public Works Programme</td>
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<tr>
<td>GI</td>
<td>Green Infrastructure</td>
</tr>
<tr>
<td>IAP</td>
<td>Invasive Alien Plants</td>
</tr>
<tr>
<td>KZN</td>
<td>KwaZulu-Natal</td>
</tr>
<tr>
<td>N</td>
<td>Nitrogen</td>
</tr>
<tr>
<td>NPV</td>
<td>Net Present Value</td>
</tr>
<tr>
<td>RQO</td>
<td>Resource Quality Objective</td>
</tr>
<tr>
<td>SANBI</td>
<td>South African National Biodiversity Institute</td>
</tr>
<tr>
<td>WRC</td>
<td>Water Research Commission</td>
</tr>
<tr>
<td>TN</td>
<td>Total Nitrogen</td>
</tr>
<tr>
<td>TP</td>
<td>Total Phosphorus</td>
</tr>
<tr>
<td>UEIP</td>
<td>uMgeni Ecological Infrastructure Partnership</td>
</tr>
<tr>
<td>UN</td>
<td>United Nations</td>
</tr>
<tr>
<td>UNEP</td>
<td>United Nations Environment Programme</td>
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<tr>
<td>WWTW</td>
<td>Waste Water Treatment Works</td>
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Summary

A component of the broader research project is to explore the economics of investing in ecological infrastructure (EI) toward water security within the greater uMgeni Catchment. This has been done at a case study level. Together, Deliverables 4, 9 and 12 (this report) form the economic work package of the overall research project. Deliverable 4 of the research project presented a literature review and outlined the methodology in support of the economic evaluation of investing in ecological infrastructure. Deliverable 9 focused on the costs of declining water quality and provided context to the call from various stakeholders for interventions to protect and improve the water quality of the greater uMgeni Catchment. The costs of declining water quality provide an indication of the benefits of protecting and maintaining water quality. Deliverable 12, this report, presents the case studies. The case studies provide an opportunity to explore and reflect on the potential costs and benefits of investing in ecological infrastructure for water security. Three case studies are reported in this deliverable.

The Mthinzinga Wetland Rehabilitation Case Study entailed an ex ante assessment of the costs and benefits of rehabilitation of the Mthinzinga Wetland in KwaZulu-Natal with the aim of establishing if the investment is worthwhile from an economic perspective. The ecosystem services approach was used in conceptualizing the benefits of investing in the rehabilitation of the Mthinzinga Wetland. Based on wetland health assessments, water quality enhancement was identified as the primary ecosystem service likely to be improved through the wetland rehabilitation and a service of specific importance in the case study context – downstream of a peri-urban settlement and upstream of a key water supply dam. The analysis focused specifically on the potential incremental increase in the effectiveness of the Mthinzinga Wetland for nutrient removal as a result of the rehabilitation. Based on the ‘hectare equivalents’ approach, the anticipated gain in functional wetland area (10.78 ha) with the rehabilitation was used as a base for estimating the potential additional nutrient removal service. The gain in functional area was multiplied by per unit area nutrient removal rates from the literature. The replacement cost valuation approach was applied to value the benefit and a cost-benefit analysis was undertaken.

Through expert engagement and consideration of several alternatives, the replacement cost’ was determined as the fixed and maintenance costs associated with a standard 1 ML waste water treatment plant. Estimated NPVs were positive across all discount rates and time periods considered indicating that the benefit of the wetland rehabilitation exceeds the wetland rehabilitation costs over the life of the investment, ceteris paribus. This outcome suggests that it is economically beneficial to invest in the rehabilitation of the Mthinzinga Wetland. The study was subject to several assumptions and limitations and the CBA results should not be considered as a ‘final answer’ on whether the rehabilitation is a worthwhile investment. Decision makers should use the results as illustrative of the magnitude of costs and benefits under the set of assumptions made and use the CBA as a tool for testing the robustness of the investment to alternative assumptions concerning the magnitude of costs and benefits, bearing in mind the limitations of the study. Given the available data, and the approach taken, this assessment indicates that it is worthwhile to invest in the rehabilitation of the Mthinzinga Wetland.

However, the dynamic nature of the context, the heavy reliance on the literature for ‘evidence’ and the resulting uncertainty of the biophysical outcomes, and the use of a cost-based valuation method mean that the confidence in the results of the CBA in terms of absolute monetary values and cost-benefit comparisons is low and raises the question of whether conventional CBA is an appropriate and useful tool in considering the benefits of investing in the rehabilitation of the Mthinzinga Wetland.
The real value of the CBA assessment, in this case, lies in the learning and understanding gained through undertaking the process; specifically:

- There is no cost-effective realistic replacement or alternative to the Mthinzima Wetland rehabilitation;
- Long-term monitoring of the biophysical outcomes of wetland rehabilitation in South Africa is needed to provide data/information on which to base economic valuations;
- Close engagement between experts (e.g. engineering/waste water treatment works design expertise, wetland ecology, water quality specialists, hydrologists, limnologists, environmental authorities, etc.) is needed in the evaluation of an investment in EI particularly at the start of the assessment so as to develop a holistic understanding of the context and determine the best approach and design of the evaluation;
- Conventional CBA is not always the most appropriate or useful way to evaluate an investment in EI; further, CBA results should not be considered as a ‘final answer’ on whether a proposed investment in EI is worthwhile.
- The more people/stakeholders involved in the process; the greater the shared learning.

The **Baynespruit Catchment Case Study** entailed an ex ante evaluation of urban water management options for the Baynespruit Catchment. Viewing urban areas as social-ecological-technological systems (SETS) and recognizing the dynamic interactions between social, ecological, and technical-infrastructural domains highlights the need for more combined approaches to urban management beyond a reliance on built and technical solutions (grey infrastructures). This case study explored ecological, grey, green / hybrid and social capital investment options for improved water quality and stormwater control to shed light on the opportunities available for the Baynespruit Catchment. When multiple potential investment options or actions are being considered, especially those involving complex functions and interactions (e.g. changes in ecosystem condition and function), and it is not feasible to conduct extensive primary research for each option, multi-criteria approaches and cost analysis are appropriate starting points for evaluating options (Rao et al., 2012; Black et al., 2016). This is the case in this study of the Baynespruit Catchment case study. A qualitative multi-criteria assessment supported by a cost comparison was undertaken as a first step towards identifying appropriate solutions to water quality and stormwater management challenges in the Baynespruit Catchment.

Based on the multi-criteria comparison, eight potential options were prioritized for further assessment to establish how they could be applied in the Baynespruit Catchment, what their potential impact on water quality and stormwater runoff could be and the associated implementation costs (monetary), benefits (identified) and threats and constraints. The costs to implement each option (investment action) in the Baynespruit Catchment were compared; equivalence in effectiveness of the options is not assumed, but we compared the eight options as an indication of their cost implications. The comparison showed that the least cost option is to implement the seven proposed floating wetlands in the Baynespruit Stream. Revegetation of degraded riparian areas in the Baynespruit Catchment provides the greatest range of benefits, contributing to improved water quality and stormwater control, as well as providing additional co-benefits. This comes at a relatively low cost. The main threats to this option are competition for land and the need for regular, but low cost, maintenance. Similarly, wetland rehabilitation has the potential to provide a range of benefits. The grey infrastructure options, while effective at achieving their main objective, provide the least opportunity for additional benefits and are relatively more expensive to implement and maintain. Conclusions for each of the options evaluated are summarized in Table S1. Ecosystem-based solutions are multifunctional relative to many grey infrastructures. This is a key difference between ecosystem-based and grey infrastructures and deserves meaningful consideration in urban planning and management.
Table S1: Summary of conclusions from the qualitative evaluation and cost comparison of potential investment options towards improved water quality and stormwater management in the Baynespruit Catchment, ranked in order of least to highest cost, options not assumed to be equivalent in effectiveness (outcomes)

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<thead>
<tr>
<th>Infrastructure</th>
<th>Option</th>
<th>Conclusion</th>
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<tr>
<td>Green/hybrid</td>
<td>Floating wetlands (FW)</td>
<td>Least cost, impact constrained by small size and limited suitable sites to locate FW, water quality benefits, no stormwater control benefits, provides some co-benefits, medium risk to long-term durability.</td>
</tr>
<tr>
<td>Social</td>
<td>Environmental advocacy</td>
<td>Relatively low cost, impact uncertain, requires long-term continuous investment, provides both water quality and stormwater benefits, and high potential co-benefits. Added benefit of supporting / complementing other investment options, extending durability of other investments. Volunteer / citizen science approaches can reduce project costs.</td>
</tr>
<tr>
<td>Ecological</td>
<td>Revegetation of riparian zone</td>
<td>Relatively low cost, potential to provide water quality, stormwater and co-benefits (ecological and social benefits). Long-term durability could be extended through environmental advocacy initiatives.</td>
</tr>
<tr>
<td>Ecological</td>
<td>Wetland rehabilitation</td>
<td>Medium relative cost, provides water quality benefits, long-term supply of benefits, high potential for co-benefits, some risk of vandalism and threats from illegal dumping and competition for space. Generally low maintenance required, but additional maintenance likely required in the Baynespruit context (e.g. waste management).</td>
</tr>
<tr>
<td>Green/hybrid</td>
<td>Waterless sanitation</td>
<td>Medium relative cost, potential water quality benefits (depending on scale of implementation), addresses only point source pollution. Additional significant benefit of water conservation and associated low operation cost. Social acceptance of waterless sanitation is a key challenge. Likely only to be ‘acceptable’ where the only alternatives are pit latrines or no sanitation (i.e. in informal, rural or peri-urban areas).</td>
</tr>
<tr>
<td>Grey</td>
<td>Rehabilitate waterborne sanitation</td>
<td>Medium relative cost, proven effectiveness at addressing point source pollution. No significant stormwater or co-benefits (beyond the benefits of improved water quality). Long lifespan if continuously maintained. Only direct alternative to this option is waterless sanitation, which is socially infeasible in the short-term.</td>
</tr>
<tr>
<td>Grey</td>
<td>Stream canalisation</td>
<td>High relative cost, effective at addressing streambank erosion and property damage issues where they are currently being experienced, but risk of transferring the issues further downstream, therefor requires significant infrastructure (gabions) at the exit point. No significant water quality benefits or co-benefits. Political pressure from affected residents to implement this option. Long lifespan and low maintenance costs likely to offset the high implementation costs.</td>
</tr>
<tr>
<td>Green/hybrid</td>
<td>Rooftop rainwater harvesting</td>
<td>High relative cost, ability to ‘control’ stormwater depends on associated water storage capacity of the system and effective use of collected water, limited in attenuating high flows (which cause damage). Effectiveness enhanced if used in conjunction with sustainable urban drainage systems. Can significantly reduce rooftop runoff, but this is only a small proportion of catchment runoff. Potential to provide benefits to households and commercial sector and save costs on purchased municipal water.</td>
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While this assessment compared the various options in isolation of each other, the different infrastructures and investment options should be viewed as complements and considered in combination with one another. For example, environmental advocacy initiatives can reduce the threats to wetland and riparian area rehabilitation. Ecosystem-based options that slow stormwater...
flows from impervious surfaces before they enter a stormwater drainage system can reduce the pressure on waste water treatment works during high rainfall events.

Urban systems should integrate a mix of grey infrastructure, ecosystem-based solutions (ecological and green infrastructure) and social initiatives to improve the management of urban water and wastes. Rather than relying solely on grey infrastructures as the default solution, planners and managers should assess and investigate opportunities for restoring and expanding ecosystems and integrating green infrastructure into developments to provide a greater range of benefits in a multifunctional approach to urban water management. To foster ecosystem-based urban innovation two key elements are needed: (i) increased cross-sectoral (and cross-departmental) collaboration and integration of ecosystem-based concepts into planning and management and (ii) increased funding as a means to generate concrete implementation action, increase the knowledge and evidence base, and build awareness of ecological and green infrastructure solutions as a more holistic approach to addressing multiple social challenges.

The information generated through this study is intended as a starting point to identifying and evaluating investment actions for water security in the Baynespruit Catchment, with a focus on ecosystem-based solutions. Specifically, the information can be used as a tool for engagement across different municipal departments (e.g. Town Planning, Water and Sanitation, Roads and Transportation (storm water management), Environment, etc.) to build a shared awareness of options across both grey and ecosystem-based infrastructures. The information can be used as guidance in designing investment and management plans towards water security in urban systems; the current assessment can be used to further prioritise investment options for more detailed analysis, for example, it could be used to inform the design of cost-benefit and / or multi-criteria analyses. The assessment has also highlighted the need to consider additional investment options, particularly green / hybrid infrastructure options as the few considered in this assessment do not adequately reflect the range of options (e.g. SUDS). Developing a deeper awareness of the range of options to manage urban water and wastes, beyond a sole reliance on grey infrastructure, and the interactions between them, is a first step towards integrating social, ecological, and grey-infrastructural options in a multifunctional approach to urban water management.

Water pricing study

Water utilities throughout the world incur costs in the processing of raw water to provide potable supply. The most important of these costs are Raw Water, Energy (pumping and treatment), Chemicals, Maintenance, Human Resources and Capital repayment costs, which together (cover about 85% of costs. This is typical for e.g. Umgeni Water and is the basis of their financial reporting system. These costs are reported in their Annual Report and provide a useful focus for any assessment of the extent to which investment in EI could offset these costs.

For this Deliverable, we provide a semi-quantitative assessment of the benefits of investing in EI for a Water Utility with Umgeni Water as a focus, concluding that there are significant benefits to be gained from investing in EI. A further analysis shows the amount of money that could be generated for different water resource management “tariffs”, based on a typical year of Umgeni Water sales. A tariff of R0.10 per cubic metre would generate approximately R40 million per year.
1 Introduction

1.1 WRC Project K5/2354 Overview

In April 2014, the Centre for Water Resources Research (CWRR) and partners were awarded a 5 year research project through a Water Research Commission (WRC) solicited call. The project is entitled:

“Demonstration of how healthy ecological infrastructure can be utilized to secure water for the benefit of society and the green economy through a programmatic research approach based on selected landscapes”.

The K5/2354 continues to focus its efforts on supporting the service provider partners of the uMngeni Ecological Infrastructure Partnership (UEIP) through research in the pilot study sites. The pilot studies continue to form the focus “landscapes” through which this project operates. SANBI and the eThekwini Municipality’s Water and Sanitation Department together with the KZN Regional Office of DWA, Umgeni Water and the Water Service Authorities of the uMgungundlovu District and Msunduzi Local Municipalities, have spearheaded the establishment of a partnership to foster better collaboration and coordination of ecological infrastructure investments aimed at improving water security in the greater uMngeni Catchment, the uMngeni Ecological Infrastructure Partnership (SANBI, 2013¹).

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Investing in Ecological Infrastructure for Water Security

“Water from the uMngeni Catchment is the cornerstone of the eThekwini and uMgungundlovu municipality’s growing economies. However the demand for water is now well beyond the available supply according to the 2009 Water Reconciliation Strategy for the KZN Coastal Metropolitan Areas. In response to this a series of expensive engineering solutions have been identified and are in the process of being implemented. These include, amongst others, the construction of inter-basin transfer schemes in the adjacent catchments of the Mooi and Mkomazi Rivers. However, it is recognised that these interventions will not be sufficient to address the water rapidly growing demand.

This situation has prompted eThekwini’s Water and Sanitation department to explore alternative solutions to address water security. A growing body of evidence has shown that investing in ecological infrastructure can enhance the efficiency of water service delivery through improving water quality, reducing sediment loads, reducing flood risk and increasing yield through increased winter baseflows. This in turn augments and enhances the efficiency of the engineering investments. The management and restoration of ecological infrastructure in the catchment therefore has huge potential to provide much of the additional water required to meet the demands.”

(SANBI, 2013)

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1.2 Deliverable Overview and Structure

A component of the broader research project is to explore the economics of investing in ecological infrastructure (EI) toward water security within the greater uMngeni Catchment. This has been done at a case study level. Together, Deliverables 4, 9 and 12 (this report) form the economic work package

of the overall research project. **Deliverable 4** of the research project presented a literature review and outlined the methodology in support of the economic evaluation of investing in ecological infrastructure. **Deliverable 9** focused on the costs of declining water quality and provided context to the call from various stakeholders for interventions to protect and improve the water quality of the greater uMngeni Catchment. The costs of declining water quality provide an indication of the benefits of protecting and maintaining water quality. **Deliverable 12**, this report, presents the case studies.

The following case studies are reported in this deliverable:

**Section 2: Mthinzima Wetland Rehabilitation Case Study**

Investments in Ecological Infrastructure: *An Ex Ante Assessment of the Costs and Benefits of Rehabilitation in the Mthinzima Wetland in KwaZulu-Natal*

[N Buthelezi, M Browne, SRD Ferrer, based on the MSc Thesis of N. Buthelezi].

**Section 3: Baynespruit Catchment Case Study**

*An Ex Ante Evaluation of Urban Water Management Options for the Baynespruit Catchment*

[M Browne and L Mugwedi]

**Section 4:**

The Green Economy is a vision built out of the need to progress toward sustainable development. Its goals are ambitious and it is legitimate to assume that the many and significant changes that will be required will necessitate difficult decisions, characterised by uncertain conditions. As noted in a CSIR report, the green economy concept is, as yet, poorly understood and will depend on the context in question (CSIR, 2014). The case studies provide an opportunity to explore and reflect on the potential costs and benefits of investing in ecological infrastructure for water security.

### 1.3 A note on terms

Several concepts and terms used regularly in this report require some clarification.

**Ecological Infrastructure**

There is no single agreed upon definition of ecological infrastructure. For the South African National Biodiversity Institute (SANBI) Ecological Infrastructure “refers to *naturally functioning* ecosystems that deliver valuable services to people, such as fresh water, climate regulation, soil formation and disaster risk reduction. It is the nature-based equivalent of built or hard infrastructure, and is just as important for providing services and underpinning socio-economic development” (SANBI, 2013:1).

*Naturally functioning* refers to “ecosystems that are in a natural, near natural or functional condition, whose basic ecosystem functions are predominantly unchanged, even though their composition and structure may have been modified” (SANBI, 2014:3).

By this definition, ecological infrastructure is seen as already – or ‘naturally’ - existing in the landscape, although in some cases it might be degraded, and does not include ‘artificial’ (created or constructed) ecosystems and is therefore distinguished from Green Infrastructure.

As with all forms of infrastructure, ecological infrastructure needs to be maintained and managed and in some cases restored, where ‘restored’ refers to the restoration of ecological functioning, rather than restoration to a pristine state (SANBI, 2014).
Ecological infrastructure is viewed as an asset, or stock, from which a range of valuable services flow (SANBI, 2014).

**Investing in Ecological Infrastructure**

According to SANBI (2014:4), investing in ecological infrastructure involves “maintaining functioning ecological infrastructure, as well as restoring degraded ecological infrastructure” where ‘Investment’ refers to “devoting time, effort, finances and/or making decisions in support of a particular undertaking with the expectation of a worthwhile result”.

SANBI (2014) advocate **seven principles of investing in ecological infrastructure:**

- Investment in ecological infrastructure should focus on achieving clearly defined benefits and outcomes
- Investment in ecological infrastructure should focus on systematically identified spatially strategic areas
- Investment in ecological infrastructure will be strengthened by a transdisciplinary approach
- Investment in ecological infrastructure should build on and learn from existing experience and programmes
- Investment in ecological infrastructure should optimise its contribution to job creation, poverty alleviation and rural development
- Investment in ecological infrastructure should take place in a participatory and socially sensitive manner
- Investment in ecological infrastructure should include monitoring and evaluation.

In this report, ‘investing in ecological infrastructure’ refers to actions taken to improve the condition of ecological infrastructure, maintain/preserve the existing condition and/or halt further declines in condition and may include physical interventions such as ecosystem restoration, rehabilitation, conservation and management activities as well as investments related to developing/strengthening institutions and influencing social behaviour amongst others.

**Green Infrastructure**

This term encompasses an array of perspectives and practices.

Broadly, ‘green infrastructure’ can be viewed as “any infrastructure that is good for the environment and promotes sustainable development” (SANBI, 2017:1). For example, public transport systems that reduce the use of fossil fuels, renewable energy infrastructure such as wind farms, or (perhaps more typically) environmentally-friendly components of built infrastructure, such as permeable pavements, green roofs and artificial ecosystems like constructed wetlands for wastewater treatment. Some definitions of green infrastructure include natural ecosystems, along with green spaces such as parks and private gardens.

Three common themes or perspectives on Green Infrastructure can be discerned (Department of Environment, Water and Natural Resources, the Government of South Australia, 2016):

a) **Linked green spaces approach.** In this approach the importance of retaining and linking green spaces, nature corridors and drainage networks in cities to enhance ecosystem functioning is emphasized. The network of Green Infrastructure is seen as analogous to the network of conventional engineering infrastructure underlying the functioning of a city. In this sense, the green infrastructure concept provides a framework for more sustainable urban development.

b) **Green engineering approach.** In this approach Green Infrastructure is viewed as a specialized form of engineering infrastructure, replacing conventional engineering structures with ‘green’ elements to perform functions such as waste and storm water management or enhance
building energy efficiency. Examples include the use of green roofs and living walls to cool buildings, or the use of vegetation to purify storm water runoff.

c) Ecosystem services approach: In this approach nature and natural cycles are recognized as delivering ecosystem services, while these natural cycles operate globally, they can also be retained, restored and maintained within cities to produce local benefits.

In the State of Green Infrastructure Report for the Gauteng Region (GCRO, 2013), ‘green infrastructure’ is the “interconnected set of natural and [hu]man-made ecological systems, green spaces and other landscape features. It includes planted and indigenous trees, wetlands, parks, green open spaces and original grassland and woodlands, as well as possible building and street-level design interventions that incorporate vegetation, such as green roofs. Together, “these assets form an infrastructure network providing services and strategic functions in the same way as traditional ‘hard’ infrastructure” (GCRO, 2013:3). In Cape Town, Green Infrastructure is receiving increasing attention as a water sensitive design strategy in the management of stormwater and surface water (de Almeida, 2015).

Further definitions of Green Infrastructure (GI) include:

- An approach to water management that uses natural processes to improve water quality and manage water quantity by restoring the hydrologic function of the urban landscape (EPA, 2015)
- Any infrastructure that is good for the environment and promotes sustainable development (SANBI, 2013).
- A planned or managed (often engineered), natural or semi-natural system designed to fill a specific need. In addition to providing the required function, green/natural infrastructure can provide more categories of co-benefits when compared to traditional grey infrastructure (WBCSD, 2015).

Ecological infrastructure may therefore be a component of some definitions of green infrastructure, however, by the SANBI definition, not all green infrastructure is considered ecological infrastructure; ecological infrastructure is understood in its own right and as distinct from parks, private gardens, or environmentally friendly components of built infrastructure (SANBI, 2017).

Grey Infrastructure

This term is used to refer to human-engineered solutions using non-living, non-self-maintaining systems (typically of concrete and steel construction) designed to provide a required function (WBCSD, 2015).

Water Security - “the capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socioeconomic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability” (UN Water, 2013)

Water Quality – “the physical, chemical, biological and aesthetic properties of water which determine its fitness for a variety of uses and for protecting the health and integrity of aquatic ecosystems” (DWAF, 1996:2).
2 Mthinzima Wetland Rehabilitation Case Study

Investments in Ecological Infrastructure: An Ex Ante Assessment of the Costs and Benefits of Rehabilitation in the Mthinzima Wetland in KwaZulu-Natal
N. Buthelezi, M. Browne, S. R. D Ferrer
(Based on the MSc Thesis of N. Buthelezi)

2.1 Introduction

Midmar Dam is a strategically significant water resource, supplying drinking water to the eThekwini, uMgungundlovu and Msunduzi Municipalities. Midmar Dam has been shown to be at risk of eutrophication from continued nutrient inputs (GroundTruth, 2012). Investments or management actions in the catchment to reduce nutrient loads to Midmar Dam are seen as a priority. The uMgungundlovu District Municipality has committed to the ‘Save the Midmar Dam Project’ which aims to restore and maintain degraded wetlands, riparian zones and grasslands, create and maintain water resource buffer zones and educate water users on the importance of conserving critical ecological infrastructure. The rehabilitation of the Mthinzima Stream is one proposed investment as part of the ‘Save the Midmar Dam Project’

The Mthinzima Stream is one of several aquatic systems flowing into Midmar Dam. Various studies and stakeholders have raised concerns regarding the quality of the water in the Mthinzima Stream and the potential negative impact on the quality of the water in Midmar Dam. Despite the low flow volumes of the Mthinzima Stream, it contributes the second highest load of soluble reactive phosphate and higher loads of other pollutants to Midmar Dam than significantly larger catchments, indicating that the Mthinzima catchment contributes a disproportionately high level of pollutants to Midmar Dam, given its small size (GroundTruth, 2012). The Mpophomeni settlement, which contains both formal and informal housing, is located in the Mthinzima Catchment upstream of Midmar Dam. Water quality issues in the Mthinzima Stream are associated with polluted run-off from the Mpophomeni settlement including raw sewage as a result of damaged and inadequate sewage infrastructure and solid waste in and around water courses and (van Deventer, 2012). Rehabilitation of an area of degraded wetland on the Mthinzima Stream upstream of the inflow into Midmar Dam has been proposed towards mitigating the impact of the poor quality water of the Mthinzima Stream on Midmar Dam.

Wetlands have the ability to reduce the loads of excess nutrients, pathogens, sediments, and other contaminants generated by various activities in the catchment (Turpie 2010; Schuyt 2005), thus they play an important role in improving water quality. This can be seen in the case of the Mthinzima Wetland, where, even in its degraded state, the wetland provides some level of water quality enhancement. In a comparison of water quality along the Mthinzima Stream, the water quality of the Stream within the Mpophomeni settlement showed the highest nutrient loads, but as the water flowed through the degraded wetlands to the Midmar Dam there was an improvement in water quality (van Deventer, 2012). At present, the Mthinzima Wetland contributes to water quality enhancement; without rehabilitation the wetland will continue to degrade leading to further losses in water treatment capacity, with rehabilitation there is potential to increase this capacity, (GroundTruth, 2015). A better understanding of the value of the potential added water treatment capacity could be used to motivate for the rehabilitation of the wetland.

2.1.1 Evaluation context and aims
Often studies that aim to value investments in ecological infrastructure (e.g., wetland rehabilitation) estimate the total economic value of the ecological infrastructure, rather than the added value as a result of the investment. The purpose of this study was to investigate the incremental change in the supply of the water treatment service with the rehabilitation of the wetland, considering the demand, supply and opportunity for water quality enhancement. The conceptual framework used in the study considers the potential of the ecological infrastructure (the wetland) to supply its services, the opportunity afforded the ecological infrastructure to supply its services (i.e., activities or circumstances that make it possible for the services to be used) and the demand for ecological services.

The focus of the study is a cost and benefit analysis of an investment in ecological infrastructure in the form of the rehabilitation of the Mthinzima Wetland with a focus on the water treatment service of the wetland. The point of departure for this case study is the economic evaluation of a proposed investment in ecological infrastructure (wetland rehabilitation) that is expected to change the supply of ecological services by the wetland, specifically to increase the water treatment capacity of the wetland. The study is thus an ex ante evaluation of the expected outcomes of the investment.

The study aims to value the incremental change in ecological services that result from the investment, taking into account the opportunity to benefit from the increase in services currently and into the future. Cost-benefit analysis (CBA) is widely applied as an appraisal technique particularly for use as an input into public decision-making processes. The cost benefit analysis technique was used to evaluate whether investing in the rehabilitation of the Mthinzima Wetland is likely to be an economically worthwhile investment. The replacement cost technique was used to value the incremental change in wetland services post rehabilitation.

2.2 Study area

The study area is part of the upper uMngeni River Catchment draining into Midmar Dam in the KwaZulu-Natal province of South Africa. The Upper uMngeni System is the main water supply to different districts within uMgungundlovu, Msunduzi and eThekwini municipal areas. Population growth will increase the demand for water from the upper uMngeni resource. Pollution inputs to Midmar Dam could lead to eutrophication of the Dam and the associated health risks and increased water purification costs in the future (Ngubane, 2016). The town of Howick, approximately two km to the east of Midmar Dam, is the main economic centre of the area.

The Mthinzima Stream is a relatively small watercourse that feeds into the Midmar Dam. The Mthinzima Catchment contains some areas of natural grassland and is dominated by the Mpophomeni settlement, a 6000 unit settlement developed in the 1960s. The settlement consists of both formal and informal housing and continues to expand, with more formal housing towards the lower part of the catchment, and poorer, less formal houses extending up the catchment (Rivers-Moore, 2016). Land cover patterns in the Mthinzima Catchment were assessed using historical aerial photographs from 1929 to 2016. Between 1929 and 1960s, the main socio-political drivers of land cover change were commercial agriculture and forestry. The Mpophomeni settlement was developed in the 1960s. From the 1960s to the present, settlement development has increasingly become be the main driver of land cover change within the Mthinzima Catchment.

Upstream of Mpophomeni, the catchment is relatively undisturbed and the water quality of the Stream is good (van Deventer, 2012). The Mthinzima Stream then flows adjacent to Mpophomeni where it joins a tributary that dissect the settlement, after which it flows under the district road (R617), through a wetland system and into Midmar Dam. Mpophomeni is approximately 2.5 km upstream of the Midmar Dam and it is a significant contributor of phosphorus and nitrogen to the Dam (Ngubane, 2016). Water quality issues in the Mthinzima Stream are associated with polluted run-off from the
Mpophomeni Settlement including raw sewage as a result of damaged and inadequate sewage infrastructure and solid waste in and around water courses (van Deventer, 2012). Results from water quality studies in the Mthinzima catchment have concluded that there has been an increase in nutrient loads and a deterioration of water quality entering Midmar Dam from the Mthinzima stream over time (Ngubane, 2016). In recent years, citizen science initiatives within Mpophomeni have been raising environmental awareness, transferring scientific skills to residents, and establishing a monitoring programme for water quality impacts.

2.2.1 The proposed waste water treatment works (WWTW)

At present, waste water from the households connected to the waterborne sewage network is pumped to the Howick Waste Water Treatment Works (WWTW). The WWTW is under increasing pressure from the expansion of the waterborne sewage network in both Mpophomeni and Howick. In addition, a second housing and light industry development, the Khayalisha Development, is planned in the upper uMngeni Catchment. A requirement of the development is that a new WWTW must be built to serve the new development. The proposed new WWTW will be located adjacent to Mpophomeni and will cater for both Mpophomeni and Khayalisha. A requirement for the new WWTW is that all treated effluent must be discharged downstream of Midmar Dam (KZN DAEA, 2014). The WWTW has been specifically designed to prevent direct discharge to Midmar. Overflows from the maturation ponds are considered to be very unlikely due to the prior implementation of the Storm Overflow Pond and the Hybrid Maturation River; in the event that overflows do occur they will have been treated and the effluent disinfected (KZN DAE, 2014). Included in the plans for the new WWTW is the refurbishment of the main sewer line through Mpophomeni to the new WWTW. There are no plans associated with the new WWTW to upgrade any further sections of the existing sewage network. It is anticipated that there will still be raw sewage flowing into the Mthinzima Stream as only the main sewer line will be rehabilitated (Terry, 2017 personal communication).

2.2.2 The proposed wetland rehabilitation

Several wetland areas are associated with the Mthinzima Stream and Mpophomeni area. Together these wetlands are known as the Mthinzima Stream Wetland Complex and consist of (i) a portion of wetland associated with the WWTW (26 ha), (ii) the wetland areas directly impacted upon by a proposed sewage pipeline (81 ha), and (iii) a portion of wetland habitat downstream of the R617 road (the Mthinzima Wetland, 98 ha). The rehabilitation of the portion of wetland habitat downstream of the R617 road, the Mthinzima Wetland, is the focus of this study, Figure 2-1. The Mthinzima Wetland is located on land owned by the Zenzele Trust and is primarily used for communal grazing of cattle (GroundTruth, 2015). The present condition of the wetland is classified as largely modified suggesting that a large change in ecosystem processes, loss of natural habitat and biota has occurred. The wetland is fed by a combination of water inputs, including artificial drainage systems associated with the upstream sewage infrastructure and lateral water inputs (GroundTruth, 2015).

Currently there are two main sources of flow to the Mthinzima wetland:

1) The Mthinzima stream, including the ‘Hlanga’ tributary which bisects Mpophomeni and drains into the Mthinzima stream upstream of the R617 road. This is natural flow with inputs from storm water run-off from Mpophomeni, surcharging manholes and failure of the sewer reticulation system and solid waste.

2) Ongoing outflows from the existing WWTW pump station and pond infrastructure (pump station failure and storm water ingress) have created a flow path through the wetland area which re-enters the Mthinzima Stream before it flows into Midmar Dam. The flow is a combination of natural seepage and semi-treated effluent.
Rehabilitation of the Mthinzima Wetland is proposed with the primary objective “to optimise ecosystem services associated with water quality enhancement, ultimately contributing towards the protection of the water resources within Midmar Dam directly downstream of the study site” (GroundTruth, 2015:7). A plan of the proposed wetland rehabilitation had been developed, Figure 2-1; wetland rehabilitation activities have not yet commenced.
Figure 2-1: The location of the Mhinzima Wetland and the proposed wetland rehabilitation strategy (GroundTruth, 2015)
A schematic diagram\(^2\) illustrates how water flows within the Mpophomeni-Mthinzinga system, Figure 2-2, photographs of the system are shown in Figure 2-3. The Mthinzinga Stream flows adjacent to Mpophomeni where it is met by a tributary that bisects Mpophomeni, the stream then flows under the district road (R617), through the Mthinzinga Wetland system and into Midmar Dam. The formal Mpophomeni Settlement forms a large portion of the Mthinzinga sub-catchment. The Mpophomeni WWTW is no longer in use; effluent from the town is pumped to the Howick WWTW. The pump-station is located at the site of the ‘old’ WWTW. The ‘old’ WWTW ponds are used in the present management of the effluent and pump-station and are subject to overflowing and seepage.

The new WWTW will be located at the site of the old WWTW (and current pump station). Treated effluent from the new WWTW will be pumped along a new pipeline and discharged downstream of Midmar Dam. The following points are noted:

- With the new planned WWTW infrastructure, it is expected that no treated effluent or raw sewage will flow from the WWTW to the Mthinzinga Stream or to Midmar Dam (under normal conditions). Once the new WWTW infrastructure is in place and operational, discharge and seepage from the pump station and old WWTW ponds will cease.
- The Mthinzinga Stream will continue to flow through the Mthinzinga Wetland area.
- Run-off from the Mpophomeni Settlement will continue to reach the Mthinzinga Stream.
- The rehabilitation of the Mthinzinga Wetland will aim to spread the flows from the Mthinzinga Stream across the wetland area.
- There is a potential risk of untreated effluent spills during construction of the new WWTW.
- The risk of failure of the new WWTW is considered low after the first year of operation until year five. After five years of operation the risk of failure of the built infrastructure begins to increase (Umgeni Water, 2017 pers. comm.). Note ‘failure’ does not imply total failure of the WWTW, nor does failure result in contamination of the Mthinzinga Stream or Midmar Dam, as several risk mitigation measures are planned as part of the WWTW development (KZN DAEA, 2014).
- It appears that some of the flows from the Mthinzinga Stream and the Hlanga Tributary will be directed through wetland areas associated with the WWTW development and then returned to the Mthinzinga Stream upstream of the Mthinzinga Wetland.

At present, the water quality of the Mthinzinga Stream is unsatisfactory. A new WWTW will address some of the water quality issues, specifically the treatment of effluent that reaches the WWTW from the reticulated sewerage system. However, run-off from the Mpophomeni Settlement, which is characterized by inputs from surcharging manholes and failure of the poorly planned sewer reticulation system, solid waste and discharges not linked to the reticulated sewerage network, will continue to drain into the Mthinzinga Stream. Even with the new the WWTW, pollution of the Mthinzinga Stream will continue.

\(^2\) The development of the flow diagram benefitted from significant input from a scientist of Umgeni Water’s Water and Environmental Services (Terry, 2017).
With the new WWTW, the flows (purple dotted lines) from the old WWTW ponds to the Mthinzima Wetland are expected to stop (under normal conditions, including high flows).

Discharge as a result of natural seepage, pump station failure and excess flows (storm water ingress).

WWTW infrastructure
Current: Pump station and non-operational WWTW infrastructure
Planned: WWTW

Stormwater run-off, surcharging manholes & failure of the sewer reticulation system, solid waste

Mphophomeni settlement
Formal housing
Higher density
Connected to formal sewage system

Mthinzima Stream splits (new path on right)

Upper catchment
Grazing land
Semi-residential, lower density
Not connected to formal sewage system

Figure 2-2: Schematic of the Mthinzima-Mphophomeni system showing the water flows to the Mthinzima wetlands.
Mthinzima Stream, upstream of waste water pump-station and ‘old’ waste water treatment works infrastructure

Outflow from ‘old’ waste water treatment works ponds’, upstream of R617 Road.

Flow path created by on-going flows from (non-operational) waste water treatment works ponds, downstream of Road R617 and looking towards Midmar Dam.

Mthinzima Stream at the R617 Road, looking upstream towards Mpophomeni

Figure 2-3: Photographs of the Mpophomeni-Mthinzima system, showing the two ‘flow paths’ feeding the Mthinzima Wetland area below the R617 Road.
2.3 Conceptual framework

The economic valuation of the outcomes of an investment in ecological infrastructure (e.g., wetland rehabilitation) is concerned with well-defined changes in the ecosystem(s) as a result of the investment (Bockstael et al. 2000; Pagola et al. 2004; Pendleton and Baldara, 2010). Rather than estimating the total value of an ecosystem, the value of a change in the ecosystem or ecosystem service is of interest. That is, the change in supply of ecosystem services / benefits (or the prevention of a loss in service provision) with the investment must be identified and quantified. This necessitates a comparison of the ‘with’ and ‘without’ investment scenarios.

The value of the outcomes of an investment in ecological infrastructure depends on both the change in supply of ecosystem services / benefits with the investment and the demand for the additional service (or benefit associated with the additional service). The extent to which ecosystem services and benefits are considered ‘valuable’ will be influenced by the physical, economic, cultural and institutional setting in which the valuation takes place (Turner et al., 2008; Barbier et al., 2009; Keeler et al., 2012). Ecosystem benefit values are context specific and influenced by spatial-biophysical factors that affect wetland benefit supply (e.g. wetland type, wetland size, location in the catchment, surrounding land-use and the presence of other wetlands in the area) and socio-economic factors that affect the demand for ecosystem benefits (e.g. consumer preferences, socio-economic status of the local or regional population, rural / urban setting, and available substitutes/alternatives for ecosystem benefits) (Ghermandi et al., 2010; Meli et al. 2014). The value of wetland rehabilitation is subject to the added capacity of the wetland to supply ecosystem benefits with the rehabilitation as well as the demand for the additional benefits.

A third element that requires consideration is the opportunity afforded the ecological infrastructure to supply its services (now and into the future). Opportunity refers to the activities or circumstances that make it possible for ecosystem functions to be used for the benefit of humans. For example, for a wetland to provide a water treatment service, the water entering a wetland system must contain pollutants, or, for a wetland to provide tourism/recreation benefits, the wetland must be accessible and generally other infrastructure and human capital inputs are required. While the ‘opportunity factor’ is often implicit in the demand for ecosystem-based benefits, it is useful to consider ‘opportunity’ more explicitly when evaluating a potential investment in the context of a dynamic socio-ecological system where other factors are changing which may affect the opportunity for the ecological infrastructure to supply its services at a particular point in time. The conceptual framework applied in this study considers the potential of ecological infrastructure to supply its services, the opportunity afforded the ecological infrastructure to supply its services, and the demand for the services (derived from the demand for the benefits associated with the services).

Investments in ecological infrastructure and investments in engineered infrastructure may both affect the supply and value of ecological services. Investments in ecological infrastructure are expected to change (increase, or prevent a decrease in) the capacity of the ecological infrastructure to provide its services. On the other hand, investments in engineered infrastructure may affect the opportunity for the ecological infrastructure to supply its services at a particular point in time. Ecological infrastructure and engineered (built) infrastructure can be alternatives / substitutes to achieving a specific objective and / or they may be complements in achieving the objective. The conceptual framework developed here is a general framework that may be applied to evaluate the outcomes of investments in ecological infrastructure and / or engineered infrastructure on the value of ecological infrastructure. A schematic representation of the conceptual framework is presented in Figure 2.4.
Figure 2.4: Schematic representation of the conceptual framework of the study.

Note: SS_E (Supply of ecological services), SS_EN (Supply of services from engineered infrastructure or any other alternative), SS (Supply of services), DD (demand for services) MV (Marginal value), PV (Present Value).

2.4 Methods

2.4.1 Investment appraisal

Cost benefit analysis (CBA) is a conventional tool used to inform decision-making. The CBA approach was applied to evaluate whether the potential benefits of the Mthimvuma Wetland rehabilitation would outweigh the costs of rehabilitating the wetland, over the life of the wetland rehabilitation. If the benefits are greater than the costs, then the project is considered worthwhile.

CBA It involves the identification and comparison of the expected outcomes (costs and benefits) of a particular action. Ideally, all relevant impacts from the whole lifespan of an action are quantified, monetized (generally) and discounted into present values, to obtain a net present value which indicates the level of overall benefits in relation to overall costs. For an ex ante evaluation, the anticipated stream of costs and benefits are estimated; for ex post applications the costs and benefits are preferably quantified by measurement. In this case, the evaluation is a partial CBA as only a single benefit of the wetland rehabilitation was considered (the incremental increase in the water treatment service of the wetland with the rehabilitation).

Shadow prices are frequently used to monetize the benefits of ecological investment actions as often these benefits do not have market prices or market prices are distorted due to market imperfections (Mullins et al., 2014). There are a number of non-market valuation techniques that have been developed to evaluate ecological benefits. These include both non-monetary valuation methods and environmental economic techniques based on a monetary metric (Farber et al., 2002). Monetary-based valuation techniques assume that individuals are willing to trade the ecosystem service / benefit being valued for other services represented by the monetary metric. Monetary valuation allows the comparison of the costs and benefits associated with changes in ecosystem services by calculating a shadow price (Farber et al., 2002).
The CBA technique involves discounting the stream of costs and benefits to present values, this allows for a comparison of the value of costs and benefits, which are incurred over different periods of time. The Net Present Value (NPV) of an investment reflects the stream of benefits less the stream of costs over the life of the investment in present terms (a specified year). It is considered beneficial to accept an investment with a positive NPV. A standardised discount rate or more than one discount rate (for comparisons) may be used for the calculation of present values of all cost and benefit streams.

There is on-going debate over an appropriate discount rate for ecosystem valuations; there are no purely economic guidelines for choosing a discount rate and the choice is really an ethical one. Frequently, in ecosystem valuations, the usual discount rate for public investments for the relevant country is applied. This approach is adopted in this study. A real discount rate of 8% is used to evaluate investments in the public sector in South Africa (Mullins et al. 2014). An 8 % discount rate was applied in this study; lower discount rates of 5% and 3% were used in a sensitivity analysis.

2.4.2 Identification and quantification of the benefits of wetland rehabilitation

The ecosystem services approach was used in conceptualizing the benefits of investing in the rehabilitation of the Mthinzima Wetland. An ecosystem services perspective is advocated as a suitable way to identify wetland outcomes (Turner et al. 2008). A qualitative assessment of potential changes in the supply of wetland ecosystem services with the proposed wetland rehabilitation, based on the results of a WET-EcoServices assessment undertaken by GroundTruth Consulting (2015) and the scoring approach for qualitative assessment of ecosystem service change proposed by DEFRA (2011). The results are summarized in the appendix (section 6.1.1).

The analysis highlighted the following:
- The rehabilitation of the wetland is anticipated to have a significant positive effect of water quality enhancement services and carbon storage,
- Water quality enhancement services are separated into specific constituents (e.g., nitrate assimilation, sediment retention etc.),
- The rehabilitation of the wetland is anticipated to have a positive effect on streamflow regulation and the provision of water for human use,
- Livestock grazing is an existing use of the wetland area; this service may be negatively affected by the proposed rehabilitation, due to limited accessibility in the wet season.

Water quality enhancement was identified as the primary ecosystem service likely to be improved through the wetland rehabilitation (there exists the potential to increase the supply of this service). Given the risk of eutrophication of Midmar Dam, a reduction in nutrient levels in inflows to Midmar Dam is considered a priority (there is a demand for the service, specifically the removal of nutrients). The potential incremental increase in the effectiveness of the Mthinzima Wetland for nutrient removal is thus the focus of this study. As such, the increase in the ability of the wetland to supply a nutrient removal service was estimated.

In wetland rehabilitation practice, the ‘hectare equivalents’ concept is used to evaluate the ecological outcomes of wetland rehabilitation (Cowden and Kotze, 2007). Hectare equivalents are used as the ‘metric’ for assessing the loss and / or gains in wetland integrity under different scenarios, and are derived from assessments of wetland condition with and without rehabilitation using the WET-Health assessment tool (Macfarlane et al., 2008). As part of the wetland assessments undertaken by GroundTruth Consulting in developing the Mthinzima Wetland rehabilitation plan, hectare equivalents were calculated. Based on the current condition of the wetland, the approximately 98.01 ha of wetland habitat is considered to be the equivalent to 55.44 ha of functional wetland habitat, Figure 2-5. Post-
rehabilitation, the improved condition is anticipated to lead to a gain in hectare equivalents of 10.78 ha (GroundTruth, 2015). In this study, the gain in functional wetland area (10.78 ha) is proposed as a base for estimating the potential additional nutrient assimilation service associated with the rehabilitation of the wetland.

![Diagram showing change in functional wetland area](image)

*Figure 2-5: A graphic representation of the change in functional wetland area associated with the wetland rehabilitation, Mthinziwa Wetland*


Given that this is an ex ante evaluation, nitrogen and phosphorus removal rates from the literature will be applied in estimating the potential increase in the nutrient assimilation service associated with the rehabilitation of the Mthinziwa Wetland.

Unfortunately, there are no published long terms studies, or monitoring results, of nutrient retention by rehabilitated wetlands (or wetlands in general) in KwaZulu-Natal (or even South Africa) are available. Applying retention rates from the international literature introduces considerable uncertainty into the study and reduces the confidence of the estimates. Land et al. (2016) provide a systematic review, and database, of nitrogen and phosphorus removal rates for freshwater restored and created wetlands. The database can be filtered based on numerous criteria including location, climatic zone, wetland type, inflow type, area, history (restored or created) among others. Filtering based on wetland type (free water surface), wetland history (restored), climate zone (Cfb which corresponds to Howick (Conradie, 2012)) produced six wetland results (all located in Europe).

Turpie et al. (2010) estimated the water treatment capacity of wetlands on a landscape scale in the South Western Cape of South Africa, by relating the water quality at catchment outflow points to the prevalence of wetlands, as well as other land uses, using multivariate statistical analysis. Wetlands were found to play a significant role in the reduction of nitrates, nitrites, and ammonium, but not dissolved phosphorus or suspended solids. The authors note that the nitrogen removal rate estimates for wetlands in the study area were higher than expected and fell within the broad ranges for nitrogen removal observed in artificial wetlands. Nitrogen and phosphorus removal rates for wetlands reported in the literature are summarized in Table 2-1 and Table 2-2 respectively. The range of removal rates is broad both across the studies reviewed by Land et al. (2016) and within the South African study by Turpie et al. (2010). The review by Land et al. (2016) also shows that in some cases wetlands can add rather than remove nutrients. Nutrient removal rates are affected by multiple factors, and the broad range of removal rates reported in the literature emphasises the uncertainty of applying rates estimated for different contexts.
Table 2-1: Comparison of wetland nitrogen removal rates from the literature

<table>
<thead>
<tr>
<th>Reference</th>
<th>Removal rate</th>
<th>Range</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>kg/ha/yr</td>
<td>kg/ha/yr</td>
<td></td>
</tr>
<tr>
<td>Land (2016) Median, N=255</td>
<td>930</td>
<td>-3 to 12700</td>
<td>Multiple - predominantly North America &amp; Europe</td>
</tr>
<tr>
<td>Land (2016) Median, N=4</td>
<td>69</td>
<td>-3 to 337</td>
<td>Filtered - Europe</td>
</tr>
<tr>
<td>Turpie et al. (2010) Estimated average</td>
<td>1594</td>
<td>307 to 9505</td>
<td>South Africa</td>
</tr>
<tr>
<td>Verhoeven et al. (2006)(^a) N=3</td>
<td>na</td>
<td>1000 to 3000</td>
<td>Temperate zones</td>
</tr>
</tbody>
</table>

Note: \(^a\) Verhoeven et al. (2006:98) suggest that these are high values, considering that they are an order of magnitude higher than fertilizer applications in intensively farmed areas.

Table 2-2: Comparison of wetland phosphorus removal rates from the literature

<table>
<thead>
<tr>
<th>Reference</th>
<th>Removal rate</th>
<th>Range</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>kg/ha/yr</td>
<td>kg/ha/yr</td>
<td></td>
</tr>
<tr>
<td>Land (2016) Median, N=146</td>
<td>12</td>
<td>-168 to 2400</td>
<td>Multiple - predominantly North America &amp; Europe</td>
</tr>
<tr>
<td>Land (2016) Median, N=6</td>
<td>2.43</td>
<td>-12 to 24</td>
<td>Filtered - Europe</td>
</tr>
<tr>
<td>Turpie et al. (2010) Estimated average</td>
<td>0</td>
<td>0</td>
<td>South Africa</td>
</tr>
<tr>
<td>Verhoeven et al. (2006)(^a) 3 studies</td>
<td>60 to 100</td>
<td>60 to 100</td>
<td>Temperate zones</td>
</tr>
</tbody>
</table>

Note: \(^a\) Verhoeven et al. (2006:98) suggest that these are high values, considering that they are an order of magnitude higher than fertilizer applications in intensively farmed areas.

2.4.3 Benefit valuation - replacement cost method

The additional water treatment capacity of the wetland with the rehabilitation was valued using a replacement cost approach: the value of the additional water treatment capacity is equated with the cost of achieving the same outcome through an alternative means. The replacement cost approach entails quantifying the removal of pollutants or nutrient loads by the wetland in the study area and estimating the equivalent cost of performing this service with human engineered systems or other alternatives which are the next best alternative (perfect or close substitutes). The replacement cost approach is commonly applied in valuing the water treatment service of wetlands: the cost of conventional water treatment (i.e. built infrastructure) is used to represent the value of the wetland water treatment service (Pagiola et al., 2004).

A well-known example of the application of the replacement cost approach was the decision to restore the Catskills catchment for the specific purpose of providing clean drinking water to New York City based on a comparison of the costs of protecting and restoring the catchment to replacing the water purification services of the catchment with a new drinking water treatment facility (Heal et al., 2005). Cost estimates indicated that building and operating the water treatment system would be significantly greater than protecting and restoring the catchment and New York City chose to protect the Catskills catchment. Barbier (2007) notes that it was sufficient for the policy decision simply to demonstrate the cost-effectiveness of the restoration and protection option compared to the alternative.
Strictly, replacement costs are not a measure of economic value as the ‘value’ estimate is not based on individual preferences and does not measure an individual’s willingness to pay for a service (King and Mazzotta, 2000; Heal et al., 2005). The key assumption of cost-based approaches is that “if people incur costs to avoid damages caused by lost ecosystem services, or to replace the services of ecosystems, then those services must be worth at least what people paid to replace them” (King and Mazzotta, 2000: section 5). Pagliola et al. (2004) (citing Shabman and Batie, 1978) note three conditions that must hold for the approach to be valid: (1) the replacement service must be equivalent in quality and magnitude to the ecosystem service (perfect substitute); (2) the replacement must be the least cost option of replacing the service; and (3) people would actually be willing to pay the replacement cost to obtain the service (there is a demand). Where the conditions do not hold, cost-based approaches are unlikely to accurately reflect the benefits of ecosystem services (Pagliola et al., 2004; Heal et al., 2005; Turner et al., 2008). The replacement cost estimate reflects a lower-bound of the value of the benefit.

In applying the replacement cost valuation approach in this study, the assumption is made that improving the quality of inflows to Midmar Dam is preferred over the risk of declining water quality in Midmar Dam (i.e. it is assumed that a precautionary approach is demanded). This is a limitation of the replacement cost valuation approach – the demand for the service/benefit is not assessed directly (i.e. through determining the ‘willingness to pay’ for the service/benefit), but assumed. Given the global, national and regional objectives to improve water quality and the consequences and associated costs of declining water quality (Deliverable 9, this WRC project) this assumption is considered reasonable. A similar assumption is argued by Turpie et al. (2010) in a study of the water quality amelioration value of wetlands in the Western Cape. The approach is illustrated in Figure 2-6.

The replacement cost approach relies on identifying and valuing the next best alternative to provide the additional nutrient removal capacity associated with the wetland rehabilitation. This was explored through an expert consultation process with hydrologists, engineers and private sector service providers. The aim was to identify and cost the next best (least cost) alternative to achieving the same reduction in nutrient load to Midmar Dam as that which is anticipated through rehabilitation of the Mthinzima Wetland. Three alternatives (perfect or close) substitutes were identified.

1. Conventional water treatment

Usually when the replacement cost method is used in respect to water quality enhancement services provided by wetlands, water treatment costs (of water treatment plants) are used to represent the benefit of water quality enhancement services provided by wetlands (Pagliola et al., 2004). For example, in the study by Turpie et al. (2010), the cost of removal of ammonium nitrogen incurred by water treatment plants (R26/kg) was used to value the nitrogen removal benefit of wetland systems in the South Western Cape of South Africa. However, the authors noted that “water treatment works are designed primarily with the removal of phosphorus in mind (and thus are driven by the average cost per kg of phosphorus removed)” (Turpie et al., 2010, p.12).

In conventional waste water treatment, the most common approach for the removal of nitrogen is heterotrophic denitrification; however several problems are associated with the process including residual nitrate and nitrite (Zhou et al. 2011). A proposed alternative is autotrophic denitrification. In experimental research, autotrophic denitrification has been shown to be feasible for the removal of nitrate and nitrite, particularly from low concentration water such as eutrophicated surface water, underground water, or wastewater treatment plant effluent (Zhou et al. 2011). While promising, this approach is still experimental and there is a lack of information on its practical implementation and associated costs.

2. Floating wetlands
Floating wetlands are a relatively new, experimental technology for improving water quality - specifically for treating nutrients - in nutrient-rich waste and drainage waters. They consist of buoyant mats that are mass planted with emergent wetland plants and are anchored on the surface of the water body (e.g., anchored to bedrock or trees). Water flows through the root zone (subsurface flow) and the roots absorb excess nutrients, purifying the water. Floating treatment wetlands have the potential to assist in the extraction of nitrogen and phosphorus from water. Experimental research and trials have shown floating wetlands to be effective at removing nitrogen and moderately effective at removing phosphorus from ponded water bodies (Hamill et al. 2010; Lynch et al. 2015; Nichols et al. 2016).

3. Upgrade the waterborne sanitation network of Mpophomeni Settlement
Poorly designed, damaged and insufficient sewage infrastructure in Mpophomeni is a primary contributor to water pollution in the Mthinzima Stream (van Deventer 2012; Felton 2017). Upgrading the sanitation network would contribute to reducing surcharges from the system which would reduce the load of nutrients to the Mthinzima Stream. However, issues of misuse of the system (e.g. the dumping of solid waste into the system) would still need to be addressed through for example citizen awareness initiatives (Felton 2017). Additional engineered infrastructure could be considered as an alternative to wetland rehabilitation.

Due to a lack of information on the practical implementation, effectiveness and costs of the floating wetland alternative, and the likely significant costs associated with upgrading the entire sanitation network for the growing Mpophomeni Settlement, the equivalent conventional water treatment cost was used as the replacement cost to attribute value to the improved nutrient removal service associated with the wetland rehabilitation.
2.4.4 Wetland rehabilitation costs

Wetland rehabilitation costs comprise the direct costs of the intervention (e.g., clearing activities, construction works, re-vegetation), the costs associated with obtaining approvals to undertake the intervention (e.g., environmental authorisations, water use licences, land-owner agreement etc.), maintenance costs over the life of the investment and monitoring and evaluation costs. There may be costs associated with the need to purchase land for the rehabilitation and indirect costs associated with a change in land-use (for example converting arable land back to wetland may result in income forgone). However, it can be argued that, in the case of severely degraded wetlands, the land becomes marginalised and land rent can be assumed to be zero in the case of agriculture as the alternative use. Further, legislation in South Africa constrains the use of wetland areas for alternative uses, in certain cases there may not be a legal alternative use for the wetland and land rents would be zero.

Dis-benefits of the intervention may also need to be considered, for example repercussions for livestock owners if livestock are excluded from the wetland area post rehabilitation when previously the wetland was used for livestock watering and dry season grazing. In the case of the Mthinzima Wetland, the present land-use is livestock grazing. However, there are no plans to exclude livestock from the wetland area post rehabilitation; as such the rehabilitation of the wetland may rather provide
additional benefits to livestock owners. The wetland rehabilitation has been designed to reduce the impact of livestock grazing to the rehabilitation structures; this additional cost is included in the construction costs.

The costs of the wetland rehabilitation were calculated from the bill of quantities provided in the rehabilitation plan and unit costs provided by various sources (including GroundTruth Consulting and commercial quotes). Maintenance plan costs / data for the rehabilitation were only available for the first five years of rehabilitation (and worked out at approximately 2% per annum of the total cost). In a study of the costs and benefits of investing in ecosystem restoration, de Groot et al. (2013) allowed for project maintenance of 2.5 % of total investment cost for wetlands. Given that maintenance may need to encompass some structural repair work during the life of the project, particularly given continued livestock grazing in the area, a 2.5% maintenance cost for the overall lifespan of the wetland rehabilitation was applied in this study.

2.4.5 Scenarios

To evaluate the benefits of the wetland rehabilitation, the two alternatives ‘with rehabilitation’ - the case where rehabilitation is implemented – and ‘without rehabilitation’ - the case where rehabilitation is not implemented – must be compared. In the case of the Mthinzima Wetland rehabilitation, the development of the new WWTW in Mpophomeni, in the near future, needs to be considered in developing the scenarios for analysis, as this development is likely to be a key driver of change in water quality in the system. In evaluating the potential water quality treatment benefit of the Mthinzima Wetland rehabilitation, four scenarios were considered, Table 2-3.

Table 2-3: Scenarios to assess the proposed investment in rehabilitation of the Mthinzima Wetland, assuming the demand for water quality improvement is constant

<table>
<thead>
<tr>
<th>Wetland Rehabilitation</th>
<th>Without</th>
<th>With</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1) Current value of wetland</td>
<td>(2) Value with no WW TW</td>
</tr>
<tr>
<td></td>
<td>• Current opportunity</td>
<td>but with rehabilitation</td>
</tr>
<tr>
<td></td>
<td>• Current capacity to supply</td>
<td>of wetland</td>
</tr>
<tr>
<td></td>
<td>• Current value</td>
<td>• Same opportunity</td>
</tr>
<tr>
<td>New WW TW</td>
<td>(3) Value with no wetland</td>
<td>• Increased capacity to</td>
</tr>
<tr>
<td></td>
<td>rehabilitation but WW TW</td>
<td>supply</td>
</tr>
<tr>
<td></td>
<td>• Different opportunity</td>
<td>(4) Value with both</td>
</tr>
<tr>
<td></td>
<td>• Same capacity to supply</td>
<td>interventions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Decreased opportunity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Increased capacity to</td>
</tr>
<tr>
<td></td>
<td></td>
<td>supply</td>
</tr>
</tbody>
</table>

The first scenario is the status quo, it reflects the current condition of the wetland and its current capacity to supply a water treatment services, and the current opportunity to provide the service (i.e. the current loads of nutrients to the wetland). The second scenario represents the ‘with rehabilitation’ case and reflects the current opportunity to provide the service (i.e. no change in nutrient loads to the wetland) and an increased capacity to supply a water treatment service. Scenarios 3 and 4 represent the ‘with’ and ‘without’ wetland rehabilitation situation, but with the building of the new waste water treatment works and reflect the anticipated change in opportunity for the wetland to provide a water treatment service (i.e. an anticipated decrease in nutrient loads to the wetland with the WW TW).

---

3 This is different to the before and after rehabilitation situation which does not capture the effects of continued degradation should the rehabilitation not be implemented.
Effectively, with the WWTW there is a potential loss in value of the wetland due to the decreased opportunity (reduced nutrient loads) attributed to the service provided by the new WWTW. However, this depends on the size of the current loads, the extent to which the current loads will be reduced by the WWTW, the risk of failure of the WWTW infrastructure and future increases in the load on nutrients as a result of continued population growth and expansion of both the formal and informal housing within Mpophomeni. As such, rather than being alternatives for addressing nutrient loads, the two infrastructures may be viewed as complements.

These scenarios assume a constant demand for water quality improvement. Important to note is that the ‘without’ rehabilitation scenario reflects the current condition of the wetland and the associated water treatment capacity, in reality it is likely that without rehabilitation the wetland will continue to degrade further reducing the water treatment capacity of the wetland (Terry 2017). Given the uncertainty regarding future declines in the condition of the wetland, this scenario was not considered in the analysis.

2.4.6 Data collection

Data for this study were gathered from a number of sources, including meetings with KZN DAEA, Umgeni Water, GroundTruth Consulting, other researchers, telephonic and email interviews (engineers), workshops with experts, municipal documents, expert reports and scientific research. Focus group meetings and expert interviews were held at various times during the study to determine the next best alternative to replace the wetland services, and to develop assumptions on various scenarios of the study. Meetings with relevant representatives of uMgungundlovu Municipality / KZN DAEA were held to get more information on the study area and the decision to rehabilitate the wetlands. Interviews were held with GroundTruth Consulting on the rehabilitation plan for Mthinzima Wetland. Information on the site’s sewage waste management system was gathered from Umgeni Water officials, and a site visit was also conducted together with Umgeni Water. Other useful sources of information were.

2.5 Results

2.5.1 The supply of water treatment services ‘with’ and ‘without’ rehabilitation

The gain in functional wetland area (10.78 ha) with the wetland rehabilitation (GroundTruth 2015) and nitrogen and phosphorus removal rates estimated by Land et al. (2016) were used to estimate the potential added capacity of the wetland to provide a water treatment service in terms of nutrient load removal, Table 2-4.

Wetland areas (GroundTruth 2015):
- Total wetland area = 98.01 ha
- Degraded wetland, functional area = 55.44 ha
- Rehabilitated wetland, functional area = 66.22 ha
- Gain in functional wetland area = 10.78 ha.

Removal rates by wetlands (Land, 2016):
- Nitrogen removal = 69 kg/ha/year;
- Phosphorus removal = 2.43 kg/ha/year.
Table 2-4: Estimated nutrient removal capacity (kg/year) of the Mthinzima Wetland, ‘with’ and ‘without’ rehabilitation

<table>
<thead>
<tr>
<th></th>
<th>‘Without’ rehabilitation (degraded wetland)</th>
<th>Incremental change with rehabilitation</th>
<th>‘With’ rehabilitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen</td>
<td>3825.36</td>
<td>743.82</td>
<td>4569.18</td>
</tr>
<tr>
<td>Phosphorous</td>
<td>134.72</td>
<td>26.20</td>
<td>160.92</td>
</tr>
</tbody>
</table>

The interaction or relationship between the ecological infrastructure (the wetland) and the built infrastructure (the WWTW) was investigated by considering the influence of the new WWTW on the opportunity afforded the wetland to supply a water treatment service, this was considered in terms of the influence of the new WWTW on the loads of nitrogen and phosphorous to the wetland. A new WWTW will address some of the water quality issues, specifically the treatment of effluent that reaches the WWTW from the reticulated sewerage system. However, run-off from the Mpophomeni Settlement, which is characterized by inputs from surcharging manholes and failure of the poorly planned sewer reticulation system, solid waste and discharges not linked to the reticulated sewerage network, will continue to drain into the Mthinzima Stream. Even with the new the WWTW, pollution of the Mthinzima Stream will continue. Even with the new WWTW, there remains the opportunity for the rehabilitated wetland to provide its water treatment services.

2.5.2 Benefit valuation

The equivalent cost of conventional waste water treatment was used as the replacement cost to attribute value to the improved nutrient removal service associated with the wetland rehabilitation. Water treatment costs estimated in a study by Turpie et al. (2010), and adjusted for inflation to reflect 2017 prices, were applied. The estimated inflated cost of removal of nitrogen (N) is **R38 per kg of N removed**. Turpie et al. (2010) found the amounts of nitrogen and phosphorus removed by treatment plants to be highly correlated, thus to avoid double-counting only the cost associated with the removal of nitrogen is applied, assuming that removal of phosphorus is correlated to that of nitrogen.

The per hectare value of nutrient removal for the Mthinzima Wetland based on the removal rates from Land et al. (2016) and the removal cost estimates from Turpie et al. (2010) was calculated as:

\[
\text{Value (R)} = \text{Max (kg N removed x CN, kg P removed x CP)}
\]

\[
= \text{Max (69 kg N x R38, 2.43 kg P x R38)}
\]

\[
= \text{Max (R2622 ha}^{-1}\text{year}^{-1}, (R92 ha}^{-1}\text{year}^{-1})
\]

\[
= \text{R2622 ha}^{-1}\text{year}^{-1}
\]

The estimated value of the additional water treatment capacity of the Mthinzima Wetland as a result of rehabilitation, based on the estimated gain in functional wetland area of 10.78 ha, is **R28 265.16 per year**. The value was estimated by multiplying the gain in functional wetland area by the value of the wetland nutrient removal service calculated above.

2.5.3 Costs of the wetland rehabilitation

The total cost of the Mthinzima Wetland Rehabilitation was estimated to be R12 million. An annual maintenance cost of R300 000 was estimated based on maintenance costs of 2.5% of the total cost. During the period of this study, the KZN Department of Economic Development, Tourism and Environmental Affairs has submitted several applications for funding the Mthinzima Rehabilitation
work. In submitting these applications, the Department estimated rehabilitation costs of approximately R10 to 12 million (Felton 2017).

2.5.4 Cost-benefit analysis

This section presents the results of the cost benefit analysis (CBA) of the Mthinzima wetland rehabilitation. The CBA technique involves discounting the stream of costs and benefits to present values, this allows for a comparison of the value of costs and benefits, which are incurred over different periods of time. The Net Present Value (NPV) of an investment reflects the stream of benefits less the stream of costs over the life of the investment in present terms (a specified year). It is considered beneficial to accept an investment with a positive NPV.

In a first step, the NPV was set to zero to establish the minimum stream of annual benefits required to offset the wetland rehabilitation costs, Table 2-5. As the discount rate increases, the annual benefits required increases; as the life of the investment (number of years) increases the annual benefits required decrease. This illustrates the influence of the discount rate and the expected life of the investment on the cost-benefit analysis.

<table>
<thead>
<tr>
<th>Table 2-5: Annual net benefit required for NPV set to zero, ceteris paribus</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Annual net benefit required (ZAR) for NPV = 0</strong></td>
</tr>
<tr>
<td>Life of investment (number of years)</td>
</tr>
<tr>
<td>Discount Rate</td>
</tr>
<tr>
<td>3 %</td>
</tr>
<tr>
<td>5 %</td>
</tr>
<tr>
<td>8 %</td>
</tr>
</tbody>
</table>

Table 2-6 shows the results of the CBA using the equivalent cost of conventional waste water treatment was used as the replacement value of the improved nutrient removal service associated with the wetland rehabilitation (Section 2.5.2). The CBA results (NPV) are negative across all discount rates and number of years, indicating that the added benefit of the wetland rehabilitation, based on the equivalent waste water treatment cost, does not exceed the rehabilitation costs (including maintenance) over the life of the investment, ceteris paribus.

<table>
<thead>
<tr>
<th>Table 2-6: CBA results considering the equivalent nutrient removal cost of a standard waste water treatment plant, ceteris paribus</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cost-benefit analysis results (NPV in ZAR)</strong></td>
</tr>
<tr>
<td>Life of investment (number of years)</td>
</tr>
<tr>
<td>Discount Rate</td>
</tr>
<tr>
<td>3 %</td>
</tr>
<tr>
<td>5 %</td>
</tr>
<tr>
<td>8 %</td>
</tr>
</tbody>
</table>
The added benefits of the wetland rehabilitation are understated in the results reported in Table 2-6 as only water treatment costs were considered. The fixed costs of building a waste water treatment plant also need to be incorporated.

In a second analysis, the fixed costs of the construction and annual running costs of a water treatment plant were considered. The approximate fixed costs of a 1 ML/day capacity water treatment plant were obtained (RHDHV 2017), average annual variable running costs were assumed to be 2.5% of the fixed cost. Table 2-7 illustrates the results of the CBA after considering the fixed cost of the water treatment plant (of 1 ML/day capacity) and average annual variable running costs which were assumed to be 2.5% of the fixed cost of construction of the water treatment plant. NPVs were positive across all discount rates and investment periods considered, indicating a socially worthwhile investment.

*Table 2-7: CBA results considering fixed and maintenance costs of a standard 1 ML waste water treatment plant, ceteris paribus*

<table>
<thead>
<tr>
<th>Cost-benefit analysis results (NPV in ZAR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Life of investment (number of years)</td>
</tr>
<tr>
<td>Discount Rate</td>
</tr>
<tr>
<td>3 %</td>
</tr>
<tr>
<td>5 %</td>
</tr>
<tr>
<td>8 %</td>
</tr>
</tbody>
</table>

2.6 Discussion and conclusion

The ecosystem services approach was used in conceptualizing the benefits of investing in the rehabilitation of the Mthinzima Wetland. Based on wetland health assessments, water quality enhancement was identified as the primary ecosystem service likely to be improved through the wetland rehabilitation and a service of specific importance in the case study context – downstream of a peri-urban settlement and upstream of a key water supply dam. The analysis focused specifically on the potential incremental increase in the effectiveness of the Mthinzima Wetland for nutrient removal as a result of the rehabilitation. Based on the ‘hectare equivalents’ approach, the anticipated gain in functional wetland area (10.78 ha) with the rehabilitation was used as a base for estimating the potential additional nutrient removal service. The gain in functional area was multiplied by per unit area nutrient removal rates from the literature. The replacement cost valuation approach was applied to value the benefit and a cost-benefit analysis was undertaken.

Through expert engagement and consideration of several alternatives, the replacement cost was determined as the costs of conventional waste water treatment to achieve a similar outcome. Based on estimates from the literature of the cost of nitrogen removal by conventional waste water treatment plants, estimated net present values (NPV) were negative across all discount rates and time periods considered. However, this approach fails to incorporate the fixed costs of constructing a conventional waste-water treatment plant. A second CBA was conducted based on the fixed and maintenance costs of a standard 1 ML waste water treatment plant to value the water treatment benefit of the wetland rehabilitation. Estimated NPVs were positive across all discount rates and time periods considered indicating that the benefit of the wetland rehabilitation exceeds the wetland rehabilitation costs over the life of the investment, *ceteris paribus*. This outcome suggests that it is economically beneficial to invest in the rehabilitation of the Mthinzima Wetland. The study was subject to several
assumptions and limitations, discussed in the following sections, as such the CBA results should not be considered as a ‘final answer’ on whether the rehabilitation is a worthwhile investment. Decision makers should use the results as illustrative of the magnitude of costs and benefits under the set of assumptions made and use the CBA as a tool for testing the robustness of the investment to alternative assumptions concerning the magnitude of costs and benefits, bearing in mind the limitations of the study. Given the available data, and the approach taken, this assessment indicates that it is worthwhile to invest in the rehabilitation of the Mthinzima Wetland.

2.6.1 Caveats and limitations

The results of the CBA showed that investing in ecological infrastructure – in the form of rehabilitation of the Mthinzima Wetland - may bring about net benefits to society. However, the value of the added water treatment benefit of the wetland rehabilitation is likely overstated as the replacement value used (fixed and maintenance costs of a conventional WWTW) is not based on an equivalent ‘service’. The capacity of a treatment works and, therefore, the potential nutrient removal level, is likely greater than the potential nutrient removal capacity of the 10.78 ha of functional wetland gained through the rehabilitation. A rigorous analysis of the flows and nutrient concentrations likely to be received by the additional area of functional wetland under different scenarios is needed.

On the other hand, the overall value of the wetland rehabilitation is understated as it is only based on the potential additional nutrient removal service of the wetland with the rehabilitation, whereas there is a range of ecosystem services and benefits associated with wetlands. The study assumed a demand for actions to improve the quality of water in the Mthinzima Stream before the stream enters Midmar Dam. The benefit of the wetland rehabilitation in contributing to this goal was valued based on the cost of achieving the same contribution through an alternative means (replacement cost). The risk of eutrophication of Midmar Dam with continued pollution was assumed and therefore any action to reduce this risk was assumed to be fully demanded. The contribution of the Mthinzima water quality to the risk of eutrophication was not assessed and nor were the resulting ‘damages’ associated with eutrophication of Midmar Dam (e.g. impacts on water treatment costs and recreation benefits) estimated. Modelling the risk of eutrophication under different scenarios is an area of future research. However, in considering estimating values for multiple ecosystem services (or values), attention must be given to the risk of ‘double-counting’. Double-counting arises in the case where one ecosystem service is integral to another, yet both are valued separately and aggregated (Turner et al. 2008).

The value of the wetland rehabilitation is also understated in that the counterfactual scenario assumed that without rehabilitation the wetland would remain in its current state – degraded, but still providing some level of water treatment service. In reality, it is likely that without rehabilitation the wetland would continue to degrade resulting in a further loss in wetland services. To more accurately capture the benefit of the rehabilitation, the ‘without rehabilitation’ scenario needs to be refined to reflect the continued degradation of the wetland over time.

The replacement cost approach is not a true measure of economic value as the ‘value’ estimate is not based on individual preferences and does not measure the willingness to pay for the benefit. For the replacement cost estimate to be considered reliable several conditions must be met. Considering the conditions in terms of this case study, the following are noted:

1. The replacement service must be equivalent in quality and magnitude to the ecosystem service (perfect substitute): it is likely that the 1ML WWTW alternative has a greater capacity for water treatment than the additional 10.78 ha of functional wetland gained with the rehabilitation.
2. The replacement must be the least cost option of replacing the service – through expert consultation an attempt was made to identify the next best option. It proved challenging to
identify a practical, cost-effective ‘next best option’. Conventional water treatment was considered one of the lower cost alternatives, although unrealistic in terms of diverting the stream through a waste water treatment facility. The challenge to identify a suitable alternative further demonstrates the value of the wetland and the value of investing in the rehabilitation and protection of the wetland. There are alternative water treatment technologies (such as autotrophic denitrification and small modular sewer treatment systems) that could be further investigated, but due to limited availability of cost data it was not possible within the scope of this study to establish the costs of these alternatives.

3. People would actually be willing to pay the replacement cost to obtain the service (there is a demand) - experts agreed that there had to be an intervention to reduce pollution loads from the Mhinzinga Stream to Midmar Dam, but as yet, no funding has been obtained for implementing the rehabilitation suggesting that, as yet, there is no one who was willing to pay for the intervention.

Further limitations and assumptions are noted below.

- Stochasticity in nutrient loads and nutrient removal was not taken into account. The study assumed constant average nutrient loads to the wetland and constant average nutrient removal. In reality, nutrient loads are driven by rainfall (runoff) and pollution incidents (e.g. surcharging sewer). There are many factors that affect the nutrient removal rates of wetlands such as the type and size of the wetland, climate and air temperature, previous land-use, soil type etc., applying nutrient removal rates from the literature, specifically from studies of northern hemisphere wetlands (as in the estimates applied in this study) introduces significant uncertainty into the results.
- The ‘without rehabilitation’ scenario assumed that the wetland would remain in its current degraded condition; in reality, it is likely to continue to degrade over time.
- The study relied on literature and expert consultation for much of the data (e.g. wetland nutrient removal rates, waste water treatment costs).
- There were several assumptions and limitations associated with the nutrient removal costs of waste water treatment plants drawn from the study by Turpie et al. (2010).
- The treatment of nitrogen and phosphorus by WWTW was assumed to be highly correlated and the average cost of treatment was therefore attributed to nitrogen, which may produce an overestimate of the cost.
- The study limited the wetland rehabilitation benefits to only the additional potential nutrient removal service.
- Ecological thresholds were not taken into account in the study, but deserve investigation in future research. Economic value is based on marginal changes over some non-critical range, when a threshold is reached economic valuation methods are likely to be less robust and marginal concepts of ecosystem valuation are unlikely to capture the effect of threshold level changes in ecosystems (e.g. the point when a dam reaches eutrophication, the water treatment threshold of a wetland before it itself becoming degraded by the pollution inputs).

2.6.2 Consideration of the opportunity for ecological services

As described in the Conceptual Framework (Section 2.3), an element of this case study requiring consideration is the opportunity afforded the ecological infrastructure (the rehabilitated wetland) to supply its services, particularly in the context of the implementation of a new WWTW upstream of the wetland. Opportunity refers to the activities or circumstances that make it possible for ecosystem functions to be used for the benefit of humans.

An analysis of the likely impact of the new WWTW on nitrogen and phosphorus loads to the Mhinzinga Wetland was beyond the scope of this study. However, as an illustration of the concept, results from a study of nutrient loads in the upper uMgeni Catchment (1987-2013) by Ngubane
(2016) were used to consider nitrogen loads to the Mthinzima Wetland under different scenarios, Table 2-8. As an indication of nitrogen loads in the case of the new WWTW, historical loads for a time when the old WWTW was operational were applied (the average of nitrogen loads from 1996 - 1999 were used; during this period the old WWTW was functioning, it was decommissioned in 1999). The results show that with the WWTW, the opportunity for the wetland to provide an additional water treatment service is reduced, effectively decreasing the value of the rehabilitated wetland.

Table 2-8: Nitrogen loads to the Mthinzima Wetland and opportunity afforded the wetland to provide a nitrogen removal service under different scenarios

<table>
<thead>
<tr>
<th></th>
<th>Load to wetland*</th>
<th>Nutrient removal by ‘degraded’ wetland</th>
<th>Opportunity ‘remaining load’</th>
<th>Additional removal capacity with rehabilitation</th>
<th>Additional removal capacity vs. opportunity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>kg/a</td>
<td>kg/a</td>
<td>kg/a</td>
<td>kg/a</td>
<td></td>
</tr>
<tr>
<td>With WWTW</td>
<td>4000</td>
<td>3825</td>
<td>175</td>
<td>744</td>
<td>Only a portion of additional capacity can be fully utilized</td>
</tr>
<tr>
<td>Without WWTW</td>
<td>11000</td>
<td>3825</td>
<td>7175</td>
<td>744</td>
<td>Can be fully utilized</td>
</tr>
</tbody>
</table>

This exercise is intended to illustrate the influence of a changing context, in this case additional built infrastructure, on the economic value of ecological infrastructure. The calculation is limited in that the loads used are unlikely an accurate reflection of current loads with and without the new WWTW (e.g., historical data don’t account for a likely increase in loads with the growth of Mpohomeni). However, it is anticipated that the addition of a new WWTW upstream of the Mthinzima Wetland will reduce the loads of nutrients to the wetland.

Determining the extent to which the pollution load to the Mthinzima Stream will be affected by the new WWTW is a challenge. Mapping of the Mthinzima catchment in terms of the proportion of households connected to the sewerage network, the proportion of households on non-connected sanitation systems and the proportion of households without sanitation would provide a clearer understanding of potential pollution inputs to the wetland (and changes in inputs with the development of planned WWTW infrastructure). Separating out the water quality improvements due to the WWTW infrastructure development and rehabilitation of the wetland is a challenge, especially if these multiple interventions occur simultaneously (or within a 3 to 5 year timeframe). A detailed, long-term monitoring programme that takes into account this aspect is needed to demonstrate the actual impact of the wetland rehabilitation on water quality.

‘Ceteris paribus’ – used in economics to mean ‘all else being equal’ – is a dominant assumption of mainstream economic thinking and is employed in economic analyses as shorthand to indicate that all other factors influencing the relationship being analysed are assumed to be constant or unchanging. The ceteris paribus assumption is used to simplify the scenario or assessment context so that a causal relationship between specific variables can be isolated and assessed. It enables the analyst to circumvent the problems of limited knowledge, variable uncertainty and complexity. While an advantage to facilitating computational ease; the ceteris paribus assumption is limiting in the real context of social-ecological-technological systems and the dynamic interactions between their elements.

The illustration of the changing opportunity afforded the Mthinzima Wetland to provide a water treatment service with the implementation of a new WWTW is one example of the limitation of the ceteris paribus assumption in attempting to articulate the value of the proposed wetland rehabilitation. In effect, the conceptual framework presented in Section 2.3 needs to be modified to more explicitly
consider how the changing context – social, technological, ecological, economic, political 4 - may influence the value (in terms of opportunity and demand) of the Mthinziwana Wetland, and therefore the value of the proposed rehabilitation overtime, Figure 2-7.

**Figure 2-7: Illustration of the modified conceptual framework to more explicitly consider the influence of a changing context – social, technological, ecological, economic, political – on the value of the wetland rehabilitation.**

Additional, clearly defined scenario analyses would assist in better understanding the changing value of the wetland with the shifting context. A range of expertise is needed to establish ‘realistic’ scenarios (e.g., engineering/waste water treatment works design expertise, wetland ecology, water quality specialists, hydrologists, limnologists, environmental authorities, etc.). This process needs to go beyond bringing together a range of relevant information, and towards a point of critical engagement between experts. Additional factors influencing the interaction between the built (WWTW) and ecological infrastructure (wetland) in the context of this case study include:

- The ‘relocation of ecological services’ to downstream of the new proposed treated was water discharge point (the Sakabula Stream); in other words, with the new WWTW there may be a ‘declining’ opportunity for the water treatment services of the Mthinziwana Wetland, but an increased reliance on the system downstream of the proposed discharge point (on the Sakabula Stream) for water treatment;

- The risk mitigation role / benefit of the Mthinziwana Wetland during the construction and initial operation of the new WWTWs and once the new WWTW is operational (and consideration of its capacity to address potential WWTW failures or extreme conditions).

In this case, the dynamic nature of the context, the heavy reliance on the literature for ‘evidence’ and the resulting uncertainty of the biophysical outcomes and the use of a cost-based valuation method (where not all the conditions are met and which is itself not a reflection of economic value), mean that

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4 STEEP context from the V-STEEP framework which provides a holistic approach to assessing the context in which wetland rehabilitation takes place (Pollard et al., 2014).
the confidence in the results of the CBA in terms of absolute monetary values and cost-benefit comparisons is low and raises the question of whether conventional CBA is an appropriate and useful tool in considering the benefits of investing in the rehabilitation of the Mthinziama Wetland.

The real value of the CBA assessment, in this case, lies in the learning and understanding gained through undertaking the process; specifically:

- There is no cost-effective realistic replacement or alternative to the Mthinziama Wetland rehabilitation;
- Long-term monitoring of the biophysical outcomes of wetland rehabilitation in South Africa is needed to provide data / information on which to base economic valuations;
- Close engagement between experts (e.g. engineering/waste water treatment works design expertise, wetland ecology, water quality specialists, hydrologists, limnologists, environmental authorities, etc.) is needed in the evaluation of an investment in EI particularly at the start of the assessment so as to develop a holistic understanding of the context and determine the best approach and design of the evaluation;
- Conventional CBA is not always the most appropriate or useful way to evaluate an investment in EI; further, CBA results should not be considered as a ‘final answer’ on whether a proposed investment in EI is worthwhile. Decision makers should use the results as illustrative of the magnitude of costs and benefits under the set of assumptions made and use the CBA as a tool for testing the robustness of the investment to alternative assumptions concerning the magnitude of costs and benefits;
- The more people/stakeholders involved in the process; the greater the shared learning.

As noted by Fish (2011, 671), the concept of ecosystem services is very ‘young’ and we are a “long way from appreciating fully the practical needs and consequences of thinking about the natural world in this way… It is easy to forget just how embryonic and tentative practical understanding of this concept really is, and in particular what propagating an ecosystem services ‘world view’ of non-human nature implies for the way we think about governance arrangements for sustainability”.

30
3 Baynespruit Catchment Case Study

An Ex Ante Evaluation of Urban Water Management Options for the Baynespruit Catchment
M Browne and L Mugwedi

3.1 Introduction

The Baynespruit Stream is a highly polluted tributary of the uMsunduzi-uMngeni River. Due to the high pollutant loads introduced into the uMngeni system by the Baynespruit Stream, interventions which would result in even low to moderate improvements in the water quality of the Baynespruit are likely to contribute to improvements in the overall water quality of the uMngeni Catchment (Ramburran, 2013). The Msunduzi Municipality has committed to the Rehabilitation of the Baynespruit Stream project with the aim of improving the water quality of the stream, as its contribution to the UEIP project and improving water security within the uMngeni Catchment area (Ramburran, 2013). Several initiatives are underway within the broader Baynespruit rehabilitation project; however there remains uncertainty in deciding how best to invest in the catchment particularly in regard to ecological infrastructure.

3.1.1 Evaluation context and aims

Water pollution and stormwater management are key water-related issues in the Baynespruit Stream system. Conventional approaches to address these issues typically focus on technological-engineered solutions (grey infrastructure) and overlook the role of ecological functions. Healthy ecological infrastructure is increasingly recognized as an opportunity for addressing water security challenges (SANBI, 2013). However, the extensive development typical of urban landscapes reduces the extent of ecological infrastructure within the catchment and therefor limits these opportunities. In urban contexts, green or hybrid approaches – which blend ecosystem functions and engineered infrastructures – provide additional opportunities for addressing water and waste management challenges. Grey, ecological and green/hybrid approaches can all play a role in securing water for the benefit of society. However, underpinning the ‘success’ of these approaches are individuals, social networks and governance systems and the dynamic interactions between the social, ecological, and technical-infrastructural domains of urban systems.

During a stakeholder workshop and in several discussions, the Msunduzi Municipality indicated that it is uncertain about ‘what to do’ in regard to investing in EI within the catchment and how to prioritize investments across the social, ecological, and technical-infrastructural domains of water security within the Baynespruit Catchment. This highlights a central challenge; that of identifying, evaluating and comparing investments in water and waste management. The challenge is increased when comparing investment options across different ‘types’ of infrastructure (e.g. grey, ecological, green, social) as the outcome/benefits of these different actions are not necessarily equivalent and therefore directly comparable. In addition, the outcomes of investing in ecological, green and social domains are context-dependent, subject to time lags and relatively more uncertain than the more familiar grey infrastructure approaches.

The study aimed to explore ecological, grey, green and social capital investment options for improved water and waste management with the intention to shed light on investment opportunities in the

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5 That is, when considering EI in the strict sense defined by SANBI as naturally functioning - ecosystems that are in a natural, near natural or functional condition (SANBI, 2014)
Baynespruit Catchment. A qualitative evaluation of identified options, supported by a cost analysis, was undertaken.

### 3.1.2 The SETS framework

The social-ecological-technological systems (SETs) framework is a conceptualization of the urban system that emphasises the **dynamic interactions** between social, ecological, and technical-infrastructural domains, Figure 3-1, (Depietri and McPhearson, 2017). The SETs approach is intended as a framework for “overcoming the limitation of a purely socio-technological approach which tends to exclude ecological functions, or of a social-ecological approach inclined to overlook critical roles of technology and infrastructure as fundamental constituents, and drivers of urban system dynamics” (Depietri and McPhearson, 2017:94). Taking a SETs view broadens the spectrum of options available for intervention (Depietri and McPhearson, 2017 citing Grimm et al. 2016) and is therefore a suitable framework to explore the range of options available for responding to water security challenges in the Baynespruit Catchment.

![Figure 3-1: The social-ecological-technical systems (SETs) approach to conceptualizing urban systems, with emphasis on the interactions between social, ecological, and technical-infrastructural domains (Depietri and McPhearson 2017:94).](image)

Using the SETs framework as a guide, we considered ecological, grey, green and social capital investment options for improved water quality and stormwater management in the Baynespruit Catchment. The contrast between ecological, grey and green infrastructures is described in Table 3-1 and illustrated in Figure 3-2 through an example of options for managing stormwater in an urban context. Social and relationship capital refers to the institutions and relationships within and between communities, groups of stakeholders and other networks and encompasses values, behaviours, key relationships, and trust.
### Table 3-1: Infrastructure categories

<table>
<thead>
<tr>
<th>Grey Infrastructure</th>
<th>Hybrid/Green Infrastructure</th>
<th>Ecological Infrastructure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hard, engineering structures</td>
<td>Blend of biological-physical and engineering structures</td>
<td>Biophysical, ecosystems and their services</td>
</tr>
<tr>
<td>Very limited role of ecosystem functions</td>
<td>Generally allows for some ecosystem functions mediated by technological solutions</td>
<td>Mainly relying on existing or restored ecosystems and ecosystem functions</td>
</tr>
<tr>
<td>e.g. canals, pipes and tunnels of drainage systems;</td>
<td>e.g. floating wetlands;</td>
<td>e.g. wetlands; riparian zones;</td>
</tr>
<tr>
<td>wastewater treatment plants and reticulation networks;</td>
<td>Sustainable Urban Drainage Systems (SUDS); green roofs;</td>
<td>floodplains; forests, woodlands, urban trees; rivers, streams and oceans</td>
</tr>
<tr>
<td>water filtration plants</td>
<td>eco-sanitation;</td>
<td></td>
</tr>
</tbody>
</table>

Source: Adapted from Depietri and McPhearson (2017:95).
Ecological, green/hybrid and grey infrastructure approaches to dealing with urban water.

Note: The hybrid approach illustrated in the centre panel combines grey and ecological approaches to maximize water absorption and infiltration (Source: adapted from Depietri and McPhearson (2017:96).
3.2 The Baynespruit Catchment

The Baynespruit Stream is located in the Msunduzi Municipality, KwaZulu-Natal and is a tributary of the Msunduzi River, which forms part of the greater uMgeni Catchment which is utilized to provide water to the cities of Pietermaritzburg and Durban and surrounding areas. The Baynespruit Stream originates in the residential area of Northdale and flows approximately 9 km through the Willowton Industrial Area before reaching its confluence with the Msunduzi River just east of the residential community of Sobantu. The Baynespruit Catchment falls within quaternary drainage region U20J, Figure 3-3. The location of the Baynespruit Catchment and stream within the Msunduzi Municipal Area is shown in Figure 3-4.

Land-cover change in the Baynespruit Catchment has been driven by agriculture, forestry, settlement, and industrial and commercial area development. In the 1940s, settlements started to expand, resulting in a decline in forestry while commercial and industrial development, and quarry mining started in the 1970s. In the 1980s, below the R33 Greytown Road, the Baynespruit Stream was diverted from its natural course and channelled. Presently, land cover change in the catchment is driven by urbanization and housing demand. The upper catchment of the Baynespruit Stream consists of high-density formal residential development; the middle reaches are comprised of numerous trade effluent regulated industries; high-density formal and informal residential areas are located downstream.

In summary:
- The Baynespruit Stream is a highly degraded aquatic system, considered to be in a 'seriously modified' condition;
- It is characterised by poor water quality;
- Pathogens (indicated by the presence of E.coli), nutrient loads and heavy metals have been identified as contaminants of concern;
- Flooding and streambank erosion has resulted in damage to property;
- The Baynespruit is a tributary of the uMsunduzi – greater uMgeni Catchment, which is a key water resource, providing water to the cities of Pietermaritzburg and Durban and surrounding areas.

Drivers of stream degradation within the catchment include:
- Aging sewerage and storm-water infrastructure;
- Influx of storm water into sewerage systems;
- Industrial pollution - accidental spillages, illegal discharges;
- Development - riparian edge, fragmented development pattern, informal settlements
- Inappropriate use and degradation of wetlands and floodplains;
- Alien plant species infestations;
- Institutional/governance challenges;
- Political history
- Additional drivers and pressures from future population growth, development and climate change.
Figure 3-3: Location of quaternary drainage region U20J, yellow shading, within KwaZulu-Natal.

Figure 3-4: Location of the Baynespruit catchment and stream within the Msunduzi Municipal Area, KwaZulu-Natal, South Africa
3.3 Method

When multiple potential investment options or actions are being considered, especially those involving complex functions and interactions (e.g. changes in ecosystem condition and function), and it is not feasible to conduct extensive primary research for each option, multi-criteria approaches and cost analysis are appropriate starting points for evaluating options (Rao et al., 2012; Black et al., 2016). This is the case in this study of the Baynespruit Stream. A qualitative multi-criteria assessment supported by a cost comparison was undertaken as a first step towards identifying appropriate solutions to water quality and stormwater management challenges in the Baynespruit Catchment.

Depietri and McPhearson (2017) applied a multi-criteria approach across a range of criteria identified from the literature to evaluate the performance of various approaches to disaster risk reduction and climate change adaptation in urban areas. The adaptation approaches were scored (low-medium-high) for eight criteria: (i) Feasibility in the urban context, (ii) reliability, (iii) no regret strategy, (iv) long-term durability or resilience, (v) reversibility and flexibility; (vi) cost-effectiveness, (vii) biodiversity conservation and (viii) other co-benefits. From their analysis, Depietri and McPhearson (2017) asserted the following main points in the context of disaster risk reduction:

- Grey infrastructure provide a wide array of drawbacks under most factors considered, but are easily adaptable to the urban context;
- Ecological infrastructures are flexible, no-regret measures and provide a wide range of benefits and co-benefits, but are often difficult to implement in the urban context;
- Hybrid / green approaches fit well to the urban context and provide many of the co-benefits of ecological infrastructure.

In a local, urban setting, hybrid /green approaches are suggested as the way forward for disaster risk reduction and climate change adaptation solutions in urbanized regions (Depietri and McPhearson, 2017).

In an investigation of solutions to future water scarcity for the Dow Chemical Company’s facility in Freeport, Texas, Reddy et al. (2015) used a two-step process to identify and prioritize possible solutions for further analysis. They held a workshop with local experts to identify a potential nature-based and collaborative (involving other water users) solutions. They applied a multi-criteria analysis to score (numerically) the options across seven criteria: expected benefits, potential for benefits to other stakeholders and ecosystems, impact to water availability, political and technical feasibility, and alignment with (water user) collaboration goals. The five options with the highest scores were selected for further investigation: reservoir flood pool reallocation - restore flood plains and reallocate reservoir flood pool storage; land management - replace invasive, highwater-use plants with native, lowwater-use plants; marsh waste water treatment - restore/create marshes to serve as a regional waste water treatment facility; irrigation efficiency – provide funds for agricultural users to install more efficient irrigation technology or fallow crops in exchange for saved water; and a municipal rebate program— provide funds for rebate programs to incentivize municipal users to install more efficient appliances or convert to low-water use landscaping.

Reddy et al. (2015) then applied cost-benefit analysis to evaluate the five solutions against the ‘business as usual solution’ of reservoir expansion. Marsh waste water treatment and land management were not cost competitive with the business as usual solution. The reservoir flood pool reallocation/floodplain restoration, irrigation efficiency, and municipal rebate program solutions were cost-competitive, but were associated with significant technical, legal, and political hurdles. All solutions were found to provide substantial collective benefits for both the public and biodiversity. Reddy et al. (2015) concluded that the nature-based and collaborative solutions show potential to complement the business-as-usual approach to improve the reliability of Dow’s water right and that such solutions may be appropriate for implementation via multi- stakeholder collaboration.
A cost analysis approach was applied by Black et al. (2016) to evaluate ecosystem-based adaptation (EbA) options compared to alternative measures to deal with the expected impacts of climate change in the Northern Cape Province of South Africa. Black et al. (2016) found the EbA options to be more costly than conventional alternatives from the perspective of the landowners (in a poverty-stricken arid region). Black et al. (2016) highlighted that the costs associated with the different options would likely be incurred at different times noting that EbA costs would usually need to be incurred in the present or near future, while costs associated with ‘conventional alternatives’ are more likely to be incurred at a much later stage, in reaction to climate changes. This difference in timing of costs would have influenced the cost comparison. Cost-benefit estimation was not attempted due to the onerous data requirements and the uncertainty surrounding the estimation of benefits associated with the ecosystem-based adaptation option (wetland restoration). Relative to alternative economic analyses, cost analysis embodies the least amount of uncertainty.

Rao et al. (2012) undertook a cost comparison of ecosystem-based and engineering solutions to river flooding and storm surges in Lami Town, Fiji and found combinations of ecosystem-based options to be the most cost competitive in reducing flood risk for Lami Town. The actual effectiveness of the different options was not determined due to a lack of information (e.g. spatial information), therefore only the costs of each of the selected adaptation options were compared. Rao et al. (2012) emphasise that it cannot be assumed that each of the identified solutions would have the same level of flood attenuation effectiveness. The least-cost analysis approach provides the specific sum of costs of each of the chosen adaptation options over a period of years so that the costs of implementing the different actions are clear (Rao et al., 2012). The authors note that the approach is used to support decision-making for infrastructure and water projects. Determining the effectiveness of the proposed options, which could then be used in a cost-effectiveness analysis or in an optimization approach, is recommended by Rao et al. (2012) as a useful next step.

3.3.1 Method steps

Drawing from the approaches applied by Rao et al. (2012), Black et al. (2016), Reddy et al. (2015) and Depietri and McPhearson (2017), the steps and associated activities summarized in Table 3-2 were undertaken. The preliminary identification of investment options was informed by a stakeholder workshop, discussions with the Municipality and a local NGO active in the area, and a review of the literature and research related to the Baynespruit catchment. These options were then compared (qualitatively) based on several criteria. The results of the comparison were used to prioritize a set of options for further assessment and cost analysis.

Table 3-2: Summary of the method steps and associated activities

<table>
<thead>
<tr>
<th>1 Establish the water security related challenges in the Baynespruit catchment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Several activities were undertaken to establish the primary water security related issues of the Baynespruit catchment, including:</td>
</tr>
<tr>
<td>• A review of documents and existing information related to the Baynespruit Stream and Msunduzi Municipal area, including consideration of the Resource Quality Objectives (RQOs) for the area and the current state of the water quality of the Baynespruit.</td>
</tr>
<tr>
<td>• A stakeholder consultation process with municipal officers, Umgeni Water representatives (bulk water supplier) and local stakeholders (NGOs, experts, and researchers) in the form of individual meetings and a group workshop. A mind-mapping exercise was undertaken during the workshop identifying the risks and opportunities associated with the Baynespruit catchment.</td>
</tr>
<tr>
<td>• An assessment of historical land cover change in the Baynespruit catchment (see</td>
</tr>
</tbody>
</table>
Deliverable 9 this project).

It was determined that water pollution and stormwater management are key challenges and that interventions which would result in even low to moderate improvements in the water quality of the Baynespruit are desirable and likely to contribute significantly to improvements in the overall water quality of the uMngeni Catchment.

Hence, this evaluation focused on potential options for addressing water quality and stormwater management issues.

### 2 Identify a broad range of potential options (investment actions) towards addressing the key challenges

The preliminary identification of investment options was informed through a stakeholder workshop, discussions with the Municipality and a local NGO active in the area, and a review of research related to the Baynespruit catchment and the broader literature. The SETS framing (Dipietri & McPhearson, 2017) was used as guide to broaden the spectrum of options considered across ecological, grey, green and social capital investment actions.

### 3 Prioritize potential options for further assessment

The broad range of identified options was then compared (qualitatively) based on several criteria adapted from Dipietri and McPhearson (2017) to narrow down the options. Classes of low, medium and high performance were assigned to each of the options with respect to the criteria and the Baynespruit context.

### 4 Assess selected options

The potential options were assessed using a mixed qualitative-quantitative approach. For each option, it was determined how the option could be implemented in the Baynespruit catchment, based on existing information (assessments, plans and reports) and basic spatial analysis. The potential impacts (i.e. the anticipated biophysical impacts of the action e.g. the potential change in a particular water quality parameter such as nitrogen) and costs of implementing the option were identified and quantified where possible (based on existing information). The resulting benefits associated with the biophysical impact, and possible threats or constraints for each option were determined.

### 5 Cost comparison

The costs to implement the options in the Baynespruit were drawn from existing budgets or project proposals specific to the Baynespruit Catchment. Where projected costs were not available, costs were estimated from similar projects within South Africa. Costs were adjusted for inflation to represent a 2017/18 rand value. The costs to implement each option were then compared.
3.4 Results

3.4.1 Selection of options

Water pollution and streambank erosion (stormwater) are key challenges in the Baynespruit catchment; hence, this study focused on potential options for addressing water quality and stormwater management issues. A number of possible options were identified across ecological, grey, green and social capital investment actions, Table 3-3. This range of options was narrowed down through a multi-criteria scoring process of each option, Table 3-4 and Table 3-5 (comments accompanying the scores are provided in Appendix 6.2.1 for Stormwater management ecological infrastructure options as an example). The criteria considered were:

- **Feasibility** in the urban context – the extent the option is realistic and practical for implementation in the Baynespruit catchment;
- **Reliability** – the effectiveness of the measure in addressing water quality and stormwater management issues;
- **Long-term durability or resilience** – the extent to which the option is durable and resilient overtime and to likely threats;
- **Reversibility and flexibility** – the ease with which the option can be reversed/removed and it’s flexibility in terms of opportunity to integrate with ecological infrastructure;
- **Costs** – an indication of (relative) implementation and maintenance costs;
- **Co-benefits** - the extent of additional positive impacts associated with the measure;
- **Dis-benefits** – the extent of negative impacts associated with the measure.

The criteria were applied taking into consideration the Baynespruit catchment context, specifically:

- Rapid urbanization with both formal and informal housing;
- Three distinct socio-economic classes - low-income residential with informal housing, medium-income residents and formal housing, and high-income residents and well developed houses;
- Historical use of the stream for manual irrigation, fishing and swimming purposes particularly by low-income households, presently a human health risk associated with use of the water;
- Illegal dumping of waste, overgrown vegetation (unmanaged open areas) associated with service delivery failures;
- Water quality issues of sewage pollution, solid waste (litter) and industry effluents (fats);
- Fluctuating water levels and high velocity flows from summer rainfall;
- Residents have become disillusioned with Municipal ability to deliver services and therefor capacity to implement stream and wetland rehabilitation initiatives;
- Agricultural potential of land adjacent to the stream, this potential is limited by water pollution, but also concerns of ‘competition for growing space’ if the water quality improves.

To begin with, the stormwater management and water quality options were considered separately, but in many cases there is overlap between them (e.g. vegetated riparian areas can play a role in both flow attenuation and water quality improvement). Stormwater management is considered primarily from a storm flow perspective, however improving the quality of runoff is also desirable.
Table 3-3: Potential options (investment actions) to address stormwater and water quality challenges in the Baynespruit catchment

<table>
<thead>
<tr>
<th>Option</th>
<th>Stormwater</th>
<th>Water Quality</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ECOLOGICAL INFRASTRUCTURE</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conservation of natural areas</td>
<td>Yes</td>
<td>Yes</td>
<td>Relevant</td>
</tr>
<tr>
<td>Wetland rehabilitation</td>
<td>Yes</td>
<td>Yes</td>
<td>Highly relevant</td>
</tr>
<tr>
<td>Revegetation of degraded riparian areas</td>
<td>Yes</td>
<td>Yes</td>
<td>Highly relevant</td>
</tr>
<tr>
<td><strong>GREY INFRASTRUCTURE</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Infiltration basin</td>
<td>Yes</td>
<td>Yes</td>
<td>Relevant</td>
</tr>
<tr>
<td>Infiltration trench</td>
<td>Yes</td>
<td>Yes</td>
<td>Relevant</td>
</tr>
<tr>
<td>Stream canalization</td>
<td>Yes</td>
<td>Yes</td>
<td>Highly relevant</td>
</tr>
<tr>
<td>Detention basin</td>
<td>Yes</td>
<td>Yes</td>
<td>Relevant</td>
</tr>
<tr>
<td>Permeable pavement</td>
<td>Yes</td>
<td>Yes</td>
<td>Relevant</td>
</tr>
<tr>
<td>Rehabilitate waterborne sanitation</td>
<td>No</td>
<td>Yes</td>
<td>Highly relevant</td>
</tr>
<tr>
<td><strong>HYBRID / GREEN INFRASTRUCTURE</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bioretention systems</td>
<td>Yes</td>
<td>Yes</td>
<td>Relevant</td>
</tr>
<tr>
<td>Constructed wetlands</td>
<td>Yes</td>
<td>Yes</td>
<td>Highly relevant</td>
</tr>
<tr>
<td>Waterless sanitation</td>
<td>No</td>
<td>Yes</td>
<td>Highly relevant</td>
</tr>
<tr>
<td>Green roofs</td>
<td>Yes</td>
<td>Yes</td>
<td>Relevant</td>
</tr>
<tr>
<td>Rain garden</td>
<td>Yes</td>
<td>Yes</td>
<td>Highly relevant</td>
</tr>
<tr>
<td>Rainwater harvesting</td>
<td>Yes</td>
<td>Yes</td>
<td>Highly relevant</td>
</tr>
<tr>
<td>Wet retention basin</td>
<td>Yes</td>
<td>Yes</td>
<td>Relevant</td>
</tr>
<tr>
<td><strong>SOCIAL CAPITAL</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pollution reduction strategies in industry</td>
<td>No</td>
<td>Yes</td>
<td>Highly relevant</td>
</tr>
<tr>
<td>Environmental advocacy - residential areas</td>
<td>Indirect</td>
<td>Yes</td>
<td>Highly relevant</td>
</tr>
<tr>
<td>(EnviroChamps)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Table 3-4: Multi-criteria comparison of potential options (investment actions) to address stormwater challenges in the Baynespruit catchment

<table>
<thead>
<tr>
<th>Option</th>
<th>Feasibility in the urban context</th>
<th>Reliability</th>
<th>Long-term durability or resilience</th>
<th>Reversibility and flexibility</th>
<th>Costs</th>
<th>Co-benefits</th>
<th>Dis-benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ecological infrastructure</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conservation of natural areas</td>
<td>Low</td>
<td>Medium to high</td>
<td>Medium to high</td>
<td>High</td>
<td>Low to medium</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Revegetation of degraded riparian areas</td>
<td>Medium to High</td>
<td>Medium to high</td>
<td>Medium to high</td>
<td>High</td>
<td>Low to medium</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Rehabilitation of degraded wetlands</td>
<td>Medium to High</td>
<td>Medium to high</td>
<td>Medium to high</td>
<td>High</td>
<td>Medium to high</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td><strong>Grey infrastructure</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Infiltration basin</td>
<td>Medium</td>
<td>Medium to high</td>
<td>High</td>
<td>Low to medium</td>
<td>Medium</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td>Infiltration trench</td>
<td>Medium</td>
<td>Medium to high</td>
<td>High</td>
<td>Low to medium</td>
<td>Medium</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td>Stream canalization</td>
<td>High</td>
<td>Medium to high</td>
<td>High</td>
<td>Low</td>
<td>High</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>Detention basin</td>
<td>Medium</td>
<td>Medium</td>
<td>High</td>
<td>Low</td>
<td>Medium</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td>Permeable pavement</td>
<td>Low to medium</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td><strong>Hybrid / Green infrastructure</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rainwater harvesting</td>
<td>Medium to high</td>
<td>Medium to high</td>
<td>Medium to high</td>
<td>High</td>
<td>Low</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td>Green roofs</td>
<td>Low to medium</td>
<td>Medium</td>
<td>Medium to high</td>
<td>High</td>
<td>Medium to high</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Bioretention systems</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
<td>High</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Constructed wetlands</td>
<td>Low to medium</td>
<td>Medium to high</td>
<td>Medium to high</td>
<td>Low to medium</td>
<td>Medium to high</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Raingarden</td>
<td>High</td>
<td>Medium</td>
<td>High</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Wet retention basin</td>
<td>Medium</td>
<td>Medium</td>
<td>High</td>
<td>Low</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>Option</td>
<td>Feasibility in the urban context</td>
<td>Reliability</td>
<td>Long-term durability or resilience</td>
<td>Reversibility and flexibility</td>
<td>Costs</td>
<td>Co-benefits</td>
<td>Dis-benefits</td>
</tr>
<tr>
<td>---------------------------------------------</td>
<td>----------------------------------</td>
<td>---------------------</td>
<td>-----------------------------------</td>
<td>---------------------------------------------</td>
<td>-------------------</td>
<td>-------------</td>
<td>--------------</td>
</tr>
<tr>
<td><strong>Ecological infrastructure</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rehabilitation of degraded wetlands</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium reversibility High flexibility’</td>
<td>Medium</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td>Revegetation of degraded riparian areas</td>
<td>Medium to high</td>
<td>Low to medium</td>
<td>Medium to high</td>
<td>High</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td><strong>Grey infrastructure</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rehabilitate waterborne sanitation network</td>
<td>Medium to high</td>
<td>Medium to high</td>
<td>Medium</td>
<td>Low</td>
<td>Medium</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td><strong>Hybrid / Green infrastructure</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Waterless sanitation</td>
<td>Low to medium</td>
<td>Medium to high</td>
<td>Medium</td>
<td>High</td>
<td>Low to medium</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td>Floating wetlands</td>
<td>High</td>
<td>Medium to high</td>
<td>Medium to high</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Wet retention basin</td>
<td>Medium</td>
<td>Medium</td>
<td>High</td>
<td>Low reversibility Medium flexibility</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>Constructed wetlands</td>
<td>Low to medium</td>
<td>High</td>
<td>Medium to high</td>
<td>Low to medium</td>
<td>Medium to high</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td><strong>Social capital</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Advocate pollution reduction strategies in industry</td>
<td>Medium</td>
<td>High</td>
<td>Medium</td>
<td>Low reversibility Medium flexibility</td>
<td>Low to medium</td>
<td>Medium to high</td>
<td>Low</td>
</tr>
</tbody>
</table>
Based on the multi-criteria comparison, eight potential options were prioritized for further assessment, Table 3-6; two ecological infrastructure options, two grey infrastructure options, three green / hybrid options and a social capital initiative.

Table 3-6: Selected potential options (investment actions) to address water quality and stormwater challenges on the Baynespruit catchment

<table>
<thead>
<tr>
<th>Action</th>
<th>Details of action</th>
<th>Description of action in BS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ECOLOGICAL INFRASTRUCTURE</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rehabilitate wetlands</td>
<td>Rehabilitate wetlands to improve ecological function and enhance water quality.</td>
<td>Rehabilitate two wetlands identified to have water quality enhancement capacity.</td>
</tr>
<tr>
<td>Revegetation of riparian areas</td>
<td>Revegetation of the riparian area to restore biodiversity and ecosystem function to improve water quality and quantity and flood attenuation (infiltration).</td>
<td>Clearing of alien invasive plants and revegetation along the stream (14 ha).</td>
</tr>
<tr>
<td><strong>GREY INFRASTRUCTURE</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rehabilitate waterborne sanitation network</td>
<td>Repairs to the sanitation network to reduce waste water pollution of the stream and improve water quality.</td>
<td>Repairs to selected sections of the sanitation network.</td>
</tr>
<tr>
<td>Stream canalization</td>
<td>Straightening and lining of the stream with concrete to mitigate flooding and stream bank erosion to protect properties and homes.</td>
<td>Concrete encasement of sections of the stream.</td>
</tr>
<tr>
<td><strong>HYBRID / GREEN INFRASTRUCTURE</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Floating wetlands</td>
<td>Buoyant mats planted with wetland plants anchored on the stream surface to improve water quality, reinstate species habitat, maintain habitat corridors and enhance the ecosystems services.</td>
<td>Seven potential sites, 2 selected to pilot the approach. Each floating wetland is 4 m².</td>
</tr>
<tr>
<td>Rooftop rainwater harvesting</td>
<td>Collection of rainwater from rooftops and stored in tanks to reduce stormwater flows and provide water for non-potable purposes.</td>
<td>Harvesting of rainwater from a portion of the 197 ha of rooftop in the catchment (&gt; 10mx10m).</td>
</tr>
<tr>
<td>Waterless sanitation</td>
<td>Installing waterless toilets to provide sanitation in informal settlements and reduce waste water production and water use.</td>
<td>Install urine diversion dry toilets in 408 households in informal settlements.</td>
</tr>
<tr>
<td><strong>SOCIAL CAPITAL</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Environmental advocacy (residential)</td>
<td>Initiatives to build civic awareness of the value of the environment to improve environmental quality.</td>
<td>20 EnviroChamps undertake door to door environmental awareness, engage local schools and communities in stream clean up and monitoring campaigns.</td>
</tr>
</tbody>
</table>
3.4.2 Assessment of options

The eight selected options (Table 3-6) were further interrogated to determine how they could be applied in the Baynespruit catchment, what their potential impact on water quality and stormwater runoff might be and the associated costs (monetary), benefits (identified) and threats and constraints. Each option is described in the sections below. For each option a general overview – description, purpose, strengths and benefits, and disadvantages and limitations – is provided, followed by a description of its application in the Baynespruit catchment.

Wetland rehabilitation

Wetlands within the Baynespruit Catchment have been subject to infilling, pollution, the development of extensive hardened surfaces in the catchment and alien plant species, which has resulted in the wetlands becoming degraded (Awuah, 2017). Rehabilitating wetlands represents a valuable opportunity for society to recover and enhance the benefits of wetlands, including improved water quality and stormwater attenuation.

What is wetland rehabilitation?

<table>
<thead>
<tr>
<th>Wetland rehabilitation</th>
<th>ECOLOGICAL INFRASTRUCTURE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Wetlands are</strong> “areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tides does not exceed six metres” (Ramsar, 2016: 9).</td>
<td></td>
</tr>
<tr>
<td><strong>Wetland rehabilitation is</strong> “the process of assisting in the recovery of a wetland that has been degraded or in maintaining the health of a wetland that is in the process of degrading” (Kotze et al., 2009a).</td>
<td></td>
</tr>
</tbody>
</table>

Wetland rehabilitation interventions include the correction of artificial surface and sub-surface drainage to improve water spread and retention time, and the re-establishment of indigenous wetland vegetation. Rehabilitation interventions can also include activities to remove or reduce the stressors or pressures on the ecological character of the wetland such as livestock grazing, burning regimes, and cultivation and land-use practices.

An example of urban wetland rehabilitation, Greater Edendale Mall, Pietermaritzburg (GroundTruth, 2016).
**Purpose**

Ecological rehabilitation actions aim to reinstate a level of ecosystem functionality towards renewed and ongoing provision of ecosystem services. Generally, wetland rehabilitation activities focus on ecosystem functionality and the delivery of targeted ecosystem services. Depending on the context, a range of benefits are derived from wetland ecosystem services.

Rehabilitating wetlands represents a valuable opportunity for society to recover and enhance benefits for human health and well-being, including improved water quality, reduced risk from storms and other extreme events and the capacity to mitigate and adapt to climate change.

**Strengths & benefits**

- A range of ecosystem services are associated with wetlands from which a diversity of benefits can be derived, rehabilitating wetlands can improve or maintain the supply of ecosystem services.
- Several water quality enhancement benefits are associated with wetland systems depending on the wetland type and characteristics:
  - Nitrate and phosphate assimilation
  - Toxicant assimilation
  - Sediment trapping
  - Erosion control.
- The best nutrient removal return is likely to be obtained by restoring moderately altered wetlands where drainage can be corrected without huge cost and where a significant proportion of the existing wetland vegetation is appropriate and does not need to be replaced.
- Once restored, the maintenance requirements of natural wetlands are likely to be low, and consist mostly of alien plant and biomass control.
- The rehabilitation of degraded natural wetlands will also enhance the biodiversity value of those wetlands.

**Limitations & disadvantages**

- Wetland rehabilitation requires space, both for the wetland basin itself, and ideally, for a buffer around the wetland. Land acquisition costs can be significant.
- There is a time lag between implementation of rehabilitation interventions and impacts on wetland condition and functioning. Benefits are not immediately realized.
- Natural wetlands exhibit considerable variation in their nitrogen removal capacity.
- Natural wetlands have only a limited long term capacity to store phosphorus.
- Wetlands have been associated with odours, pests (e.g. mosquitos, snakes) and security risks.
- There remains uncertainty about the effectiveness of wetlands in mitigating urban pollution.
- Optimising for water quality improvement may compromise other services.

Source: Adapted from Turner et al. (2008), Kotze et al. (2009a, b), Hamill et al. (2010) and Ramsar (2016).

**Description of the action in the Baynespruit Catchment**

There are 54 wetlands in the catchment. A study of the wetland systems of the catchment identified two potential sites for wetland rehabilitation, specifically with a focus on improving water quality, Greytown Road and Sobantu Wetlands (Auwah 2017). The Greytown Road wetland was found to have the most rehabilitation potential for improved water quality followed by the Sobantu wetland (Auwah 2017). The location of the wetland sites in the catchment is shown in Figure 3-5 and key features of the wetlands relevant to their rehabilitation potential are summarized in Table 3-7.
Figure 3-5: Baynespruit catchment area showing the location of the three wetland rehabilitation sites.

Table 3-7: Key features of the wetlands relevant to their rehabilitation potential

<table>
<thead>
<tr>
<th>Feature</th>
<th>Greytown Road wetland</th>
<th>Sobantu wetland</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>Seep</td>
<td>Channelled valley bottom</td>
</tr>
<tr>
<td>Size (ha)</td>
<td>0.8</td>
<td>18</td>
</tr>
<tr>
<td>Present Ecological State</td>
<td>D Largely modified</td>
<td>E Great loss of ecosystem process and natural habitat</td>
</tr>
<tr>
<td>Potential to improve retention capacity within the wetland</td>
<td>Limited Retention capacity is already very high and characterized by diffuse flow</td>
<td>High There is high potential to reactivate a larger area than the current permanent and seasonally wet areas on the relatively flat valley floor</td>
</tr>
<tr>
<td>Potential to re-direct stormflows into the wetland</td>
<td>High Presently almost all of the stormflows are directed around the wetland</td>
<td>High Artificial drains currently carry stormwater straight into the historical channel of the Baynespruit, flows could be spread more diffusely across the wetland</td>
</tr>
<tr>
<td>Source of potential water inputs</td>
<td>High Portion of the catchment currently being drained by the drain around the wetland is largely hardened surfaces</td>
<td>High Stormwater from the Sobantu community as well as additional stormflows directed through the current drains</td>
</tr>
<tr>
<td>Feature</td>
<td>Greytown Road wetland</td>
<td>Sobantu wetland</td>
</tr>
<tr>
<td>---------</td>
<td>----------------------</td>
<td>-----------------</td>
</tr>
<tr>
<td><strong>Constraints in relation to wetland attributes</strong></td>
<td>Moderately low</td>
<td>Moderately low</td>
</tr>
<tr>
<td>Measures are likely to be required to ensure that stormwater directed into the wetland safely enters and exits the wetland</td>
<td>Measures may be required to ensure that stormwater directed into the wetland safely enters and exits the wetland</td>
<td></td>
</tr>
<tr>
<td><strong>Constraints in terms of infrastructural development surrounding/within the wetland</strong></td>
<td>Low</td>
<td>Moderate</td>
</tr>
<tr>
<td>There still remains a relatively high degree of an undeveloped buffer around the wetland</td>
<td>Sobantu settlement has been developed up to the boundary of the wetland</td>
<td></td>
</tr>
<tr>
<td><strong>Proposed structural rehabilitation interventions</strong></td>
<td>Moderately low</td>
<td>Moderately High</td>
</tr>
<tr>
<td>Proposed infrastructure is a weir, drop inlet and a berm</td>
<td>A number of drains need to be completely or partially decommissioned, proposed interventions include a berm, weir and spreader canal</td>
<td></td>
</tr>
<tr>
<td><strong>Proposed non-structural wetland interventions</strong></td>
<td>Remains dominated by indigenous vegetation</td>
<td>Removal of invasive alien plants, rubble and fill material in and surrounding the wetlands is likely to improve the water holding capacity of the wetland and provide an improvement in aesthetics of the respective areas</td>
</tr>
<tr>
<td>Restrict trespassing through the wetland as this is one of the direct causes of general solid domestic waste</td>
<td>Restrict trespassing through the wetland as this is one of the direct causes of general solid domestic waste</td>
<td></td>
</tr>
</tbody>
</table>

Source: Adapted Awuah (2017).

**Potential impact**

The primary anticipated outcome of rehabilitating wetlands in the Baynespruit catchment is an improvement in water quality, particularly the removal of nutrients (nitrogen and phosphorus). Pollution inputs to the Baynespruit Stream include stormwater runoff from the highly developed catchment, overflows from an aging and misused sewerage system and industry effluent. Studies have shown wetlands to be effective at removing nutrients from inflow waters (Land et al. 2016). Key elements related to the potential of the selected wetlands for improving the water quality of the Baynespruit Stream are summarized in Table 3-8.

**Table 3-8: Key aspects related to the potential of the selected wetlands for improving the water quality of the Baynespruit Stream**

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Greytown Road wetland</th>
<th>Sobantu wetland</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enhanced wetland area (ha) from rehabilitation interventions</td>
<td>0.8</td>
<td>9.0</td>
</tr>
<tr>
<td>The entire wetland area is likely to be enhanced by rehabilitation measures</td>
<td>A portion of the wetland adjacent to the Sobantu community is likely to be enhanced</td>
<td></td>
</tr>
<tr>
<td>Aspect</td>
<td>Greytown Road wetland</td>
<td>Sobantu wetland</td>
</tr>
<tr>
<td>--------------------------------------------</td>
<td>-----------------------------------------------------------</td>
<td>-----------------------------------------------------</td>
</tr>
<tr>
<td>Contribution to water quality enhancement</td>
<td>High current effectiveness - phosphate trapping, nitrate removal, toxicant removal</td>
<td>Moderately high current effectiveness - phosphate trapping, nitrate removal, toxicant removal</td>
</tr>
<tr>
<td></td>
<td>Moderately high future opportunity</td>
<td>Moderately high future opportunity</td>
</tr>
<tr>
<td>Potential for rehabilitation to improve the contribution to water quality enhancement</td>
<td>Has rehabilitation potential for improved water quality (the most potential, relative to the other sites)</td>
<td>Has rehabilitation potential for improved water quality</td>
</tr>
</tbody>
</table>

Source: Adapted from Awuah (2017).

Considering the two wetlands together, the enhanced wetland area from the proposed rehabilitation interventions is 9.08 ha. By way of indication of the potential water quality enhancement of the rehabilitated wetlands, the literature was consulted for nitrate and phosphorus removal rates (see Appendix for additional details). Few published long terms studies, or monitoring results, of nitrogen and phosphorus removal by wetlands systems in KwaZulu-Natal or even South Africa are available. Drawing on the unit area nutrient removal values reported by Land et al. (2016) as a lower bound and Hamill et al. (2010) as an upper bound, the added nutrient removal potential associated with the proposed wetland rehabilitations was estimated, Table 3-9. The estimates indicate that, when considered together, the rehabilitated wetlands have the potential to remove in the order of 454 to 2679 kg of nitrogen per year and 64 to 91 kg of phosphorous per year. Given the many factors that influence nutrient removal performance by wetlands and the variability in unit area nutrient removal values reported in the literature, these estimates are reported with a low level of confidence.

Table 3-9: Nutrient removal potential for the proposed Baynespruit Wetland rehabilitation

<table>
<thead>
<tr>
<th>Removal potential</th>
<th>Based on Land et al. (2016)</th>
<th>Based on Hamill et al. (2010)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area (m²)</td>
<td>90800</td>
<td>90800</td>
</tr>
<tr>
<td>Removal rate (g/m²/d)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TN</td>
<td>0.014</td>
<td>0.081</td>
</tr>
<tr>
<td>TP</td>
<td>0.002</td>
<td>0.003</td>
</tr>
<tr>
<td>Removal (g/d)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TN</td>
<td>1 244</td>
<td>7 339</td>
</tr>
<tr>
<td>TP</td>
<td>174</td>
<td>249</td>
</tr>
<tr>
<td>Removal (g/yr)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TN</td>
<td>454 000</td>
<td>2 678 600</td>
</tr>
<tr>
<td>TP</td>
<td>63 560</td>
<td>90 800</td>
</tr>
</tbody>
</table>

**Cost**

For both wetlands, structural rehabilitation interventions are proposed including weirs and berms (both wetlands) and a drop inlet (Greytown Road wetland) and a spreader canal (Sobantu wetland). In addition, non-structural interventions are proposed for the Sobantu wetland including invasive alien plant removal and the removal of rubble and fill material. Wetland rehabilitation costs are site specific; however, the costs for the proposed wetland rehabilitation interventions were not estimated as part of the Baynespruit Wetland rehabilitation study. As such, wetland rehabilitation costs were drawn from alternative sources, specifically the per area costs estimated for the proposed Mthinzima Stream Wetland rehabilitation, a site also in the uMngeni Catchment (see Appendix 6.2.3 for further details).
Applying the per area costs estimated for the Mthinzima Wetland rehabilitation study to the proposed Baynespruit Wetlands results in a construction cost of R 1 111 719, adding one year of maintenance takes the cost to R 1 139 513. The capital costs of rehabilitating wetlands occur in the immediate term, whereas the services supplied by the wetland extend into the future. A 40 to 50 year basic life is considered plausible for wetlands designed for water treatment (Kadlec and Wallace, 2009).

Benefits
The primary anticipated outcome of rehabilitating wetlands in the Baynespruit catchment is an improvement in water quality, particularly the removal of nutrients (nitrogen and phosphorus). The main benefit of reduced nutrient loads in the Baynespruit Stream is a reduction in the contribution of nutrients to the downstream system, thereby reducing the risk of eutrophication and excessive algae growth in the downstream water supply system. This is a public benefit that accrues to the users of potable water supplied through the uMgeni system. Provided the wetland is managed overtime, these benefits will extend into the future – 40 to 50 years – with no operating costs and relatively low maintenance cost, unlike similar built infrastructure treatment options.

Wetlands also have the ability to supply additional water quality enhancement services such as toxicant (e.g. metals, biocides and salts) removal and sediment trapping. For the Greytown Road and Sobantu wetlands, an ecosystem services assessment of the wetlands scored toxicant removal as moderately high for both wetlands (Awuah, 2017). Healthy wetlands have the capacity to supply many other ecosystem services, depending on their physical characteristics and the context of the surrounding landscape. Potential benefits associated with wetland ecosystem services relevant to the Baynespruit Stream include:

- Biodiversity conservation (through habitat provision, especially for birds),
- Aesthetic and recreation benefits (green urban spaces),
- Research and development.

In the case of the Sobantu wetland, although the proposed rehabilitation interventions would improve the condition of the wetland and provide benefits in terms of water quality, the rehabilitation could have negative effects for the adjacent residents. Diverting flows and stormflows into the wetland could lead to an increase in flood risks to the adjacent area, while odours from the polluted inflow waters are a dis-benefit. Additional dis-benefits may include pests (mosquitos and snakes) and a security risk associated with vegetated areas.

Potential threats and constraints
The already highly developed catchment and conflicting land-use interests pose a constraint to wetland rehabilitation in the Baynespruit Stream. Residences and industrial developments extend right up to the riparian edge in many places along the Baynespruit; in addition some of the wetlands are under subsistence agricultural production. Given the urban nature and relatively low economic status of the areas surrounding the wetlands, built infrastructure components of wetland rehabilitation interventions may be at risk of being removed for use as building materials. The long-term sustainability and effectiveness of wetland rehabilitation efforts in the Baynespruit catchment will depend on continued management of the wetlands (e.g. invasive alien plant control and litter removal) and maintenance of the rehabilitation structures.

Stakeholders at the community level (i.e. local residents of Sobantu and neighbouring communities living around the wetlands) have highlighted several challenges which could disrupt initiatives to rehabilitate degraded wetlands and polluted rivers, but they have also identified incentives which could facilitate the rehabilitation process (Naidoo 2018), Table 3-10.
<table>
<thead>
<tr>
<th>Disincentives</th>
<th>Incentives</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Land-grab</strong> – residents highlighted the risk of</td>
<td><strong>Community pride</strong> – community members want</td>
</tr>
<tr>
<td>people from outside the communities entering</td>
<td>to improve the overall appearance of the area as</td>
</tr>
<tr>
<td>and establishing informal settlements on the</td>
<td>a sense of pride and stewardship are important</td>
</tr>
<tr>
<td>wetland and “taking ownership” of the land.</td>
<td>aspects of their daily lives.</td>
</tr>
<tr>
<td><strong>Municipal distrust</strong> – residents claimed that</td>
<td><strong>Co-management</strong> – a large proportion of</td>
</tr>
<tr>
<td>the Msunduzi Municipality have failed in their</td>
<td>community members want to work in</td>
</tr>
<tr>
<td>role to govern the land and prevent issues such</td>
<td>collaboration with the municipality to help</td>
</tr>
<tr>
<td>as the illegal dumping of waste, and overgrown</td>
<td>rehabilitate the wetlands and river. Some</td>
</tr>
<tr>
<td>vegetation. The residents are concerned about</td>
<td>community members understand the financial</td>
</tr>
<tr>
<td>whether a rehabilitation intervention will even</td>
<td>constraints experienced by the local municipality</td>
</tr>
<tr>
<td>occur.</td>
<td>and would volunteer to assist in proposed</td>
</tr>
<tr>
<td><strong>Competition of space</strong> – concern that if the</td>
<td>projects, but several other members emphasized</td>
</tr>
<tr>
<td>areas surrounding the wetlands are rehabilitated</td>
<td>that they will only assist if they are financially</td>
</tr>
<tr>
<td>and if the water quality is improved, there will</td>
<td>compensated.</td>
</tr>
<tr>
<td>be conflict among the residents as to whom is</td>
<td><strong>Agriculture</strong> – the prospect of clean water to</td>
</tr>
<tr>
<td>allowed to plant vegetables and how much space</td>
<td>irrigate crops is a major influence in encouraging</td>
</tr>
<tr>
<td>exactly each individual community member is</td>
<td>ecological infrastructure initiatives such as</td>
</tr>
<tr>
<td>entitled to. Given that the land is municipal</td>
<td>wetland rehabilitation.</td>
</tr>
<tr>
<td>owned, the issue of “planting space” must be</td>
<td><strong>Invasive alien vegetation</strong> – the removal of</td>
</tr>
<tr>
<td>addressed to prevent landownership conflict.</td>
<td>invasive alien vegetation is welcomed by</td>
</tr>
<tr>
<td></td>
<td>community members as they feel uncomfortable</td>
</tr>
<tr>
<td></td>
<td>with tall and dense vegetation dominating the</td>
</tr>
<tr>
<td></td>
<td>area as it offers hiding places for criminals.</td>
</tr>
</tbody>
</table>
Revegetation of riparian areas

The Baynespruit Stream is approximately nine kilometres in length. The vegetation in the riparian area has been severely degraded by anthropogenic activities and invasive alien plants (IAPs). The Baynespruit Catchment has three vegetation types, the Moist Coast Hinterland Ngongoni Veld, the Dry Coast Hinterland Ngongoni Veld and the Coast Hinterland Thornveld (Ramburran 2015). The Coast Hinterland Thornveld vegetation type is rich in floristic diversity, but this diversity and its associated ecosystems services (e.g., medicinal plants) have been lost due to continuous burning throughout the year and extreme overgrazing pressures. The IAPs that are growing in the riparian zone include Acasia meamsii, Arundo donax, Chromolaena odorata, Eucalyptus spp., Lantana camara, Melia azedarach, and Solanum mauritianum. The nature and severity of the impact of IAPs depends on the extent of the infestation, but can include impacts on streamflow and a decline in the water quality and river health as IAPs often use more water than the natural vegetation. The IAPs also have a significant negative impact on the ecological integrity of the ecosystem, particularly through changing the regime, frequency and intensity of fires, thus reducing ecosystem services that are important for human well-being (e.g., medicinal plants).

What does revegetation of degraded riparian areas entail?

<table>
<thead>
<tr>
<th>Revegetation of riparian areas</th>
<th>ECOLOGICAL INFRASTRUCTURE</th>
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</thead>
<tbody>
<tr>
<td>Revegetation of degraded areas involves active and / or passive restoration methods aimed at reinstating the vegetation (plant species) that has been lost due to anthropogenic activities. Passive restoration is the exclusion of degrading factors (e.g., fire exclusion and abandoning cultivation along the stream banks) to facilitate vegetation recovery. Active restoration involves seeding or transplanting of seedlings to speed up the revegetation process.</td>
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</tbody>
</table>

Invasive alien *Eucalyptus* trees and *Morus alba* (in the foreground) in the Baynespruit Catchment

*Lantana camara* dominant thickets in the Baynespruit Catchment

Purpose

The main purpose of this intervention is to restore the ecosystem function and biodiversity of riparian areas in order to improve water quantity and quality, and flood attenuation. Riparian zones play a significant role in regulating the chemical contents of adjacent streams (i.e. filtering pollutants from water before it enters the stream). They also provide flow attenuation services, opportunities for recreation, ecosystem goods (e.g., medicinal plants) and contribute to biodiversity conservation. Invasion of riparian areas with IAPs can reduce stream flows, as IAPs often use more water than the natural vegetation.
Strengths and benefits

- Vegetation cover in the catchment area enhances ground water recharge during intense rainfall events, thus reducing the likelihood of flooding.
- Riparian vegetation is effective in filtering pollutants such as nutrients and heavy metals.
- Riparian vegetation stabilizes stream banks thus preventing loss of land / property through erosion.
- Revegetation enhances biodiversity conservation (fauna and flora) by providing natural habitat.
- The action of revegetating riparian areas can contribute to job creation for local community members through IAPs clearing, seeding and seedling transplanting.
- Cleared invasive alien trees can be used as firewood.
- Urban vegetated areas provide aesthetic and recreational benefits.

Limitations & disadvantages

- Revegetation of degraded areas is usually seen as an obstacle to alternative land-uses such as residential expansion.
- If the area is severely degraded, vegetation recovery might take longer and higher maintenance costs can be incurred.
- The time lag between implementation and expected outcomes may be long (e.g., more than five years) and is largely influenced by degradation level.
- Vegetated areas are often viewed as hiding places for criminals.

Source: adapted from Rey Benayas (2005); Oldfield et al. (2015); Palma et al. (2015); González et al. (2016).

Description of the action in the Baynespruit Catchment

In the Baynespruit Catchment, revegetating degraded riparian areas could contribute to water quality improvement and flow attenuation. IAP clearing has been taking place over the years, but its success has been limited due to the lack of an overarching management plan and systematic follow-up treatments. The Msunduzi Municipality has proposed a project to clear IAPs in 14 ha along the stream with two follow up treatments in the following two years (Figure 3-6). Following the initial clearing, transplanting of indigenous trees and seeding of indigenous grass and forb seeds will be done. Indigenous tree saplings will be transplanted while seeds of indigenous grasses and forbs will be sown (Ramburran pers. comm., 2018).

Figure 3-6: The Baynespruit Stream showing invasive alien Solanum mauritianum in the riparian zone.
**Potential impacts**

Riparian zones occupy a small amount of the landscape, but they play a significant role in regulating the chemical contents of adjacent streams. About 91% of sediments in runoff can be trapped in the first 0.6 m of vegetation buffer and larger particles can be trapped in five meters of buffer (Gharabaghi et al. 2002). Five meters of grass cover with one meter of tree cover or 10 m of tree cover can filter 70% of nitrates while a vegetation buffer of 20 to 30 m can remove 100% of nitrate (Gharabaghi et al. 2002). In the US, major conservation programs have long promoted the restoration of degraded riparian vegetation to reduce the load of chemicals and sediment to streams. However, the time frame and potential level of water quality response is largely determined by the amount of degradation that occurred, land use in the catchment, topography (e.g., slope/elevation), pollutant source, vegetation type and age, and geology and soil (Lintern et al. 2018). For example, in the US, long-term removal of vegetation and crop farming followed by revegetation to grass resulted in 70, 83 and 92% reductions in total Kjeldahl nitrogen, total phosphorus and nitrate, respectively, three years following restoration (Clausen et al. 2000).

The clearing of IAPs has the potential to increase surface water flows (Dye and Jarman 2004; Bignalot et al. 2007) thus contributing to nutrient dilution (Chamiere et al. 2012). The long-term expected impact of this intervention is improved water quality due to nutrient filtering by vegetation and nutrient dilution due to increased streamflow.

**Costs**

Revegetation costs were obtained from eThekwini Municipality; IAP clearing and maintenance costs were obtained from Msunduzi Municipality. Based on 14 ha, the initial clearing will require 2132 person days, 1079 and 546 person days will be required in the first and second follow up treatments, respectively. For the revegetation, active restoration will be undertaken and 103 person days are needed for site preparation, transplanting and seeding. Salaries were calculated based on the Expanded Public Works Programme (EPWP) 2018, 2019 and 2020 wages. The cost for implementing both actions is R772 919 (2018 Rand value). A local NGO (Wildlands Conservation Trust) has offered to donate 1000 saplings of indigenous trees valued at R50 000. Therefore the total cost of this intervention is R822 919.

**Benefits**

Revegetation of riparian areas is expected to contribute to improving the water quality of the Baynespruit Stream. Several benefits are associated with good quality water in the Baynespruit: (i) increased opportunities for / reduced health risks of in situ water use (e.g., recreation, cultural and spiritual uses) and abstraction of water for non-potable use by local residents (e.g., for irrigating household gardens); and (ii) a reduction in the contribution of nutrients to the downstream system, thereby reducing the risk of eutrophication and excessive algae growth in the downstream water supply system.

Revegetation of riparian vegetation enhances biodiversity conservation through the reintroduction of indigenous flora, which creates habitat and provides food that attracts fauna, and the creation of a corridor between fragmented habitats allowing species dispersal and gene flow. Local human communities can also benefit from ecosystem services provided by natural vegetation such as access to medicinal plants, and aesthetic, recreation and environmental education benefits (Mugwedi et al. 2017).

**Potential threats or constraints**

A major threat that can compromise revegetation success in the Baynespruit Catchment is a lack of follow up treatments. Follow up treatments are critical, because after the initial clearing, IAPs can recruit in higher densities, especially from the soil seed bank and from cut stumps that were not treated with herbicides. Lack of weeding, poor rainfall and fire can also lead to mortality of planted
saplings. In the Baynespruit Catchment, the frequent occurrence of veld fires poses a threat to sapling establishment.

Competition for space, lack of sanitation in informal settlements and illegal dumping are further threats to revegetated riparian zones; reducing their effectiveness and limiting aesthetic and recreational benefits and/or increasing maintenance costs. Resource constraints and limited access to some areas reduces the likelihood of regular maintenance of these areas by the local municipality. However, maintenance requirements could be met through expanded public works programmes with the additional benefit of some local job creation, or through environmental advocacy initiatives that encourage citizen (and industry) stewardship for the rehabilitated areas.

Environmental advocacy in residential areas

The activities of local residents and industries also contribute to deteriorating water quality and ecosystem degradation in the Baynespruit Catchment. The activities include illegal dumping of litter, misuse of the waterborne sanitation systems (e.g. flushing of litter) and illegal connection of sewers to storm water drainage and construction or development on floodplain (wetland) areas (Ramburran 2015). Building civic awareness of the damage to ecosystems that these activities cause can discourage negative behaviour towards the environment and encourage civic interventions which improve environmental quality. A number of environmental advocacy initiatives, through the use of environmental champions (known as Enviro-Champs), have been successful in influencing communities to look after their environment (Matta 2016; Ward 2016; DUCT 2018). Msunduzi Municipality has begun engaging with local industries, ward councillors and the surrounding communities (Northdale, Willowton and Sobantu) in the co-development and co-implementation of management interventions to address environmental issues in the area (Ramburran 2015).

Who are Enviro-Champs?

<table>
<thead>
<tr>
<th>Environmental advocacy</th>
<th>SOCIAL CAPITAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enviro-Champs are people (often young people under the age of 35) who are passionate about addressing environmental issues within their local communities. Enviro-Champs work to build civic awareness of the value of the environment through, for example, door to door environmental education and activities such as litter clean ups. Enviro-Champs are trained in accredited and non-accredited eco-literacy and specific skills such as communication and community engagement, invasive alien plant identification, business planning, permaculture, water quality monitoring (e.g., miniSASS), establishing recycling initiatives, tourism marketing and budgeting, equipment procurement and drama productions.</td>
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</tr>
</tbody>
</table>
**Purpose**

Improve environmental quality through civic awareness. Enviro-Champ initiatives aim to build civic awareness of the value of the environment, encourage pro-environmental behaviours and inspire residents to be custodians of their environment.

**Strengths and benefits**

- Enhancement of civic awareness for both individuals (the Enviro-Champs) and communities and development of knowledge and skills to address environmental issues in the area.
- Community members encouraged to become custodians of their environment.
- Can be effective in changing negative behaviour (e.g., illegal dumping) towards the environment.
- Engagement of local schools and communities can lead to successful clean up campaigns.
- Skills development can lead to new opportunities such as starting up SMMEs, e.g., waste recycling.
- Can create opportunities for community members to generate income for example through ecological-agriculture gardens (gardens based on a permaculture model).
- There is an improvement in social cohesion when community members work together, e.g., during clean up campaigns.
- Creates opportunities for residents to socialise and additional community recreation opportunities can emerge, for example trail runs through riparian corridors.
- It's often possible to leverage support (e.g., training, funding and equipment) from local and national government, environmental NGOs and private sector for Enviro-Champ initiatives.

**Limitations & disadvantages**

- Finding an effective channel of entry into the community can be challenging.
- Recruitment of Enviro-Champs can cause tensions within the community if a proper, equitable recruitment process is not followed (i.e., advertisement and interviews).
- The roles and responsibilities of each actor involved in the initiative should be co-developed, co-defined and agreed upon by all parties.
- It is likely to take time to achieve the expected outcome.
- There is a need for ongoing support (Municipal, NGO, etc.).

Source: Adapted from Matta 2016; Ward 2016; DUCT 2018.
Description of the action in the Baynespruit Catchment

An Enviro-Champs programme has not yet been implemented in the Baynespruit Catchment. The Baynespruit Catchment area is made up of four ward councils, therefore an Enviro-Champ programme for the Baynespruit Catchment should recruit at least 20 Enviro-Champs (five per ward). Enviro-Champs would receive training before undertaking activities including monitoring and reporting of surcharging sewers, door to door environmental education and street theatre, and engaging local schools and communities in activities such as sewer monitoring and stream clean up campaigns and citizen science activities such as water quality monitoring (e.g., miniSASS), and the representation of data on platforms such as Google Earth.

In addition to Enviro-Champs, Eco-schools and Enviro-Clubs should be established within the Baynespruit community and at local schools. Eco-schools are local schools involved in environmental advocacy initiatives. Eco-schools work with Enviro-Champs and receive environmental awareness education for example training on water quality monitoring tools such as miniSASS. After the training, they are involved in activities such as sewer and water quality monitoring and waste clean-up campaigns. Ideally, each Enviro-Champ would support at least one Eco-school orEnviro Club. Apart from schools involvement, the Enviro-Clubs can also include community members who are willing to volunteer their time in catchment management (e.g., IAPs clearing, waste collection, and sewer and water quality monitoring and reporting). Several schools and religious organisations in the Baynespruit Catchment are already active in water quality monitoring which presents opportunities for recruiting Enviro-Champs and establishing Eco-Schools and Enviro Clubs.

Potential impacts

Civic awareness of the value of the environment and the impacts of certain activities on water and ecosystem quality can positively influence residents’ behaviour towards their environment. The primary anticipated outcome of environmental advocacy in the Baynespruit Catchment is to promote behavioural change in activities that lead to water quality deterioration, particularly illegal dumping of litter, illegal connections of sewers to storm water drainage and dumping of solid waste into the sewer reticulation system.

Results from the Mpophomeni Enviro-Champs programme showed that the monitoring and reporting of leaking sewers directly to plumbers improved the response time to repair the blockages or leaks (Ward 2016). Water quality improvements have been observed at some of the routine miniSASS monitoring sites (Ward 2016). The DWS has acknowledged that sewer monitoring in Mpophomeni has been an effective and efficient solution to improve water quality within the catchment (Matta 2016).

Costs

While based on citizen science and volunteer approaches, there are costs associated with the establishment of Enviro-Champs initiatives. The costs include programme administration to, for example, recruit Enviro-Champs, organise training, provide logistical support, prepare educational awareness materials and facilitate relationship building between Enviro-Champs and other key actors. Often, programme administration activities are undertaken by a supporting partner (such as a local NGO, or municipal department) and the costs are not always explicit. Enviro-Champ type initiatives often form part of larger projects, making it difficult to isolate the specific costs for these initiatives.

There are different models for structuring Enviro-Champs initiatives. Enviro-Champs programmes in the uMgeni Catchment have been set-up in two different ways. In Edendale and Imbali, a local NGO (DUCT) received funding from the WWF Nedbank Green Trust to establish Edendale and Imbali Greenhubs as part of the Msunduzi Green Corridor Pilot Project (MGC). Funding for the project was R3 million over 3 years and included stipends for Enviro-Champs. As a result, DUCT used a formal
employment process (i.e. advertising the positions and conducting interviews). Twelve Enviro-Champs were recruited, six from Edendale and six from Imbali, and were hosted by two local community-based organisations. Their programme ran for a year with a monthly stipend of R3000 per Enviro-Champ or R432 000 per year (2017 rand value).

In Mpophomeni, local community members who showed an interest in addressing environmental issues (water quality and waste management) in their area were recruited into an Enviro-Champs programme with a focus on reporting sewer leak incidents. Twenty Enviro-Champs were recruited and provided R200 a month to buy airtime for reporting sewer leak incidents or R48 000 per year.

**Benefits**

There are both public and private benefits associated with Enviro-Champs initiatives. Good water quality in the Baynespruit is a public benefit associated with increased opportunities for, or reduced health risks of, in situ water use (e.g., recreation, cultural and spiritual uses) and abstraction of water for non-potable use by local residents (e.g., for irrigating household gardens); and a reduction in the contribution of nutrients to the downstream system, thereby reducing the risk of eutrophication and excessive algae growth in the downstream water supply system.

Many of the Enviro-Champs in Edendale, Imbali and Mpophomeni have indicated that their lives have been enriched as a result of their involvement in programmes aimed at improving catchment management and water quality improvement. Specific benefits highlighted were the accredited training that has opened-up job opportunities in the field of water management, ideas for establishing small enterprises, field trips, capacity and skills development that has enabled Enviro-Champs to help their children with homework (Ward 2016; DUCT 2018) and salaries for a year (for Edendale and Imbali Enviro-Champs). Waste recycling businesses can minimise illegal dumping and reduce the amount of waste going to the landfill site. Enviro-Champs also enjoy recognition by their community members (Ward 2018). Enviro-Champs regard field excursions as an opportunity to socialise. Field activities could be expanded and developed to include the broader communities and local schools in activities such as stream trails and fun runs which build social cohesion and contribute to fitness.

The positive energy displayed by Enviro-Champs, community members and local schools can attract additional support from actors such as government, NGOs, local businesses and donors for water and waste management. For example, during the litter clean-up campaign in Edendale and Imbali, Msunduzi Municipality provided refuse bags and pick-up trucks to collect litter bags. The Pietermaritzburg Chamber of Business donated R60 000 to this clean-up campaign. Local experts provide technical support on river health and wetland rehabilitation and various aspects of catchment management.

Involving local communities in activities such as water quality monitoring, litter campaigns and environmental advocacy can build a sense of stewardship of the stream and riparian areas and ensure that other interventions to improve water quality (e.g., floating wetlands) can be implemented and are maintained/safeguarded by local communities (Matta 2016). In addition, local community monitoring and reporting of water quality and/or water quality issues can pressurize state entities into action (Matta 2016).

**Potential threats or constraints**

Establishing an effective channel of entry into the community can be challenging; navigating political tensions requires local knowledge, familiarity and time. The initiative needs to be relevant to the community’s needs and contextualized within the local setting.

Behaviour change can take a long time and can quickly be reversed if reliant on the influence of specific individuals or incentives that are withdrawn. For environmental advocacy to be successful in
the long-term, Ward (2016) note four mechanisms that should be prioritized: (i) the ability to work vertically with a diversity of role players; (ii) personal and community capacity development; (iii) accessing, generating and using information; and (iv) ownership and recognition.

Resourcing of Enviro-Champs programmes is required at a number of different levels:
- Individual Enviro-Champs (e.g. the R200 contribution to airtime, reimbursement for their time
- Coordination (e.g. gathering information, organising meetings, etc.);
- Project management (managing funds, logistical support, networking); and
- Associated programmes such as Eco-Schools that contribute indirectly to the work of the Enviro-Champs.

Existing Enviro-Champs initiatives within the greater uMgeni Catchment have been supported by a range of institutions. This support is vital to the sustainability of such initiatives (Ward 2016). A number of organisations (UMDM, DUCT, WESSA, WWF-South Africa, University of KwaZulu-Natal and Institute of Natural Resources) have an interest in water quality in the Baynespruit Catchment and could provide support to a Baynespruit Enviro-Champs initiative.

Enviro-Champs initiatives in several other areas within the uMgeni Catchment (Edendale, Mpophomeni and Imbali) have had a positive impact on reducing illegal dumping. Community members now put solid waste in bags for the municipality to collect. However, these bags are not always regularly collected by the relevant municipalities, which can discourage these actions in future. This highlights the importance of the role of both citizens and governments in water and waste management and the need for collaboration to establish which approaches are likely to work in the given situation (Matta 2016; Ward 2016; DUCT 2018).
**Floating wetlands**

Nutrient (nitrogen and phosphorous) levels appear to be increasing in the Baynespruit Stream (Ramburran 2013). In parts of the stream, the extent of nitrate sources in the site’s catchment has been classed as ‘Moderately High’; similarly the extent of sediment sources and the extent of other potential phosphate sources had been classified as ‘Moderately High’ (Awuah 2017). Performance evaluation studies of floating wetlands indicate that these emerging technologies are effective at removing nutrients from urban stormwater runoff (Nichols et al. 2016).

**What are floating wetlands?**

<table>
<thead>
<tr>
<th>Floating Wetlands</th>
<th>HYBRID / GREEN INFRASTRUCTURE</th>
</tr>
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<tr>
<td>Floating wetlands are a relatively new, experimental technology for improving water quality - specifically for treating nutrients - in nutrient-rich waste and drainage waters. They consist of buoyant mats that are mass planted with emergent wetland plants and are anchored on the surface of the water body (e.g., anchored to bedrock or trees). A floating wetland is an artificial structure which can be constructed using natural materials (e.g., reeds) or plastics to form a floating mat. The floating mat is covered with a growing medium planted with indigenous aquatic plants. Water flows through the root zone (subsurface flow) and the roots absorb excess nutrients, purifying the water.</td>
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![Image of floating wetland](https://tcwp.tamu.edu/floating-wetland-islands/)

**Purpose**

Floating treatment wetlands have the potential to assist in the extraction of nitrogen and phosphorus from water. Experimental research and trials have shown floating wetlands to be very effective at removing nitrogen and moderately effective at removing phosphorus from ponded water bodies.
**Strengths & benefits**

- Floating wetlands do not require the purchase, lease or donation of land to be utilised.
- Floating wetlands adjust to varying water depths typical of event-driven stormwater systems.
- Initial research suggests floating treatment wetlands can remove twice as much nitrogen as constructed wetlands with the same nutrient load.
- The plant material growing on the wetlands can be mechanically harvested to increase plant vigour and nutrient uptake.
- Floating wetlands may provide additional wildlife habitat (especially for birds), although this may lead to problems with plant damage and additional manure loads generated by the birds.

**Limitations & disadvantages**

- The reach of this technology is limited by stream / pond size and the availability of sites to locate floating wetlands.
- The removal of nitrogen by treatment wetlands is directly proportional to the nitrogen concentration of incoming water.
- There is some doubt about winter nutrient extraction performance and plant survival, especially in areas prone to frosts.
- While the installation of these systems on small, accessible wastewater ponds appears to be straightforward, how the system will establish on open waters and what the on-going maintenance costs will be are less well known.
- There is little information to suggest how long a floating wetland will perform before the plant material or floating mat needs to be replaced.


**Description of the action in the Baynespruit Catchment**

Floating wetland systems have been identified as a potential option for addressing poor water quality in the Baynespruit Stream and actions are underway towards implementation. Seven potential sites were identified for installing floating wetlands and two have been selected (sites 1 and 4, Figure 3-7) to pilot the approach (and test two different designs) with the view of rolling out floating wetlands on a larger scale within the Baynespruit Stream (GroundTruth 2018). The selected sites both present relatively linear river reaches, laminar flows due to downstream hydraulic controls, secure anchoring opportunities and direct vehicular access (GroundTruth 2018). Each floating wetland is designed to be 2m x 2m in size.

In the context of river restoration and stormwater management, floating wetlands have the added advantage of being able to accommodate fluctuating water depths (Headley and Tanner 2012) and can be applied without by-passing the stream flow (Pavlineri et al., 2017).

Implementing floating wetlands within the Baynespruit Stream is aimed at improving water quality, reinstating species habitat, maintaining surrounding corridors and enhancing the ecosystems services and benefits supplied by the Baynespruit Stream (GroundTruth 2018).
Figure 3-7: Baynespruit catchment area showing the location of the two floating wetland pilot sites.

**Potential impact**

Performance evaluation studies of floating wetlands indicate that these emerging technologies are effective at removing nutrients from urban stormwater runoff (Nichols et al. 2016) and are capable of performing as well as, or even better than, conventional pond and wetland treatment technologies (Hamill et al. 2010; Headley and Tanner 2012). Pollution inputs to the Baynespruit Stream include stormwater runoff from the highly developed catchment, overflows from an aging and misused sewerage system and industry effluent.

The area of the floating wetlands designed for installation in the Baynespruit is 4 m² each. Thus, all seven potential floating wetland sites in the Baynespruit Stream provide a total of 28 m² of floating wetland area. By way of indication of potential impact on water quality of floating wetlands, the literature was consulted for nitrate and phosphorus removal rates by floating wetlands (see appendix 6.2.2). Drawing on the unit area nutrient removal values reported by Wang (2013) and Tanner et al. (2011), the nutrient removal potential for the proposed Baynespruit floating wetlands was estimated, Table 3-11.

The estimates indicate that, when considered together, the seven floating wetlands have the potential to remove in the order of 2044 to 3475 g of nitrogen per year and 41 to 82 g of phosphorus per year. Given the many factors that influence nutrient removal performance by floating wetlands and the variability in unit area nutrient removal values reported in the literature, these estimates are reported with a low level of confidence.
### Table 3-11 Nutrient removal potential for the proposed Baynespruit floating wetlands (FW)

<table>
<thead>
<tr>
<th>Removal potential</th>
<th>Based on Tanner et al. (2011)</th>
<th>Based on Wang (2013)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area (m²)</td>
<td>Single FW</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>7 FWs</td>
<td>28</td>
</tr>
<tr>
<td>Removal rate (g/m²/d)</td>
<td>TN</td>
<td>0,200</td>
</tr>
<tr>
<td></td>
<td>TP</td>
<td>0,004</td>
</tr>
<tr>
<td>Single FW: removal (g/d)</td>
<td>TN</td>
<td>0,800</td>
</tr>
<tr>
<td></td>
<td>TP</td>
<td>0,016</td>
</tr>
<tr>
<td>Total (7 FWs): removal (g/d)</td>
<td>TN</td>
<td>5,600</td>
</tr>
<tr>
<td></td>
<td>TP</td>
<td>0,112</td>
</tr>
<tr>
<td>Single FW: removal (g/yr)</td>
<td>TN</td>
<td>292</td>
</tr>
<tr>
<td></td>
<td>TP</td>
<td>6</td>
</tr>
<tr>
<td>Total (7 FWs): removal (g/yr)</td>
<td>TN</td>
<td>2044</td>
</tr>
<tr>
<td></td>
<td>TP</td>
<td>41</td>
</tr>
</tbody>
</table>

### Costs

The proposed cost to design, construct and maintain (for a 12 month period) the two pilot floating wetlands within the Baynespruit Catchment is R23 200 each (Msunduzi Municipality 2018 Purchase Order, excluding VAT, 2018 rands). Replicating the costs across the seven sites gives a total cost of R162 400 for 28 m² of floating wetland and a unit area cost of R5 800 / m².

The capital costs of installing floating wetlands occur in the immediate term, whereas the services supplied by the floating wetland extend into the future. At this stage, there is little information to suggest how long a floating wetland will perform.

### Benefits

The primary anticipated outcome of implementing floating wetlands in the Baynespruit Stream is an improvement in water quality, particularly a reduction in nutrient (nitrogen and phosphorus) loads to the downstream system. The Baynespruit Stream joins the uMsunduzi River which flows into the uMngeni River. Inanda Dam, on the uMngeni River downstream of the Baynespruit Stream, is a key water supply dam for Durban City and surrounds. Excessive nutrient loads and algae growth are associated with the Inanda system (Umgeni Water 2014; Rangeti 2014). The presence of algae (and related taste and odour elements) in raw water abstracted from storage dams has been reported as a significant driver of chemical dosage at the water treatment works which treats water from Inanda Dam (Rangeti 2014). Thus a key benefit of reduced nutrient loads in the Baynespruit Stream is a lower contribution of nutrients to the downstream system, thereby reducing the risk of eutrophication and excessive algae growth in the downstream water supply system. This is a public benefit that accrues to the users of potable water supplied through the uMngeni system.

Additional anticipated co-benefits associated with the implementation of floating wetlands in the Baynespruit Stream include increased biodiversity through reinstating species habitat and maintaining surrounding habitat corridors and aesthetic benefits associated with the better maintained riparian area (GroundTruth 2018).
**Potential threats and constraints**

Due to the proximity of all seven sites to informal settlements and the regular use of the areas as footpaths, there is a risk of vandalism and theft (GroundTruth 2018). While floating wetlands are designed to accommodate fluctuating water depths, they are likely to be vulnerable to high velocity flows, possibly becoming detached or damaged from bumping against the stream banks. Degradation of the structure over time is expected (and will depend on the construction materials). It is likely that the vegetated mat will attain auto-buoyancy by the time the structure degrades; however, there is little information to suggest how long a floating wetland will perform before the plant material or floating mat needs to be replaced (Hamill et al. 2010).

**Rehabilitate waterborne sanitation network**

A key driver of poor water quality in the Baynespruit Stream is aging sanitation infrastructure. Broken pipes and dislodged joins frequently cause sewer blockages, which result in effluent overflows and require regular repairing (Msunduzi Municipality 2017). Regular water quality monitoring (by Umgeni Water and Msunduzi Municipality) and water quality studies of the Baynespruit Stream confirm severe microbial contamination of the stream (Gemmell and Schmidt 2013; Govender 2016).

In 2016-2017 there were 3839 mainline blockages in the Msunduzi Municipal sanitation network. The number of mainline blockages has shown an increasing trend over the last several years, attributed to aging infrastructure (Msunduzi Municipality 2018). A physical inspection of the structural integrity of approximately 800 km of sanitation network showed that 49 km needed to be replaced, 7 pump stations required upgrading and 257 major point repairs were identified (Ramburran 2013). The aging sanitation infrastructure in the Msunduzi Municipality has increased operating and maintenance costs (Msunduzi Municipality 2017).

**What is a waterborne sanitation network?**

<table>
<thead>
<tr>
<th>Waterborne sanitation network</th>
<th>GREY INFRASTRUCTURE</th>
</tr>
</thead>
<tbody>
<tr>
<td>A waterborne sanitation network is the built infrastructure system that conveys wastewater from residences and industries to a waste water treatment works. The main components of the system are drains, collectors, pipes and pumps.</td>
<td></td>
</tr>
<tr>
<td>Continued maintenance and rehabilitation of the system is required to ensure that all its components are kept in good operating condition.</td>
<td></td>
</tr>
<tr>
<td>The diagram below shows how wastewater enters the network into a combined reticulation system and is carried to a centralized waste water treatment plant.</td>
<td></td>
</tr>
</tbody>
</table>
The red arrows indicate how the environment can impact on the system – infiltration of rainwater – and how the network can impact on the environment through leakages as a result of, for example, poor connections, damaged or old pipes (Bester et al. 2010).

**Purpose**
The function of a waterborne sanitation system is to collect and convey wastewater in a hygienic manner.

**Strengths & benefits**
- For high-density urban areas, piped wastewater systems to central treatment plants are a safe and, compared to on-site treatment, space-saving, cost-effective way to separate people and drinking water from waste water.
- Regular maintenance and rehabilitation of these systems extends their useful life (20 to 30 year lifespan).
- Regular maintenance reduces costs since planned maintenance and repairs are more cost effective than emergency repairs.

**Limitations & disadvantages**
- Naturally subject to a variety of operational problems. Depending on the wastewater flow characteristics, surrounding soil conditions, quality of construction, etc., the sewer pipeline can clog, scour, corrode, collapse or become damaged which leads to the deterioration of the collection system.
- Designed for a specific useful life and thus it is essential to provide adequate operation and maintenance to maximize the benefit gained from the infrastructure investment.
- Requires continuous expenditures in operation, maintenance and rehabilitation; maintenance and rehabilitation form a crucial part of the success of the overall useful life of the system.
- Vulnerable to influx of stormwater (through faulty pipes and manholes) which can affect effectiveness of wastewater treatment at the waste water treatment plant.

Source: Adapted from Bester et al. (2010); van Vuuren and Van Dijk (2011); UNEP (2015).
Description of the action in the Baynespruit Catchment

Within the Baynespruit Catchment, several recurring sewerage system issues have been identified, including the:

- Grix Road sewer and pipe bridge (Msunduzi Municipality 2009).
- Baijoo Road sewer (Ramburran 2013)
- New Greytown Road sewer stream crossing (Ramburran 2013)

The location of these sites is shown in Figure 3-8. Rehabilitation of sanitation infrastructure is part of the Integrated Development Plan for the Msunduzi Municipality and includes upgrades to these three problematic areas along the Baynespruit Stream.

![Baynespruit Catchment area showing the location of three recurring sewage system issues.](image)

**Figure 3-8: Baynespruit Catchment area showing the location of three recurring sewage system issues.**

Potential impact

While not the only source of pollution to the Baynespruit Stream, failures in the sewage network result in regular discharges of untreated wastewater into the stream. Regular *E. coli* (an indicator of faecal contamination) monitoring by Umgeni Water illustrates the resulting water quality impacts downstream of known sewerage network issues. For example, *E. coli* levels are consistently higher below the known Grix Road sewer network issue compared to upstream of the area, Figure 3-9.
Eliminating, or significantly reducing, leakages from the sewer network will have a significant impact on the water quality of the Baynespruit in terms of faecal contamination and nutrient loads. Without data on how much pollution is entering the Baynespruit Stream from the waterborne sanitation network, the likely impact on pathogen and nutrient loads in the stream cannot be quantified. However, historical accounts of the Msunduzi Municipality are a good example of how an effective waterborne sanitation system results in improved water quality. Before there was a waterborne sanitation system in the Msunduzi Municipality, the water quality of the Msunduzi River had deteriorated significantly with population growth (Dyer, 2012). The laying of a waterborne wastewater network in the early 1900s had a positive impact on the water quality of the Msunduzi River to the point that the river was again considered fit for swimming sports and a boating club (Dyer, 2012).

**Costs**

Costs related to sanitation system repairs in the wards of the Baynespruit Catchment were extracted from various Msunduzi Municipality reports including the (Draft) Integrated Development Plan for the 2016/17 to 2020/21 and the Msunduzi Municipality Annual Report – 2016/17. These include:

- R1 319 000 allocated to the rehabilitation of sanitation infrastructure for each of four wards falling within the Baynespruit catchment for the 2017/18 year (a total of R5 276 000) (Msunduzi Municipality 2018);
- R2 850 000 to replace 1 km of sewer pipe (Msunduzi Municipality 2018:412);
- An amount of R1 million for repairs to the Grix Road Sewer and Pipe Bridge was reported in the review of the Spatial Development Framework for the Municipality (Msunduzi Municipality, 2009);
- In 2015, the Municipality was spending roughly R500 000 annually to deal with sewer blockages and R1 million annually for maintenance of the sewer system (Mtolo, 2015).

An annual maintenance budget of 4 to 8 % of the average total replacement cost for the maintenance of sewer infrastructure (given a 20-30 year life span) is recommended (Bester 2010). The maintenance cycle is not static and includes three general components (i) normal annual maintenance, (ii) emergency maintenance (for example a burst water pipe as a result of a severe storm) and (iii) periodic refurbishment (for example relining of pipes).
Benefits

The main outcome of this intervention is a significant reduction in faecal contamination and nutrient loads to the Baynespruit Stream. Situated along the lower reaches of the Baynespruit Stream is the Sobantu community, a high-density formal and informal residential area. Residents of the Sobantu Community undertake subsistence and small-scale market farming making use of different sources of irrigation including polluted water from the Baynespruit (Govender 2016). However, high pathogen levels in the water make it unsuitable for domestic, recreational or agricultural use (Gemmell and Schmidt 2013; Govender 2016). Contaminated irrigation water poses a health risk to farmers, particularly – as is the case of the Sobantu farmers – when irrigating manually using buckets and watering cans (Govender 2016). Farmers are at high risk of infection due to direct contact through the collection of polluted water and the application of this water onto crops.

Contaminated irrigation water also poses a threat to the consumers of produce irrigated with polluted water. Pathogens from polluted water are known to accumulate on the surface of crops as well as within them. A study of produce irrigated with water from the Baynespruit Stream detected levels of food hygiene indicators on the produce in excess of limits for safe consumption (Gemmell and Schmidt 2012). These organisms could have been transferred to the produce from contaminated irrigation water (Gemmell and Schmidt 2012). If cultivation is avoided altogether because of the health risks, subsistence farmers may suffer dietary implications from reduced access to fresh foods and dietary diversity. Crop producers may lose their livelihood if they cannot source sufficient water from an alternative source.

A key benefit of limiting faecal contamination of the Baynespruit Stream is to reduce the health risks associated with the use of the water for irrigation, thereby supporting the subsistence and small-scale market farmers of the Sobantu community.

Sewage water is also a source of nutrients. Eliminating, or significantly reducing, leakages from the sewer network will reduce the contribution of nutrients to the downstream system, thereby reducing the risk of eutrophication and excessive algae growth in the downstream water supply system.

Potential threats and constraints

Waterborne sanitation addresses point source pollution. While making a significant contribution to improving the water quality of the Baynespruit Stream, an effective waterborne sanitation network doesn’t address non-point source pollution, for example runoff from informal settlements not connected to the waterborne sanitation system.

Waterborne sanitation networks are vulnerable to inflow/infiltration of stormwater which may cause sewer surcharges, local flooding and burden the waste water treatment plant (Stephenson and Barta 2005). Common problems experienced with waterborne sanitation networks are sanitation spills from overloading of the system and from blockages caused by roots of trees, foreign objects, breakages and deterioration of the network. Routine maintenance of sewers is essential to minimise spills (CIDB & CSIR 2007).

Waterborne sanitation uses large amounts of treated (potable) water to transport wastes to the treatment works, this is a wasteful use of potable water. New innovations in waterless (ecological) sanitation technologies present opportunities to address sanitation backlogs and increasing demands for potable water and should be considered in the planning of sanitation services as an alternative or complement to waterborne sanitation.
Waterless sanitation

There is a rapid expansion of informal settlement lacking sanitation infrastructure in the Baynespruit Catchment (Msunduzi Municipality 2016). A lack of sanitation poses a significant threat to water quality. Providing waterless sanitation toilets within the informal settlements has the potential to mitigate this risk. Waterless sanitation systems are designed to reduce human excreta to hygienically safe organic matter without the need for a waterborne reticulation system. A typical example of waterless sanitation is the Urine Diversion Dry Toilet (UDDT) which has been rolled out in rural, peri-urban and informal settlements in the KwaZulu-Natal and Northern Cape provinces (Matsebe 2011).

What are Urine Diversion Dry Toilets (UDDTs)?

<table>
<thead>
<tr>
<th>Waterless sanitation</th>
<th>HYBRID / GREEN INFRASTRUCTURE</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Urine Diversion Dry Toilet (UDDT) is a toilet that operates without water. It consists of a pedestal (seat) situated above a vault. Urine is diverted away from faeces via a specially designed plastic pedestal while faeces and toilet paper fall into the vault below the toilet. The dry conditions in the vault facilitate the desiccation of the contents, and faecal pathogens are greatly reduced or destroyed through the combined effects of lack of moisture, solar heat and time. Urine is diverted to a soak way and then penetrates the soil (Roma et al. 2013). Urine diversion is done to minimize health risks to humans during the removal and emptying of the vault.</td>
<td></td>
</tr>
</tbody>
</table>

A double vault system is generally used. The toilet seat is fitted to the first vault and once the first vault is full, the seat is moved to the second vault. One vault usually takes between six to 12 months to fill, but depends on the household size and diet. Once the second vault is full, the content in the first vault which has undergone the composting process is emptied. The content in the vault usually has a sandy look and is odour free. |

Bench UDDT (Rieck et al. 2012) and schematic representation of a UDDT (Mnkeni and Austin, 2009).

Purpose

To reduce the health risks related to sanitation, contaminated water and waste; to prevent surface and groundwater pollution; to conserve treated/potable water and to allow the safe recovery and recycling of nutrients from human excreta which can be used for soil fertility improvement. The main purpose of UDDTs in the Baynespruit Catchment is to reduce water pollution.
**Strengths and benefits**
- Can be installed in any residential set up, e.g., peri-urban or rural.
- Do not require water to function.
- No ground water pollution (as in the case of pit latrines).
- Structures can be designed to be temporary or permanent.
- Produce organic content that is environmental friendly and can be used to improve soil fertility.
- Work best in in dry and hot climates (suitable for the Baynespruit Catchment region).
- Lower emptying and disposal costs than pit or septic tank systems, therefor long-term operational costs are lower than for pit latrines, and much lower than for any water-based toilet system.

**Limitations & disadvantages**
- Generally considered socially unacceptable, unless in the short-term when no other options are available.
- Minors can find it difficult to use the system.
- Effective operation and continuous maintenance is essential.
- Users need to adhere to the set conditions to mitigate odour problems.
- There is a need for promotional support, training and demonstrations to users.
- Users must empty the vaults themselves or pay a fee to local service providers.

Source: Scott (2002); Mnkeni and Austin (2009); eThekwini Municipality (2011); Kramer et al. (2011); Matebe (2011); Tissington (2011); Rieck et al. (2012); Roma et al. (2013); Mokoena (2015); Mkhize et al. (2017).

**Description of the action in the Baynespruit Catchment**

In their 2016/17 – 2020/21 Integrated Development Plan, Msunduzi Municipality indicated that there is a need to provide hygienic toilets to informal settlements in the catchment (Msunduzi Municipality 2016). The primary purpose of implementing UDDTs in the Baynespruit Catchment is to meet this need (e.g. government’s madate of basic sanitation service for all people, DWAF 2001). The secondary purpose, which has strong links to this study, is to mitigate potential water contamination and outbreaks of waterborne diseases such as cholera. The risk of waterborne diseases increases with the rapid expansion of informal settlement in the catchment. For example, in the eThekwini Municipality, the implementation of UDDTs in rural, peri-urban and informal settlements was mainly driven by a cholera epidemic experienced in the KZN province from August 2000 to July 2001. The epidemic resulted in 105 389 registered cases and 219 documented deaths (Mudzanani et al. 2003).

Three informal settlement sites were identified in the Baynespruit Catchment (Figure 3-10). At the first site which is located in the upper catchment, pit latrines were observed, but not all households appeared to have one. This settlement is located in one of the Baynespruit tributaries, and the water table is close to the surface (seepages were observed during a site visit). Therefore, there is a high likelihood of ground water contamination by pit latrines and stream water pollution is likely to occur as a result of open defecation. The second informal settlement is located along the Baynespruit Stream in the middle-lower catchment, and no pit latrines were observed in this settlement. It is highly likely that there is open defecation in this area. The third informal settlement is located in the lower catchment area, and a few pit latrines were observed.

Faecal contamination of the Baynespruit Stream is prevalent as indicated by the high levels of *Escherichia coli* (*E. coli*). Although the high levels of *E. coli* are largely attributed to surcharges and leaks in the waterborne sanitation system, it is highly likely that open defecation and surface runoff within the informal settlements is contributing to the pollution load.
Potential impacts

While informal settlements are expanding at a rapid rate, there is a lack of recent data on the number of households with no sanitation. For this study, the 2011 data from Statistics South Africa were used to estimate the number of households with no sanitation. It is acknowledged that some of the households may have acquired access to sanitation since 2011; however, it is also likely that there are many new households without sanitation since 2011 with the expansion of informal settlements. In 2011, 408 households in the Baynespruit Catchment lacked access to sanitation.

Installation of UDDTs in informal settlements is likely to contribute to improved water quality, or reduce further declines, in the Baynespruit in terms of faecal contamination. Without data on how much faecal contamination from informal settlements is entering the Baynespruit Stream, the likely
impact on pathogen levels in the stream cannot be estimated. The installation of UDDTs will help mitigate the outbreak of waterborne diseases such as cholera.

**Costs**

Costs related to the installation of UDDTs were extracted from an eThekwin Municipality report (eThekwi Municipality 2011). The cost of installing one household double vault UDDT in eThekwi Municipality was R6341 (2011 rands) (Table 3-12). Therefore, to install 408 UDDTs in the informal settlements of the Baynespruit Catchment would cost in the region of R3 857 304 (2018 rands).

*Table 3-12: Cost breakdown of a household double vault Urine Diversion Dry Toilet (eThekwi Municipality 2011)*

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost (2011 Rands)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earth works</td>
<td>240</td>
</tr>
<tr>
<td>Concrete work</td>
<td>766</td>
</tr>
<tr>
<td>Structural work (foundations, superstructure, block work)</td>
<td>957</td>
</tr>
<tr>
<td>Reinforcing and slabs</td>
<td>383</td>
</tr>
<tr>
<td>Metal work</td>
<td>192</td>
</tr>
<tr>
<td>Carpentry and joinery</td>
<td>383</td>
</tr>
<tr>
<td>Ironmongery (door locks)</td>
<td>96</td>
</tr>
<tr>
<td>Roof work</td>
<td>240</td>
</tr>
<tr>
<td>Plumbing and drainage (plastic urine diversion pedestal, flanges, cover lid, urinal, urine pipe and vent pipe)</td>
<td>718</td>
</tr>
<tr>
<td>Local Labour</td>
<td>786</td>
</tr>
<tr>
<td>Project management, Institutional and Social</td>
<td>718</td>
</tr>
<tr>
<td>Development consultants, facilitation and security</td>
<td>562</td>
</tr>
<tr>
<td>Managing Contractor (local)</td>
<td>862</td>
</tr>
<tr>
<td><strong>Total for one household UDDT</strong></td>
<td><strong>6341</strong></td>
</tr>
</tbody>
</table>

**Benefits**

The installation of UDDTs is regarded as the most cost effective technology towards addressing the sanitation “backlog” in informal settlements (eThekwi Municipality 2011), thereby contributing to reduced faecal contamination of surface waters. Furthermore, if UDDTs are more widely used, there would be a reduced need to build and operate expensive sewage treatment plants and the quality of waters in rivers would improve as a result of reduced waste water from the treatment plants (Lutchminaraya 2007). Installing UDDTs in new developments and informal settlements also reduces the burden on old and low capacity sewage infrastructure that is susceptible to leaks and surcharges (as is the situation in the Baynespruit Catchment).

An additional significant benefit of UDDTs is water conservation, especially when compared to waterborne sanitation, as water use is limited to hygiene and toilet cleaning (Scott 2002).

The installation of UDDTs can also provide socio-economic benefits. Since some households can find emptying vaults unacceptable (Roma et al. 2013; Mkhize et al. 2017), local contractors can supply this service (after receiving training). Households in eThekwi paid local contractors between R48 and R96 to empty the vault (eThekwi Municipality 2011). Additional job opportunities are associated with providing education on UDDTs and their use. During project implementation, local labour is recruited in construction and maintenance. Local businesses such as hardware, brick yards, sand and concrete supplies can also benefit (Roma et al. 2013).
While there is an economic benefit associated with using the recovered urine and faecal compost in agricultural production, this benefit is unlikely to be realized in the immediate future as many people are uncomfortable with the practice and uncertain of the health risk (Mkhize et al. 2017).

### Potential threats and constraints

Social acceptance of UDDTs is a significant challenge (Mkhize et al. 2017). In the eThekwini Municipality, Mkhize et al. (2017) recorded lower levels of acceptance of UDDTs among the elderly who are accustomed to pit latrines. Furthermore, most users aspire to own flush toilets, because they are perceived to reflect a higher economic status within the community (Mkhize et al. 2017). This is supported by Matsebe (2011) who reported that some of the UDDT users perceive UDDTs as unacceptable, because they are associated with poverty.

Emptying of the vaults can sometimes result in conflicts within the household because people feel undermined by the activity and are concerned about the health risk or it conflicts with certain cultural beliefs / behaviour (Mkhize et al. 2017). The establishment of local business enterprises that offer vault emptying services could help to resolve household conflicts.

Continuous social engagement (e.g., house to house visits) will be needed in conjunction with implementing UDDTs to change communities’ perceptions and attitude towards UDDTs and to promote proper use and maintenance. Even still, in the short to medium term, this option is likely only to be ‘acceptable’ where the only alternatives are pit latrines or no sanitation (i.e. in informal, rural or peri-urban areas).

### Stream canalsation

Damage to property associated with flooding and erosion has occurred along the Baynespruit Stream, particularly in the middle regions of the catchment. Residents have experienced flood and erosion related issues for over 30 years. Anecdotal evidence suggests that the stream has widened from 2 to 10 meters in some areas (News24 2017). The sports ground of a school adjacent to the stream has been negatively affected by erosion of the stream bank (Msunduzi Municipality 2017). Flooding and erosion has been exacerbated by an increasing area of impervious surface connected to the stream by stormwater drainage. Canalsalisation of the stream channel is one option to mitigate these challenges in areas where stream bank loss has been significant. Municipalities are legally obligated to reduce flood risk (van Zyl et al. 2004). A budget of R11 million has been allocated for the canalsalisation of parts of the Baynespruit Stream in ward 30, Raisethorpe.

### What is stream canalsalisation?

<table>
<thead>
<tr>
<th>Stream canalsalisation</th>
<th>GREY INFRASTRUCTURE</th>
</tr>
</thead>
<tbody>
<tr>
<td>In urban areas, to protect residents and property from flooding, streams are often lined with concrete beds and walls, because it is stabilizes the stream banks and is regarded as hydraulically the most efficient means of increasing the discharge of a channel (Luger 1998).</td>
<td></td>
</tr>
</tbody>
</table>

**Purpose**
The primary purpose for implementing stream canalsalisation is to mitigate flooding, stream bank erosion and loss of property.

**Strengths and benefits**
- Canalisation is effective in mitigating floods in cities, thus protecting loss of properties and homes.
- A canal can withstand high water velocity.
- There is little maintenance required.
- If properly constructed, a canal can last for many years (>100 years).
• Canalisation is done along the stream and requires little additional space.

Limitations & disadvantages
• Significant implementation costs.
• There is an increase in the magnitude and frequency of high flow velocities, thus causing flooding in the receiving streams. A canal aims to remove water as quickly as possible from urban areas.
• Concrete bed and walls prevent exchange of water between the stream and the ground water, thus lowering the water table.
• There is a decrease in aquatic, riparian and floodplain area and deterioration in water quality (e.g., higher pH).
• Steep and smooth walls prevent some animals from crossing the stream while other animals may fall into the canal and become trapped and/or drown.
• A concrete canal is not aesthetically pleasing.
• There is little water purification.

Sources: adapted from Luger 1998; Ewart-Smith and Racliffe 2002; van Zyl et al. 2004; Msunduzi Municipality 2017.

Description of the action in the Baynespruit Catchment
Canalisation of a section of the Baynespruit as well as a section of one of its tributaries is planned and is likely to be implemented in 2018, Figure 3-11. The canal of the tributary is approximately 150 m long, 4 m wide and 2.5 m deep. The canal in the Baynespruit Stream is a concrete encasement that will be a 150 m long trapezoidal channel with a 5 m bottom width, 3 m depth and side slopes at 1:1. Gabions and reno mattresses will be constructed to transition the stream and tributary into the canals and at the downstream end to prevent scour (Msunduzi Municipality 2017).

Figure 3-11: Baynespruit Catchment area showing the location of planned stream canalisation.
**Potential impacts**

The canal will contain peak storm flows that have historically eroded stream banks, thus mitigating damage to properties and homes. The canal will be able to contain and convey up to the 1:5 year flood effectively. Canalization will stabilize the stream banks and prevent further degradation; without the proposed canalisation, the Baynespruit channel will continue to degrade (Msunduzi Municipality 2017). However, increased scour and erosion may be experienced downstream of the proposed canal as a result of increased stormflows and velocities.

Canalisation of stream sections can lead to the loss of indigenous vegetation and aquatic fauna (Ewart-Smith and Racliffe 2002). Stream canalisation reduces habitat connectivity, because some terrestrial animals find it difficult to cross the canal (Pepper and Rickard 2009). Canalisation of sections of the Baynespruit Stream will lead to biodiversity loss (fauna and flora) and its associated ecosystem services. Furthermore, this will limit future stream rehabilitation opportunities aimed at enhancing biodiversity and ecosystem services. Canalisation changes the hydrology of the stream (Ewart-Smith and Racliffe 2002) and prevents stream and ground water exchange, thus reducing ground water recharge. The hydrology of the Baynespruit Stream will be negatively impacted as a result of reduced ground water exchange.

Stream canalisation significantly reduces the potential of the stream to purify water from nutrients (especially nitrogen and phosphorus) and heavy metals (DWAF 2004). Canalisation will lead to reduced instream water purification. If stream canalisation is implemented without landscaping or without rehabilitation of natural vegetation, there are a few or no aesthetic and recreational benefits (van Zyl et al. 2004).

Additional impacts are associated with the development. Within 500 m from where the canal will be constructed, there are three wetlands. Two of them are seriously modified and one is critically modified as a result of construction, illegal dumping of rubble and high densities of IAPs. The current assessment of their ecosystem services showed that there is a low supply of ecosystem services. During canal construction, 0.05 ha of the wetland will be lost. Water pollution will occur during the construction phase (Msunduzi Municipality 2017).

**Costs**

A budget of R11 million has been allocated to the project (News24, 2017).

**Benefits**

The primary anticipated outcome of implementing stream canalisation in the Baynespruit Stream is to protect properties from damages caused by flooding and stream bank loss. At present, streambank erosion is leading to loss of land, the collapse of property boundary walls / fences and general negative aesthetics. Protection of properties from flooding can lead to an increase in property value and property rates (van Zyl et al. 2004). Although canalisation supports little aquatic biodiversity, it can provide an aquatic corridor for the movement of fauna (Ewart-Smith and Racliffe 2002).

Additional benefits associated with the proposed intervention include employment opportunities for local people (during the construction phase) and improved aesthetics of the surrounding area (compared to the current degraded condition of the stream and riparian area). Rehabilitation of indigenous vegetation along the canalised sections could make the area more aesthetically pleasing and to create opportunities for recreational activities such as running trail.

**Potential threats and constraints**

Gabion protection works will be installed at the downstream end of the concrete canal. Gabions have a short life span; therefore, there is a need for intensive maintenance measures to avoid high cost
implications associated with the replacement of dislodged gabions. Gabions are prone to theft and vandalism due to easy access to the rocks and basket material (Msundusi Municipality 2017). If the gabions become dislodged or damaged, there will be an increase in stream bank erosion during rain events.

During the construction and operational phase, the canal will be built within the channel and a portion of wetland will be lost. Given that the system is critically modified and is not currently offering any ecological services of note, it was recommended that the loss of wetland be offset through the rehabilitation of the remaining wetlands identified within the study area.

**Rooftop rainwater harvesting system (RWHs)**

Damage to property associated with stormwater flows and erosion has occurred along the Baynespruit Stream and is exacerbated by an increasing area of impervious surface connected to the stream by stormwater drainage. There is a need for further control of stormwater in the catchment. In recent years, urban stormwater management has shifted toward approaches that encompass stormwater ‘source control’ (SC) systems in addition to traditional systems (e.g., storm drains). SC can be defined as a system that “tries to manage small quantities of rainwater, as close as possible to its falling point, through small devices to store and/or to infiltrate it” (Petrucci et al. 2012:45). The incorporation of SC in stormwater management is now widely practiced in areas which are already urbanised and are experiencing stormwater management challenges (Petrucci et al. 2012). One of the SC systems is rainwater harvesting (RWH). RWH can be defined as “an intentional collection of water from various catchments such as roads, hillsides, pastures and within fields and rooftops, and the storage of such water in physical structures or within the soil profile depending on final use” (WRC 2013:1). In urban areas, rooftop collection is the most common RWH method used to reduce stormwater problems (Petrucci et al. 2012).

**What is a rooftop rainwater harvesting system?**

<table>
<thead>
<tr>
<th>Rooftop rainwater harvesting (RWH)</th>
<th>HYBRID / GREEN INFRASTRUCTURE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roof RWH is a system where water is collected from the roof and stored in aboveground or underground tanks to be used for non-potable purposes in domestic, commercial, institutional and industrial sectors (Kahinda et al. 2007; Ghisi 2010; Petrucci et al. 2012). Examples of non-potable water use include laundry and flushing of toilets, car washing and garden irrigation (Kahinda et al. 2007; Ghisi 2010).</td>
<td></td>
</tr>
<tr>
<td>A typical roof RWH system is made up of five components: roof surface area, conveyance system, filter, storage tank(s), and water pump(s). The roof surface area largely dictates how much water can be collected and the storage tank size needed (Petrucci et al. 2012). Conveyance systems transfer rainwater from the roof to the storage tanks. A filter prevents and reduces the concentration of contaminants (e.g., debris and bird droppings) from the first flush of a rain event from being conveyed directly into the storage tank. The pump distributes water to its end uses either directly or indirectly depending on the type of RWH system (Petrucci et al. 2012). The volume and quality of the rainwater that could be harvested from the roof is dependent on the rainfall pattern, roof surface area, roofing material and the surrounding environment (Kahinda et al. 2008b).</td>
<td></td>
</tr>
</tbody>
</table>
A typical roof RWH system (Fisher-Jeffes et al. 2017).

**Purpose**
The primary purpose for implementing the roof RWH system in the Baynespruit Catchment is to reduce urban runoff. Roof RWH reduces storm water runoff (volume and velocity) by intercepting and storing runoff from catchment areas (Woods-Ballad et al. 2007; Zhang et al. 2009; Basinger et al. 2010; Kim et al. 2012), except during major rainfall events (Neumann et al. 2011; Maheepala et al. 2013).

**Strengths and benefits**
- Reduces stormwater runoff.
- Can be installed in any area with roof surfaces (e.g., commercial, industrial or residential).
- Stored rainwater can be used when water is scarce or to supplement alternative water supplies.
- Rainwater is a free and moderately clean source of water provided at, or near, the point where it is needed.
- Can alleviate pressure on municipal water supply from the increased water demand caused by urbanization.
- Can reduce utility costs.
- Owner-operated and managed, which supports self-sufficiency.
- With proper treatment, roof RWH can provide potable water.
- Can improve food security when used for irrigation in small scale gardens.
- Can improve hygiene in households/schools not connected to a municipal water supply.
- Systems can be designed to be permanent or temporary.
- Low operation and maintenance costs and not labour-intensive.

**Limitations & disadvantages**
- Reliant on rainfall (i.e. seasonality).
- Impact on stormwater management depends on storage capacity of water tanks and management of overflows.
- Low storage capacity of the rainwater tank can limit the optimum use of harvested rainwater.
- If not well researched, the capital cost of the plumbing can be high, reducing the viability of the system
• Most suitable for non-potable purposes such as toilet flushing, laundry, irrigation, washing hard surfaces, and cars.
• Potential health risk from contamination if water is not treated prior to drinking.
• Regular monitoring and testing of water quality is advised.


Description of the action in the Baynespruit Catchment

Roof RWH has not been implemented on a large-scale in the Baynespruit Catchment. Roof surface area (RSA) in the Baynespruit Catchment was calculated using a basic remote sensing image classification technique to discriminate and isolate RSAs greater than 10m x 10m (100 m²) within the Baynespruit Catchment (owing to the 10m spatial resolution (pixel size) of Sentinel-2 optical imagery), Figure 3-12.

In the Baynespruit catchment, an area of approximately 1 972 431 m² (197 ha) was estimated, based on unit RSAs greater than 100 m². This is a considerable area with respect to RWH and potential impact on stormwater runoff in the catchment, depending on the storage capacity and management of overflows associated with the RWH.

![Figure 3-12: Potential roof RWH area (197 ha) in the Baynespruit catchment.](image)

Potential impacts

Roof RWH reduces storm water runoff (volume and velocity) by intercepting and storing runoff from catchment areas (Woods-Ballad et al. 2007; Zhang et al. 2009; Basinger et al. 2010; Kim et al. 2012), except during major rainfall events (Neumann et al. 2011; Maheepala et al. 2013). The main anticipated impact of installing roof RWH systems in the Baynespruit Catchment is reduced runoff volume (and velocity). In a study of residential areas in the Liesbeek River catchment (Cape Town), Fisher-Jeffes et al. (2017) found that roof RWH has the potential to significantly reduce, by up to 44%,
the runoff volume emanating from roofs (1300 ha) in the catchment (2600 ha), but is not effective at attenuating peak flows. As a stormwater control approach, roof RWH becomes ineffective when the storage capacity of the system is reached, depending on the management of the overflows. If tank overflows are connected directly to a formal drainage network (e.g., storm drain or sewer network), then the RWH system becomes less effective for stormwater control once the storage tanks are full. The effectiveness of roof RWH in stormwater mitigation can be enhanced by combining roof RWH with sustainable urban drainage systems (SUDS) (e.g., infiltration trenches and bioretention) to capture excess overflow from the storage tank(s) (Kim and Yoo 2009; Kim et al. 2012). The SUDS infiltrate and treat water that would have entered the stormwater drain network.

In order to determine the potential volume of water that is likely to be harvested from the roof RWH system, the mean annual rainfall (MAR) of the location and yield must be calculated in conjunction with the roof area, tank size, installation method and demand profile (Hall 2013). The potential volume of water likely to be captured by the roof area (yield) can be estimated from the monthly or yearly rainfall (mm), the roof area (m²) and a roof runoff coefficient (based on the roof material) (Thomas and Martinson 2007). However, in this study, data on roof types and therefore runoff coefficients were not available.

As an indication of the amount of water that could potentially be harvested, a simplified version of the above relationship was applied (as used in The Stakeholder Accord on Water Conservation South Africa 2009, Table 3-13). The simplified relationship assumes that 100 % of the rainfall is captured in the rainwater harvesting system and is therefore an overestimate. Potential rainwater harvest (m³) was estimated for the total roof surface area (100 %, 197 ha) and for 50 % (98.5 ha) of the Baynespruit Catchment roof area, Table 3-13.

![Table 3-13: Indication of the amount of water that could potentially be harvested from roof surfaces in the Baynespruit catchment (for unit roof surface areas greater than 100 m²)]

| Potential Rainwater Harvest (m³) = Annual rainfall (mm) x Rooftop area (m²) / 1000 |
|---|---|
| Mean annual rainfall (mm) | 900 |
| Roof surface area (m²) | 100 % of roof surface area | 1 972 431 |
| | 50 % of roof surface area | 986 216 |
| Potential rainwater harvest (m³) | 100 % of roof surface area | 1 775 188 |
| | 50 % of roof surface area | 887 594 |

The impact of roof rainwater harvesting on runoff depends on how much of the harvested water can be stored and released slowly (e.g., through reuse, SUDSs).

**Costs**

In this study, the costs for implementing roof RWH systems were sourced from a study of the feasibility of rainwater harvesting of commercial buildings within the Kommetjie business area, Cape Town (Viljoen 2017). An average roof surface area of 802m² was estimated for commercial buildings (n=33, Viljoen, 2017). The cost to implement a roof harvesting system was estimated at R34 090 (2017 rands), based on a 5000 l above ground storage tank and including a pump (Viljoen 2017). The cost of the pump is the largest cost component.

Applying these figures, an illustrative cost to implement roof RWH in the Baynespruit Catchment was estimated, Table 3-14. Costs based on the entire area and for 50 % of the area were calculated. The
cost estimates are based on a 5000 l tank per commercial unit (802m², i.e. 2 459 tanks); however this storage capacity is unlikely to be sufficient to capture the estimated potential rainwater harvest even if all the tanks are emptied multiple times throughout the year. The lifespan of a rainwater tank is in the region of 25 years, 10 to 15 years for a pump and 50 years for household plumbing (Gurung et al. 2012).

Table 3-14: Illustrative costs to implement rainwater harvesting in the Baynespruit catchment

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost (R)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roof surface area (m²)</td>
<td>1 972 431 R</td>
</tr>
<tr>
<td>Cost (R/m² – Viljoen 2017)</td>
<td>42,51 R</td>
</tr>
<tr>
<td>Total cost (R)</td>
<td></td>
</tr>
<tr>
<td>100 % of roof surface area</td>
<td>83 840 614 R</td>
</tr>
<tr>
<td>50 % of roof surface area</td>
<td>41 920 307 R</td>
</tr>
</tbody>
</table>

**Benefits**

For this study, the intended purpose of installing roof RWH systems in the Baynespruit Catchment is to reduce runoff volume and velocity, the main direct benefit of which is reduced streambank erosion and property damage. At present, streambank erosion is leading to loss of land, the collapse of property boundary walls / fences and general negative aesthetics. Protection of properties from flooding can lead to an increase in property value and property rates (van Zyl et al. 2004).

Stored rainwater can be used for industrial and domestic purposes, reducing household / industry water consumption. For example, the Illovo Sugar warehouse located in the Baynespruit catchment uses runoff water for non-potable purpose (ablutions) and saves about 30 kl of municipal water per month (Illovo Sugar, pers. comm., 2018), an equivalent of R13 303 per annum (at the municipal rate of R37.28 / kl).

Roof RWH offers considerable benefits to households (Kahida et al. 2007; O’Brien 2014; Fisher-Jeffes et al. 2017). For example, roof RWH can improve food security when used for irrigation in small scale gardens (Ngigi et al. 2005; Kahinda et al. 2007; Helmreich and Horn 2009), thus improving nutrition particularly for women and children in impoverished communities (Amos et al. 2014; Gwenzi and Nyamadzawo 2014). Roof RWH can also be a good source of non-potable water for purposes such as toilet flushing, personal hygiene, laundry, gardening and car washing. For example, in Cape Town, it was found that 29 % of potable water was used for toilet flushing, 13 % for laundry and dishwashing and 35 % for gardening (DWAF 2004). Hypothetically, about 64 % of the water consumed in Cape Town could be replaced with roof harvested rainwater.

Combining roof RWH and SUDSs can provide additional benefits such as groundwater recharge, restoration of the hydrologic cycle in an urban environment, further runoff volume and velocity reduction and peak flow mitigation (DeBusk and Hunt 2014). SUDS can also improve runoff water quality by filtering pollutants (Fisher-Jeffes et al. 2017).

**Potential threats and constraints**

RWH is viewed as a ‘source control’ approach to urban stormwater management through attenuating flows and reducing runoff volumes. While having the potential to significantly reduce runoff volume emanating from roofs, its effectiveness depends on the associated storage capacity and management of overflows. Roof RWH was found to be less effective at attenuating peak flows (Fisher-Jeffes et al. 2017). From a flooding and risk perspective, peak flow rate is an important consideration. In addition, the run-off from roofs is often only a small proportion of the total runoff in the catchment. In the
Baynespruit Catchment the estimated roof area of 197 ha is roughly six percent of the total catchment area.

The relatively high implementation costs of roof RWH, its suitability only for non-potable uses (unless treated) and its reliance on the rainy season constrain the implementation of roof RWH systems. At a household level, RWH becomes more attractive when the capital cost is subsidised and the owner is only responsible for operational and maintenance costs (Domènech and Sauri 2011; Roebuck et al. 2011). Across most of South Africa, household roof RWH tanks have a relatively low yield, and are found to be financially infeasible for some homeowners especially in cases where an alternative water source from the municipal water distribution is reliable and cheaper (O’Brien 2014). Roof RWH systems become more financially attractive as the number of uses of the rainwater increases.

The quality of rainwater is a topic of debate. Some studies have reported that rainwater from rooftops generally meets the international guidelines of potable water (e.g., Handia et al. 2003; Zhu et al. 2004; Sazakli et al. 2007) while other studies have reported chemical and/or microbial contaminants that often exceed international guidelines for drinking water (e.g., Nevondo and Cloete 1999; Vasudevan and Pathak 2000; Abbott et al. 2006; WRC 2017). In the Baynespruit Catchment, rainwater harvested from the roof of a warehouse was analysed and showed a high lead content, which is suspected to be from vehicle exhaust gases. The quality of the harvested rainwater depends the surrounding environment.

3.4.3 Cost comparison and discussion

The costs to implement each option (investment action) in the Baynespruit Catchment were compared, and ranked from least to greatest cost in Table 3-15. The relative magnitude of the likely contribution of each option to addressing water quality and stormwater challenges in the catchment as well as the extent each option is likely to provide co-benefits - benefits in addition to water quality and stormwater management benefits – is also reflected in Table 3-15. The equivalence in effectiveness of the options is not assumed, but we compared the eight options as an indication of their cost implications.

The comparison shows that the least cost option is to implement the seven floating wetlands in the Baynespruit Stream. Floating wetlands predominantly address nutrient loads and have been found to be very effective at removing nitrogen and moderately effective at removing phosphorus from water. However, the impact of this option is constrained by the relatively small size of the floating wetlands (4m² each) and the limited suitable sites to locate floating wetlands in the stream. When considered together, the seven floating wetlands have the potential to remove in the order of 2 to 3.5 kg of nitrogen per year and 0.04 to 0.08 kg of phosphorous per year. Rehabilitation of degraded wetlands in the catchment has the potential to remove in the order of 454 to 2679 kg of nitrogen per year and 64 to 91 kg of phosphorous per year. While the confidence in these estimates is low, the assessment does show the different order of magnitude of the two options. However, the ability to provide the nutrient removal service depends on the actual loads of nitrogen and phosphorus to the Baynespruit Stream. While the co-benefits of rehabilitated wetlands are potentially greater than for floating wetlands, there are several dis-benefits associated with wetlands including pests (mosquitos and snakes), a security risk associated with vegetated areas and competition for space / land in the catchment.

Degradation of the floating wetland structure over time is expected, however there is little information to suggest how long a floating wetland will perform. On the other hand, with regular maintenance, the lifespan of wetlands, in terms of water treatment capacity, can extend to 40 or 50 years (depending on the extent of construction materials used (e.g. gabions, concrete) and external pressures driving
changes in the system). Litter pollution is a threat to both floating wetlands and rehabilitated wetlands either reducing their effectiveness or increasing maintenance costs. Both investment options are at risk of vandalism and theft (e.g. removal of built components for use as housing materials). In the case of wetlands, the already highly developed catchment and conflicting land-use interests pose a constraint to wetland rehabilitation; the continued competition for space is likely to reduce the long-term durability or resilience of wetland rehabilitation in the Baynespruit Catchment.

The most expensive option to implement in the Baynespruit Catchment is rooftop rainwater harvesting (RWH). The high cost is a result of the large roof surface area used in the cost calculation, but even still, the costs to install individual household (R15 000 to R 20 000) or commercial systems (R34 000 to R90 000) is relatively high. The pump and storage components are the main cost drivers; where pumps can be avoided and storage systems centralized, costs could be reduced. However, from the perspective of stormwater source control, the effectiveness of rooftop RWH is uncertain; due mainly to the fact that the run-off from roofs is often only a small proportion of the total runoff in the catchment and that flow attenuation depends on the associated water storage capacity. The effectiveness of rooftop RWH in stormwater management could be significantly enhanced if combined with sustainable urban drainage systems (SUDS) which promote infiltration of overflows once storage capacity is reached. Rooftop RWH offers benefits in the form of water available for non-potable use. This can be beneficial for both households and businesses in the form of reduced municipal water use and cost savings. This benefit is limited by seasonal rainfall, unless significant water storage capacity is incorporated into the system.

Revegetation of degraded riparian zones is one of the relatively lower cost options and contributes to both water quality enhancement and stormwater attenuation while providing considerable co-benefits (both ecological and social benefits). Benefits include:

- Reduced likelihood of flooding through infiltration of surface flows;
- Reduced loss of land and property damage through reduced flooding and erosion of stream banks;
- Filtering of pollutants such as nutrients and heavy metals;
- Enhanced biodiversity conservation (fauna and flora) by providing natural habit;
- Job creation for local community members through IAPs clearing, seeding and seedling transplanting;
- Cleared invasive alien trees can be used as firewood; and
- Aesthetic and recreational benefits associated with urban green spaces (that are regularly maintained).

A major threat that can compromise revegetation success in the Baynespruit Catchment is a lack of follow up treatments for controlling IAPs. In this assessment, two years of follow-up treatment costs were included in the estimated costs as this is considered a minimum and therefore can be regarded as part of the implementation costs. However, regular maintenance of these areas will be required at additional cost. Competition for land, lack of sanitation in informal settlements and illegal dumping are further threats to revegetated riparian zones; reducing their effectiveness and limiting opportunities for aesthetic and recreational benefits and / or increasing maintenance costs. Resource constraints reduce the likelihood of regular maintenance of these areas by the local municipality. However, maintenance requirements could be met through expanded public works programmes with the additional benefit of some local job creation, or through environmental advocacy initiatives that encourage citizen (and industry) stewardship for the rehabilitated areas.
Table 3-15: Cost comparison of selected options (investment actions) to address water quality and stormwater challenges in the Baynespruit catchment

<table>
<thead>
<tr>
<th>Infrastructure</th>
<th>Option</th>
<th>Implementation cost (R)</th>
<th>Lifespan (years)</th>
<th>Impact</th>
<th>Co-benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green/hybrid</td>
<td>Floating wetlands</td>
<td>162 400</td>
<td>Uncertain</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Social</td>
<td>Environmental advocacy</td>
<td>432 000</td>
<td>Uncertain</td>
<td>✓✓✓</td>
<td>✓</td>
</tr>
<tr>
<td>Ecological</td>
<td>Revegetation of riparian zone</td>
<td>822 919</td>
<td>Indefinite</td>
<td>✓✓✓</td>
<td>✓</td>
</tr>
<tr>
<td>Ecological</td>
<td>Wetland rehabilitation</td>
<td>1 111 719</td>
<td>40-50</td>
<td>✓✓✓</td>
<td>✓</td>
</tr>
<tr>
<td>Green/hybrid</td>
<td>Waterless sanitation</td>
<td>3 857 304</td>
<td>15</td>
<td>✓✓✓</td>
<td>-</td>
</tr>
<tr>
<td>Grey</td>
<td>Rehabilitate waterborne sanitation</td>
<td>5 276 000</td>
<td>20-30</td>
<td>✓✓✓</td>
<td>-</td>
</tr>
<tr>
<td>Grey</td>
<td>Stream canalisation</td>
<td>11 000 000</td>
<td>100</td>
<td>-</td>
<td>✓</td>
</tr>
<tr>
<td>Green/hybrid</td>
<td>Rooftop rainwater harvesting</td>
<td>41 920 307</td>
<td>15-20</td>
<td>✓✓✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

Note: For ‘impact’ ✓✓✓ indicates a positive contribution to addressing water quality and stormwater challenges in the Baynespruit catchment, the more ✓✓✓ the greater the contribution; ‘-’ indicates no significant contribution. A positive contribution to addressing stormwater challenges refers to attenuation of flows specifically for reducing streambank erosion and damage to property. For ‘co-benefits’ ✓✓✓ indicates that the option provides benefits in addition to water quality and stormwater management benefits, the more ✓✓✓ the greater the number of co-benefits; ‘-’ indicates no significant additional benefits were identified.
In terms of relative implementation costs, the ecological infrastructure options fell below the median value over all the options. Both options were associated with multiple benefits and a long lifespan, suggesting that upfront implementation costs will be offset by long term benefit flows. Maintenance of both rehabilitated wetlands and revegetated riparian areas is required regularly, but at relatively low cost and can be linked to social benefit initiatives that provide local jobs.

The grey infrastructure options were relatively high cost to implement; the costs for both the rehabilitation of waterborne sanitation and the canalisation of a section of the Baynespruit were greater than the median value. Both these options are associated with a high effectiveness of addressing the key objective (water quality and stormwater control respectively) and a long lifespan, but with few additional benefits.

The implementation costs for the green / hybrid infrastructure options were spread across the range of costs, with floating wetlands being the least cost option and rooftop rainwater harvesting being the most costly. The lifespan of the options considered were relatively short to medium, and medium to high co-benefits were identified. There is a much broader range of green / hybrid infrastructure options than the few considered in this assessment. For example, the sustainable urban drainage system (SUDS) is a promising approach to improve the quality of stormwater and aquatic environments specifically in the urban environment.

Empirical evidence and / or carefully elicited expert judgement about the effectiveness of each option is required to elevate this cost comparison to a cost-effectiveness analysis. Such an analysis is further complicated in that the mix of options considered address different issues (e.g. water quality vs. stormwater; nutrients vs. pathogen contamination).
3.5 Discussion and conclusion

This case study explored ecological, grey, green / hybrid and social capital investment options for improved water quality and stormwater control to shed light on the opportunities available for the Baynespruit Catchment. A qualitative evaluation of selected options, supported by a cost analysis, was undertaken. Conclusions for each option are summarized in Table 3-16.

The information generated through this study is intended as a starting point to identifying and evaluating investment actions for water security in the Baynespruit Catchment, with a focus on ecosystem-based solutions. Specifically, the information can be used as a tool for engagement across different municipal departments (e.g. Town Planning, Water and Sanitation, Roads and Transportation (storm water management), Environment, etc.) to build a shared awareness of options across both grey and nature-based infrastructures. Viewing urban areas as social-ecological-technological systems (SETs) and recognizing the dynamic interactions between social, ecological, and technical-infrastructural domains highlights the need for more combined approaches to urban management beyond a reliance on built and technical solutions (grey infrastructures).

The information can be used as guidance in designing investment and management plans towards water security in urban systems; the current assessment can be used to further prioritise investment options for more detailed analysis, for example, it could be used to inform the design of cost-benefit and / or multi-criteria analyses. The assessment has also highlighted the need to consider additional investment options, particularly green / hybrid infrastructure options as the few considered in this assessment do not adequately reflect the range of options (e.g. SUDS).

This study focused on the objectives of water quality enhancement and stormwater management. There are other objectives (e.g., social, economic, ecological) as well as interactions and trade-offs between objectives that will need to be considered in selecting investment options. The results of this assessment are intended to be one line of information in considering investment options towards water security in the Baynespruit Catchment.

3.5.1 On the results

Conclusions for each of the options evaluated are summarized in Table 3-16.

Table 3-16: Summary of conclusions from the qualitative evaluation and cost comparison of potential investment options towards improved water quality and stormwater management in the Baynespruit Catchment, ranked in order of least to highest cost, options not assumed to be equivalent in effectiveness (outcomes)

<table>
<thead>
<tr>
<th>Infrastructure</th>
<th>Option</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green/hybrid</td>
<td>Floating wetlands (FW)</td>
<td>Least cost, impact constrained by small size and limited suitable sites to locate FW, water quality benefits, no stormwater control benefits, provides some co-benefits, medium risk to long-term durability.</td>
</tr>
<tr>
<td>Social</td>
<td>Environmental advocacy</td>
<td>Relatively low cost, impact uncertain, requires long-term continuous investment, provides both water quality and stormwater benefits, and high potential co-benefits. Added benefit of supporting / complementing other investment options, extending durability of other investments. Volunteer / citizen science approaches can reduce project costs.</td>
</tr>
<tr>
<td>Infrastructure</td>
<td>Option</td>
<td>Conclusion</td>
</tr>
<tr>
<td>----------------</td>
<td>---------------------------------------------</td>
<td>----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Ecological</td>
<td>Revegetation of riparian zone</td>
<td>Relatively low cost, potential to provide water quality, stormwater and co-benefits (ecological and social benefits). Long-term durability could be extended through environmental advocacy initiatives.</td>
</tr>
<tr>
<td>Ecological</td>
<td>Wetland rehabilitation</td>
<td>Medium relative cost, provides water quality benefits, long-term supply of benefits, high potential for co-benefits, some risk of vandalism and threats from illegal dumping and competition for space. Generally low maintenance required, but additional maintenance likely required in the Baynespruit context (e.g. waste management).</td>
</tr>
<tr>
<td>Green/hybrid</td>
<td>Waterless sanitation</td>
<td>Medium relative cost, potential water quality benefits (depending on scale of implementation), addresses only point source pollution. Additional significant benefit of water conservation and associated low operation cost. Social acceptance of waterless sanitation is a key challenge. Likely only to be ‘acceptable’ where the only alternatives are pit latrines or no sanitation (i.e. in informal, rural or peri-urban areas).</td>
</tr>
<tr>
<td>Grey</td>
<td>Rehabilitate waterborne sanitation</td>
<td>Medium relative cost, proven effectiveness at addressing point source pollution. No significant stormwater or co-benefits (beyond the benefits of improved water quality). Long lifespan if continuously maintained. Only direct alternative to this option is waterless sanitation, which is socially infeasible in the short-term.</td>
</tr>
<tr>
<td>Grey</td>
<td>Stream canalisation</td>
<td>High relative cost, effective at addressing streambank erosion and property damage issues where they are currently being experienced, but risk of transferring the issues further downstream, therefor requires significant infrastructure (gabions) at the exit point. No significant water quality benefits or co-benefits. Political pressure from affected residents to implement this option. Long lifespan and low maintenance costs likely to offset the high implementation costs.</td>
</tr>
<tr>
<td>Green/hybrid</td>
<td>Rooftop rainwater harvesting</td>
<td>High relative cost, ability to ‘control’ stormwater depends on associated water storage capacity of the system and effective use of collected water, limited in attenuating high flows (which cause damage). Effectiveness enhanced if used in conjunction with sustainable urban drainage systems. Can significantly reduce rooftop runoff, but this is only a small proportion of catchment runoff. Potential to provide benefits to households and commercial sector and save costs on purchased municipal water.</td>
</tr>
</tbody>
</table>

The results suggest revegetation of degraded riparian areas in the Baynespruit Catchment provides the greatest range of benefits, contributing to improved water quality and stormwater control, as well as providing additional co-benefits. This comes at a relatively low cost. The main threats to this option are competition for land and the need for regular, but low cost, maintenance. Similarly, wetland rehabilitation has the potential to provide a range of benefits. The grey infrastructure options, while effective at achieving their main objective, provide the least opportunity for additional benefits and are relatively more expensive to implement and maintain.

While this assessment compares the various options in isolation of each other, the different infrastructures and investment options should be viewed as complements and considered in combination with one another. For example, environmental advocacy initiatives can reduce the threats to wetland and riparian area rehabilitation. Ecosystem-based options that slow stormwater flows from impervious surfaces before they enter a stormwater drainage system (such as wetlands, vegetated riparian areas and other green infrastructure options such as rain gardens and bioswales) can reduce the pressure on waste water treatment works during high rainfall events. Effectively, the different ‘infrastructures’ support and improve the effectiveness of each other.
Urban systems should integrate a mix of grey infrastructure, ecosystem-based solutions (ecological and green infrastructure) and social initiatives to improve the management of urban water and wastes. Rather than relying solely on grey infrastructures as the default solution, planners and managers should assess and investigate opportunities for restoring and expanding ecosystems and integrating green infrastructure into developments to provide a greater range of benefits in a multifunctional approach to urban water management. To foster ecosystem-based urban innovation two key elements are needed: (i) increased cross-sectoral (and cross-departmental) collaboration and integration of ecosystem-based concepts into planning and management and (ii) increased funding as a means to generate concrete implementation action, increase the knowledge and evidence base, and build awareness of ecological and green infrastructure solutions as a more holistic approach to addressing multiple social challenges.

Ecological and green infrastructures provide greater potential for co-benefits, and are thus able to contribute to multiple social goals, compared to grey infrastructure approaches. Ecosystem-based solutions are multifunctional relative to many grey infrastructures. This is a key difference between ecosystem-based and grey infrastructures and deserves meaningful consideration in urban planning and management.

3.5.2 On the method

Multi-criteria and cost analysis approaches have been recommended for evaluating investment options, particularly in the case of multiple potential options, various targets and limited resources (Rao et al. 2012). These approaches can provide an alternative to, or first step in, the more frequently applied, but often contested, cost-benefit analysis (which requires the step of assigning a monetary value to each benefit). While the main aim of this assessment was to apply multi-criteria and cost analysis approaches to evaluate potential investment options for the Rehabilitation of the Baynespruit Stream project, it is also useful to consider the approach taken to derive lessons learned.

The application of this approach to the Baynespruit case study demonstrates that the method can be used to broaden the spectrum of potential investment options considered and therefor, for undertaking a more integrated evaluation across a range of investment types (ecological, grey, green and social capital) with different outcomes, benefits and subject to varying risks and constraints. Nevertheless, the assessment reveals remaining challenges and suggests avenues for future research.

1) Description of the investment options
For some options, detail on the implementation of the action in the Baynespruit catchment was available or could be ascertained (e.g. floating wetlands, wetland rehabilitation), for other options details were less clear (rehabilitation of sanitation network) or more tentative (e.g. rooftop rainwater harvesting, environmental advocacy). The anticipated level of adoption for certain options needs investigating (e.g. rooftop rainwater harvesting). Clarity on what each option would entail is required to more confidently estimate the likely outcomes of the investment action.

2) Scale aspects
The temporal scale differs between investment options. The time to implement the action, the time lag between implementation and effect / outcome, the lifespan, and timeframe of benefit flows differs across the options and needs to be clarified for each option. A timescale for comparison of the options can then be defined, to account for the differences in timing of costs incurred and benefits received. A lifecycle approach can help identify the timing of costs and benefits.
The (physical) scale of implementation can influence the effectiveness of the investment. Consider options at different scales of investment, to explore how varying the scale of investment influences the effectiveness of the investment. Benefits are also likely to vary across scales, specifically between the local and regional scale. Certain benefits may only accrue at the local scale (e.g. water for irrigating garden cultivation), but the value of these benefits maybe significant to the affected group.

3) Equivalence of effectiveness
The investment options evaluated range in effectiveness in addressing water quality and stormwater management challenges. The equivalence in effectiveness of different options cannot be assumed. Hence, in this assessment implementation costs were estimated and compared as an illustration of likely upfront costs associated with each option, but not as an indication of the cost of each option to achieve the equivalent outcome (cost-effectiveness). To quantify and compare effectiveness, the overall objective / target needs to be more narrowly defined. The goals of water quality improvement and stormwater control are both very broad and very different. While many of the options evaluated contribute to both, in order to assess effectiveness they would need to be considered separately and resource units / indicators for each objective / target would need to be clearly defined (e.g. kg of nitrogen removed; volume of rainfall retained on site). Empirical evidence of the effect of each option on the objective / target is then required. Alternatively, when empirical evidence (e.g., scientific data) about the effectiveness of each option is lacking, carefully elicited expert judgement can be used (Addison and Walshe, 2015).

4) Quantitative monitoring and reporting of investment outcomes
Uncertainty regarding the outcomes of, particularly ecosystem-based and social capital, investment options, inhibits their consideration in urban planning and management. With limited empirical evidence of the direct outcomes of investing in ecosystems, green infrastructure and people for urban water management, municipalities continue to favour single-purpose grey infrastructure projects to address water needs and waste management. Concrete implementation action (e.g. through pilot studies and / or integration into new developments) combined with quantitative monitoring of outcomes will increase the knowledge and evidence base and support the evaluation of the actual effectiveness and benefits of investment actions. Monitoring is also a key component of adaptive management, guiding the allocation of further investment away from underperforming interventions to those that exceed expectations. Without empirical evidence and implementation experience, evaluations of urban water management options remain somewhat speculative. However, uncertainties exist regarding the extent to which the outcomes and effectiveness of investments across all infrastructure types (grey, ecological, green and social capital) can be quantified.

5) Specification of costs
Further specification on the costs of investment actions is required. A lifecycle cost approach is needed to account for costs incurred at different stages (e.g. planning, implementation, operation, maintenance). A breakdown of costs over multiple cost categories (e.g. fixed costs, variable costs, administration, salaries, materials etc.) is particularly useful in gauging the costs of scaling-up and identifying areas of cost savings (e.g. through economies of scale, integrating various actions). A standardised framework for reporting costs would facilitate future evaluations of investment options.

6) Interactions between investment options
In this assessment, the various investment options were evaluated in isolation of each other. In practice, there are dynamic interactions between social, ecological, and technical-infrastructural domains. These interactions need to be explored to determine how investments across theses domains can support each other. For example, environmental advocacy initiatives can reduce the threats to wetland and riparian area rehabilitation in the Baynespruit catchment. The effectiveness of rooftop rainwater harvesting can be improved through an integrated sustainable urban drainage system. In addition, choosing to not invest in a particular option, for perhaps cost reasons, could
reduce the effectiveness of another option. For example, rehabilitating waterborne sanitation networks may be less effective without simultaneously investing in source control options for stormwater management and options to address misuse of sanitation and drainage systems. While the ideal is to investment in all, or at least multiple options, to manage urban water and wastes, this is not feasible in the short-run. Investments must be prioritized. Developing a deeper awareness of the range of options to manage urban water and wastes, beyond a sole reliance on grey infrastructure, and the interactions between them, is a first step towards integrating social, ecological, and grey-infrastructure options in a multifunctional approach to urban water management.
4 Water pricing study

The water pricing study is presented as a narrative in Appendix 6.3
5 References

5.1 Mthinzima case study


5.2 Baynespruit case study


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DWAF (Department of Water Affairs and Forestry, South Africa) (2003). Strategic Framework for Water Services: Water is Life, Sanitation is Dignity. Department of Water Affairs and Forestry,


Gemmell ME, Schmidt S. 2012. Microbiological assessment of river water used for the irrigation of fresh produce in a sub-urban community in Sobantu, South Africa. Food Research International, 47:300–305.


6 Appendices
6.1 Appendix: Mthinzima Stream case study

6.1.1 Qualitative assessment of potential changes in the supply of wetland ecosystem services with the proposed wetland rehabilitation, Mthinzima Wetland

*Illustrative scoring approach for qualitative assessment of ecosystem service change (DEFRA, 2011:24)*

<table>
<thead>
<tr>
<th>Score</th>
<th>Assessment of potential/likely effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>++</td>
<td>Potential significant positive effect</td>
</tr>
<tr>
<td>+</td>
<td>Potential positive effect</td>
</tr>
<tr>
<td>0</td>
<td>Negligible effect</td>
</tr>
<tr>
<td>-</td>
<td>Potential negative effect</td>
</tr>
<tr>
<td>--</td>
<td>Potential significant negative effect</td>
</tr>
<tr>
<td>?</td>
<td>Gaps in evidence/contention/uncertainty</td>
</tr>
</tbody>
</table>
### Qualitative assessment of potential changes in the supply of wetland ecosystem services with the proposed wetland rehabilitation, Mhinzima Wetland

<table>
<thead>
<tr>
<th>Ecosystem service</th>
<th>Description</th>
<th>Anticipated change in ecosystem services</th>
<th>Likely impact</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Flood attenuation</strong></td>
<td>The spreading out and slowing down of floodwaters in the wetland, thereby reducing the severity of floods downstream.</td>
<td>Results of the WET-EcoServices assessment indicate that the extent to which the wetland is currently (2015) able to supply this service is intermediate. The extent of supply is not anticipated to change with the proposed rehabilitation.</td>
<td>0</td>
</tr>
<tr>
<td><strong>Streamflow regulation</strong></td>
<td>Increase in base flows due to storage of floods and high flows in the wetland for later and more gradual release, thereby sustaining streamflow during low flow periods.</td>
<td>Results of the WET-EcoServices assessment indicate that the extent to which the wetland is currently (2015) able to supply this service is high. The extent of supply is anticipated to increase with the proposed rehabilitation.</td>
<td>+</td>
</tr>
<tr>
<td><strong>Groundwater recharge</strong></td>
<td><strong>Not incl. in WET-EcoServices</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Sediment retention</strong></td>
<td>The trapping and retention in the wetland of sediment carried by runoff waters.</td>
<td>Results of the WET-EcoServices assessment indicate that the extent to which the wetland is currently (2015) able to supply this service is high. The extent of supply is not anticipated to change with the proposed rehabilitation.</td>
<td>0</td>
</tr>
<tr>
<td><strong>Phosphate assimilation/trapping</strong></td>
<td>Trapping and removal by the wetland of phosphates carried by runoff waters.</td>
<td>Results of the WET-EcoServices assessment indicate that the extent to which the wetland is currently (2015) able to supply this service is moderately low. The effectiveness of the wetland in supplying the service is anticipated to increase to moderately high with the proposed rehabilitation.</td>
<td>++</td>
</tr>
<tr>
<td><strong>Nitrate assimilation</strong></td>
<td>Removal by the wetland of nitrates carried by runoff waters.</td>
<td>Results of the WET-EcoServices assessment indicate that the extent to which the wetland is currently (2015) able to supply this service is intermediate. The effectiveness of the wetland in supplying the service is anticipated to increase to moderately high with the proposed rehabilitation.</td>
<td>++</td>
</tr>
<tr>
<td><strong>Toxicant assimilation</strong></td>
<td>Removal by the wetland of toxicants (e.g. metals, biocides and salts) carried by runoff waters.</td>
<td>Results of the WET-EcoServices assessment indicate that the extent to which the wetland is currently (2015) able to supply this service is intermediate. The effectiveness of the wetland in supplying the service is anticipated to increase to moderately high with the proposed rehabilitation.</td>
<td>++</td>
</tr>
<tr>
<td><strong>Erosion control</strong></td>
<td>Controlling of erosion at the wetland site, principally through the protection provided by vegetation.</td>
<td>Results of the WET-EcoServices assessment indicate that the extent to which the wetland is currently (2015) able to supply this service is moderately low. The effectiveness of the wetland in supplying the service is anticipated to increase to moderately high with the proposed rehabilitation.</td>
<td>++</td>
</tr>
<tr>
<td><strong>Micro-organism/pathogen assimilation</strong></td>
<td>Removal by the wetland of pathogens.</td>
<td><strong>Not a separate category in WET-EcoServices, but often included under toxicant assimilation</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Carbon storage</strong></td>
<td>The trapping of carbon by the wetland, principally as soil organic matter.</td>
<td>Results of the WET-EcoServices assessment indicate that the extent to which the wetland is currently (2015) able to supply this service is intermediate. The extent of supply is anticipated to increase to moderately high with the proposed rehabilitation.</td>
<td>++</td>
</tr>
<tr>
<td>Ecosystem service</td>
<td>Description</td>
<td>Anticipated change in ecosystem services</td>
<td>Likely impact</td>
</tr>
<tr>
<td>-----------------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------------------------------------</td>
<td>---------------</td>
</tr>
<tr>
<td><strong>Biodiversity maintenance</strong></td>
<td>Results of the WET-EcoServices assessment score Biodiversity maintenance as high, with no overall increase with the rehabilitation, however an increased in wetland integrity is noted.</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td><strong>Provision of water for human use</strong></td>
<td>The provision of water extracted directly from the wetland for domestic, agriculture or other purposes; related to access to water.</td>
<td>Results of the WET-EcoServices assessment indicate that the extent to which the wetland is currently (2015) providing this service is intermediate. The potential supply of this service is anticipated to increase with the proposed rehabilitation.</td>
<td>+</td>
</tr>
<tr>
<td><strong>Natural resources</strong></td>
<td>The provision of natural resources from the wetland, including wild foods (plants and animals), raw materials (e.g. craft &amp; ornamental plants), medicinals &amp; grazing for livestock.</td>
<td>Results of the WET-EcoServices assessment indicate that the extent to which the wetland is currently (2015) providing this service is moderately high. The potential supply of this service is not anticipated to change with the proposed rehabilitation.</td>
<td>0</td>
</tr>
<tr>
<td><strong>Cultivated foods</strong></td>
<td>The provision of areas in the wetland favourable for the cultivation of foods.</td>
<td>Results of the WET-EcoServices assessment indicate that the extent to which the wetland is currently (2015) providing this service is intermediate. The potential supply of this service is not anticipated to change with the proposed rehabilitation.</td>
<td>0</td>
</tr>
<tr>
<td><strong>Cultural significance</strong></td>
<td>Places of special cultural significance in the wetland, e.g., for baptisms or gathering of culturally significant plants.</td>
<td>Results of the WET-EcoServices assessment indicate that the extent to which the wetland is currently (2015) providing this service is moderately low. The potential supply of this service is not anticipated to change with the proposed rehabilitation.</td>
<td>0</td>
</tr>
<tr>
<td><strong>Tourism and recreation</strong></td>
<td>Sites of value for tourism and recreation in the wetland, often associated with scenic beauty and abundant birdlife.</td>
<td>Results of the WET-EcoServices assessment indicate that the extent to which the wetland is currently (2015) providing this service is moderately low. The potential supply of this service is not anticipated to change with the proposed rehabilitation.</td>
<td>0</td>
</tr>
<tr>
<td><strong>Education and research</strong></td>
<td>Sites of value in the wetland for education or research.</td>
<td>Results of the WET-EcoServices assessment indicate that the extent to which the wetland is currently (2015) supplying this service is low. The potential supply of this service is not anticipated to change with the proposed rehabilitation.</td>
<td>0</td>
</tr>
</tbody>
</table>

Note: In WET-EcoServices the following services are scored in terms of their current use and a mix of opportunity & demand factors.

Note: evaluation based on WET-EcoServices results (drawing only from the effectiveness component where a difference between effectiveness and opportunity is specified) (GroundTruth, 2015).
6.2 Appendix: Baynespruit Stream case study
### 6.2.1 Multi-criteria assessment tables

*Example: Multi-criteria assessment of potential options (investment actions): Stormwater management, ecological infrastructure options*

<table>
<thead>
<tr>
<th>Aspect</th>
<th>ECOCOLOGICAL INFRASTRUCTURE</th>
<th>Rehabilitation of degraded wetlands</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Feasibility in the urban context</strong></td>
<td><strong>Conservation of natural areas</strong></td>
<td><strong>Revegetation of degraded areas</strong></td>
</tr>
<tr>
<td>Low</td>
<td>It might prove difficult to obtain a conservation area due to conflicting land use interests</td>
<td>It might prove difficult to rehabilitate all the degraded areas due to conflicting land use interests</td>
</tr>
<tr>
<td><strong>Reliability</strong></td>
<td>Medium to high</td>
<td>Medium to high</td>
</tr>
<tr>
<td>Rain frequency and intensity will affect the reliability</td>
<td>Rain frequency and intensity will affect the reliability</td>
<td>Rain frequency and intensity will affect the reliability</td>
</tr>
<tr>
<td><strong>Long-term durability or resilience</strong></td>
<td>Medium to high</td>
<td>Medium to high</td>
</tr>
<tr>
<td>There is a possibility of land transformation (e.g., development) or degradation</td>
<td>There is a possibility of land transformation (e.g., development) or degradation</td>
<td>There is a possibility of land transformation (e.g., development) or degradation</td>
</tr>
<tr>
<td>Resilience is dependent on rainfall frequency and intensity, including ecosystem disturbance by anthropogenic factors</td>
<td>Resilience is dependent on rainfall frequency and intensity, including ecosystem disturbance by anthropogenic factors</td>
<td>Resilience is dependent on rainfall frequency and intensity, including ecosystem disturbance by anthropogenic factors</td>
</tr>
<tr>
<td><strong>Reversibility and flexibility</strong></td>
<td>Highly reversible</td>
<td>Highly reversible</td>
</tr>
<tr>
<td>Highly flexible</td>
<td>Highly flexible - it can be combined with built infrastructure management options, e.g., stream bank stabilisation using mesh wire</td>
<td>Highly flexible - it can be combined with built infrastructure management options, e.g., channelling of water using a built furrow</td>
</tr>
<tr>
<td><strong>Costs</strong></td>
<td>Low to medium</td>
<td>Low</td>
</tr>
<tr>
<td>Costs increase in the case where land has to be purchased</td>
<td>Costs can include land acquisition, labour to carry out planting, planting materials and site maintenance</td>
<td>Costs increase in the case where land has to be purchased</td>
</tr>
<tr>
<td>Aspect</td>
<td>Conservation of natural areas</td>
<td>Revegetation of degraded areas</td>
</tr>
<tr>
<td>---------------</td>
<td>-----------------------------------------------------------------------------------------------</td>
<td>-----------------------------------------------------------------------------------------------</td>
</tr>
</tbody>
</table>
| Co-benefits   | High  
Biodiversity Conservation  
Water quality improvement through filtering of pollutants such as nutrients and heavy metals  
Potential aesthetic and recreational benefits  
Carbon storage, air quality improvement, heat reduction | High  
Biodiversity Conservation  
Water quality improvement through filtering of pollutants such as nutrients and heavy metals  
Potential aesthetic and recreational benefits  
Carbon storage, air quality improvement, heat reduction | High  
Biodiversity Conservation  
Water quality improvement through filtering of pollutants such as nutrients and heavy metals  
Potential aesthetic and recreational benefits  
Carbon storage, air quality improvement, heat reduction  
Socio-economic enhancement, e.g., food (fish), and wetlands products for making art and craft |
| Dis-benefits  | Low  
Security threat to adjacent communities, e.g., the conservation area may act as a haven for criminals | Low  
Security threat to adjacent communities, e.g., the vegetated area may act as a haven for criminals if unmanaged | Low  
Wetlands can be breeding grounds for mosquitoes |

**ECOLOGICAL INFRASTRUCTURE**
6.2.2 Floating wetlands – supporting information

Nutrient removal rates

Floating wetlands have been poorly studied and existing studies have largely been mesocosm laboratory type experiments (Pavlineri et al., 2017). A review of the literature shows a wide range of reported floating wetland performance values. Multiple factors influence the nutrient removal performance of floating wetlands including the “chemical forms of pollutants, macrophyte species and ages, raft materials and coverage, experiment locations and seasons, experiment water volumes, detention time, flow condition, and temperatures” (Wang, 2013:21).

Wang (2013) provides a comparison of floating wetland performance for nitrogen (N) removal (8 studies) and phosphorus (P) removal (7 studies). The review by Wang (2013) covered a range of studies across different experiment types (laboratory and in field experiments), countries and inflow waters (urban stormwater, agricultural runoff, domestic wastewater). The review also included studies where solutions made from chemicals were used, which provide nutrients in readily available forms and can overestimate performance (Wang, 2013). The reported unit area nutrient removal values range from 0.34 to 5.3 g/m2/day for nitrogen and 0.08 to 0.74 g/m2/day for phosphorus. Unit removal rates reported by Wang (2013) showed an increase with increasing initial (input) nutrient concentrations.

Hamill et al. (2010) derived removal rates from preliminary trial data from experiments in New Zealand, including flow-through field trials using 0.6 m × 0.6 m floating mats. Estimates were based on the assumption that floating wetlands would be treating stream water with a high concentration of nitrogen. Reported unit area removal values for nitrogen were 0.2 g/m2/day and for phosphorus 0.004 g/m2/day.

Costs

Hamill et al. (2010) report a unit area cost for establishment and 1-yr of maintenance for a floating wetland of $400 / m² (at 2010 US dollars, or R5 200/m² at a 13 to 1 rand-dollar exchange). Additionally, Hamill et al. (2010) report an estimated maintenance cost of $6 / m² per year.

6.2.3 Wetland rehabilitation – supporting information

Nutrient removal rates

Land et al. (2016) provide a systematic review, and database, of nitrogen and phosphorus removal rates for freshwater restored and created wetlands. The database can be filtered based on numerous criteria including location, climatic zone, wetland type, inflow type, area, history (restored or created) among others. Filtering based on wetland type (free water surface) and wetland history (restored) produced 18 wetland studies (9 estimates for nitrogen removal and 18 estimates for phosphorus removal). The median value across the studies yielded estimates of 5 g/m2/yr for nitrogen and 0.7 g/m2/yr for phosphorus removal. The range across the whole dataset (N=203) for nitrogen removal is -25 to 1270 g/m2/yr and -17 to 240 g/m2/yr for phosphorus removal. Based on a review of studies, Hamill et al. (2010) report unit removal rates for natural surface flow wetlands of 29.5 g/m2/yr for nitrogen (higher than the median estimate from Land et al., 2016) and 1 g/m2/yr for phosphorous removal (higher than the median from Land et al., 2016).

The estimates of nutrient removal are an indication of the potential level of nitrogen and phosphorous removal based on the area of wetland likely to be enhanced through implementing the proposed rehabilitation interventions. This is not a representation of the potential increase in the water quality enhancement service entirely as a result of the rehabilitation, as the ‘with’ and ‘without’ rehabilitation
scenarios were not compared, it is likely that the wetlands are performing some level of water quality enhancement in their current degraded state. Furthermore, the estimates are an indication of the potential level of nutrient removal service the wetlands could supply, however the opportunity to perform this service depends on the loads of nutrients the wetland areas receive.

There is considerable variation in nutrient removal rates for surface flow wetlands recorded in the literature (Land et al., 2016). The key variables driving wetland performance - hydraulic loading, incoming nutrient concentration, seasonal temperatures and wetland hydrology (e.g. residence time) - are specific to the case being studied (Hamill et al., 2010). Applying removal rates from the literature introduces considerable uncertainty and thus reduces the confidence of the estimates. Kadlec and Wallace warn strongly against the extrapolation of wetland performance data (see Kadlec and Wallace, 2009:200 for a detailed discussion).

In estimating the nutrient removal potential of wetlands in the Baynespruit catchment, the seep wetland (Greytown wetland) and channelled valley bottom wetland (Sobantu) were combined and unit removal rates based on surface water flow wetlands were applied, there is some evidence that seep wetlands and surface flow wetlands perform differently in terms of nutrient reduction efficiency (Hamill et al., 2010).

The estimated nutrient removal performance estimated in this study was based on the assumption of constant daily performance (removal rate) over a year, which is highly unlikely given that the Baynespruit wetlands are subject to episodic flows, fluctuation in inflow nutrient loads (a key driver of removal performance) and seasonal effects.

Costs
In a case study of the Mthinzima stream wetland (also in the uMgeni Catchment), wetland rehabilitation costs were estimated to be R122 436/ha (2017 prices) based on intervention construction costs which included concrete weir structures, earthen berms, a diversion channel intervention, earthworks and revegetation. Given the large area of the wetland (98 ha) and the numerous structural interventions this is likely an overestimate of the costs for the Baynespruit rehabilitation interventions. Annual maintenance costs were assumed to be 2.5% of construction costs, R3061/ha/yr (year 1). Black et al. (2016) report average wetland rehabilitation costs in the same order of magnitude (R143 345/ha at 2013 prices) across several rehabilitation interventions in the Kamiesberg region. These costs are also likely greater than those for the Baynespruit sites due to the shallow soils, steep slopes and severe erosion characteristics of the sites evaluated by Black et al. (2016). Only implementation costs were considered, including gabion structures, concrete structures, alien plan removal, earth structures, earth works and revegetation.

Ideally, estimates of wetland rehabilitation costs should consider all of the following costs over the lifetime of the wetland:

- Rehabilitation planning
- Consent aspects (e.g. permits, land owner/user consultation, land acquisition)
- Rehabilitation implementation (e.g. construction, planting, alien plant clearing)
- Management and maintenance costs.

In this study, only the implementation costs and one year of maintenance costs were included.
6.3 Water Pricing in the UMngeni Catchment
Costs, benefits and financial flows from water at a catchment scale: Linking green and grey infrastructure

Graham Jewitt on behalf of a large project team

Centre for Water Resources Research
Rockstrom and colleagues have highlighted the importance of the natural environment in achieving the SDGs. In essence, services to society and the economic benefits that can be derived from these depend upon healthy natural systems to deliver the “raw material”.
This has been recognized in the latest NATIONAL WATER AND SANITATION MASTER PLAN VOLUME 1: CALL TO ACTION. Protecting and restoring ecological infrastructure is seem as a key component in an integrated water resources management and planning environment.
In South Africa, Strategic Infrastructure Projects have been the focus of development for some time. SIP 18 deals with water, but missing in the SIPS was any consideration of the value of the natural environment, SIP 19 on Ecological Infrastructure” has been proposed to fill this gap.

This reflects an understanding of the importance of the integration of El (green infrastructure) and built (grey) infrastructure in combining to provide water services to society. These include water for agriculture (both dryland and irrigated), recreation as well as being the core supply to constructed reservoirs, irrigated schemes, interbasin transfers etc. In addition, the catchment (green infrastructure) is also the recipient of waste generated by society through its use of water and essentially, provides the finishing stage of good waste water management – or in the case, of poor waste water management, IS the only treatment system available!
This figure reflects the components of South Africa’s National Water Pricing Strategy. The strategy is based on four principles:
- Social equity, ecological sustainability, financial sustainability and economic efficiency. These different components make up the water resources management charges at different stages of the water resources management cycle. Cycle starts with the water resources management charge. In the case of the uMngeni catchment, this is collected from bulk water sales by the water utility i.e. Umgeni Water and paid to DWS. The water resources development charge and bulk water tariff or costs incurred by the bulk water utility and handed over to DWS. Water is then treated and distributed to the bulk water buyers who are the municipalities and some other clients. The retail water tariff is the price that the consumer pays to the municipality, and this is often loaded as an income generation stream. The municipality is also charge the consumers for sanitation disposal both individuals and industry in the case of bulk. In theory, the water just charge charge is levied against all water returning to the stream (based on the “polluter pays” principle.), but this has not been implemented.
South Africa has been developing a comprehensive water pricing strategy since Ecological sustainability is supposed to include:
- Safeguarding the ecological reserve;
- The ecological management of the catchment;
- Water quality protection; and
- Water conservation and demand management;
However, the focus over the past few years has been on the Reserve and largely reduces to being considered a demand on the system by water resources managers and planners
A key point is that At the moment the vast majority of the money flows through grey infrastructure components of the cycle – this is well illustrated by tan analysis of the uMngeni Catchment.
- less than one percent of the finances flowing in this catchment are generated from the catchment (i.e. water resources management charge and zero percent of that is returned to it.
Water utilities throughout the world incur costs in the processing of raw water to provide potable supply. This slide shows the most important of those (covering about 85% of costs). This is typical for e.g. Umgeni Water and is the basis of their financial reporting system. These costs are reported in their Annual Report and provide a useful focus for any assessment of the extent which investment in EI could offset these costs.

The cost benefit analysis has several components. One of these is an assessment of the operational benefits that UW (or any other) bulk water utility could gain through investment in EI. Evidence for Raw Water, Chemical and Energy benefits are the focus as this addresses the core of a water utilities business.
uMngeni Catchment Case Study

Costs and Benefits of Investing in Ecological Infrastructure
The uMngeni catchment, KwaZulu-Natal, South Africa
The uMngeni river has its origins in the pristine uMngeni Vlei (a RAMSAR site).
However, that catchment is dominated by one of South Africa’s most important development corridors (also a SIP) i.e. the Durban – Gauteng corridor, which is continually developed to link the port of Durban to Gauteng and then the rest of Africa.

Associated with this development is a growing population, an increase in water demand and deterioration in water quality.
There is gig influx of people and corresponding rapid degradation of landscape (This slide is annotated). Informal and unregulated settlements are growing rapidly.
Water quality deteriorates as one moves downstream. This is of most concern in Inanda dam, but also Midmar Dam in the future. Although water quality at Albert Falls is also at risk, the risk to UW is lower as water to be treated is first released to Nagle Dam and is aerated, mixed etc by the river (another EI benefit that is very difficult to quantify).
There is a corresponding increase in water demand as the population grows and the catchment develops. The reconciliation strategy highlighted risks to the catchment water supply and the focus on addressing this is through the construction of new build infrastructure i.e. Spring Grove and soon Smithfield Dam. Water demand management is also part of the mix. But restoration of ecological infrastructure has not been considered.

The importance of the study and this figure should not be underestimated. It drives most of the water resources planning decisions made in the catchment and the future financing. Consumers are already paying a levy of approximately R0.10 per cubic metre to finance the future construction of Smithfield Dam and the associated network.

Umgeni water are currently updating the hydrology underpinning the study.
Costs and Benefits of Investing in EI to enhance water supply
Through the previous study funded by the Green Fund through DBSA and SANBI, costs for rehabilitation of areas of invasive alien plants and degraded grasslands were estimated. These include initial clearing and rehabilitation as well as future maintenance costs.

This is a weakness in the study, as the sample from which the costs were derived is relatively small and this aspect of the study needs to be updated with further information from DEA and Umgeni Water (as an implementing agent).
Benefits in terms of hydrological flows are simulated by a hydrological model. Hydrological models need to be informed by observation as it is through this that we can represent the relevant processes and parameterize the model.
In the study the ACRU hydrological model was set up for the entire catchment at a relatively fine spatial resolution on a daily time step. This allows us to simulate the water resources in terms of streamflow, base flow, sediment load etc in the catchment.

The model was configured to use the latest land cover information available, and one set up could be used to simulate various scenarios of rehabilitation in the catchment and provide information on the benefits associated with the scenarios.

The study is well reported and Catherine Hughes PhD and in forthcoming papers in Water SA.
Benefits

- Xm3 per catchment hectare
- Xm3 per Riparian hectare
- Floods
- Sediments
- Nutrients

On average, 1 ha of wattle uses about 220m3 per hectare per month more than grassland. i.e. 2500m3 per hectare per year. Thus, at 50c per m3, each ha cleared and maintained – or prevented from being invaded saves UW R1250 per year.

Based on the work of Mtshali (2017), there are 125km2 or 12 500ha of invasive wattle or the Lions and uMngeni catchments upstream of Midmar. In 2007, mapping suggested 30km2. Assuming 70km2, clearing this would save UW R3 500 000 per year. Alternatively, this is costing UW R3 500 000 per year. Scenarios of e.g. fully cleared or business as usual (limited clearing), no clearing/double invasives etc can then give us a cost:benefit analysis. Some estimates were made in the Green Fund project, but these are now being updated by Shaeden Gokool.

In addition, all water sold by UW incurs a R0.52c per m3 levy/charge to repay the costs of building SpringGrove Dam. This is not factored in to any cost benefit analysis at the moment.

Th analysis is very conservative as it is based only on pumping costs, no capital replacement etc. 220 m3 per year saved for clearing wattle is also very conservative.

There are 425km2 of grassland upstream of Midmar – if these were invaded with wattle, the loss of water would cost R50 million per year in pumping costs.
There is 150km² of commercial forestry in the catchment. Is the “real” cost of their water use R18 million per year? At the moment the SFRA income generated from forestry in the catchment will be around R18 000. Alternatively, would the industry be willing to sell the land back to the state at the equivalent of R0.50c per m³ per year (approx. R1200 per ha)?
In 2017, UW spent R23 million on electricity pumping water from Mearns/Spring Grove to Midmar. Because of Albert Falls low level, it was not able to fully supply parts of Durban, so additional water had to be pumped from Inanda to Durban Heights treatment works - at a cost of R32 million.

The average cost of water pumped for these three pump stations is R0.46 per m3. Therefore, every m3 produced by the catchment upstream of those two dams means that that water does not have to be pumped, so saves UW at least R0.46c per m3.

How do we value this? In “normal” i.e. not drought years, there may not be a need to pump. The water will be more important in drought years and will have a higher “value” then.
Based on the model output we could then accumulate the benefits at different spatial and temporal scales within the catchment.

In this table, we have focused on the catchments upstream of the main water supply dams.

We can then estimate the costs of producing one cubic metre of water from these various options from investment in ecological infrastructure.

There are some uncertainties in this however. In particular what discount rate should be applied to the ecological infrastructure component of the analysis? There is an ongoing debate in the literature about whether green or ecological infrastructure should be discounted at the same rate as built infrastructure.

In the table above, discount rates of 6% over 50 years i.e. the same as for the built infrastructure are applied as well as a discount rate of 0%. This makes a huge difference.

The URV matches the process used for build infrastructure and is illustrative in this regard. However because the benefits of EI will persist beyond 50 years at a lower cost, there are strong arguments that a different discount rate should be applied.
and there has been some recent work which applies sliding rates - see following slide and notes.
Discount Rates
There is some controversy amongst economists about the appropriate discount rate that should be applied to EI projects. One the one hand, the argument is that in order to fully comparable, the same discount rates should be applied to both the built and green infrastructure project. However, the counter-argument is that investments in EI will persist well beyond the life of the built infrastructure providing benefit for future generations.

In the Table above, Unit Reference Values which are typically used in South Africa to assess the cost of infrastructure development for water resources are shown. For the URV’s, the discount rate used in most capex projects is applied i.e. 6% and the assumed life of the project is 50 years.
In addition, the cost per m3 of water released through investment in EI is also estimated using the ‘Social Discount Rate’. The discount rate used in computing the value of funds spent on social projects. Based on Fenichel et al. 2017, [http://www.nber.org/papers/w23591](http://www.nber.org/papers/w23591) the discount rate applied is 1.53%.

However, catchment rehabilitation tends to incur fairly large upfront costs and lower maintenance costs thereafter. Therefore, further exploration of this issue will take place with the consideration of hyperbolic and declining discount rates over time.
If we apply the traditional URV approach, investments and E I still seem to be beneficial when compared to those from built infrastructure. However, there is an additional uncertainty in this analysis as the assurance of supply from E I is not the same as that for built infrastructure.

In addition the volumetric amount is relatively small.
In addition to quantifying the hydrological benefits from investing in EI, we can also identify where in the catchment interventions should take place to optimize various benefits.

This work has now been enhanced with the application of the RIOS model which will form part of a later Deliverable.
The cost benefit analysis has several components. One of these is an assessment of the operational benefits that a bulk water utility could gain through investment in EI.

Evidence for Raw Water, Chemical and Energy benefits are the focus as this addresses the core of a water utilities business.

Energy costs were not part of the original analysis, but now we do have these available. On average it costs the utility about $0.50 per cubic metre to pump water. Therefore every cubic metre saved or gained in the catchment potentially saves this pumping cost. We are investigating economic replacement cost theory and avoided cost theory to expand on this thinking.

Michelle Brown has now completed some work looking at the potential benefits of EI in maintaining the water quality of Midmar dam and we are expanding this to better understand the risks and associated costs of poor water quality which also form part of Deliverable 12

EI may also reduce maintenance costs in treatment works if the water quality and sediment load remains low. But this is an aspect that still needs further investigation.

Is unlikely that there will be a staff cost benefit, though it may be that fewer staff are needed depending on operational and maintenance requirements.

As illustrated in the figure, it may be that EI can fill the gap between demand and supply in the short term and so delay the construction of new built infrastructure. HEI also provides a buffet and a way of mitigating risk.

From a water quantity perspective, it is unlikely that investment in EI can avoid the construction of built infrastructure. However, in the case of water quality this may not be the case, and is the focus of our work going forward. The Catskills example was based on avoided costs of being able to not build a treatment works.

Basically, avoiding capital expenditure is a huge benefit to a water utility and this is an area which we need to explore more for South African conditions. In the case of the Catskills, the expected lifetime of the investment in built infrastructure will soon be reached. However the investment in the Catskills i.e. Green Infrastructure means that the benefit persists and now far exceeds the original expectations and intentions. This has reference to the argument about the discount rate which was raised earlier.
The question that arises is how much money is available within the catchment for investment in ecological infrastructure. Based on 2017 sales by Umgeni Water and returning to the water resources pricing strategy, the water resources management charge in the uMngeni only generates about R8 million per year.

However, if the charge was $0.10 per cubic metre, it would generate about R42 million per year. And this is actually a very small percentage of the total cost and then even smaller percentage when it reaches the consumer.
A further question arises as to where this money should sit should it be collected. Arguably, Umgeni Water is already collecting funds which it re-invests into built infrastructure, so investing in green infrastructure should pose no administrative problem. However, investing the catchment does bring additional stakeholder implications. In the green fund project, an investment plan and associated governance structure which addresses these issues was proposed.

There is also information from so-called “water funds” throughout the world that maybe useful information in this discussion. In particular, leveraging of available funds to attract input from corporate and other potential funders is an area with the Nature Conservancy has had much success.

The proposed governance structure for such a “Water Fund” is illustrated in this figure.

Pringle et al 2015: An Investment Plan for securing Ecological Infrastructure to enhance water security in the uMngeni River catchment.
Conclusions

• Huge under-investment in Green Infrastructure relative to benefits
• Investment in Green Infrastructure reliant on external sources of funding
  • User pays versus subsidies and external funding?
• Cost-Benefit analysis suggest significant benefits for relatively low expenditure
  • What discount rate should be applied to NBS?
• Working with water utility to build a case and sustainable financial model