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

By

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ABSTRACT

The uMgeni River is an important water resource in KwaZulu-Natal. It is, however, one of the major systems identified as having water that may pose a serious health risk to users of its (untreated) water. Increasing pollution in the upper catchment, supplying the Midmar Dam has been attributed to sewage effluent due to inadequate sewage infrastructure, expanding agricultural lands and household waste from Mpophomeni Township. The Mthinzima River flows adjacent to the settlement where it joins a tributary that flows through Mpophomeni settlement (a 6000-unit settlement that was developed in the 1960s), after which it flows under the district road (R617), through a degraded wetland system (The Mthinzima wetland) and into Midmar Dam. The Mpophomeni township development was poorly planned and should not have been situated near a strategic water resource, because it posed threats to the water resource.

Two interventions were proposed to reduce the pollution flowing from the Mpophomeni Township into Midmar Dam: a new Waste Water Treatment Works (WWTW) would be built in conjunction with rehabilitation of ecological infrastructure. The rehabilitation of ecological infrastructure would primarily entail wetland rehabilitation. Ecological infrastructure has value that is important for human well-being. However, the key incentive challenge is the public dimension of the value. Often studies that aim to value investments in ecological infrastructure give total economic value of the ecological infrastructure instead of the change in total economic value attributable to the investment. The purpose of this study was to investigate the incremental change in supply of services from the wetland post rehabilitation, considering the demand, supply and opportunities for those wetland services.

The new conceptual framework introduced in this study considered the potential of ecological infrastructure to supply its services, the opportunity (activities or circumstances that make it possible for the wetland to be used) afforded to the ecological infrastructure to supply its services and the demand for ecological services. It also examines the impacts of investments (or disinvestments) in ecological infrastructure and/ or engineering infrastructure on the value of ecological infrastructure.

Economic Cost-benefit analysis (CBA) was used for this analysis, it is widely applied as an appraisal technique particularly for use as an input into public decision-making processes. CBA both helps inform decision-makers and helps hold them accountable for their decisions. The cost benefit analysis technique was used to evaluate whether investments in ecological infrastructure bring about a worthwhile change in ecosystem services. The study was limited by data shortages and used the replacement cost technique (one mega litre waste water treatment works) to value the incremental change in wetland services post rehabilitation.

The net present value results of the CBA were all positive, the estimated net present value for change in wetland services post rehabilitation over the period of 20 years was found to be between R7 086 573 and R11 935 240 using different discount rates. The net present value of the wetland rehabilitation investment showed an increasing pattern as the wastewater treatment plants maintenance costs were assumed to be a higher percentage of the wastewater treatment plant. Therefore, the study concluded that investments in ecological infrastructure in the form of the Mthinzima wetland rehabilitation was worthwhile as the investment yielded net positive marginal results post rehabilitation. The results of CBA do not govern the choice of investment especially as data availability was limited, rather it is a useful tool to test the robustness of a project to alternative assumptions concerning the magnitude of costs and benefits, and the various social demands with respect to the return on invested capital. Based on this the results of the CBA, the study concluded that investing in wetland rehabilitation of the Mthinzima wetland is robust.

Keywords: cost benefit analysis, ecological infrastructure, ecological services, economic evaluation, incremental change, wastewater treatment

DECLARATION: PLAGIARISM

I, *Nothando Buthelezi*, declare that:

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I hereby agree to the submission of this thesis for examination:

Signed: ______________________________ Date: ______________________

Dr Stuart Ferrer (Supervisor)

Signed: ______________________________ Date: ______________________

Ms Michelle Brown (Co-Supervisor)

DEDICATION

I dedicate my dissertation work to my family and many friends. A special feeling of gratitude to my loving dad, Nkosinathi Buthelezi whose words of encouragement, prayers and support kept me persistent. I dedicate this dissertation work to my whole family as proof that they may achieve anything they put their minds to and work hard towards. I also dedicate this dissertation to my many friends and church family who have supported me throughout the process, I will always appreciate all they have done. A special dedication to Nomzamo Khanyile who listened to my worries and prayed with me when I felt stuck. I dedicate this work and give special thanks to my step mom Nokulunga and my wonderful brother Samkelo for being there for me throughout the entire master's program. Both of you have been my best cheerleaders.

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LIST OF ACRONYMS

ABD	Autotrophic Biological Denitrification
CBA	Cost Benefit Analysis
CUA	Cost Utility Analysis
CVM	Contingent Valuation Method
DEA	Department of Environmental Affairs
DIN	Dissolved Inorganic Nitrogen
H-trib	Hlanga tributary
LM	Lower Mthinzima
MM	Middle Mthinzima
N	Nitrogen
NPV	Net Present Value
P	Phosphorus
PES	Present Ecological State
PSV	Present Salvage Value
SRP	Soluble Reactive Phosphorus
TN	Total Nitrogen
TP	Total Phosphorus
UEIP	Umgeni Ecological Infrastructure Partnership
UM	Upper Mthinzima
UN	United Nations
USPV	Uniform Series Present Value
WTA	Willingness-to-Accept
WTP	Willingness-to-Pay
WWTW	Waste Water Treatment Works

CHAPTER 1. INTRODUCTION

1.1 General Research Problem

Water related ecological infrastructure is important for human well-being. Humans rely on clean water for consumption and as a productive resource. Although access to water is a basic human right, at a global level more than one billion people are denied the right to clean water and 2.6 billion people lack access to adequate sanitation. The world has sufficient water for its population; the problem is that the millions of people live in rural areas where water infrastructure is scarce, especially in underdeveloped populations. Approximately 1.4 billion people live in river basins where water use is greater than recharge rates (Watkins, 2006). As a result of the overuse of water, rivers are drying up, groundwater tables are falling, and water-based ecosystems are constantly being degraded. The world's natural resources are declining and as a result, future generations will be faced with an unsustainable ecological debt, meaning that they would bear the consequences of environmental degradation and depletion of natural resources. There is an increasing demand for clean water because of population growth, urbanization, industrial development and agriculture (Watkins, 2006).

Wetlands are a type of water related ecological infrastructure. Wetlands are well known for their functions to reduce the loads of excess nutrients, sediments, and other contaminants generated by mostly human activities in their catchment areas (Turpie *et al.*, 2010). Wetlands also provide habitats to rare endangered plants and animals; they provide a host of ecosystem services which directly and indirectly benefits the surrounding communities (Barbier *et al.*, 1997). The ecosystem services provided by wetlands, such as fish and reeds, regulating services, opportunities for recreation and scientific research often fail to be noticed by governments/policy makers (Emerton, 1998) and can result in distorted decisions (Turpie *et al.*, 2010).

Wetlands are one of the most threatened habitats all over the world (Turpie *et al.*, 2010). Since the 1900s, it has been estimated that more than half of the world's wetlands have been lost or destroyed to other land uses (Barbier 1993, cited by Turpie *et al.*, 2010). Wetlands are negatively influenced by human activities, drainage, crop effluent disposal and water abstraction; this holds true for South Africa. One of the major contributors to the international trend of destroying wetlands is that their value is not well understood (Turpie *et al.*, 2010).

Freshwater accounts for 0.01% of the world's water and covers about 0.8% of the earth's surface (Dudgeon *et al.*, 2006), and this small portion of freshwater is largely threatened by climate change and pollution from human activities. Globally, biodiversity has continued to decline due to development, economic growth, climate change and population growth, and affects less developed countries more because they have most of the world's environmental resources and rely on them for their basic needs (Christie *et al.*, 2012). A global issue with available water resources is the declining water quality as the population continues to grow, industrial and agricultural activities expand, and climate change threatens the hydrological cycle (UN, 2011).

Rehabilitation of ecological infrastructure is the process of restoring natural/ ecological driving forces within part or the whole of a degraded watercourse to recover former or desired ecosystem structure, function, biotic composition and associated ecosystem services (General Authorisation for section 21 (c) and (i) of the National Water Act 36 of South Africa (1998); Department of Water and Sanitation, 2016). Wetland rehabilitation is the process of aiding recuperation of a degraded wetland in terms of its condition, function, and associated biodiversity or maintaining the health of a wetland that is threatened by degradation, through active interventions or preventative measures. Wetland rehabilitation is recovering a wetland to a desired state and discontinuing further degradation (Ground Truth, 2015).

Valuing the service of water treatment by wetlands is often challenging as it is difficult to put monetary values on nature. Knowledge about the value of wetlands, the water treatment capacity and other services they provide are important, as it would bring a balance between conservation and activities that degrade or replace wetlands (Turpie *et al.*, 2010). Economic valuation of wetlands (and other ecological infrastructure) is important as it can justify and set priorities for programs, policies and actions that may protect and rehabilitate them (King and Mazzotta, 2000). Economic valuations give basis for measuring and comparing the various benefits from wetlands and the costs associated with their conservation, economic valuations assist in understanding user preferences and relative values placed on ecosystem services (De Groot *et al.*, 2012).

By 2025, the global demand for clean water is expected to exceed the amount that is currently available by 56% (Barlow, 2010). This water crisis has challenged food policy in its goal of eradicating extreme hunger and poverty (Hanjra and Qureshi, 2010) as water is an important resource for agricultural production. The persistent increase in water demand for irrigation has resulted in changed water flows, land clearing and low stream water quality (Hanjra and Qureshi, 2010).

Water is important for food and energy security, and for long-term social and economic growth. Water is essential because it supports health, nutrition, well-being and economic progress, especially in developing countries (Bigas, 2012). Developed nations also face water supply and quality problems. In the USA, water availability has been noted as one of the country's major security problems, and has thus resulted in the reduction of the country's food and energy needs (Bigas, 2012). Overall, water scarcity continues to increase globally; this is more severe in mid-latitude countries. The increasing population growth is competing with the natural environment for water (Bigas, 2012) i.e. water stress degrades the environment.

High water consumption and water pollution will negatively impact on agricultural production, ecosystem function, and urban supply in the near future (Jury and Vaux, 2007). The global population is growing faster than food production and is expected to increase by three billion people by 2050 (Jury and Vaux, 2007). This would negatively impact on poor and water-scarce countries more. South Africa is one of the water scarce countries in the world and the problem is ever increasing. The lack of proper sanitation services contributes the most to water pollution.

South Africa's water resources have been diminishing. Approximately 13041 x 10^6 m^3 of water was used in the year 2000 which equates to 98.6% of that year's water supply. It is expected that the demand for water will exceed water supply in the near future (Blignaut and Van Heerden, 2009). Water has no substitute (Blignaut and Van Heerden, 2009) therefore, it is important to find solutions on how to use the available water resources in a sustainable manner.

Water quality and water quantity deserve more attention. With the global water crisis and climate change, there is a need to identify ways to mitigate and alleviate water-based threats. 'Sanitation and drinking-water investments have high rates of return in costs avoided, lives saved, reduced disease and health-care expenses, more healthy workdays, improved education and increased productivity' (UN Water, 2011). Investments in ecological infrastructure such as wetlands may improve water quality. Wetlands are known for their ability to reduce the amount of excess nutrients, pathogens, sediments, and other contaminants generated by various activities in their catchment areas (Turpie *et al.*, 2010), thus, they play a role in improving water quality.

1.2 Consequences of degraded environmental infrastructure (Eutrophication)

Human-induced pollution may lead to eutrophication; eutrophication is the degradation freshwater systems through the reduction of water quality and changing the ecosystem condition and function. In a study to analyse the potential economic damages of eutrophication in U.S fresh waters, Dodds *et al.* (2008) evaluated the amount of nitrogen (N) and phosphorus (P) concentrations for the United States (Environmental Protection Agency) nutrient ecoregions with estimated historical concentrations. The current nutrient median loads of N and P values for rivers and lakes was more than the historical median values in all ecoregions. In approximately 86% of the ecoregions, more than 90% of rivers currently exceed reference median values. Dodds *et al.* (2008) estimated the annual value of losses in recreational water, waterfront real estate, spending on recovery of threatened and endangered species, and drinking water. The results showed that the total costs were about $2.2 billion per year due to eutrophication. The biggest economic losses were attributed to lakefront property values which ranged between $0.3 to $2.8 billion annually and a recreational value of $0.37-1.16 billion per year (Dodds *et al.*, 2008).

Eutrophication has several negative consequences therefore, a framework of cost categories was developed to analyse social and ecological damage costs and also policy response costs in England and Wales (Pretty *et al.*, 2003). The results indicated that there is a great effect on nutrient loads and eutrophication in many sectors of the economy. The costs of freshwater eutrophication in England and Wales were found to range from $105 to $160 million per year (Pretty *et al.*, 2003). The policy response costs are measured as the costs of how much needs to be spent to reduce the damage, and these policy response costs were $77 million per year.

The greatest proportion of damage costs were found to be at least $15 million per year for reduced value of waterfront residents, nitrogen removal treatment, lower recreational and amenity value, drinking water treatment costs for removal of algal toxins and decomposition products, reduced value of the non-polluted areas, negative ecological effects on biota, and total economic losses from the tourism industry (Pretty *et al*., 2003). These damage costs would represent a cost reduction if damage was prevented at the source (Pretty *et al*., 2003).

Africa has plentiful freshwater resources, which are unevenly distributed among countries: approximately 14 countries in Africa have water shortages and an estimated 11 countries are expected to suffer from water stress in 25 years. Wetlands provide water and nutrients that are required for biological productivity and human survival. Wetlands have an economic value that accrues to both the local residents living in the wetland area and those living outside of the area (Schuyt, 2005). Wetland services have those characteristics of a public or impure public good, many people may benefit from them at no cost, but have a little incentive to invest in their protection or rehabilitation.

The Hadejia-Nguru wetland is within the floodplains of the Hadejia-Jama which is based in Northeast of Nigeria. The wetland provides flood attenuation services. It was reported that flooding lessened from 250 000-300 000 ha during the 1960s to approximately 70 000-100 000 ha in more recent years (Schuyt, 2005). Most of the threats to the wetland are due to human activities and natural pressures. Drought is one of the major natural pressures that threatens the sustainability of this wetland. Valuation studies estimated the annual value of groundwater recharge to be $17 391 in 1998 with the benefits of flood attenuation outweighing the net return of upstream water related development projects. It was estimated that changes in groundwater recharge function would result in a decline in human well-being.

Past studies have shown the economic benefits of sustainable management and conservation of the wetland as opposed to the allocation of its land and waters to their opportunity cost. When comparing agricultural activities, fishing and fuel wood benefits of the Hadejia-Nguru wetlands, that would be lost through reduced downstream flooding. This would be caused by upstream irrigation projects with the value of irrigation production, it was concluded that the economic value of the wetlands far exceeds the expected present value of upstream irrigation projects (Schuyt, 2005). However, the market fails to invest on this public resource due to the incentive problem of public goods.

If wetlands continue to be degraded or converted, it will result in losses to the local residents therefore not exclusively, though human losses need to be considered in decision making processes and compared against the benefits of converting the wetland. The two case studies above have one characteristic in common: they are all being threatened by human activities.

1.3 Specific Research Problem

The previous section argued that ecological infrastructure, specifically wetlands:

1. Provides valuable services for humans.
2. Degradation of wetlands is a pervasive problem in South Africa, Africa and globally.
3. Valuation of ecological services to motivate for investments to rehabilitate and maintain them is challenging.

The focus of this study is to demonstrate application of economic valuation of investments in ecological infrastructure to a case study. The purpose of this section is to introduce the particular problem of that case study. The study aims to value the incremental change in ecological services that result from investment, considering the opportunity to benefit from the increase in current services and in the future.

The water quality of the Midmar Dam continues to decline as a result of the current land use activities and associated impacts such as the Mphophomeni settlement, agriculture and emerging threats from the potential Khayalisha social housing project (van Deventer, 2012). Currently, there is a Save the Midmar Dam Project which aims to restore and maintain degraded wetlands, riparian zones and grasslands, creating and maintaining water resource buffer zones and finally, educating water users on the importance of conserving critical ecological infrastructure within Mthinzima stream, the Lions River and Mooi River. The project was to be implemented over three years starting in 2015. Partnering with the uMgungundlovu Municipality, the aim of this study is to outline the importance/benefits of investing in ecological infrastructure (in the specific case of wetland rehabilitation) to human well-being through an economic cost-benefit analysis.

According to Felton (2016), the decision to rehabilitate the Mthinzima wetland was partially based on public perceptions, including, concerns that the Midmar Mile may be cancelled if the water quality of Midmar Dam declines. It was also motivated by studies that estimated that the Midmar Dam would be eutrophic by 2028 (van Deventer, 2012). Eutrophication occurs when water in a river or dam is enriched with plant nutrients, usually nitrogen and phosphorus compounds (Van Ginkel, 2002 cited by van Deventer, 2012). Nutrient enrichment is one of the most widespread water quality problems that impacts freshwater and coastal ecosystems. Although the process of eutrophication is natural over a large period of time, human activities within catchments have drastically sped eutrophication by altering natural biochemical cycling of nutrients (Oberholster and Ashton, 2008).

The Mthinzima system flows beside the Mpophomeni settlement where it is met by a tributary that flows through Mpophomeni. Thereafter it flows under the district road (R617), through a wetland system and into Midmar Dam. The settlement is approximately two kilometres from Midmar Dam. The water quality threats within the Mpophomeni settlement range from solid waste in and around water courses to damaged and inadequate sewage infrastructure, which has resulted in raw sewage flowing directly to the degraded wetlands and transported to Midmar Dam, surcharging sewage manholes and river bank erosion (van Deventer, 2012).

Past studies have shown that the Mthinzima wetland in its current degraded state does offer some water treatment benefits. In a comparison of water quality along the Mthinzima, water quality within the Mphophomeni 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 does provide the service of water quality enhancement, but there is an opportunity to increase this capacity to supply the service through rehabilitation of the wetlands. In 2017, a focus group of experts concluded that the consequences of degraded ecological infrastructure in the context of the Mthinzima wetland has a negative impact on the Midmar Dam by shortening the period of time before Midmar Dam is expected to become eutrophic.

The wetland rehabilitation will take place in conjunction with the engineered waste water treatment infrastructure (sewerage treatment plant). This is because even with the engineered infrastructure, there may still be occurrences of sewer surcharges, blockages and runoffs, which may result in untreated waste water entering the Mthinzima Stream and ending up in the dam (Felton, 2016). This is due to only the main sewer line being refurbished (GroundTruth, 2015), and there may still be sewage water flowing directly to Midmar Dam from the Mphophomeni area. In this case, the rehabilitated wetlands provide risk mitigation for the engineered infrastructure. Therefore, it is expected that both the engineered and ecological infrastructure will add value to the quality of water. Other costs and benefits of various water treatment technologies are explored later on in this study to inform municipal planners on the cost and benefits of other alternatives for water treatment.

The upper uMgeni catchment that feeds into the Midmar Dam is a vital water resource for the economy of KwaZulu-Natal (KZN). It supplies clean drinking water to the eThekwini, uMgungundlovu and Msunduzi municipalities (van Deventer, 2012). There has been a decline in quality of this water resource resulting in increased water treatment costs (Felton, 2016). The decline in water quality in the Midmar Dam may reduce the dams' recreational value with risks that the Dusi Canoe Marathon and Midmar Mile being cancelled should the water quality continue to decline. Livestock and consumers of water from downstream of Midmar Dam may also get sick and may incur other health related risks.

In a study that assessed water quality and ecosystem health impacts of land uses on Midmar Dam, the results indicated that with the land use activities that prevailed at the time of the study, urban development and agriculture posed a threat to the quality of Midmar Dam as a water resource. A study by van Deventer (2012) concluded that further transformation of the catchment to urban development and agriculture could further decrease the quality of the water entering Midmar Dam and contribute to nutrient enrichment of the dam. If Midmar Dam reaches a eutrophic state, the cost of supplying clean drinking water to the eThekwini, uMgungundlovu and Msunduzi municipalities would increase (van Deventer, 2012).

Ecological infrastructure provides a stream of beneficial services; for example, improving water quality may also be an insurance in a natural disaster such as the recent drought in KwaZulu Natal. The capacity of ecological infrastructure to provide services is reduced when it becomes degraded. Water that flows through a degraded wetland may not be improved in quality to the same extent as water that flows through an intact wetland. This is the case with the Mthinzima wetlands that feed into the Midmar Dam (Van Deventer, 2012).

Gaps in literature with respect to valuation of ecological infrastructure investments are identified in this study. Many valuation studies have focused on total economic value of ecological infrastructure. These studies also focus on only the demand of services from an ecological infrastructure. This study attempted to close the identified gaps in the literature through its contribution on focusing on the supply, demand and opportunity for ecological infrastructure services and focusing on the incremental value of investing in an ecological infrastructure rather that total economic value. It conducts an expected outcomes valuation of the proposed Mthinzima wetland rehabilitation.

1.4 Research Objectives

1.4.1 General Objective

Investments in ecological infrastructure may add incremental value in the quantity of services they provide. The general objective of this study is to know the extent to which investments in the rehabilitation of the Mthinzima wetland will result in increased value of the services it provides. Although wetlands offer a vector of services, the primary wetland service provided by the Mthinzima wetland is water purification. The study evaluates the costs and benefits of investing in ecological infrastructure in the form of wetland rehabilitation for improvements in water quality. Past studies have focused on valuation of the total economic value of ecological services, whereas it is the value of the change in water quality service as a result of investment in ecological infrastructure that is of interest in this study, using a theoretical framework that considers supply, demand and opportunity of the ecological infrastructure services.

Supply focuses on the supply of ecological services and the factors that affect the supply of services from an ecological infrastructure. Opportunity examines the opportunity afforded to the ecological infrastructure to supply its ecological services, for example, polluted water from the Mpophomeni Township entering the rehabilitated wetland system would create opportunity for the wetland to absorb nutrients, which would result in relatively more purified water entering Midmar Dam. The demand looks at whether the services provided by the ecological infrastructure are demanded by at least one person. If there is no opportunity for the ecological infrastructure to supply its services, and there is no demand for its services, then in terms of investments in an ecological infrastructure, the increase in services as a result of investments may be of no value to society. Therefore, it is important to consider the supply, demand and opportunity of ecological services when considering investing in ecological infrastructure.

1.4.2 Specific research objectives

The main objective will be achieved through the following specific objectives:

- To investigate whether current (baseline scenario) supply of ecological services provided by the Mthinzima wetland are adequate by considering the opportunity and demand for its ecological services.
- To investigate whether current supply of ecological services provided by the Mthinzima wetland would be adequate post construction and commissioning of the proposed new Waste Water Treatment Works (WWTW).
- To investigate the impact of the proposed new WWTW on the value of the Mthinzima wetland (value of ecological services derived from the wetland).
- To investigate the impact of the proposed wetland rehabilitation on the value of the wetland (value of ecological services derived from the wetland).
- To determine and compare the present value of the costs and benefits of investing in the Mthinzima wetland through wetland rehabilitation post construction of and commissioning of the proposed WWTW.

1.5 Structure of the dissertation

This dissertation follows a logical progression; the theory of valuing investments in ecological infrastructure is presented in Chapter 2. The chapter is divided into two sub-sections, the first section reviews the theory of valuation of ecological services. An important aspect of this review is the shift from basing valuations on the supply of ecological services only, to also accounting for the demand for those services. Given this knowledge, the second sub-section of the chapter represents the conceptual framework that this study will employ.

Literature on various approaches to valuing ecological infrastructure is presented in Chapter 3. In particular, past studies on the valuation of water quality treatment services related to ecological services provided by wetlands are also reviewed. A purpose for the literature review is to identify and learn from the strengths and weaknesses of previous studies. A particular aim of Chapter 3 is to discuss how ecological services have been valued to highlight their importance/role in the improvement of water quality and purification. This provides a necessary background for deciding which values will be accounted for in this study and which techniques are suitable for estimating those values. Literature reviewed focused on general approaches that have been used to value ecological infrastructure and specifically, wetland valuation studies as the study's purpose is to value the costs and benefits of investing in ecological infrastructure, through the rehabilitation of the Mthinzima wetland. Finally, the chapter reviews literature on the applications of a cost benefit analysis.

In the next chapter the study area is presented and the reason for its selection is discussed. Chapter 4 lays out the study area location, its proximity to Midmar Dam and its associated biophysical attributes. The study area chapter also gives more information on the proposed interventions in the area. Chapter 5 consists of the methodology that will be applied to achieve the studies research objectives of the study, different scenarios given the two interventions (rehabilitation and new WWTW), methods of data collection,sensitivity analysis and methods are presented and justified. The results chapter then follows, it initially investigates the opportunity, demand and supply of ecological services from the wetland post rehabilitation. The costs and benefits that will feed into the cost benefit analysis are then presented.Lastly the chapter presents the results of the CBA. The discussion chapter then discusses the results, limitations, areas for future research and how the results may be used in decision making. Finally, a summary of the whole study is presented.

CHAPTER 2. THEORY OF VALUING INVESTMENTS IN ECOLOGICAL INFRASTRUCTURE

The purpose of this chapter is to review economic theory relevant to the topic of investments in ecological infrastructure. It has been divided into three sub-sections, the first of which discusses the theory of public goods, the second sub-section reviews the theory of valuation of ecological services. An important aspect of this review is the shift from basing valuations on the supply of ecological services only, to accounting for the demand of those services. Bearing this in mind, the third sub-section of the chapter represents the conceptual framework used in this study.

2.1 Public goods/ impure goods theory

In economics public goods are goods that have some degree of non-rivalry and non-excludability (Samuelson, 1954). The non-rival nature of public goods means that once they are provided the additional resource cost of another person consuming the good is zero. Non-excludability means that preventing other people from consuming the good is very expensive or impossible. Private goods on the other hand are excludable and rival in consumption. Pure public goods are perfectly non-rival and non-excludable. Impure public goods meet the two conditions of public goods (non-rival, non-excludable) but not perfectly. Table 2.1 defines different types of goods by analysing if they are excludable or rival in consumption.

Table 2.1 Defining Pure and Impure public goods

		Is the good rival in consumption?	
		Yes	No
Is the good excludable?	Yes	Private good	Impure public good
	No	Impure public good	Public good

This sub-chapter focuses on impure public goods because environmental quality is essentially an impure public good in the context of improved water quality. For example, if the water quality of a significant water source that provides a community with drinking water is improved through investments in ecological infrastructure, everyone in that community benefits from lower rates of providing clean drinking water (derived from lower water treatment costs). Although the good is non-rival but it can be excludable to those who do not pay the municipality for water.

When an investment has a personal cost but yields common benefit, individuals have an incentive to underinvest or let others pay for the good, and this brings about the free rider problem. As a result of the free rider problem the private market undersupplies public goods because free riders will attempt to use the public good without paying for it. To overcome the free rider problem government often charges taxes for public goods, requiring through the law that everyone contributes. Also putting on social pressures, and other specific situations (e.g. paying for water) where markets have discovered a way to collect payments may reduce. Often public goods are produced by partners who want the benefits of the public good (Schmitz, 2015). There may be a "public–private partnership" in which the responsibility for the delivery of public goods is shared between the state and the private sector. However, the incentive of free riding on some public or impure public goods may be difficult to eliminate. The next subchapter focuses on economic value and appraisals of investment in ecological infrastructure. It also presents a conceptual framework with a new perspective on how to analyse investments or disinvestments in ecological infrastructure.

2.2 Economic value derived from ecosystems and ecosystem investment appraisals

It is often challenging to place value on the incremental value derived from an investment in ecological infrastructure, especially in instances where there is no direct market for its ecosystem services. This section reviews economic valuation methods that have been used to estimate values of ecosystem services to develop an understanding of the value of ecological infrastructure. The discussion is enriched by reviewing relevant literature on ecosystem investment appraisals.

2.2.1 Deriving economic value from ecosystems

The relationship between ecosystems and human welfare is presented in Figure 2.1. Haines-Young *et al*. (2012) explained that biophysical structures and processes generate ecosystem functions (ESF) which, in turn, provides ecosystem services (ESS) to humans benefitting from them. Spangenberg *et al.* (2014) merged ecosystem structures and processes, and the functions they provide as emergent properties of the ecosystem into one category. This category of ecosystem properties represents the biophysical elements of services provided (Figure 2.1).

Ecosystem service potentials (ESP, Figure 2.1) is an additional stage between ESF and ESS. Neither are the ESP determined by the ESF nor can they be assessed by analysing the ESS. ESP are generated in complex social processes, and they determine the kind of services ultimately realised. Initially, an ESF must be recognised followed by identifying the variety of uses and services the ecosystem can potentially provide. This is called step use-value attribution; it results in the societal determination of a set of ESP.

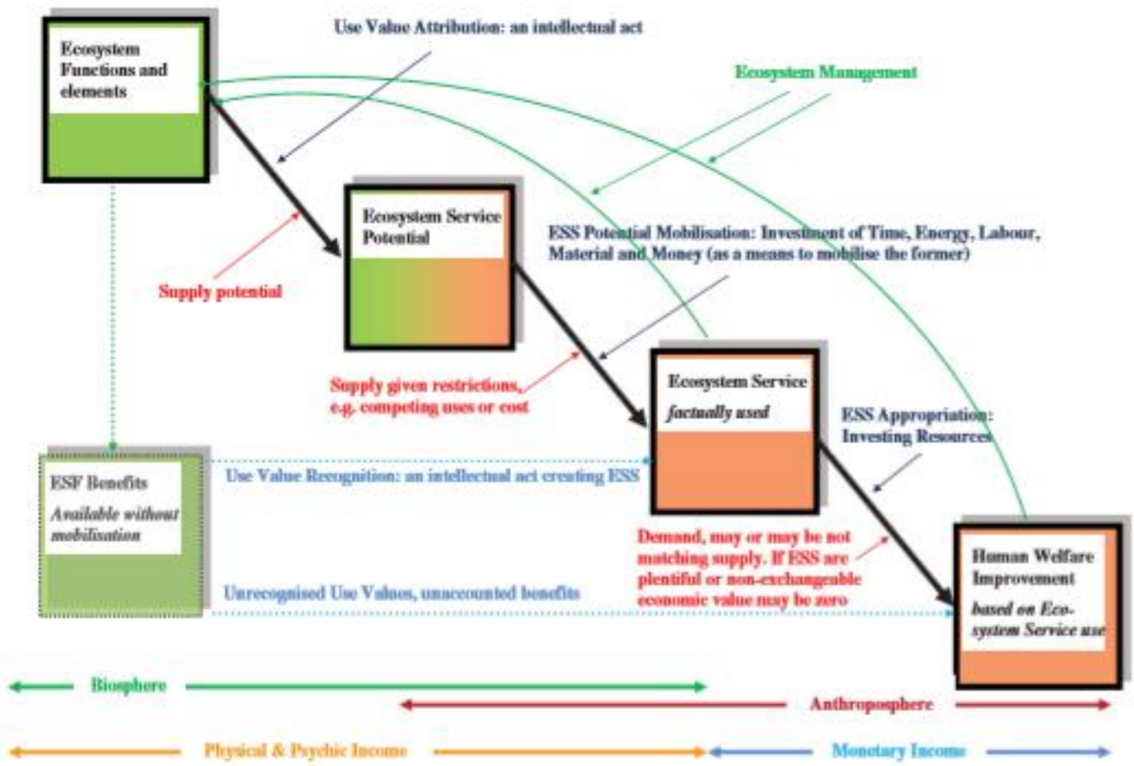


Figure 2.1. The ESF, ESP and ESS process
Source: Fisher, (1906) cited by Haines-Young *et al*. (2012); Spangenberg *et al.* (2014)

The ESP are then mobilised, to provide the available ESS. The ESS are suitable to be consumed directly or used to produce other goods or marketed as products. All the aforementioned options bring about benefits, direct non-monetary benefits the first, direct monetary benefits the last and indirect benefits the middle one. All the steps in the process from ESF, ESP to ESS reduces down the amount of potentially available benefits (Spangenberg *et al.*, 2014). In pluralistic societies any given ecosystem function may be assigned to different use potentials by different stakeholders, restrained by a lack of knowledge or imagination or society needs. This shows that ecosystem services have a (different) value to human well-being, therefore, it is important to understand the value in the services they provide.

Valuing ecosystems and the services they provide is important as they offer a range of services that are important for human well-being. Understanding their value helps justify their conservation, protection and management.

2.2.2 Appraisal of ecological infrastructure (ecosystem) investments

Economic and social aspects have recently been included in the design and investment decisions for restoration projects. This study focuses on restoration investment projects because ecological infrastructure has value and it is important to understand that value to justify investing in its protection or rehabilitation. The main objective of the study is to examine whether investments in the form of the Mthinzima wetland rehabilitation result in benefit or cost/loss. A lot of ecological rehabilitation studies that include the economics of rehabilitation often focus only on assessing the costs of rehabilitation projects. Economic principles, techniques, and instruments should not be limited to the costs of rehabilitation, but they must be applied to other different factors that may affect project success (Iftekhar *et al*. 2017). Iftekhar *et al* (2017) considered the effects of applying economics to address four main challenges of ecological rehabilitation. The study assessed social and economic benefits, estimating overall costs, project prioritization and selection, and long-term financing of restoration programs. Their findings were that it is uncommon to consider all types of benefits (e.g. nonmarket values) and costs (e.g. transaction costs) in restoration projects. Securing long-term funding is also important to achieving restoration goals and can be achieved by establishing connections with existing programs, public-private partnerships, and financing through taxation. The reason for this is that the services of ecological infrastructure are not purely private.

Most ecosystems are degraded because they are under protected and are often common-property, but they provide streams of benefits for human well-being. Government intervention to protect ecosystems may be lacking because their values are not well understood. Politicians are not interested in investments of long-term nature i.e. costs of investment in ecological infrastructure are of immediate nature and the benefits are neither quick nor visible. This is why they are often set aside. Blignaut *et al.* (2010) investigated whether a payment for ecosystem goods and services system with suitable management and rehabilitation of natural capital in rural areas within the Maloti-Drakensberg mountain could be developed so that it benefits communities, the commercial sector and the environment.

Two study areas were selected within the Maloti-Drakensberg Mountain. Overall, the mountain only occupies 5% of South Africa's surface yet it provides 25% of its water. The threat to this water source is that 25000 km^2 is not protected and it is therefore subject to degradation due to various agricultural practices. As a result, the quality and quantity of the water is impacted negatively. The results showed that the benefits of improved management measures outweighed the cost in the low-medium degraded areas and not as much in the heavily degraded areas. From this study it was concluded that the ecosystem value which provides good quality water exceeds that engineered water purification systems (Blignaut *et al.*, 2010).

The three strategies to move human society to a more sustainable well-being were identified to be sustainable technologies, relooking at human behaviour including reproduction and consumption patterns, and more investments in the restoration of natural capital (Blignaut *et al.*, 2014a). Investments in natural capital restoration are not only required from a biophysical perspective, to cater for the increasing demand for ecosystem goods and services and the diminishing stocks of natural capital, but also that it makes good economic sense to invest heavily in restoration of natural capital (Blignaut *et al.*, 2014a), such as investing in wetland rehabilitation.

There are various controversies between ecologists and economists, although they have reached a general consensus that there is a crucial need to reinforce the diminishing natural capital which is very important for the economy and human well-being (Blignaut *et al.*, 2014b). It is feasible to slow down and in some cases, reverse the loss of natural capital which will improve human well-being, while slowing the adverse degradation of natural capital (Blignaut *et al.*, 2014b), which is largely due to human activities.

Investments in ecological infrastructure have yielded very high returns, which has even led to the establishment of payment for ecosystem services schemes in some parts of the world (Crookes *et al.*, 2013). Ecological infrastructure restoration is often expensive as the restoration process is undertaken when the environment has already been adversely degraded and therefore, it is costly to undo all the damage to the environment (Crookes *et al.*, 2013).

In a study conducted in Cape Town that aimed to highlight the value of ecological goods and services for decision making, investment in ecological infrastructure was found to yield high economic value in city economies (de Wit *et al.*, 2012). The results showed that money spent on maintenance and enhancements of ecosystems was 1.2 to 2 times higher than other money the municipality spent on improving the city's economy. Investments and maintenance of ecological infrastructure can produce economically valuable services that can potentially contribute to a city's economy. It was further estimated that ecological infrastructure produces a range of ecosystem services that are valued in the order of R4 billion per year and range between R2 billion and R6 billion per year in the city of Cape Town. The bigger portion of this value for the city was generated through the tourism industry, parks recreation, open spaces and beaches. In addition, specific industries were also found to benefit largely from the flow of services provided by well-functioning ecosystems (de Wit *et al.*, 2012).

Investments in ecological infrastructure rehabilitation have been misunderstood as they are often seen as expensive (de Groot *et al.*, 2013). This is partly because the conventional cost-benefit analysis often does not take into account human well-being in the goods and services from ecosystems (de Groot *et al.*, 2013). de Groot *et al.* (2013) investigated whether investments in ecological infrastructure yield net benefits. They presented evidence from the field based on analysing more than 300 case studies in which they reported the costs or benefits of ecological restoration.

The costs were from 94 studies and comprised of direct capital investment and maintenance of the restoration project. The benefits (225 studies) were calculated in monetary value of the total bundle of ecosystem services provided by the restored ecosystem. The net present value was calculated at the social discount rates of 2% and 8%. Two thresholds cum sensitivity analyses were conducted and the results showed that even in a worst-case scenario investment in restoration breaks even and, in some cases, yields a financial profit. Results from the benefit-cost ratios ranged from 0.05:1 (for coral reefs and coastal systems, in the worst-case scenario) to a high of 35:1 (for grasslands, in the best-case scenario). These results reflected partial estimates of benefits at one point in time and 'show the lower limit of the welfare benefits of ecosystem restoration because scarcity of and demand for ecosystem services is increasing, and new benefits of natural ecosystems and biological diversity are being discovered' (de Groot *et al.*, 2013).

As the population grows, there is also a growing demand of ecosystem goods and services and expansion of urban areas, therefore there are challenges and opportunities to create more sustainable, healthy and resilient cities. In a study to assess the benefits of restoring ecosystem services in urban areas, Elmqvist *et al.* (2015) used data from 25 urban areas in the USA, Canada, and China. The results showed that investments in ecological infrastructure in urban areas are ecologically, socially, and economically desirable and advantageous (Elmqvist *et al.*, 2015). The data showed that the reviewed ecosystems provided benefits within the range of US$ 3 212 to $17 772 per hectare per year.

South Africa is a water scarce country and relies on Lesotho for some of its water supply. Water shortages threaten people's well-being and the South African economy. Hydrological modelling has shown that protecting and rehabilitating ecological infrastructure could result in the same order of magnitude as built infrastructure (Mander *et al.* 2017). Investments in ecological infrastructure on the other hand may have a range of other benefits. The types of rehabilitation depend on the needs of the local water users.

Studies reviewed above show that investments in ecological infrastructure have significant benefits though they may have focused solely on the total economic value of investments in ecosystems and the services that they provide. The studies reviewed focused mainly on the demand side of ecological infrastructure. Economic valuation of investments in ecological infrastructure should value the incremental change in the provision (supply) of ecological services that result from the investment and relate that benefit to the cost of the investment required, considering the opportunity to benefit from the increase in services and in future. This study aims to value the costs and benefits of investments in wetland rehabilitation considering the supply, demand of and opportunity for ecological infrastructure services. Next, the conceptual framework for valuing the impact of investments in ecological and engineered infrastructure is explained in detail.

2.3 Conceptual framework

From the first subsection on the theory of valuation of ecosystem services, it can be deduced that ecosystem services have value as they provide services that benefit humans (Human

Welfare Improvement, Figure 2.1). The ecosystem services that are realised from ecosystems may differ across different societies and is dependent on the needs and knowledge of these societies. Lack of understanding of ecosystem services value has led to their degradation but investing into the rehabilitation of these ecosystems has shown to yield high economic benefits. The reviewed studies have focused on the total economic value of investments in ecological infrastructure and ecosystem services.

The conceptual framework that this study will use to value the incremental change in wetland services from the Mthinzima wetland is presented in this section. It is important to note that it is the change in the value of ecosystem services provided that result from investment in ecological infrastructure that is of interest. The conceptual framework is a general framework that may be applied to measure the impact of investments (or disinvestments) in ecological infrastructure and/or engineering infrastructure on the value of ecological infrastructure. The conceptual framework considers the potential of ecological infrastructure to supply its services, the opportunity afforded to the ecological infrastructure to supply its services, and the demand for the services. Opportunity refers to the activities or circumstances that make it possible for the wetland services to be used, for example, waste water entering a wetland system allows the wetland an opportunity to utilise its water quality improvement service. It is important to note that ecological infrastructure offers a vector of ecological/environmental services. For example, wetlands offer a vector of services such as habitat for species, protection against floods, water purification, amenity and recreational opportunities. Figure 2.2 presented below is a schematic representation of the conceptual framework used for this study.

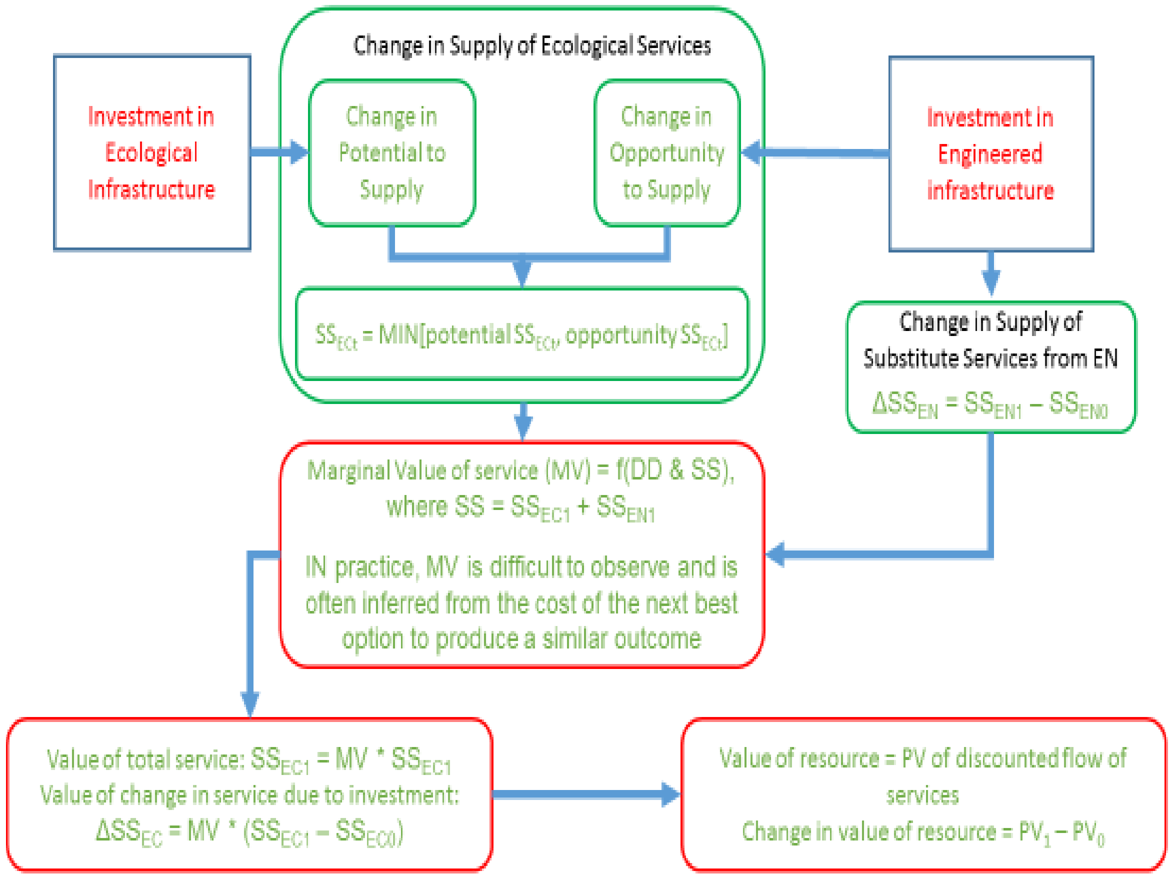


Figure 2.2 Schematic representation of the conceptual framework that will be applied to evaluate investments in wetland rehabilitation, SS_{EC} (Supply of ecological services), SS_{EN} (Supply of services from engineered infrastructure or any other alternative), SS (Supply of services), MV (Marginal value), PV (Present Value).
Source. Author's compilation

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) the capacity of the ecological infrastructure to provide its services. On the other hand, investments in engineered infrastructure or another substitute may affect the opportunity for the ecological infrastructure to supply its services at a particular point in time. This can be represented by the equation below:

SS_{ECt} = MIN (potential SS_{ECt}, opportunity SS_{ECt})…2.1

Where SS_{ECt}, is a vector of ecological services supplied at a particular point in time. In equation 2.1, the supply of ecological services depends on the potential of the system to supply the service and the opportunity afforded to the system to provide the service (opportunity). The supply of ecological services is the minimum potential that the ecological infrastructure may offer its services, or the minimum opportunity afforded to the ecological infrastructure to offer its services. If the opportunity to supply ecological services is greater than the potential capacity of ecological infrastructure, then the supply of ecological services is at the minimum potential. If the opportunity to supply ecological services is less than the potential capacity that ecological infrastructure may offer, then the supply of ecological services is at its minimum opportunity. The opportunity for a wetland to perform water cleansing service is provided by the presence of sediment, nutrients, or some other contamination of the water.

The marginal value of ecological services is determined by the demand for the services and supply of the services (from the ecological and engineered infrastructure). This is represented below in equation 2.2 and 2.3. In practice, when valuing ecological services from ecological infrastructure, the marginal value (MV) is often difficult to measure because there is no direct market for ecological services. As a result, MV is often inferred from the cost of the next best option to produce the similar outcome.

$MV = f\,(DD \;\&\; SS)$ …2.2

$SS = SS_{EC1} + SS_{EN1}$ … 2.3

Where:

DD = Demand for services

SS = Supply of services

SS_{EC1} = Supply of ecological services post investment

SS_{EN1} = Supply of engineered services post investment

Total supply of services or the final benefit is the summation of the supply of services from ecological and engineered infrastructure. If the supply of engineered services takes away all opportunity for the ecological infrastructure to provide its services (e.g. the engineered infrastructure purifies all waste water), there may be little or no demand for ecological services and therefore, the value of the ecological infrastructure may be low. This does not mean that the services of ecological infrastructure and engineered infrastructure are mutually exclusive but emphasises that there has to be opportunity (polluted water flowing into the stream) afforded to the ecological infrastructure to offer its services for it to have economic value. The ecological infrastructures value is derived from the services it provides and therefore there has to be opportunity for its services.

Ecological infrastructure has economic value when its (incremental) change in services are demanded by at least one person and there is opportunity to supply its services now and in the future. Therefore, the value of the change in supply of ecological services can be represented as follows:

Value of SS_{EC1} = MV * SS_{EC1} … 2.4

Value of ΔSS_{EC} = MV * ($SS_{EC1} - SS_{EC0}$) … 2.5

Where:

SS_{EC0} = Supply of ecological services prior to the investment

ΔSS_{EC} = Change in supply of ecological services post-investment

The value of the supply of total services post rehabilitation is the marginal value or price of the total service supplied multiplied by the supply of total services post rehabilitation which includes services prior and post investment. The focus for this study is the change in ecological services as a result of impacts of investments, therefore the change in supply of ecological services is the MV of the services multiplied by the change in the supply of services post investment ($SS_{EC1} - SS_{EC0}$). Therefore, the value of the ecosystem is equal to the discounted flow of services, and thus, change in its value is the present value (PV) of the difference in flow of services prior and post investment. This can be represented in equation form as follows:

Value of ecological infrastructure = PV of discounted flow of services …2.6

Change in value of ecological infrastructure = $PV_1 - PV_0$ … 2.7

Where:

PV_0 = present value prior investment

PV_1 = present value post investment

For a positive value change or added value in ecological infrastructure, the change in value of the resource must be positive in equation 2.7 therefore, PV_1 must exceed PV_0, and then it can be concluded that investments in ecological infrastructure were worthwhile. It is important to note that PV_1 is a sum of the incremental benefits subtracted by the costs of investment and PV_0 represents the benefits prior to investments. A negative net present value would indicate negative returns to investment and other alternatives may need to be considered.

CHAPTER 3. LITERATURE REVIEW ON APPROACHES OF VALUING THE REHABILITATION OF ECOLOGICAL INFRASTRUCTURE

3.1 Valuation of economic benefits vs impacts and contributions

Economic impacts of ecological restoration/ rehabilitation can be grouped into two categories: (1) economic benefit studies and (2) economic impact and contributions. Benefits and contributions are not the same measures, the benefits focus on the value produced, while the contributions focus on the impact on the economy (BenDor *et al.,* 2015), this distinction is important. Economic benefit studies measure the economic benefit of restoration (often without accounting for opportunity or restoration costs), including both market and non-market value (BenDor *et al.*, 2015). Economic impact and contributions analyse how expenditures in restoration impact the whole economy in various ways including indirect impact on employment and investment (BenDor *et al.*, 2015). Evaluations of restoration projects may consider information from both economic benefits and economic impact and contribution assessments.

The criteria that guides the choice between the two options or categories of evaluation on investment in ecological infrastructure is the purpose of analysis and availability of information. If the purpose of the study is to evaluate if society is better off (or worse off) as a result of a (ecological infrastructure) restoration project (Department of Interior's (DOI), 2011), then the researcher may use the economic benefit analysis. When it comes to economic impact and contribution, the focus is on the impact of the restoration investment such as the employment of local labour and the use of local materials for the restoration. Economic impact and contribution studies focus on how expenditures in one industry impact the economy and stimulate impact in other industries. For the economic impact and contributions, it is important to have information on indirect impact on the broader economy.

Some economic evaluations of ecological infrastructure restoration projects use both economic benefits and economic impact and contributions methods. The two methods (benefits and contributions) are different measures: the former focuses on the value produced from the investment, while the latter focuses on gross output and employment (DOI, 2011). Many studies that analyse economic benefits have been applied in South Africa. However, there have been relatively few studies that have focused on economic impact and contributions. This may be due to lack of data availability to carry out economic impact and contribution studies.

3.2 Approaches to valuing ecological infrastructure in general

From the conceptual framework developed in chapter 2, the value of ecological infrastructure is derived from the value of the ecosystem services that it provides. Furthermore, having established that the cost benefit analysis (CBA) and other techniques are used to appraise investments in ecological infrastructure. It is clear that such analyses typically include information on the value of ecosystem services (or change in the value of ecosystem services). Therefore, this section reviews approaches to valuing ecosystem services.

The concept of valuing ecological infrastructure services has the potential to change how society views nature's importance for human well-being. Valuing ecosystems, understanding their benefits and increasing awareness to preserve natural habitats may change the way society perceives ecosystems and view them as natural capital, one of society's important assets. Understanding ecosystems and their value is receiving much attention currently as ecosystem services are becoming increasingly scarce (Costanza *et al.*, 2010). To justify investments in ecological infrastructure, it is important to value ecosystems and the services they provide.

Ecosystem services valuation involves evaluating the contributions of ecosystem services to society; it is an important tool that provides for comparisons of natural capital to engineered solutions and human capital regarding their contributions to human welfare. It also monitors the quality and quantity of natural capital over a period of time with respect to its contribution to human welfare, and allows for evaluation of projects that will affect natural capital stocks (Costanza *et al.*, 2010).

There are a number of non-market valuation techniques that have been used to value ecosystem services. These include non-monetary valuation methods and environmental economic techniques based on a monetary metric (Farber *et al.*, 2002). Monetary metric evaluation techniques assume that individuals are willing to trade the ecosystem service being valued for other services represented by the metric. Monetary valuation allows the measurement of the costs and/or benefits associated with changes in ecosystem services by calculating a shadow price (Farber *et al.*, 2002).

Farber *et al.* (2002) discussed six major ecosystem service economic valuation techniques when market valuations do not adequately capture social value. Table 3.1 captures a summary of various economic valuation methods to value ecosystems. The valuation methods listed in Table 3.1 have their strengths and weaknesses and different services have suitably different techniques and some services may be valued using different techniques together.

Table 3.1. Economic valuation techniques for ecosystem services

Economic Valuation Method	**Description**
Avoided Cost	Service are valued based on costs avoided, or of the way in which ecosystem services allows the avoidance of costly averting behaviours, including mitigation (e.g., well-functioning ecological infrastructure reduces costly incidents of high water treatment)
Replacement Cost	The value of ecosystem service is valued based on the perfect or close substitute that would replace the service (e.g., natural waste treatment can be replaced with costly engineered treatment systems)
Factor Income	Services are valued in terms of their contributions to income improvement (e.g., good quality water positively impacts commercial fisheries, improving income)
Travel Cost	This valuation considers how much people are willing to spend to get to site based amenities (e.g., travel cost to go swimming or for any other recreational purpose to a dam)
Hedonic Pricing	The service is valued based on on what are people willing to pay for services of associated goods (e.g., beach houses often outweigh inland house prices)
Contingent Valuation	Service demand is based on what people would be willing to pay (WTP) or willing to accept (WTA) under different hypothetical scenarios (e.g., willingness to pay for cleaner air)

Source. Extracted from Farber *et al.* (2002) and Costanza *et al*. (2010)

3.2.1 Application of various economic valuation techniques

This section reviews literature that has applied the valuation techniques listed in Table 3.1. The purpose is to see how the various approaches have been applied and to determine which valuation procedure may be the most suitable approach for valuing additional/incremental services that the Mthinzima is estimated to supply post rehabilitation investment. This section also specifically includes the economic valuation of wetlands as the study aims to investigate the incremental value of the Mthinzima wetland as a result of the rehabilitation investment.

3.2.1.1 Avoided cost

Often societies must choose between different uses of the natural environment. In order to make informed decisions amongst the different uses for the natural environment, it is vitally important to know both what are the ecosystem services provided by the environment and the value of those services. Avoided cost valuation method is one approach that may be used to value services from ecosystems. The approach values ecosystem services on the costs avoided.

Goulder and Kennedy (1997), used an example of farming production inputs from ecosystem services such as pest control, flood control, soil fertilisation and water filtration to illustrate how ecosystem services may be valued using the avoided cost approach. These services are important inputs to sustainable production of agricultural products. It is possible to place value on these services by examining what costs or expenditures agricultural producers manage to avoid to the availability of these input services provided by ecosystem. For example, where ecosystems provide pest control, farmers can avoid undertaking expenditure on alternative pest control methods such as purchasing chemical pesticides. Data on chemical pesticide prices would provide an indication of the value of the pest control service provided by the ecosystem. Another example is flood control services offered by wetland ecosystems, this service eliminates the need to alternative flood control expenditures. Therefore, the service would be valued based on data available on other alternative methods to control floods. For the avoided cost method market data may be readily available and robust. However, it may be difficult to relate damage levels to ecosystem quality.

3.2.1.2 Replacement cost

The replacement cost method is commonly used for valuation of environmental projects, the replacement cost method is based on non-market behaviour (Sundberg, 2004). Replacement cost method uses costs of a potential or actual replacement technique to value the change in environmental quality. Therefore, a replacement cost is the cost of replacing an ecosystem service with a substitute to quantify the economic value of the ecosystem service (Sundberg, 2004).

In order to use the replacement cost method a substitute for the ecosystem service must be identified. It is important that the cost of investment and the maintenance are included in the replacement cost. The method is based on finding perfect substitutes to ecosystem services. Bearing that in mind, the validity of the method does not only depend on the possibility of finding perfect substitutes. Three conditions need to be met for the replacement cost method to be a valid measure of the economic value of the ecosystem service. Sathirathai (1998) defined the conditions and these conditions are also discussed in Freeman (2003) cited by Sundberg (2004). The conditions are the following:

1. The human engineered system which is the perfect substitute for the ecosystem service must provide functions that are equal in quality and magnitude to the ecosystem service. Perfect substitutes for ecosystem services rarely exist therefore, close substitutes may be used to find a close to actual value of the ecosystem service.

2. The human engineered system alternative must be the lowest cost alternative way of replacing the ecosystem service. This implies that various alternatives have to be considered and the most cost-effective technique must be used for the replacement cost.

3. Individuals should be willing to pay for the human engineered system if the ecosystem service was no longer available.

The replacement cost economic valuation method must satisfy the three conditions listed above to achieve a valid measure of economic value. This condition overcomes bias of overstating the ecosystem service; the alternative method must be the most cost effective and demanded by society.

Wetlands provide a stream of services such as reducing excess nutrients, pathogens, sediments and other contaminants, though it is often difficult to value the stream of benefits provided by wetlands (Turpie *et al.*, 2010). Knowledge of the value of wetlands and their services would successfully bring about the equilibrium between conservation and other development or human activities that degrade or in other cases replace wetlands (Turpie *et al.*, 2010). Certain past valuation studies have lacked information on how wetlands can improve water quality passing into systems downstream (Turpie *et al.*, 2010).

A study undertaken in the South-Western Cape of South Africa estimated the water treatment capacity of wetlands on a landscape scale approach and estimated the economic value of the wetlands. The study's focal point was on nutrient reductions (Nitrogen and Phosphorus) and suspended solids. A replacement cost approach was used to value the water treatment capacity of wetlands. Turpie *et al.* (2010) found the estimated removal rates of nutrients to have ranged from 307 to 9,505 kg N per ha^{-1} $year^{-1}$, with an average of 1,594 ± 1,375 kg N per ha^{-1} $year^{-}$. Data from a number of water treatment works was used and suggested that the cost of removal of ammonium nitrogen was R26 per kilogram, and when applied in the wetlands under the study area this suggested that the average value of the water treatment service provided by wetlands in the study area is about R14.350 ± 12.385 ha^{-1} $year^{-1}$ in 2009 (Turpie *et al.*, 2010). From the results, Turpie *et al.* (2010) concluded that the estimated water treatment values were sufficiently high to compete with the alternative land uses that threaten their existence and that wetlands should be given more attention in land-use planning and regulation.

Another study that employed the replacement cost approach valued the Nakivubo wetland in Kampala, Uganda. The Nakivubo wetland has been degraded over the years, and is threatened by the spread of industrial and residential developments (Emerton *et al.*, 1999). This is due to the perception that wetlands have little or no value relative to the other developments which produce more instantaneous and direct profits. The wetland contributes to economic activity in various ways; these include treating and purifying domestic and industrial wastes and effluents, and thus maintaining the quality of urban water supplies (Emerton *et al.*, 1999).

Emerton *et al.* (1999), conducted a study that investigated and quantified the economic values associated with Nakivubo wetland services. The replacement cost method was used to measure the costs that would be incurred to replace artificially the waste treatment and water purification services of Nakivubo wetland. The costs of the constructing sewerage and sanitation facilities in low-cost settlements around the wetland, and connecting of Nakivubo Channel to Bugolobi sewage treatment plant and its extension to cope with the resulting additional waste water load were used (Emerton *et al.*, 1999).

The goods and services from the Nakivubo wetland were valued and produced economic benefits to an estimated USh 2 billion a year (at 1999 USh). Water treatment and purification services made up most of this net value, they were worth between USh 3 and 5 million/ha/year. Crop cultivation contributed relatively more to the value of resource utilisation activities. These values did not represent Nakivubo's total economic value as they excluded other benefits generated by the wetland, essentially non-use values such as those that are linked to conservation of biodiversity, cultural and aesthetic values, and particular indirect values such as groundwater recharge services (Emerton *et al.*, 1999).

The replacement method is often easier to use for statistical analysis because data on manmade substitutes may be relatively easier to obtain. The shortfall of this valuation method however, is that it tends to understates the value of ecological infrastructure because manmade equivalents generally do not provide the same benefits as ecosystems. Ecological infrastructure often offers a wide range of services whereas manmade or built infrastructure often provides relatively less services. Another limitation of this valuation method is that the substitute of ecological infrastructure may not meet all the three conditions of the replacement method mentioned above.

3.2.1.3 Factor income

On-farm and off-farm ecosystem values must be included to account for total value. Approaches to estimating on-farm values of ecosystem services factor income production or cost function approaches and econometric analyses of opportunity costs. Some of the valuation techniques typically used for off-farm effects can also be applied to on-farm effects (Swinton *et al*., 2007). Some on-farm values of ecosystem services to agriculture commonly can be measured with the factor-income approach (Farber *et al*., 2002; Swinton *et al*., 2007). This valuation approach aims to link ecosystem services to incomes from agriculture. A common method used to identify the effect of an ecosystem services on income would be to identify its effect on yields or costs. For example, if ecosystem services enhance yield without altering production costs, the increased yields directly translate into increased gross margin or net income (Ricketts *et al*., 2004). However, the remaining challenge is how much of the increase in yield can be attributed to ecosystem services.

When ecosystem services in agriculture affect agricultural outputs or various inputs, a production function approach may be used to value the ecosystem services. A production function relates the quantity of output (agricultural yields) to various levels and combinations of inputs. The value of ecosystem services to agriculture is estimated by using the production function to compute how the expected present value of agricultural profits will change given a change in ecosystem services (Swinton *et al.*, 2007). Most classical agricultural production functions include an intercept term to describe output achieved without external inputs. This base yield level may be attributed primarily to natural ecosystem services (Liu *et al.*, 2006).

Whilst the approach described thus far estimates a single value for a particular level of ecosystem services, the on-farm effects on income for a range of ecosystem service levels may differ. The combined effects may then be used to produce a trade-off frontier that facilitates assessment of the cost-effectiveness of providing differing levels of off-farm ecosystem services (Swinton *et al.*, 2007). The ecosystem service trade-offs in relation to agricultural incomes may be elucidated, without directly valuing the ES outcomes. By comparing changes in the profitability of different farming practices in relation to changes in levels of off-farm ecosystem services that affect the farm (Coiner *et al.*, 2001). The ecosystem service trade-offs in relation to agricultural incomes may be elucidated, without directly valuing the ES outcomes.

3.2.1.4 Travel cost

One method that is commonly used to value recreational value derived from ecosystems is the cost of travel to destinations where there are recreational ecosystems such as wildlife viewing, hunting, fishing and sport (e.g. many recreational sportsmen and women paddle the Dusi Canoe marathon each year). Travel costs give information about WTP for outdoor recreation. The relationship between people's recreation activity and their travel costs are used to estimate recreation demand functions. The demand can be related to levels of ecosystem services provided, then changes in ecosystem services will shift the demand functions and can be used to value changes in the ecosystem services. This approach has been used to estimate values associated with agricultural conservation programs that affect water quality (Baylis *et al.*, 2002). It is important to note that travel cost method cannot always attribute all recreational value to ecological services.

The benefit of using this method is that it is based on actual or observed behaviour. The main limitation is that the value of ecological infrastructure is limited to only the recreational value benefit. The method has limited use for valuing anything other than parks and charismatic species that can provoke travel behaviour. It is therefore difficult and complex to work out the value of the ecological infrastructure as a whole. This method also has high data requirements and difficulties arise when trips are made to multiple destinations.

3.2.1.5 Hedonic pricing

Hedonic valuations use relationships between land property prices and property features to value changes in their characteristics. The price of property is related to its characteristics; therefore, this approach measures the value that is included into the value of property. Sikhakhane. (2001), used the hedonic pricing method to evaluate the decrease in the price of houses due to the odours and flies caused by sludge from the Darvill Waste Water Works (DWWW) in Pietermaritzburg. Houses that were closer to the DWWW decreased in value by R15953 compared to those houses that were further away from the DWWW. On average, house prices declined by R6650 per kilometre closer to the DWWW (Sikhakhane, 2001).

The total benefit of clean air for the surveyed households was estimated to be approximately R28 480 518 per year. The effect of water pollution on the health of residents that consume potable water from the Msunduzi River was estimated to be R1 243 373 while the estimated revenue loss from the cancellation of the Duzi Canoe Marathon owing to episodes of diarrhoea reported during the race was an estimated R3 744 975 (Sikhakhane, 2001). Both these cost indicators showed that improving water quality of the Msunduzi River would be beneficial to society (Sikhakhane, 2001) and would improve the residents well-being.

Hedonic valuation method is based on market data, so it employs relatively robust figures or data. The problem with using this method is that it is very data-intensive and it is related mainly to property related services. Accurate data on the ecological infrastructures attributes to market prices of property is also rarely available. It is also often difficult to use the hedonic pricing method when conducting an *ex ante* analysis as there is often lack of data and uncertainties on how much the ecological services may affect property value. There are also very few applications using hedonic pricing method on published literature.

3.2.1.6 Contingent valuation

Abu Dhabi is well known for its coastal and marine resources and is a holiday destination to high value individuals and tourists. The main threat to the coastal and marine resources is the eruption of harmful algae blooms due to the decline in water quality as a result of high nutrient loads in the water source. This decrease in water quality has implications for the individuals or tourists that visit Abu Dhabi with the decline in water quality threatening the amenity value that can be enjoyed at the beach. The amenity value of Abu Dhabi consists of the beach, aesthetic value, recreational value and many more (Blignaut *et al*, 2016).

Blignaut *et al.* (2016), used a contingent valuation method to assess the amenity value of the coastal and marine resources of Abu Dhabi to the beach visitors using data from a sample of 103 beach visitors. The contingent valuation is a questionnaire based technique usually used to evaluate preferences for environmental quality. The sample respondents were first assessed on whether they would be willing to accept compensation for visiting another beach had there been a harmful algae bloom in the Abu Dhabi beaches or alternatively, if they would be willing to pay an annual fee for restoration and reduction of the beach pollution (Blignaut *et al*, 2016).

The results showed that the beach amenity value is estimated at US$8.3 million/ha and US $13.8 million/ha based on the beach size. It was also concluded that other factors such as the travel time from place of current residence to the beach, where the respondents lived, the number of beach visits and household size and income also affected the willingness-to-accept (WTA) compensation for visiting another beach of the respondents.

Sustainable management of wetlands is important for the long-term health, safety and well-being of many communities (Schuyt, 2005). Protecting wetlands also protects other goods and services that have an economic value, people depend on wetlands for water, food and other goods and services (Schuyt, 2005). The Baltic Sea has not been in a good ecological condition due to increased loads of polluting substances such as toxic substances and nutrients which may be due to the fact that no cost and benefit analysis has been conducted on pollution cutback required to restore the Baltic Sea. This resulted in the reduction of cod and seal stocks, and an increased frequency of anoxic deep basins and of blue green algal blooms (Gren *et al.*, 1997).

Some measures of reducing nutrient pollutant substances are livestock reduction and wetland restoration which may reduce both nitrogen and phosphorus nutrients. Nutrient pollution is caused by excessive nitrogen and phosphorus in the water. Nitrogen and phosphorus support the growth of algae and aquatic plants and when excess nitrogen and phosphorus enters water through human activities, the water becomes polluted. This is because excess nitrogen and phosphorus causes algae to grow faster resulting in algal blooms. These measures reduce the load of one of the nutrient's while the load of the other nutrient is also reduced at no charge (Gren *et al.*, 1997). This implies that the above measures of nutrient reduction are relatively less costly for simultaneous nitrogen and phosphorus reductions compared to when they are individually being reduced.

Sewage treatment plants, the agricultural sector, and restoration of wetlands each accounts for about 30% of the total reduction in nitrogen and phosphorus (Gren *et al.*, 1997). Sewage treatment plants account for a 50% phosphorus (P) load reduction which is 65% of the total P reduction. A decrease in nutrient retention rates, an increase in wetland nitrogen purification capacity and an increase in the leaching impact of agricultural land use changes, all imply a decreased total minimum cost (cost effectiveness). When evaluating the costs and benefits of ecological infrastructure restoration, it is preferable to have information on the sources of nutrient loads, costs of pollution reduction, ecological impacts of nutrient reductions and the valuation of ecological recovery in monetary terms (Gren *et al.*, 1997).

In the region of the Baltic Sea a lack of sewage treatment was found to be the main contributor of phosphorus into the sea. Approximately a 30% reduction in phosphorus would result if a modern sewage plant (engineered infrastructure) was to be built in Riga (Gren *et al.*, 1997). A decrease in phosphorus concentrations in the sea was expected to reduce the amount of cyanobacterial bloom during late summer.

In the Baltic Sea study, the benefits were not quantified according to the reduction in nutrient concentration but rather to the eutrophication reduction which impacts people's well-being (Gren *et al.*, 1997). The impact is related to people's recreation at the shores of the Baltic Sea. More algal blooms and a changed composition of the algae flora along the beaches could discourage people from beach recreation; oxygen shortage situations in coastal waters may affect angling (Gren *et al.*, 1997). Unfortunately, the quantitative relationship between the nutrient concentration and eutrophication impact is yet to be established, thus, there is no clear-cut comparison between the costs and benefits.

Gren *et al*. (1997) used contingent valuation methods (CVM) to get information on the Swedish public's willingness to pay for a large-scale international plan against eutrophication. The CVM requires details on changes of services/benefits from the ecological infrastructure. Residents closer to the Baltic Sea who were aware of eutrophication and recognized it as a serious environmental problem showed that they had a higher willingness to pay (WTP) for action against eutrophication, which was about SKr 3000 per person per year (Gren *et al.*, 1997). Another CVM that was similar to the Swedish CVM was carried out in Poland. The Polish mail CVM questionnaire was sent out to 600 randomly selected Polish adults. The WTP estimate was approximately SKr 300 per person per year. Overall the costs and benefits of the large-scale international plan against eutrophication were found to be almost equal.

Darvill Waste Water Works (DWWW) treats domestic and industrial waste water from the city of Pietermaritzburg, in KwaZulu-Natal. Sludge from the waste water treatment is sprayed onto surrounding lands, causing odour and fly problems. Treated effluent flows out into the Msunduzi River, harming water quality. The study on the DWWW used several economic valuation techniques to analyse the costs and benefits of improving air and water quality to overcome the problems caused by DWWW. The Sobantu residential area had the least mean monthly WTP. This was expected because Sobantu is a relatively low income area and is characterised by high levels of unemployment and lower household incomes than the other residential areas (Sikhakhane, 2001).

There is a big difference between measuring use and non-use (bequest and existence) values, this is because participants to surveys evaluating non-use values usually do not know about the product or service which they are asked to value (McClelland *et al*, 1992). Therefore, for non-use values, the participants must be informed about every aspect of the product or service in the survey instrument. For on-use values, the survey instrument must provide all the information needed for respondents to place values. Therefore, there is an opportunity for bias in the survey design if insufficient information is provided (McClelland *et al*, 1992). Perfect information includes information on substitute products or services, and how changes in the level of provision of the product or service will affect the respondents. Therefore, perfect information emphasizes the need of giving the complete psychological context (information) of the economic decision (Fischhoff and Furby, 1988).

This method primarily involves directly asking people how much they would be willing to pay to protect or rehabilitate ecological infrastructure. It uses willingness-to-pay and willingness-to-accept. When using the contingent valuation method, the researcher can capture use and non- use values of ecological infrastructure. The method can be used when there are limitations on the time and resources for detailed research. The limitation of this valuation method is that respondents may be biased with what they may be willing to pay for the services of ecological infrastructure because of its nature as a public good (incentive problem of public goods). It can also be very expensive and time-consuming, because of the extensive pre-testing and survey work.

3.2.1.7 Other valuation techniques

Ecosystem services are undervalued because of the limit of ecosystem service valuations to those services with direct use value and market prices, thus not accounting for all the environmental and economic trade-offs associated with decisions. Keeler *et al.* (2012) attempted to address important missing components in the current valuation of aquatic ecosystem services by designing a comprehensive and generalizable framework for describing and valuing water quality related services. The approach was comprehensive in that it integrated biophysical and economic research, was sensitive to alternative land use and aims to avoid double counting costs and benefits.

The generalised framework of Keeler *et al.* (2012) for water quality valuation included four steps: (1) identifying actions and beneficiaries of interest, (2) identifying shared inputs/outputs of biophysical and economic models, (3) selecting appropriate biophysical models and, (4) considering existing models and data sources. Even when following the framework and robust biophysical and economic data, application of the framework was time-consuming and needed consideration of modelling assumptions and uncertainty (Keeler *et al.*, 2012).

Keeler *et al*. (2012) concluded that water quality assessments would be more significant to the public if modelled changes were presented in terms of risks to drinking water contamination, reduced fish and shellfish catches or diminished recreational opportunities other than concentrations of nitrogen (N) or phosphorus (P). Thus, the generalised framework is able to inform decision makers on how their actions would affect these valuable services. The generalised framework ‘overcomes many of the shortcomings of existing approaches by integrating biophysical and economic models, basing value estimates on marginal changes in service provision, and accounting for multiple sources of value without double counting' (Keeler *et al.*, 2012, p. 18621).

Many studies have been undertaken on the main factors that determine wetland values, though none of these studies have focused on developing countries. Chaikumbung *et al.* (2016) investigated the benefit transfer for wetlands in developing countries using meta-regression analysis (MRA). The data used consisted of 379 studies of economic valuations of wetlands in developing countries. The aim of the analysis was to provide a combination of prior research of wetland valuations in developing countries, to identify the factors that influence wetland valuations and to construct a benefit transfer function.

The MRA was applied to 1432 estimates of the economic value of 379 distinct wetlands from 50 countries. The results showed that wetlands with a normal wetland size had a negative effect on wetland values, and urban wetlands and marine wetlands were found to be more valuable than other wetlands. Wetland values estimated by stated preferences were lower than those estimated by market price methods. The MRA benefit transfer function had a median transfer error of 17%. Overall, MRA appeared to be useful for deriving the economic value of wetlands at policy sites in developing nations.

3.2.2 Discussion

Ecological infrastructure is important for human well-being as it offers valuable services to people, for example, water and climate regulation, soil formation and disaster risk reduction (SANBI, 2016). Ecological infrastructure is a natural substitute of built or engineered infrastructure and plays a vital role in providing services and underpinning socio-economic development (SANBI, 2016). Ecological infrastructure does this by providing cost effective, long-term solutions to service delivery that can supplement, and sometimes even substitute, engineered infrastructure solutions.

From the studies reviewed above, it can be concluded that ecosystems/ ecological infrastructure has an important value to society. The main service that was focused on for the purpose of this study was the ecosystems (wetlands) water quality improvement service. This was the main focus because the major threat to the Midmar Dam is low quality water from Mpophomeni

Township therefore, the Mthinzima wetland may offer an incremental water purification service. The study assumes that it is preferred to treat or improve water quality before it reaches the Midmar Dam than addressing issues associated with a decline in water quality of the dam such as eutrophication, which would potentially increase water treatment costs for uMgeni water and consumers would have to pay a much higher price for water.

There is no single technique that can be used but the researcher must ensure that the combination used does not double-count the values of some ecological services and must also be aware of any services not valued. The valuation approaches use non-use values of ecological services. The factor income approach uses use-value to estimate the direct value of income from the ecological service. To capture the non-use value of ecological services, respondents in the above-mentioned valuations must be informed about the ecological services from an ecological infrastructure and their substitutes. Often with use values, respondents are familiar with the particular services and have a real-world decision context to frame their value. The values estimated using the reviewed approaches measure the present value of the ecological services. Some valuation techniques may appear appealing but could misrepresent willingness to pay (WTP) or willingness to accept (WTA) valuation concepts in some instances. This is common when using Replacement Cost valuation methods. There may be situations when the social benefits that may be lost when ecosystem services are unavailable are less than the cost of replacement of those services or when the benefits gained from enhanced services are less than alternative means of providing those services (Farber *et al.*, 2002).

Ecosystem services that are realised from ecological infrastructure differ across different societies. They differ according to society’s needs and knowledge. Selecting a valuation technique may depend on the service/s to be valued and the available information. This study will use the replacement cost to value the incremental change in the water quality improvement service. The study will examine perfect or close substitutes that would replace this service. The choice of this approach is based on the lack of information to employ the other valuation approaches. Next, the methods of appraising investments in ecological infrastructure are reviewed, bearing in mind that ecological infrastructure has important value and it should be included in investment decisions.

3.3 Methods to appraise ecological infrastructure

Having reviewed various approaches to valuing ecological services from ecological infrastructure, the attention of the next section turns to how these estimates of value may be incorporated in an appraisement of an investment in ecological infrastructure.

3.3.1 Economic cost benefit analysis

Cost benefit analysis (CBA) is often applied to value investments in ecosystem services, because its approach offers a way to achieve the most optimal environmental results at a lower overall cost to society (Ackerman and Heinzerling, 2002). CBA identifies the impact of a project in terms of the costs and benefits resulting from it. To conduct a CBA, the costs and benefits need to be quantified by measurement and for *ex ante* projects, the stream of costs and benefits may need to be estimated. There are various measurement and estimation techniques to use according to the nature of the costs and benefits. Cost and benefit analysis uses streams of costs and benefits measured using monetary values to value investments. Shadow prices are usually used for environmental projects as some costs and benefits streams do not have market prices or are inappropriate because they are distorted due to market imperfections (Mullins, 2014). The CBA technique involves discounting of 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. A standardised discount rate (Mullins, 2014) or more than one discount rate (for comparisons) may be used for the calculation of present values of all cost and benefit streams. The cost-benefit analysis assesses whether a certain project is worthwhile or not, if the benefits are greater than the costs, then the project is considered worthwhile.

A cost-benefit analysis was carried out to evaluate whether the two alternative methods of upgrading DWWW would be beneficial to society as a whole. The estimated total benefits of reducing odours, flies and effluent problems were R256 662 840 when different valuation techniques were used. These benefits were compared to the two alternative costs of upgrading the DWWW, which were co-disposal option and land disposal option. The benefit-cost analysis ratios of the above mentioned two alternatives were 1:51 and 1:52 respectively. These results suggested that it would benefit society to upgrade the plant in order to remove its unfavourable environmental impact (Sikhakhane, 2001). The approaches to valuing ecological infrastructure in 3.3 above provide the values needed to carry out CBA, even though some of the techniques may not be suitable for an *ex ante* CBA.

Social benefits include the private and external benefits resulting from a particular investment e.g. jobs created and clean water flowing close to a residential area. Social cost is the total cost paid for by the society or government (from taxes) for an investment that aims to benefit society. It is the sum of all the external and private costs. While private benefits are the benefits received by those directly involved in the decision to consume or produce a product e.g. revenues earned, and savings to business. Private costs are the costs directly involved in the decision to consume or produce a product e.g. cost of borrowing and hiring labour and other costs of a private investment. For public (government) investments society will incur the benefits and costs of investment.

3.3.2 Cost utility analysis (CUA)

Whilst CBA continues to be widely used to guide public policy decisions, some authors contend that there are significant difficulties with respect to the application of economic CBA in analyses that use monetary valuation.. Both benefits and costs must be valued in monetary value, for example the costs and benefits of an investment in ecological infrastructure must be expressed in Rands or Dollars. Often benefits are non-market (unpriced) and some are not tangible, as is often the case for water quality projects (Hajkowicz *et al*., 2008). The difficulties of expressing unpriced benefits led to the emergence of CUA. CUA is an extension of cost effectiveness analysis (CEA). While CEA considers the attainment of only a single attribute, CUA considers the attainment of multiple attributes and totals them into a utility function.

Under CUA, the costs for alternative projects are expressed in monetary value and the benefits, being less tangible, are expressed by a utility function (Hajkowicz *et al*., 2008). Cullen *et al*. (2001), used a measure called COPY (conservation output protection years) to assess the outcomes of threatened species programmes in New Zealand. Other associated environmental utility metrics have been applied to quantify water quality benefits in the Great Barrier Reef catchments of Australia (Hajkowicz, 2006), assess land use change to improve catchment water quality in New South Wales (Hajkowicz *et al*., 2005) and to measure the benefits of land and water conservation projects across the United States (Ribaudo *et al*., 2001). These metrics are a combination of multiple attributes, often measured in different units, into a single utility score. These metrics are used to maximise utility subject to a budget constraint or determine a set of projects/activities which deliver a desired utility score at least cost (Hajkowicz *et al*., 2008).

3.4 How to deal with uncertainty in the supply of ecological services

Ecological infrastructure provides ecological services that have important value for human well-being. Therefore, it is important to understand the value of the services they provide to justify their investments and know whether society would be better off or worse of as a result of investment in ecological infrastructure. There are many uncertainties that may affect the supply of ecological services from ecological infrastructure. This section reviews literature on ways to deal with uncertainty in the supply of ecological services from ecological infrastructure.

3.4.1 Scenario planning approach to uncertainty

The future provision of ecological services is filled with uncertainty. There is a need estimate the future's uncertainty and to develop models to clarify aspects that are difficult to examine. Bohensky *et al*. (2006), suggested that scenarios deserve more prominence in scientific efforts to understand and manage uncertainty in ecological and conservation decision making. Scenarios were used in a four-year millennium ecosystem assessment program which was launched in 2001 (Bohensky *et al*., 2006). The aim of the program was to provide decision makers with scientific information about the relationships between ecosystem change and human well-being.

Scenarios were defined as a set of possible narratives that portray alternative pathways to the future (Bohensky *et al*., 2006). Scenario planning involves creation and use of scenarios in a structured way to stimulate thinking and evaluate assumptions about future events or trends and to make uncertainties about these trends clear (Bohensky *et al*., 2006). Scenario planning is useful for dealing with uncertainty when there is a lack of sufficient information about the probabilities that different events will occur.

In the millennium ecosystem assessment, a scenario working group comprising of ecologists, economists, and social scientists representing academia, research institutes, nongovernmental organizations, businesses, and indigenous groups from around the world developed participatory, policy relevant global scenarios to describe the evolution of ecosystem services, human well-being, and their interactions over time. The focus was specifically on ways in which decisions may drive future ecosystem change, ecosystem change may constrain future decisions, and ecological feedbacks may lead to surprise (MA, 2005).

The working group developed scenarios that would link with assumptions about ecosystem resilience. Four scenarios focused on uncertainties related to the extent of globalization or regionalisation, and a proactive or reactive approach to environmental problems. The global scenario portrayed a globalized and reactive world, which aimed to bring the world's poor out of poverty. The second scenario was the order from strength scenario, the world is regionalized, reactive, and driven by a desire for security. The third scenario was the adapting mosaic scenario which was characterized by a regionalized but proactive society and increasing reliance on local institutions and learning to improve ecosystem management. The final scenario was a techno-garden scenario which described a globalized, proactive world driven by a pursuit of eco-technologies (MA, 2005). It was concluded that scenarios are a powerful tool for ecology and conservation.

3.4.2 Other approaches for dealing with uncertainty in the assessment of ecosystem services

In most landscape analyses, the main uncertainties arise from landscape complexity and methodological uncertainties (Hou *et al.*, 2013). Uncertainty sources of ecosystem service assessments, the complexity of the natural system, respondents' preferences and technical problems have a huge impact on uncertainty of the provision of ecosystem services in the future. Hou *et al*. (2013) analysed the assessment process and found that the initial data uncertainty fills the whole assessment and argued that the limited knowledge about the complexity of ecosystems is the main origin of uncertainties. When analysing uncertainties in assessments, Hou *et al*. (2013) proposed systems analysis, scenario simulation and the comparison method as promising strategies. In order to reduce uncertainties, actions should integrate continuous learning, expanding respondent numbers and sources, considering representativeness, improving and standardizing assessment methods and optimizing spatial and geo-biophysical data (Hou *et al.*, 2013).

3.5 Summary

The literature reviewed in this Chapter motivates the need to value the incremental change in economic value of the Mthinzima wetland as a result of rehabilitation investment. The results from the studies reviewed have found the services that wetlands provide in water treatment and purification to be useful and valuable. It is important to put an economic value to the change in benefits ecosystems provide post investment so that decision makers can realise the importance and roles of ecological infrastructure investments. It is important to also carefully analyse the valuation methods and applications presented in this chapter, given their advantages, disadvantages and the resources available for the study. It can also be concluded from the literature reviewed in this chapter that valuation of ecological infrastructure is very difficult because the ecological environment is multi-dimensional. The choice of valuation and appraisal method for this study is presented in detail later on in Chapter 5.

CHAPTER 4. BACKGROUND TO THE STUDY AREA

4.1 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 uMgeni System, is the main water supply to different districts within uMgungundlovu, Msunduzi and eThekwini (Outer West) municipal areas (van Deventer, 2012). The uMgeni River is an important water resource in KwaZulu-Natal, though it is one of the major systems that were identified as having water that may cause a serious health risk to its consumers (Rivers-Moore, 2016). The increasing pollution in the upper catchment area, supplying the Midmar Dam has been attributed to sewage effluent, expanding agricultural lands and household waste (Ngubane, 2016).

The uMgeni River was also identified as a system with increasing water quality problems due to poultry farms, effluent from cattle feedlots and lack of sanitation (Rivers-Moore, 2016). The amount of potable water demanded from the system per day was estimated to be 268Ml/day. This water is supplied to the three major districts shown in Figure 4.1. below. This is an important water source providing water to many communities, the site was chosen based on its importance and current and emerging threats that endanger its existence in the long-run.

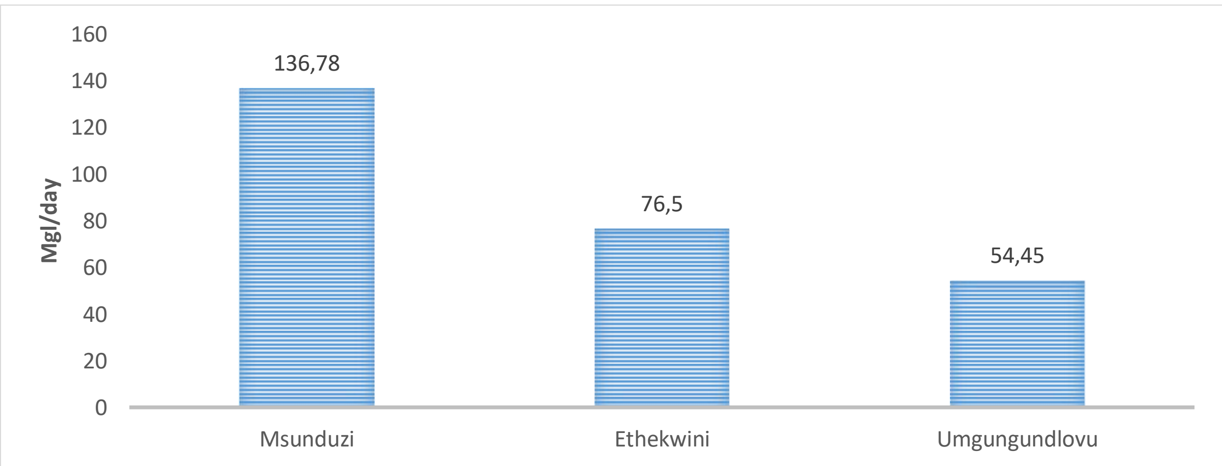


Figure 4.1. Demand for water from the upper uMgeni resource (Mgℓ/day)
Source: van Deventer (2012)

Population growth will increase the demand for water from the upper uMgeni resource. Concerns surrounding pollution of the Midmar Dam involve reduced water clarity, excessive algal blooms, unpleasant odour and high microbial activity (Breen *et al*., 1983, cited by Ngubane, 2016), this could potentially lead to eutrophication and associated health risks and increased water purification costs in the future (Ngubane, 2016). The current trophic status of Midmar Dam is mesotrophic, one trophic level below oligotrophic, (which is the most desirable in terms of drinking water supply) and one trophic level above eutrophic thus, the water quality is currently good in general. Most of the surrounding wetlands have been degraded by human activities and the status of the remaining wetlands differs greatly; some are in relatively good condition while others are damaged, and their functions are therefore reduced (van Deventer, 2012). This study focuses on the Mthinzima Wetland (Figure 4.2) and its rehabilitation, which is in one of the sub-catchments within the upper uMgeni catchment.

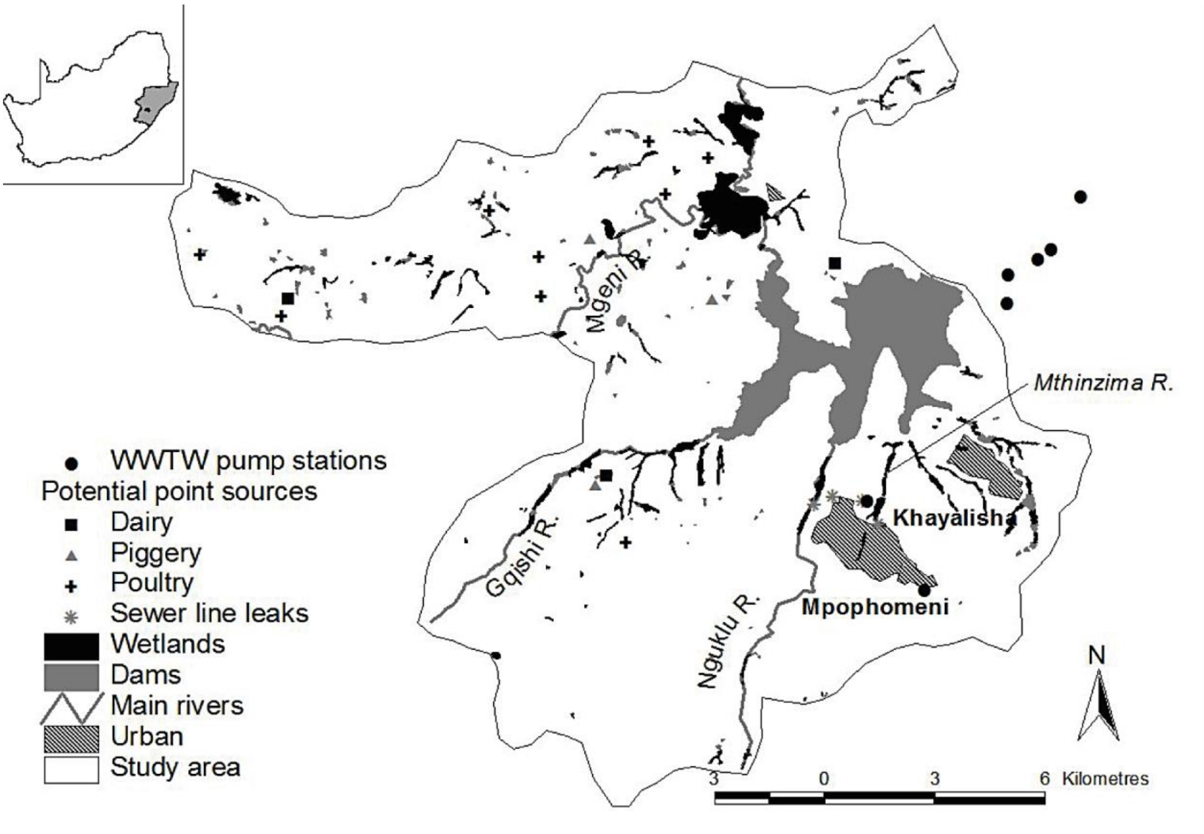


Figure 4.2. Quaternary catchment, with salient features to demonstrate where the Mthinzima Wetland/ River falls in the bigger catchment.
Source: Rivers-Moore (2016)

The Mthinzima stream is a relatively small watercourse that feeds into the Midmar Dam. Upstream of the Mpophomeni Settlement, Mthinzima’s water quality is very good as it seeps into the streambed from a relatively pristine catchment. As the Mthinzima stream flows to the

Midmar Dam it picks up large volumes of raw sewage which trickle down into the stream from some of the poorly serviced townships that have been built on the surrounding hillsides (South African National Biodiversity Institute (SANBI, 2015). Relatively high levels of *E. coli* were measured in the Mthinzima Stream draining into Midmar Dam, however, the *E. coli* counts were above safe levels for human contact with water in 2009 (Ground Truth, 2015).

The Mthinzima wetland is located in Mpophomeni settlement, a 6000-unit settlement that was developed in the 1960s. Mpophomeni housing development was built as a dormitory suburb for black workers who came from rural areas to Howick town to work at SARMCOL (south African Rubber Manufactoring Company Limited) and also to work in the construction of the Midmar Dam.Considering that human development impact may pose a threat to water resources in the area, the Mphophomeni development was poorly planned as there should not have been a large development near a strategic water resource (Felton, 2016). The Mthinzima River flows adjacent to the settlement where it joins a tributary that dissects Mpophomeni, after which it flows under the district road (R617), through a wetland system and into Midmar Dam. Mpophomeni is approximately 4 km upstream of the Midmar Dam and it is a significant contributor of phosphorus and nitrogen entering the dam (Ngubane, 2016).

The main sources of pollution in the Mpophomeni area where the Mthinzima wetland is located are solid wastes in and around water courses, damaged and insufficient sewage infrastructure and surcharging sewage manholes which result in raw sewage flowing directly into the water course, and river bank erosion (GroundTruth, 2015; van Deventer, 2012). According to News24 (2009) some residents in homes close to the manholes complained about the smell and that their children often suffer from diarrhoea, rashes and sore eyes, whereas others have sold their homes and relocated. The cause of surcharging manholes and blockages may be a result of the insufficient sewage infrastructure operating beyond its design capacity. Results from hydrological studies that have monitored historical flows and water quality trends in the Mthinzima catchment have concluded that there has been an increase in nutrient loads and a deterioration of water quality entering Midmar over time, and that these changes are most likely a consequence of direct sewage entering the Mthinzima stream (Ngubane, 2016).

Ngubane (2016), collected nutrient data on the Mthinzima stream; dissolved inorganic nitrogen (DIN) loads in Mthinzima Stream showed increases between the years 1989 to 1992, from about two tons per year to approximately ten tons per year. During the period of 1992 to 1993, less than one ton per year was observed. A rapid increase during the period of 1995 to1996 was recorded, followed by a gradual decrease in the period of 1996 to 1999. Increases in DIN loads were also captured from the year 2010 to 2013 with the loads in this period having exceeded 10 tons per year. DIN showed to be less driven by the flow as DIN loads increased despite the decreasing flow. Soluble reactive phosphorus (SRP) and total phosphorus (TP) followed the same patterns as DIN (Ngubane, 2016), the difference was that TP was always found to have higher loads when compared to SRP. This is because TP comprises of all forms of phosphorus, including SRP. These loads showed an increase from 1988 to 1992 and a sharp decline in the period of 1992 to 1993 (Ngubane, 2016).

There are several areas of wetland within the Mthinzima catchment; rehabilitation plans have been developed for three of these areas. The first area of wetland rehabilitation is associated with new planned waste water treatment works infrastructure (in the area of the existing pump station) and the second area of wetland rehabilitation is associated with a proposed sewer line upgrade. The rehabilitation of these two areas of wetlands (Figure 3) are a condition of the environmental authorisation and water use license applications associated with planned (not yet built) sewerage infrastructure (WWTW) in Mpophomeni. These two wetlands will not be part of the analysis as a combination of them is small areas and post rehabilitation the flow of water through the system would be diverted away from the downstream wetland area where rehabilitation is proposed (GroundTruth, 2015). The two wetlands were also not part of the Save Midmar Dam project. A third area of wetland located downstream of Mpophomeni (and the R617 road) has also been proposed for rehabilitation (referred to as the Mthinzima wetland), this is the main wetland area of focus in this study. The location of the three wetland rehabilitation areas is shown in Figure 4.3 below.

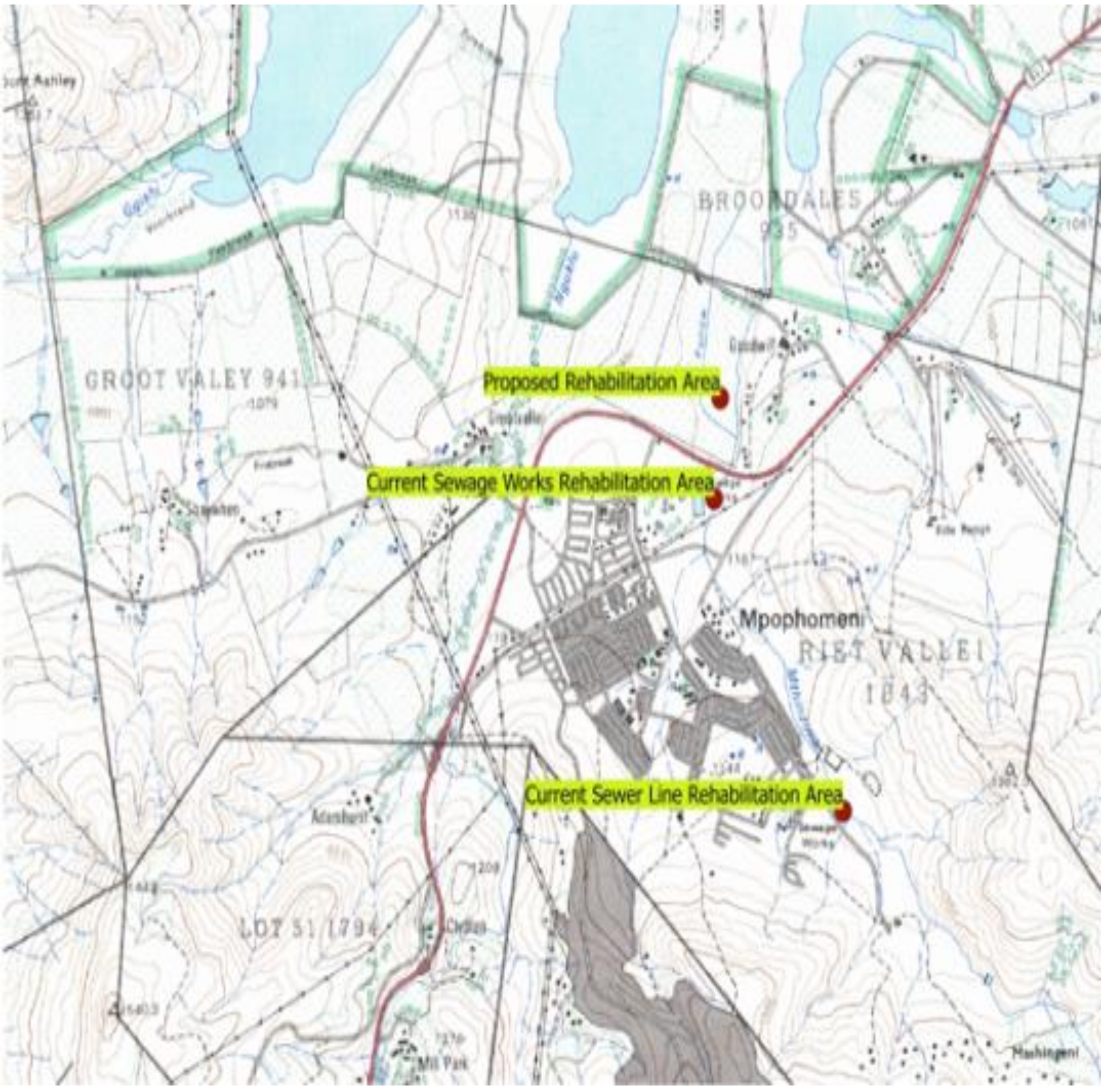


Figure 4.3. Location of the three wetland rehabilitation areas
Source: GroundTruth (2015)

Ecological infrastructure between Mpophomeni and Midmar Dam is valuable because the wetlands provide services that otherwise require engineered solutions. Although engineered infrastructure will be built for sewage treatment (Felton, 2016), wetlands in the area have an important insurance value. In the worst state of nature, the engineered infrastructure fails due to blockages, surcharging manholes and leakages. The Mthinzima wetland was listed as one of the high priority wetlands according to NFEPA – Rehabilitation Priority (Ground Truth, 2015). Figure 4.4 illustrated the location of the wetland area that will be evaluated for this study, which is followed by the rehabilitation strategy for the wetland area in Figure 4.5. This includes the engineered infrastructure that will also be built. The main aim of this rehabilitation was to maximise ecosystem services that are related to water quality enhancement.

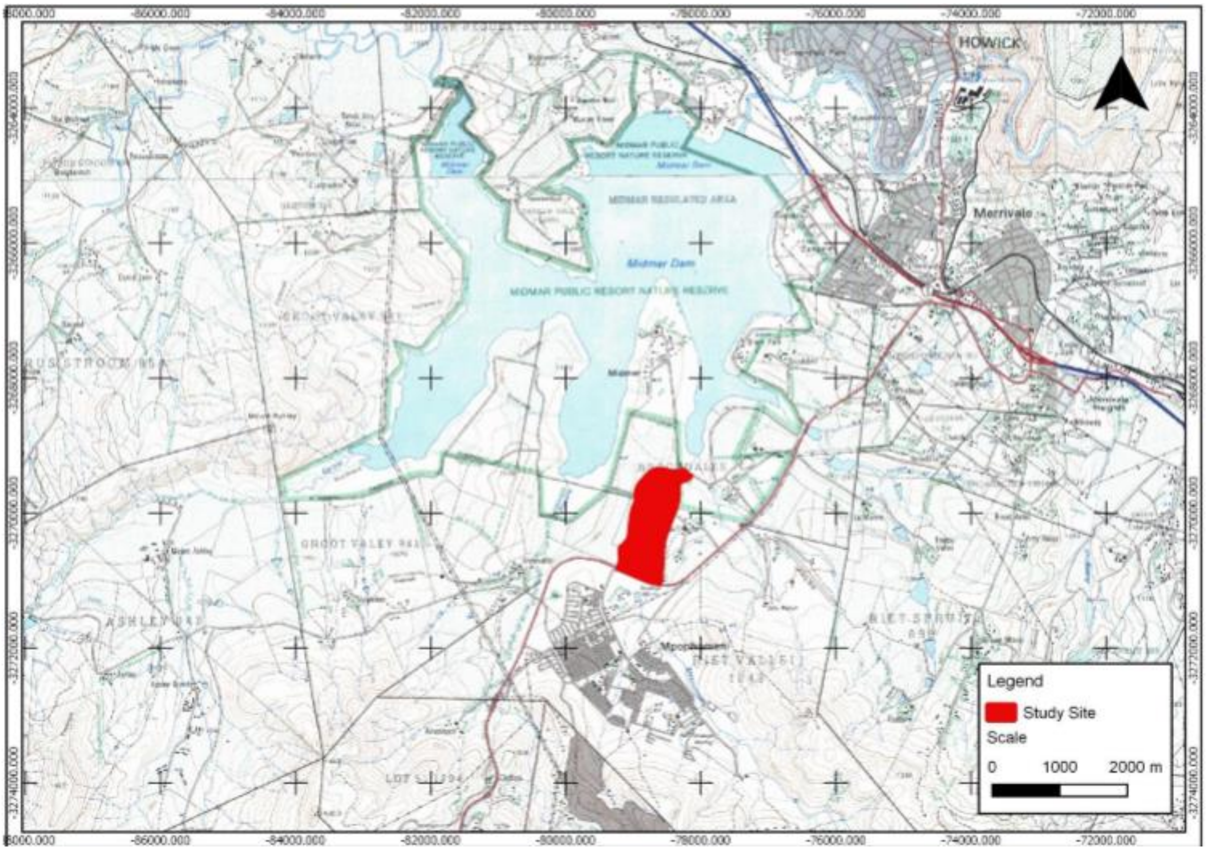


Figure 4.4. Location of the rehabilitation site for the focus of this study (Mthinzima wetland)

Source: Ground Truth, 2015

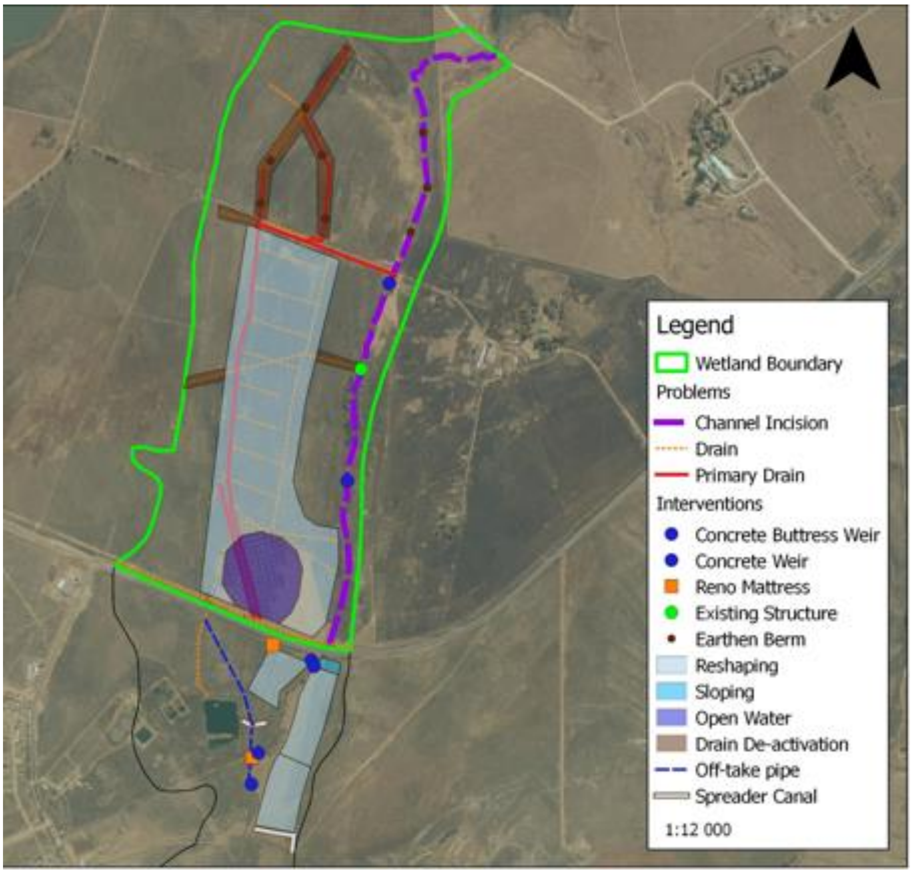


Figure 4.5 Map of Mphophomeni Wetland Rehabilitation Strategy

Source: Ground Truth, 2015

The land where Mthinzima wetland is located (Figure 4.5) is owned by the Zenzele Trust and the other wetland areas below the R617 is on land owned by the community (Ground Truth, 2015). It is primarily used for communal grazing of cattle. The grazing of livestock in the wetland can be a cause of soil erosion, and therefore, may contribute to degradation of the wetland. The objectives of wetland rehabilitation are summarized in Table 4.1.

Table 4.1 Potential Benefits of Wetland Rehabilitation

Direct benefits of wetlands	Indirect benefits of wetlands
Water Supply	Flood attenuation
Provision of harvestable resources	Stream flow augmentation
Socio-cultural significance	Erosion control
Tourism and recreation	Carbon storage
Education and research	Sediment trapping

Source. Ground Truth (2015)

4.2 The Proposed Waste Water Treatment Works (WWTW) in Mpophomeni

A WWTW authorisation was issued in 2014 by the Department of Agriculture and Environmental Affairs (DEA) under the uMgungundlovu District Municipality for construction of a WWTW adjacent to Mpophomeni. It was initiated by the proposed Khayalisha development which required that a new WWTW must be built to serve the new development and that it must meet specific treatment requirement (particularly on phosphates). The WWTW was proposed to cater for both Mpophomeni and Khayalisha, because the Howick infrastructure capacity was insufficient to handle the loads from Howick and Mpophomeni. A further requirement for the new WWTW was that all treated effluent would not be discharged straight into the Midmar Dam; it had to be discharged below Midmar Dam wall (Felton, 2016).

UMgungundlovu District Municipality plans to refurbish parts of the existing Mpophomeni WWTW and build a new WWTW infrastructure at the Remi/ Reit Vallei Farm 1043 in Mpophomeni. The WWTW will treat waste water from the Mpophomeni residential area, Khayalisha residential area which is still under development and the Khayalisha light industrial area. The WWTW will be built with a capacity to process six million litres of waste water per day and to further manage peak flows of 24 million litres per day (DEA, 2014).

The spec to minimize risk of sewage spillages from the proposed new WWTW

Overflows will take place at different points in the process and will be managed as follows:

Screened sewage will overflow upstream of the Inlet Works outlet measuring flume and will gravitate to the existing refurbished 2250kℓ Storm Overflow Pond. The maximum overflow rate will be 240 kℓ/h. An empty 2250 kℓ Storm Overflow Pond will fill up in 9.38 hours at the maximum overflow rate (DAE, 2014). It is considered unlikely that this overflow rate will continue for that amount of time, because new main sewers will be constructed for the Mpophomeni area and 30% of the sewer reticulation (Khayalisha and Mpophomeni reticulation refurbishment) will be new (DAE, 2014).

If the Storm Overflow Pond becomes full and wet weather overflows continue then provision is to be made to overflow the excess to the existing Maturation Ponds with a capacity of approximately 18 000 kℓ. It would take a further 72 hours at the maximum overflow rate to fill up these maturation ponds before any effluent spilled out of the maturation ponds towards Midmar Dam (DAE, 2014). It would take extreme and sustained storm rainfall conditions for this to occur.

Should the effluent quality suspended solids content worsen, then flows will be diverted just upstream of the Hybrid Maturation River directly to the existing maturation ponds. This attribute is not only an additional protection to the Hybrid Maturation River, but it also protects the Effluent Balancing Pond and subsequently the effluent disposal. If the flow diversion occurs, then it would take 3 days at an average flow rate to fill up the existing Maturation Ponds before overflows to Midmar Dam would occur. The prevalence of this occurrence is not predictable as it is determined by the equipment redundancy in the WWTW process. However, if it occurs, then the Maturation Pond will also provide some settlement and treatment before any effluent is discharged towards Midmar Dam (DAE, 2014).

Overflow from a full Effluent Balancing Pond will move to the existing Maturation Ponds. 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. Overflows that do occur will have been treated and effluent disinfected, so the system is designed to prevent direct discharge to Midmar Dam (DAE, 2014).

The pumped recycling of overflows will be a two-stage process as follows, 1) Recycling pumps will be provided in the effluent pump station to recycle waste water from the existing Maturation Ponds to the 2.25 Mℓ Storm Overflow Pond. A control system is to be implemented so that this recycle system does not overfill the Storm Overflow Pond. The proposed recycle flow rate is 160 kℓ/h. 2) The Recycle Pump Station from the previous WWTW will be refurbished and new Storm Recycle Pumps will be installed to recycle 160 kℓ/h from the Storm Overflow Pond to the Inlet Works. This flow rate was selected to provide a self-cleansing velocity of 1 m/s in the existing 250 mm recycle system pumping main effluent back to the Inlet Works. A control system will be implemented connected to the flow meter at the Inlet Works Measuring Flume to switch the pumped recycle system on and off depending on the measured inflow (DAE, 2014).

Umgeni Water will operate and maintain the WWTW. The expected lifespan of this civil engineering infrastructure is assumed to be 50 years. With the construction of the sewerage infrastructure and the Mpophomeni WWTW, overflows of raw sewage from the new WWTW into the Mthinzima wetland are highly unlikely. This will contribute positively to better water quality through the wetland (DAE, 2014). However, because not all problems in sewage infrastructure will be addressed (only the main sewer line will be rehabilitated, it is anticipated that there may still be sewage flowing into the Mthinzima system as only the main sewer line will be rehabilitated (Terry, 2017 *personal communication*).

4.3 Mthinzima Stream Flow Diagram

Two schematic diagrams of the Mthinzima system were developed to illustrate the flow of water in the system and the relationship between the stream and the infrastructure components of relevance in this study. Figure 4.6 below is an illustration of the current situation, while Figure 4.8 shows the expected scenario if the proposed new WWTW goes ahead. Figure 4.7 presents the photographs of the study area presented in the schematic diagrams. This flow diagram was also an attempt to establish the opportunity of the Mthinzima wetland in providing water enhancement service, given that the rehabilitation will take place in conjunction with the construction of the new WWTW. The flow diagram was compiled with assistance from Dr Terry, a scientist of uMngeni Water's Water and Environmental Services.

The Mthinzima Stream flows adjacent to the Mpophomeni settlement where it is met by a tributary that dissects Mpophomeni with the stream then flowing under the district road (R617), through the Mthinzima wetland system and into Midmar Dam (Figure 4.6). The formal Mpophomeni settlement forms a large portion of the Mthinzima sub-catchment and indeed the largest high-density urban development in the greater upper uMngeni catchment (van Deventer, 2012).

Several water quality issues have been identified within the Mpophomeni settlement and Mthinzima stream system. Currently the main pollutants that have been noted to have water quality impact within Mpophomeni range from solid waste in and around water courses, damaged and inadequate sewage infrastructure (existing sewage pump station), and surcharging sewage manholes. An old WWTW is located adjacent to the Mthinzima Stream. Historically, the WWTW treated domestic waste water from the Mpophomeni settlement; at present the WWTW is not operational (Figure 4.6), and the sewage from the township is currently pumped to the Howick WWTW.

The Upper Mthinzima (UM) is situated upstream of the Mpophomeni settlement. This area is semi-rural, has no formal sewer reticulation and some grazing takes place in the area. This part of the Mthinzima stream is relatively less disturbed. The Hlanga tributary (H-trib) dissects the Mpophomeni settlement before entering the main Mthinzima channel (Figure 4.6). The Middle Mthinzima (MM) is adjacent to and below the Mpophomeni settlement (Figure 4.6). This area receives urban run-off including raw sewage from the existing decommissioned WWTW, solid wastes, and storm water from Mpophomeni. The Lower Mthinzima (LM) is in the lower section of the Mthinzima Stream, including the inlet entering into the Midmar Dam (Figure 4.6). Studies have reported algal growth in this part of the Mthinzima stream (Ngubane, 2016).

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 (26ha), (ii) the wetland areas directly impacted upon by a proposed sewage pipeline (81ha), and (iii) a portion of wetland habitat downstream of the R617 road (the Mthinzima Wetland, 98ha). The wetland areas are described in detail in three wetland rehabilitation plan reports by GroundTruth consulting (GroundTruth, 2014, 2015). The rehabilitation of the portion of wetland habitat downstream on the R617 road is the focus of this study, represented as ‘Proposed wetland rehabilitation B’ in Figure 4.8. 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, the feeding of the system by artificial drainage systems associated with the upstream sewage infrastructure and lateral water inputs (GroundTruth, 2015b). In Figure 4.8. 'Proposed wetland rehabilitation A' represents the portion of wetland associated with the Waste Water Treatment Works.

In a water quality assessment of the stream, Van Deventer (2012) reported improvements in water quality from the sites immediately downstream of Mpophomeni (Figure 4.6. MM and H-trib) and the site at the Midmar inflow (Figure 4.6. LM). The existing wetland portion below the R617 road is located on the flow path leaving the old WWTW site and includes portions of wetland that have developed because of the persistent flows from the old WWTW (Terry, 2017 pers. com). The presence of the wetland in its degraded state could justify the reduction in some of the pollutants' concentrations, due to the purification functions of wetland systems (van Deventer, 2012). The water quality study of van Deventer (2012) found the quality of the water at the Upper Mthinzima site (UM) upstream of the formal Mpophomeni settlement to be better than at the lower sites. Water quality and ecological integrity were consistently the poorest over the sampling period at sites H-trib and MM suggesting Mpophomeni as the source of water quality impact (van Deventer, 2012).

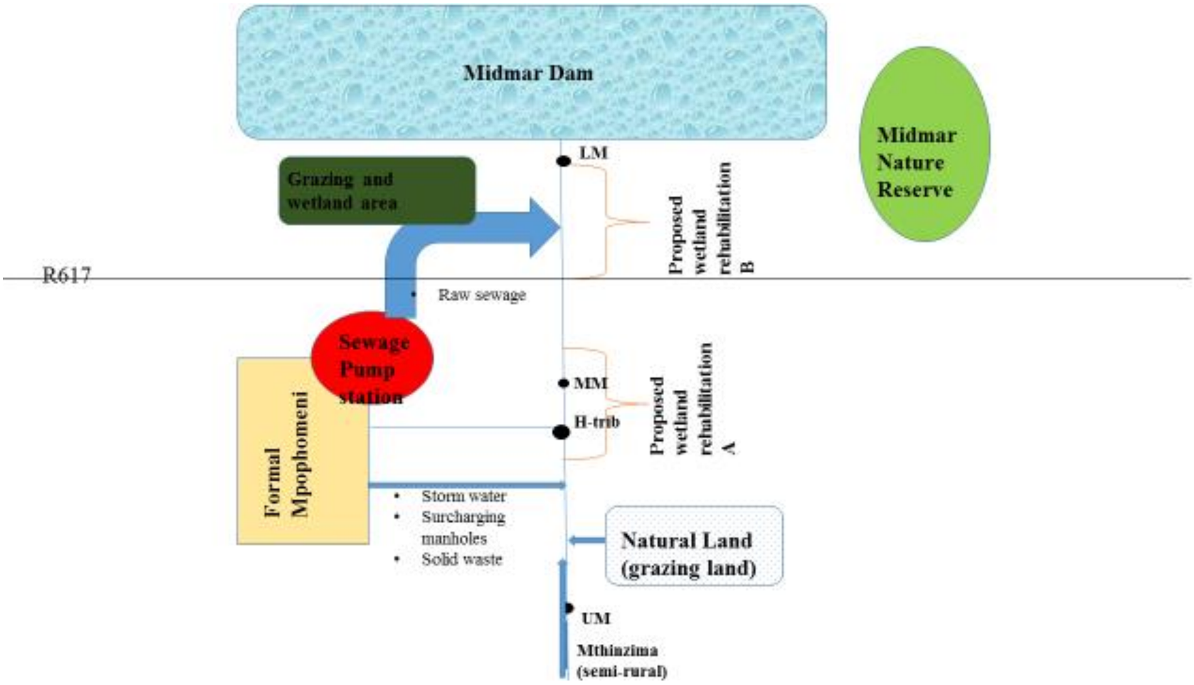
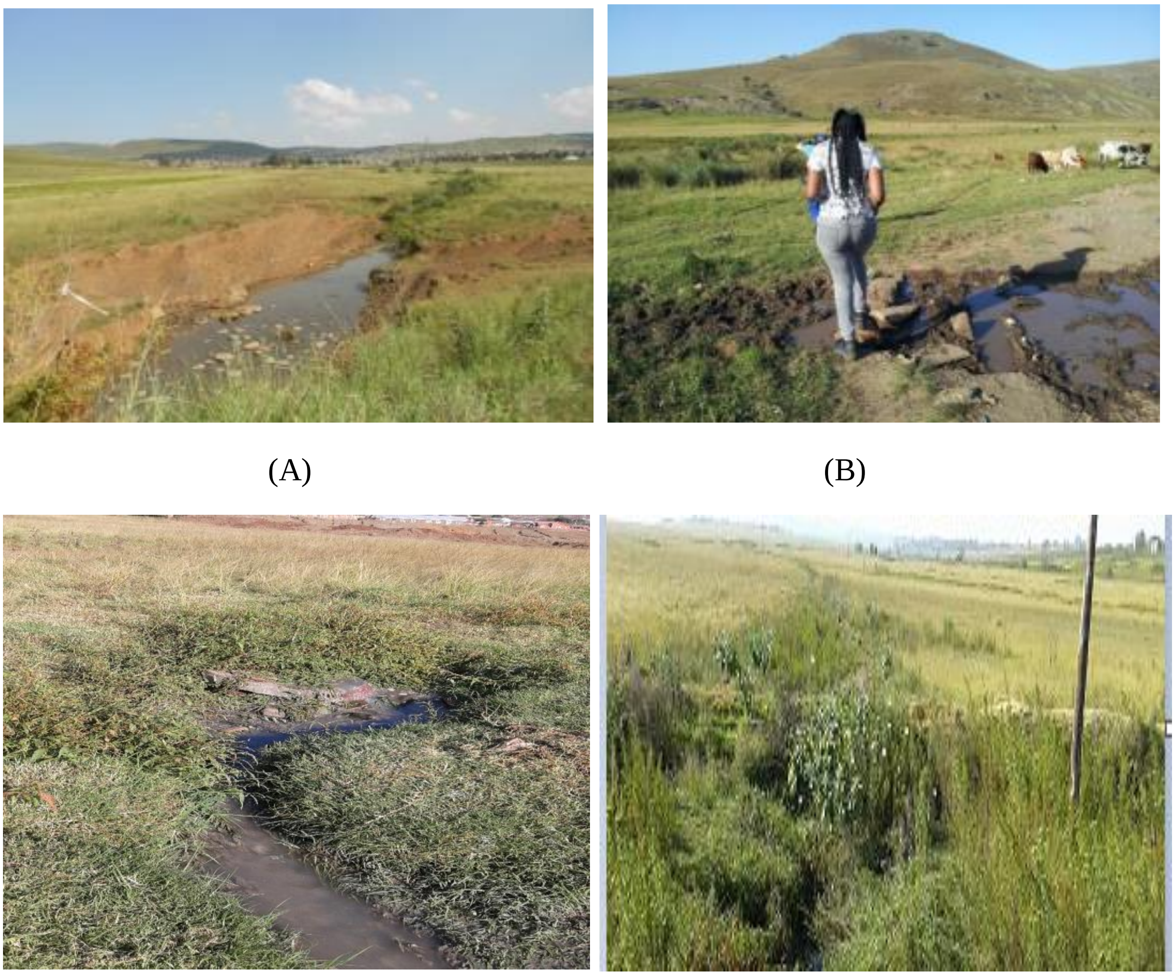


Figure 4.6. Schematic Diagram indicating flows from the Mthinzima stream to the Midmar Dam currently with no interventions.



(A) (B) (C) (D)

Figure 4.7. A and B - Mthinzima Stream, upstream of waste water pump-station infrastructure; C - Mthinzima Stream from the R617 Roadi; D - Mthinzima Wetland from the R617 Road, looking downstream towards Midmar Dam, 2017
Source. **Author Compilation**

The old Mpophomeni WWTW is to be upgraded by the uMgungundlovu District Municipality in KwaZulu-Natal. Included in the upgrade is the refurbishment of a sewer pipeline network adjacent to the Mpophomeni settlement between the settlement and the Mthinzima Stream in Figure 4.8. below.

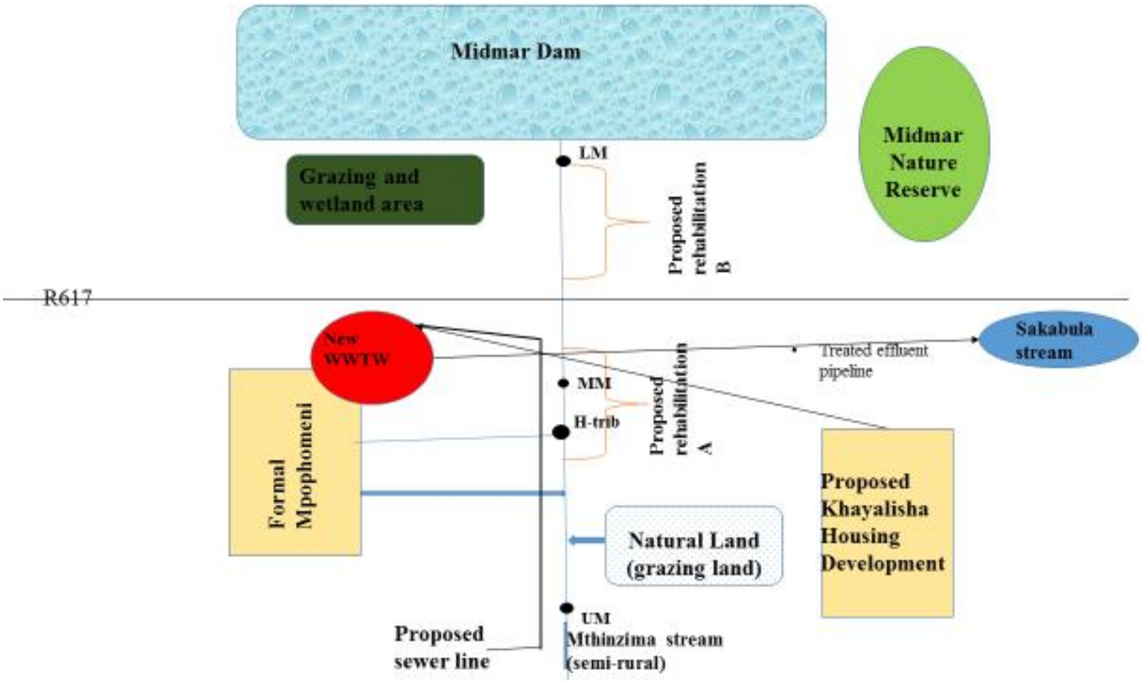


Figure 4.8 Schematic diagram of the Mthinzima with proposed interventions to improve water quality entering Midmar Dam

The WWTW (Figure 4.8) will treat waste water from sections of the Mpophomeni residential area that are on a piped sewerage system as well as from the proposed Khayalisha housing development which lies outside of the Mthinzima catchment. The new WWTW will have the capacity to process six million litres of waste water per day and will also be able to manage peak flows of up to 24 million litres per day. To minimize overflows, the existing wet weather storage dam will be refurbished to give extra storage of raw sewage when overflows exceed six million litres per day. In the event that peak flows continue, the wet weather storage dam will flow into a waste stabilisation pond. Treated effluent from the new WWTW will be pumped along a new pipeline from the Mpophomeni WWTW to the Sakabula Stream (Figure 4.8.) to be further polished (GroundTruth, 2015). Therefore, under normal conditions, no treated effluent will flow from the WWTW directly to the Midmar Dam.

Only the main sewer line (Figure 4.8) will be refurbished and not the entire Mpophomeni sewer pipeline network. Given the existing issues with the sewer network, it may be expected that raw sewage may still enter the Mthinzima Stream from surcharging manholes, and blockages and spillages from pipelines not rehabilitated as part of the proposed WWTW upgrade. Solid waste, some raw sewage and storm water from the Mpophomeni settlement will still continue to drain into the Mthinzima Stream.

From Figures 4.6 to 4.8 and water quality studies by Ngubane (2016) and van Deventer (2012), it can be concluded that there is an opportunity for water quality improvement within the Mthinzima system before the water reaches Midmar Dam even after the new WWTW is commissioned. This is the case as run-off from Mpophomeni settlement, surcharging manholes and failure of the poorly built sewer reticulation system, solid waste and other discharges not linked to the sewer reticulation system will still end up in the Mthinzima stream and transported to the Midmar Dam.

CHAPTER 5. RESEARCH METHODOLOGY

This study focused on the analysis of economic benefits of investments in wetland rehabilitation as there was insufficient information on the impact of water quality in Midmar Dam and its consequent effect on the economy is unavailable. The study evaluated if society would be better (or worse off) as a result of an ecological infrastructure investment project through the rehabilitation of the Mthinzima wetland.

Measuring value of ecological infrastructure is important in determining the optimal levels of pollution and in cost-benefit analysis (Sikhakhane, 2001). When determining the optimal levels of pollution, the focus is on the marginal costs of reducing pollution. These are costs of reducing the quantity of pollution emitted into the environment, i.e., the costs of preventing pollution that would otherwise affect the water quality. Marginal damages are the result of environmental degradation which are determined by relating human exposure to water pollution. The impact on health, treatment costs and recreational activities as a result of poor water quality are measured and then valued to give an estimate of the benefits of reducing pollution (improving water quality).

The economic cost benefit analysis was chosen for this study to analyse whether investment in the rehabilitation of Mthinzima would be worthwhile. The cost-benefit analysis that was proposed in this study, was based on comparing the estimated benefits and costs of a particular improvement in the water quality of the Mthinzima Stream before it reached Midmar Dam. The study focused on incremental change in ecological services as a result of the wetland rehabilitation investment considering the potential to supply, demand and opportunity to supply.

5.1 Economic Cost benefit analysis

Traditionally the cost benefit analysis (CBA) was developed in the 1930s to analyse large public investments in the water sector in the United States (Dixon, 2012). The goal was to simply analyse if a project yielded positive net benefits over time. With more experience in project CBA, it was noted that important environmental and social impacts were being ignored (Dixon, 2012). Actions to expand the CBA of projects was taken, the first step was the inclusion of environmental (and social) aspects in a qualitative manner. Another step was to use monetary valuation since projects were developed and implemented to increase social welfare (usually measured in monetary terms), it would also be easier to analyse alternative projects, mitigation measures, and remaining impacts if all of the benefits and costs, financial and environmental could be measured using monetary valuation (Dixon, 2012).

The main aim of economic cost-benefit analysis is to examine whether society will be better off if a particular project or policy is implemented. Cost-benefit analysis can address both the quantifiable and non-quantifiable effects of environmental degradation (Barbier *et al.*, 1997). The cost-benefit analysis assesses the costs and benefits involved usually in restoring or protecting ecosystems. This entails attaching a numerical value, examining all of the measurable benefits and costs, and then comparing them (King and Mazzotta, 2000). Non-quantifiable effects are measured using consumers preference. Therefore, a single policy or project may be evaluated to examine if it provides net benefits to society as a whole. The cost-benefit analysis can also be used to determine which policy or project would provide the most economic benefits to society when there are different policy or project options available (King and Mazzotta, 2000). The cost-benefit analysis seeks to find the best alternative with the greatest net economic benefit.

Measuring value is important in determining and regulating acceptable levels of pollution and also in cost-benefit analysis. Determining the most acceptable levels of pollution uses the concept of marginal pollution reduction costs: these are the costs of reducing the amount of pollution that is discharged into the environment which are the costs incurred in putting up measures that would reduce pollution discharged into the environment. Marginal damages are determined by making a connection between human exposure to environmental pollution (Sikhakhane, 2001). The impact of environmental pollution subjection to humans exposed to it may be health, aesthetic or recreation impact, thus, these effects are valued to give an approximate value of the benefits of reducing pollution (improving water quality). In cost-benefit analysis, the main aim is to compare all the estimated benefits and costs of a particular project (Dixon, Scura, Carpenter & Sherman, 1985 cited by Sikhakhane, 2001).

The value of environmental services such as improved water quality by wetlands gives an estimate of the benefits of those services to society. When estimating benefits, individuals are said to benefit from a particular environmental project/policy if they are better-off than they were before the policy or project was implemented. The benefits of ecosystem services are valued based on what individuals are willing to pay (WTP) for that environmental service (such as improvements in water quality).

The use of WTP to measure what individuals are willing to pay for environmental services is based on individuals' preferences where consumers are assumed to be rational individuals and they are likely to show preferences for one product over another. Individual preferences are measured as factors that are correlated to income. Individuals often place a value on a product they consume depending on the utility they obtain from consuming the product, therefore the value will be what the individual is willing to pay for that product. The estimated individual's WTP gives an estimate of the benefits of that good being made available to that individual - for example, better quality drinking water and clean air (Dixon *et al.*, *1985* cited by Sikhakhane, 2001). Economic values are based on society's preferences, therefore they may not be the best ecologically, for a particular ecosystem (King and Mazzotta, 2000).

Discounting is the process of determining the present value of an investment that is to be received in the future. Discounting is often applied when conducting a cost-benefit analysis for two main reasons. It is applied to benefits received and costs incurred because people predominantly prefer to receive benefits sooner rather than later, and to pay costs later rather than sooner (King and Mazzotta, 2000). This is an application of the time value of money concept (Barry *et al*, 2000), which explains that a rand received tomorrow is worth less than a rand received today due to inflation, risk and opportunity cost.

When conducting a cost-benefit analysis for natural resources the discount rate should reflect society's preferences for allocating natural resource use over time. However, determining the social discount rate is often not easy because people have different preferences. The choice of discount rate is important as it may influence the results of a cost-benefit analysis (King and Mazzotta, 2010). The greater the discount rate, the greater the weight of the present compared to the distant future, and therefore, benefits to the current generation are given more weight than benefits to future generations (King and Mazzotta, 2010). Some have argued that a social discount rate that is lower than the market rate is preferred for environmental projects because it would leave more opportunities for the future generations; often it is the government that sets the discount rate.

Intra-generational discounting is best when used to analyse costs and benefits that result from an investment over a relatively short period of time. The approach does not explicitly account for the long-time horizons and impacts of an investment decision on future generations. The inter-generational discounting approach is best suited for discounting future costs and benefits derived from an investment over long term periods, in which the impact of which will spread over more than a generation. The inter-generational discounting approach is commonly used for discounting long term effects such as climate change (Mullins *et al*. 2014). For the purpose of this study, the inter-generational discounting approach will be used as wetland rehabilitation investment is a long-term investment with an expected life span of 20 - 40 years.

When choosing an appropriate social discount rate, the following should be considered: economic literature, rates in other countries as shown in Table 5.1 below, and rates used by international development institutions. Table 5.1 below provides a survey of the social discount rates used by different countries around the world. From Table 5.1, discount rates differ amongst countries and institutions. The difference in discount rates in different countries may be due to society's time preferences. Developing countries use relatively higher discount rates relative to developed countries, this may be explained by the fact that developing countries have a capital shortage compared to developed countries, different inflation rates and other factors (Mullins *et al*. 2014).

Whilst various approaches have been used to estimate the real social discount rate for South Africa, Luus and Mullins (2008) found that most of these estimates ranged between 8.4% and 9.6% in real terms. When using historical per capita income and expenditure data for South Africa and global empirical research on pure discount rates, a Social Time Preference Rate method (STPR) of 8.35% was determined. A real discount rate of 8% is used in project evaluations in the public sector (Mullins, 2014). The 8% discount rate would also be closer to the theoretically argued and calculated rates based on opportunity costs and time preferences (Mullins, 2014). Therefore, it seems appropriate to use 8% as the applicable real discount rate for South Africa. From the above motivation, this study used an 8% discount rate in valuing the Net Present Value of investment in wetland rehabilitation. Lower discount rates of 5% and 3% were also be used for purposes of sensitivity analysis.

Table 5.1. Different real social discount rates of selected countries and institutions

Country	Discount Rate (percent)	Theoretical Basis
Philippines	1991: 8% : SOC rate annually reviewed	SOC approach
Canada	10%	SOC approach
Peoples Republic of China	8% for short term and medium term projects: lower than 8% for long term projects	Weighted Average Approach
France	Real discount rate set since 1960:set at 8% in 1985 and 4% in 2005	1985 : To keep a balance between public and private sector investment
Germany	1999 : 4% 2004 : 3%	Based on federal refinancing rate, which was over the late 1990s was 6% nominal: average GDP deflator (2%) giving 4% real.
India	12%	SOC Approach
Italy	5%	SRTP Approach
New Zealand	10% as a standard rate whenever there is no other agreed sector discount rate	SOC Approach
Norway	1978 : 7% 1998: 3.5%	Government borrowing rate in real terms
Pakistan	12%	SOC approach
Philippines	15%	SOC approach
Spain	6% for transport : 4% for water	SRTP approach
United Kingdom	1967 : 8% 1969 : 10% 1978 : 5% 1989 : 6% 2003 : 3.5% Different rates lower than 3.5% for long term projects over 30 years	SOC approach until 1980s; thereafter SRTP approach
US (Office of Management and Budget)	Before 1992 : 10%;after 1992 : 7%	Mainly SOC approach
US (Congressional Budget Office and General Accounting Office)	Rate of marketable Treasury debt with maturity comparable to project span	SRTP approach
US (Environmental Protection Agency)	Intragenerational discounting: 2-3% subject to sensitivity analysis in the range of 2-3% and at 7%. Intergenerational discounting : range of 0.5-3% and at 7%.	SRTP approach

Source: Asian Development Bank (ADB). (Zhuang *et al*., May 2007, cited by Mullins *et al*., 2014).

5.1.1 With and without scenario

To evaluate the benefits of wetland rehabilitation, four scenarios were developed (Table 5.2), which were; the current scenario with no intervention, 'with rehabilitation only' – this was the scenario where rehabilitation would be implemented without new WWTW – and 'without rehabilitation' – this was the scenario with the new WWTW without the wetland rehabilitation, *ceteris paribus* and the final scenario with both wetland rehabilitation and new WWTW. Focus group experts agreed that there had to be an intervention in place to improve the water quality from the Mthinzima stream before it reaches the Midmar Dam. The participants agreed that if everything was left the same, the water quality in the Midmar Dam would become worse and might reach the eutrophic rate faster. It was further agreed that it was vital to treat water before it reached Midmar Dam. At the time of this research the wetland was degraded, and no rehabilitation work had been undertaken. Since the engineered waste water treatment infrastructure was to be built in conjunction with the wetland rehabilitation, the fourth scenario (Table 5.2) did not consider a lag between the rehabilitation of the wetland and commissioning of the new WWTW.

Table 5.2. Scenarios to assess proposed investments in wetland rehabilitation assuming the demand for water quality improvement is constant

		Wetland Rehabilitation	
		Without	With
WWTW	Without	Current value of wetland (1) o Current opportunity o Current capacity to supply o Current value	Value with no WWTW but with rehabilitation of wetland (2) o Same opportunity o Increased capacity to supply
	With	Value with no wetland rehabilitation but WWTW (3) o Different opportunity o Same capacity to supply	Value with both interventions (4) o Decreased opportunity o Increased capacity to supply

(Scenarios)

The first scenario was counterfactual because it was the current state of the wetland. It was used to compare changes with the other scenarios as it was known with more certainty. Therefore, the second scenario was whereby only the engineered infrastructure was implemented. The third scenario quantified the change as a result of wetland rehabilitation, and the fourth scenario assumed that both the new engineered infrastructure and wetland rehabilitation were implemented (Table 5.2). The main water quality effects as the result of wetland rehabilitation were evaluated which included a marginal change in water quality and the implications it has for Midmar Dam.

The study analysed the value of change in the Mthinzima wetland with the new engineered infrastructure and wetland rehabilitation (scenario four) to estimate the loss of value due to decreased opportunity attributed by the new WWTW. The 'with rehabilitation' scenario quantified the risk mitigation value (the role of ecological infrastructure to act as a safety net in cases of uncertainty) of the Mthinzima wetland. It also looked at the protection and maintenance of the Mthinzima wetland; without protection of the investment in ecological infrastructure, the rehabilitation of the wetland would not be worthwhile. Since the risk mitigation value of the wetland was unknown, alternatives for achieving the same level of water quality enhancement as provided by the rehabilitated wetland were further researched in this study. The without rehabilitation scenario considered the risk of no rehabilitation to the functioning of Midmar Dam.

This section details a tentative approach to estimating the potential additional water quality enhancement service of the rehabilitated wetland (wetland rehabilitation outcome). Additional work/investigation was needed to test the assumptions made in this chapter and to improve the confidence of the estimates. The focus was on the nutrient retention service of the wetland, considered a priority considering the risk of eutrophication of Midmar Dam.

GroundTruth undertook a Present Ecological State (PES) assessment of the wetland with the focus on hydrology, geomorphology and vegetation. The results of the PES showed that there had been extensive modification, associated with historic agriculture and infrastructure within the wetland systems and the surrounding landscape. Post rehabilitation the estimated ecological integrity of the wetland would be moderately modified with a reasonable change in ecosystem processes. Loss of natural habitat had taken place in the wetlands' current degraded state but post rehabilitation, the natural habitat would remain predominantly intact (GroundTruth, 2015:19). Hectare equivalents were used to evaluate the ecological outcomes of wetland rehabilitation interventions (Cowden and Kotze, 2007 cited by GroundTruth, 2015).

Hectare equivalents were used as the ‘currency’ for assessing the loss of and/or gains in wetland integrity under different scenarios and were derived from assessments of wetland conditions with and without rehabilitation using the WET-Health assessment tool (Macfarlane *et al.*, 2008). As part of the wetland assessments undertaken by GroundTruth in developing the Mthinzima wetland rehabilitation plan, hectare equivalents were calculated: “Post-rehabilitation, the improved PES would lead to a gain in hectare equivalents of 10.78ha” (GroundTruth, 2015:20); an increase of 10.78ha of functional wetland habitat as a result of the rehabilitation (Figure 5.1). In this case, the gain in functional wetland area (10.78ha) was proposed as a base for estimating the potential additional water quality enhancement service (nitrogen assimilation and phosphorus removal) as a result of the rehabilitation interventions.

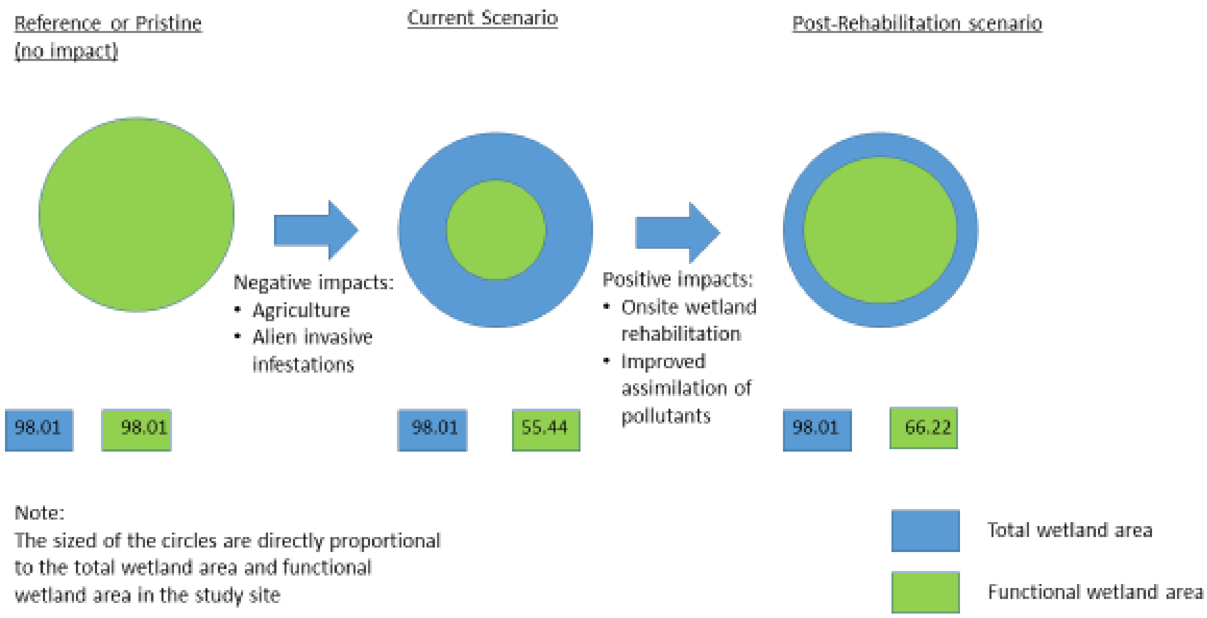


Figure 5.1. Graphical representation of the wetland area post rehabilitation
Source. GroundTruth (2015:21)

5.1.2 Identifying and quantifying costs and benefits of wetland rehabilitation

Wetlands provide a stream of benefits for human well-being, such as water quality enhancement for human consumption and flood control. Ecosystem services which are essential for human well-being have not had priority in policy decision making for their investments and conservation. This may be due to the fact that in today's developing world, high technologies and global transport of food and other commodities (Kotze *et al*, 2008) are prioritised more than ecosystems and their ecosystem services. This is because these commodities have markets and are relatively easy to quantify. The wetland ecosystem services framework of Kotze *et al*. (2008) was used to identify the benefits of wetland rehabilitation. Table 5.3 below shows ecosystem services that are generally supplied by wetlands and the benefits they provide.

Table 5.3. Ecosystem services assessed in WET-EcoServices[1]

Ecosystem services supplied by wetlands	Indirect benefits	Regulating and supporting benefits	Flood attenuation		The spreading out and slowing down of floodwaters in the wetland, thereby reducing the severity of floods downstream
			Streamflow regulation		Sustaining streamflow during low flow periods
			Water quality enhancement benefits	Sediment trapping	The trapping and retention in the wetland of sediment carried by runoff waters
				Phosphate assimilation	Removal by the wetland of phosphates carried by runoff waters
				Nitrate assimilation	Removal by the wetland of nitrates carried by runoff waters
				Toxicant assimilation	Removal by the wetland of toxicants (e.g. metals, biocides and salts) carried by runoff waters
				Erosion control	Controlling of erosion at the wetland site, principally through the protection provided by vegetation.
			Carbon storage		The trapping of carbon by the wetland, principally as soil organic matter
	Direct benefits	**Biodiversity maintenance[2]**			Through the provision of habitat and maintenance of natural process by the wetland, a contribution is made to maintaining biodiversity
		Provisioning benefits	Provision of water for human use		The provision of water extracted directly from the wetland for domestic, agriculture or other purposes
			Provision of harvestable resources		The provision of natural resources from the wetland, including livestock grazing, craft plants, fish, etc.
			Provision of cultivated foods		The provision of areas in the wetland favourable for the cultivation of foods
		Cultural benefits	Cultural heritage		Places of special cultural significance in the wetland, e.g. for baptisms or gathering of culturally significant plants
			Tourism and recreation		Sites of value for tourism and recreation in the wetland, often associated with scenic beauty and abundant birdlife
			Education and research		Sites of value in the wetland for education or research

[1] The wetland benefits included in WET-EcoServices are those considered most important for South African wetlands and which can be readily and rapidly described. These do not include all wetland services, other benefits include groundwater recharge and discharge biomass export, which may be important but are difficult to characterize at rapid assessment level.

[2] Biodiversity maintenance is not an ecosystem service as such, but encompasses attributes widely acknowledged as having potentially value to society.

Source. Kotze *et al*. (2008)

Table 5.4 and 5.5 highlight the ecosystem services valued for the Mthinzima wetland case study. Water quality was the key challenge in the catchment area, therefore, the focus and main objective of this study was based on the improvement of water quality. Consequently, the ecosystem services that were of focus for the purpose of this study and proposed rehabilitation were those that were linked with a change in water quality. These benefits were expected to result from the rehabilitation of the Mthinzima wetland (Table 5.4).

When selecting ecosystem benefits to use for this particular study, three elements were considered. Supply, Opportunity and Demand must consider incremental change in ecosystem service. The supply considered the ability to increase the potential to supply services by way of rehabilitation. The opportunity determined whether there were pollution levels that exceeded the current capacity of the wetland to provide water quality improvements. Therefore, the incremental increase in supply must increase water quality, at least some of the time. The increase in water quality must be valued/ provide benefit to at least one individual (demanded).

Table 5.4. Benefits of ecosystem services derived from rehabilitation

Ecosystem service benefits	**Ecosystem services**	**Economic Valuation**	**Reference**
Water quality enhancement • good quality drinking water and maintained recreational potential for Midmar Dam • avoided water treatment costs	Sediment trapping Phosphate assimilation Nitrate assimilation Toxicant assimilation Erosion Control	Replacement Cost Method	(Turpie and Kleynhans, 2010), (Dubgaard, 2004)
Risk Mitigation in a worst-case scenario (sewerage spills, blockages) • Insurance value	The wetland has the potential to act as an insurance when the engineered infrastructure fails	Damage Costs Avoided	(Turpie and Kleynhans, 2010)

The Replacement Cost Method was used to value the wetland's water treatment functions. Wetlands have the ability to absorb nutrients and slow down water flows which allows particles to settle down on the bottom. Wetlands can absorb approximately 96% nitrogen and 97% phosphorus (Bolund and Hunhammar, 1999), thus improving water quality. This approach considered the costs that was saved in terms of treatment costs of water. The actual use of the wetland service was estimated because even with the engineered infrastructure the wetland would be improving water quality from agricultural run-off and storm-water run-off from Mpophomeni settlement. Water quality is of high importance in South Africa because of the scarcity of it and a large number of people, especially in rural areas, directly rely on rivers, it was reasonable to assume that good water quality was demanded in all systems (Turpie and

Kleynhans, 2010). From these findings, the study assumed that treating water before it entered the Midmar Dam was preferred to treating poor quality water abstracted from Midmar Dam as a result of eutrophication. The assumption of treating water before it reached Midmar Dam was important for Midmar Dams recreational and sporting activities/events, and mainly for delaying eutrophication of Midmar Dam.

5.1.3 The estimation of rehabilitation costs

The land where the rehabilitation was going to take place was used as communal grazing land, for the rehabilitation investment to provide long-term benefits the area had to be managed sustainably or monitored in order for the rehabilitation to not be degraded by the grazing of cattle. The engineers involved in the rehabilitation planning specified that the rehabilitation would be built in a way that reduces the impact of cattle grazing the rehabilitation structures. Table 5.5 below shows a summary of the costs with their valuation criteria.

Table 5.5. Costs for the CBA for evaluation of Mthinzima wetland rehabilitation

Costs	Economic Valuation	Reference
Maintenance and Protection costs	Direct Costs of Maintenances/Protection	(Dubgaard, 2004)
Project Cost	Investment Cost Costs associated with surveying, designing and construction work. These costs will also include the costs of obtaining environmental permits and licences to undertake the rehabilitation.	(Dubgaard, 2004), (Jansen, 2005)

5.1.4 Net Present Value method

The Net Present Value (NPV) method values the difference between the social benefits and social costs (the net Benefit/cost) in the specified year/s, discounted to the present by using the social discount rate. The discounted sum of all these net benefits over the economic project life is defined as the net present value (NPV) of the project.

$$\textbf{NPV} = \sum Bj/ (1 + i)^{j} - \sum Cj/ (1 + i)^{j}.$$

Where:

B = Stream of Project benefits

C = Stream of Project Costs

i = Discount rate

j= 1… 20, 30 and 40 years

Usually this criterion is used when there is more than one project option to choose from, a project with the highest or positive NPV is selected; therefore, normally funds would be invested into the project only if the analysis produced a positive net present value (Mullins *et al*. 2014). For the purposes of this study, there were no alternative project options, the NPV determined if investing in wetland rehabilitation was an economically worthwhile investment based on the expected water quality improvement benefit. However, in reality there is always an option of not investing, therefore the benefits and costs are incremental costs and benefits.

5.2 Replacement cost method

The study reviewed several ecological services valuation approaches and found that approaches of valuing on-farm effects of ecological services were not particularly relevant. The travel cost cannot always attribute all recreational value to ecological services. It was also difficult to estimate the value of ecological services in an expected outcomes assessment as there were many uncertainties.

Therefore, the value of the increased water treatment capacity of a rehabilitated wetland was evaluated using the replacement cost approach. The underlying assumption was that treating water before it reached the Midmar Dam was preferred to the consequences of declining water quality within the dam, including treating poor-quality water abstracted from Midmar. The replacement cost approach entails quantifying the removal of pollutants or nutrient loads by the wetlands in the study area and estimating the equivalent cost of performing this service with human engineered systems or other alternatives which would be the next best alternative (perfect or close substitutes). Relevant data was needed to start the cost and benefit analysis and more information required for the analysis was obtained from other disciplines such as hydrologists and engineers that were involved in the Umgeni Ecological Infrastructure Partnership (UEIP) and other various consultants.

5.3 Data

Information and data was gathered from various sources. 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 discussed in detail in the methodology chapter. Meetings with relevant representatives of uMgungundlovu Municipality were held to get more information on the study area and the decision to rehabilitate the wetlands.

Local planning and economic development documents were used for data purposes. Other interviews were held with GroundTruth (wetland consulting firm), to get more details and understanding of the rehabilitation plan of 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:

- Published scientific research
- Umgeni Ecological Infrastructure Partnership (UEIP)
- Personal correspondence (telephonic and e-mail interviews)

5.4 Expected water quality enhancement services of the rehabilitated wetland

There were several alternative methods that could be applied in Mthinzima to replace the wetland services associated with water quality enhancement. Wetland services include a habitat for species, protection against floods, water purification, amenities and recreational opportunities. This study focused mainly on the water purification service. These services often have no market price and a measure of their values can only be obtained through non-market valuation techniques (Woodward and Wui, 2001). Many wetland valuation studies have been conducted and the range of these estimates have been very high and although some general trends are beginning to emerge, the prediction of a wetland's value based on previous studies remains highly uncertain and therefore, there is a need for site-specific valuation (Woodward and Wui, 2001).

GroundTruth (2015), assessed Mthinzima's valley-bottom wetland ecosystem services using the following rating outlined by Kotze *et al*. (2008) below:

- <0.5 Low
- 0.5-1.2 Moderately Low
- 1.3-2.0 Intermediate
- 2.1-2.8 Moderately High
- >2.8 High

Table 5.6. Summary of changes in ecosystem services for Mthinzima currently and post-rehabilitation

Ecosystem service	Current Scenario	Post-rehabilitation	Change in the supply of ecosystem services
Flood attenuation	2.4	2.4	0
Stream flow regulation	3.0	3.2	0.2
Sediment trapping	2.9	2.9	0
Phosphate trapping	2.6	3.1	0.5
Nitrate removal	2.8	3.3	0.5
Toxicant removal	2.8	3.3	0.5
Erosion control	1.9	2.7	0.8
Carbon storage	1.3	2.3	1.0
Maintenance of biodiversity	3.0	3.0	0
Water supply for human use	1.3	1.4	0.1
Natural resources	2.2	2.2	0
Tourism and recreation	0.6	0.6	0

Education and research	0.3	0.3	0

Source. GroundTruth (2015:22)

The above table highlights that the highest scores are linked to water quality enhancement; this reflects that with rehabilitation there is an expected increase in the ability of the wetland to supply this service. Overall, it was perceived that the rehabilitated wetland would supply the above-mentioned ecosystem services at intermediate to high levels. The wetland would play an important role in enhancing water quality in the landscape.

Table 5.7 shows the estimated nutrient loads to Midmar Dam and the Hartbeespoort Dam for comparison. The height of Midmar Dam is 30m with the length of 1 423m, the size of Hartbeespoort Dam is 59m in height and 1923m in length. The study by Ngubane (2016) showed that there has been an increase in nutrient loads compared to other earlier studies (van Deventer, 2012) in the area. Given the measured loads of nutrients to Midmar Dam from the Mthinzima Stream, there was an opportunity for the wetland to provide this service.

Table 5.7. Estimated nutrient loads to Midmar Dam, 1983-2013

Study Area and location	Total Phosphorus (TP) kg/ year	Total Nitrogen (Ammonia + Nitrite + Nitrate) kg/ year	Form of Nitrogen
Midmar Dam (Ngubane, 2016) **Nutrient loads from UMG, MTH, and LIO[a]**			
Average	8300	34900	DIN[b]
Maximum	22800	121300	DIN
Annual	10699	29000	DIN
Mthinzima input Only	<500 to 5500	1500 to 13000	DIN
Loads to Hartbeespoort Dam (HBS) **Dudula (2008)**			
Loads (kg/yr)	316000	2330000	Total Nitrogen

[a]UMG, MTH and LIO – Umgeni river, Lions river and Mthinzima Stream [b]DIN – dissolved inorganic Nitrogen

Source: Produced from Ngubane (2016) and Dubula (2008)

Although site-specific valuation and data are preferred when evaluating a wetland, there was an absence of measured data of the nitrogen and phosphorus removal rates of the Mthinzima wetland, removal rates from the literature were applied. A few long terms studies and monitoring results of nitrogen retention of wetlands in KwaZulu-Natal (and South Africa) were available. Applying retention rates from the literature introduced considerable uncertainty and thus reduces the confidence of the estimates. This study will relied on past literature to obtain the most conservative estimates for the removal rates of nitrogen and phosphorus by wetlands.

Below, Table 5.8 and Table 5.9 give preliminary comparisons of nitrogen and phosphorus removal rates by wetlands from the literature respectively.

Table 5.8. Wetland nitrogen removal rates from various literature sources

Reference (Source)	Measurement	Removal rate (kg/ha/year)	Range (kg/ha/year)	Location
Land (2016)	Median, N=255	930	-3 to 12700	Multiple – mostly North America and Europe
Land (2016)	Median, N=4	69	-3 to 337	Multiple – Europe
Turpie *et al.* (2010)	Estimated average	1594	307 to 9505	South Africa
Verhoeven *et al.* (2006)	3 studies	N/A	1000 to 3000	Temperate zones

Table 5.9. Wetland phosphorus removal rates from various literature sources

Reference (Source)	Measurement	Removal rate	Range (kg/ha/year)	Location
Land (2016)	Median, N=146	12	-168 to 2400	Multiple – mostly North America and Europe
Land (2016)	Median, N=6	2.43	-12 to 24	Multiple – Europe
Turpie *et al.* (2010)	Estimated average	0	0	South Africa
Verhoeven *et al.* (2006)	3 studies		60 to 100	Temperate zones

The range of removal rates of nitrogen and phosphorus from literature was broad across all the studies reviewed. Land *et al*. (2016) showed that in some instances, wetlands may add nutrients instead of removing them, therefore, there were factors that affected nitrogen removal from wetlands.

5.5 Identification of the next best alternative to provide wetland services

This section provides possible alternative options to wetland rehabilitation for enhancing water quality in the Mthinzima stream before it reaches Midmar Dam. These alternatives were suggested by hydrologists, environmentalists and other experts interviewed in focus group meetings. The replacement cost valuation approach was used to value the water quality enhancement benefit of the wetland. The replacement cost estimate reflects a lower-bound of the value of the benefit. Strictly, three conditions must hold for the approach to be valid: (1) the alternative used has to be the perfect substitute of the wetland - replacement service must be equivalent in quality and magnitude to the ecosystem service; (2) the replacement must be the least cost option of replacing the service; and (3) there is a demand for that alternative - people would actually be willing to pay the replacement cost to obtain the service (Shabman and Batie, 1978 cited by Sundberg 2004).

In this study, the following points were noted with respect to the three conditions:

1. Identifying the perfect substitute for the replacement service involved identifying the cost of alternative removal and remedial actions should the wetland rehabilitation not be undertaken. This was explored through an expert consultation workshop which was attended by hydrologists, economists and engineers. The aim was to answer the question of ‘What wwas 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? The Mthinzima Wetland as a risk mitigation (or insurance value) was further explored.
2. Four different alternative (perfect or close) substitutes were identified at the expert workshop. The most cost-effective alternative was chosen, and the choice of the alternative also relied on data availability for the cost benefit analysis.
3. For the purposes of this study, it was assumed that any treatment service provided by the wetland was in demand. It is part of global, regional and national objectives to improve water quality and with the consequences and associated costs of declining water, the assumption was made so that there was a demand to improve the water

quality of the Mthinzima Stream, particularly with the aim of protecting the water quality of Midmar Dam. A similar assumption is argued by Turpie *et al*. (2010).

The possible alternatives for the Mthinzima wetland follow, with each alternative briefly discussed.

5.5.1 Treatment Cost

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 often used to represent the benefit of water quality enhancement services provided by wetlands (Pagiola 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 P [phosphorus] in mind (and thus are driven by the average cost per kg of P removed)" (Turpie *et al*., 2010, p.12). The analysis would involve the following steps:

Calculating change in wetland area as a result of wetland rehabilitation

1. Estimating the nutrient (nitrogen and phosphorous) removal rate of functional wetland
2. Estimating the water flows that flow through the wetland to identify the opportunity for the wetland (receiving loads)
3. Use the conventional cost of removing nutrients from water (water treatment costs) given the points above.

Given all of the above, the change in wetland benefits can be quantified.

5.5.2 Treatment/ Floating wetlands

Treatment wetlands are constructed artificial treatment wetlands. They are engineered systems designed to enhance the processes and interactions that occur in natural wetlands between water, plants, microorganisms, soils and the atmosphere in order to remove contaminants from polluted waters in a relatively passive and natural manner. Treatment wetlands have had positive results. For example, in a study in the Parismina River Basin in eastern Costa Rica, four of five of the treatment wetlands were found to be effective in the reduction of nutrient levels of effluents from a dairy processing plant, a banana paper plant, and a landfill before water was discharged to rivers (Nahlik and Mitsch, 2006). Therefore, this could have been an alternative that could have been used in this study to replace the wetland and thus, enhancing water quality before it reaches Midmar Dam.

Nahlik and Mitsch (2006) results showed that nitrate nitrogen removal was variable but occurred in low concentrations in the inflows (less than 1 mg N L^{-1}). Phosphate phosphorus was present in high levels but was effectively reduced through the wetlands (92% and 45% reductions through dairy farm wetlands, 83% reduction through banana paper wetlands, and an 80% reduction through dairy processing wetlands). Retention of phosphate phosphorus was between 0.1 to 10.7 g P m^{-2} $year^{-1}$ in the treatment wetlands.

Treatment wetlands have been found to be effective in water quality enhancement and are more desirable to use as they have a low cost, easy to operate and maintain and have a high potential to be applied in developing countries (Kivaisi, 2001). This effective technology of treatment wetlands has not been widely used because of a lack of awareness and local expertise to develop the technology on a local level. Usually, the total cost and maintenance costs of this technology are available from the detailed plan of the treatment wetland which is carried out by engineers.

5.5.3 Autotrophication denitrification

Influx of nitrogen from anthropogenic activities is the main cause of eutrophication of freshwater systems. The main source of anthropogenic nitrogen in the WBNERR bay was found to be sewage discharged from septic tank systems, which served more than 85% of the homes in that region (Sengupta and Ergas, 2006). Septic systems remove at most, approximately 23% of the nitrogen in the influent waste water, therefore, there was an opportunity to introduce technologies that can be applied to onsite waste water treatment that can achieve a higher percentage of nitrogen removal (Sengupta and Ergas, 2006).

The conventional heterotrophic denitrification methods of using an external electron donor can produce better results but has some disadvantages: (i) using toxic chemicals such as methanol, and (ii) resulting in large amounts of biological sludge that must be handled or disposed off. Autotrophic Biological Denitrification (ABD) was then proposed to denitrify freshwater systems. ABD has the potential to achieve almost complete nitrogen removal and does not suffer from the limitations of heterotrophic denitrification (Sengupta and Ergas, 2006). This method uses elemental sulfur or hydrogen as the electron donor (Sengupta and Ergas, 2006). Autotrophic biological denitrification of waste water was investigated using H2 and S0 as electron donors. Tests were conducted at lab-scale bioreactor tests at UMass Dartmouth and Amherst campuses, and tests were also conducted at a field-scale level at the Massachusetts Alternative Septic System Test Center in Sandwich. The findings indicated high denitrification rates could be achieved in a sulfur oxidizing bioreactor system treating nitrified waste water with a hydraulic residence time of eight hours, sufficient pH buffering, and crushed oyster shells were found to be the most suitable solid-phase buffer in sulfur-oxidizing denitrification systems (Sengupta and Ergas, 2006). From the results of the study that showed high denitrification rates, the study proposed ABD technology be used as it has the potential for immediate commercial application and can be a useful tool for government, and local water quality administrators.

5.5.4 Redoing the sewer line of Mpophomeni

The main point source of pollution that was impacting water quality in the Midmar Dam was sewage spillages from the Mpophomeni Township. Ngubane (2016) had some monitoring points in the Mpophomeni area as part of his research. He reported four confirmed sewage spillages and a suspected 11 more, all leaking into the tributaries that lead into the Midmar dam (News24, 2015).

The main sources of pollution in the Mpophomeni area where the Mthinzima wetland is located are solid wastes in and around water courses, damaged and insufficient sewage infrastructure, and surcharging sewage manholes (van Deventer, 2012). Raw sewage from the area flowed directly to watercourses. As sewage was the main contributor of the deteriorating water quality of Midmar Dam, fixing or redoing the sewer network in Mpophomeni would eliminate the problem at its source.

Fixing the sewer line would be more effective if Mpophomeni residents were educated about solid waste management and regular provision of municipal services to remove solid waste (Felton, 2017), as this had the potential to result in less blockages of the sewer network and less solid waste and sewage in the Mpophomeni tributaries and wetland systems feeding into Midmar Dam. Eliminating this sewage problem from Mpophomeni may have had a positive impact on the health of Midmar Dam as the Mpophomeni Township was found to be the biggest contributor of pollution that threatens Midmar Dam. The key point was that the WWTW does not fully address the problem. Additional engineered infrastructure could be considered as an alternative to wetland rehabilitation.

5.6 Additional potential benefits

The Zenzele Trust land overall, has dry land and agricultural potential was moderate due to a restrictive climate which was characterized by frost, a shorter growing season and molted and deficiently drained soil. The area has about 30% of good potential farm land, while approximately 50% of the land has moderate potential and 16% of land was wetland area. The best agricultural use of the farmland should be permanent pasture and natural veld (Barichievy, 2015). The land had not been ploughed for more than 10 years due to the re-activation of its protection status. With the wetland rehabilitation, the supply of water may increase which would result in greener pastures and natural veld.

5.7 Summary

This chapter presented the methodology and data that was going to be used for the assessment of the costs and benefits of rehabilitation of the Mthinzima wetland. Due to unavailability of data to employ on other valuation methods reviewed in the literature chapter, the study used the cost benefit analysis method to measure whether it would be beneficial to invest in the rehabilitation of the Mthinzima wetland. Measuring value of ecological infrastructure is important in determining the optimal levels of pollution and in cost-benefit analysis. The economic cost benefit analysis was used because it examines whether society will be better off if a particular project or policy is implemented. Another important element of the economic cost benefit analysis is the discount rate. The study found that an 8% discount rate would be closer to the theoretically argued and calculated rates based on opportunity costs and time preferences (Mullins, 2014). Therefore, it seemed appropriate to use 8% as the applicable real discount rate for South Africa. The net present value method was to be used when conducting the economic cost benefit analysis because it values the difference between the social benefits and social costs (the net Benefit/cost) in the specified year/s, discounted to the present by using the social discount rate.

Different scenarios were made to analyse if there was an opportunity for wetland services under different assumptions of investments and disinvestments (current situation) in ecological infrastructure and engineered infrastructure. The gain in functional wetland area (10.78ha) was proposed as a base for estimating the potential additional water quality enhancement service (nitrogen assimilation and phosphorus removal) as a result of the rehabilitation intervention. Wetland rehabilitation costs and benefits were discussed in the Chapter and the Replacement Cost Method was to be used to value the wetland's water treatment functions. In this chapter there are also different alternatives are presented that may provide wetland services and can be used as a replacement cost of the wetland. The chapter 6 below is the results chapter and presents the results using the methodologies explained in this chapter.

CHAPTER 6. Results and discussion

This section reports all the costs and benefits that were estimated for the Mthinzima wetland rehabilitation analysis and further presents the results of the cost and benefit analysis. This section represents different wetland opportunities under different scenarios that were discussed earlier in detail in 5.2. The wetlands replacement cost chosen for this analysis is also represented. The first section presents computation of the change in quantity of ecological services provided by Mthinzima wetland due to construction of the WWTW and the proposed wetland rehabilitation. The following sections explain the computation of the economic costs of rehabilitation of the wetland and the benefits of the wetland rehabilitation, then the results of the economic cost benefit analysis follow.

6.1 Computation of the supply and opportunity of ecological infrastructure services under different scenarios

6.1.1 The first scenario

The first scenario (Table 5.2) was the current situation, where the area was experiencing inadequate sewage infrastructure which resulted in sewage spillages, surcharging manholes and blockages. As a result, raw sewage flowed directly to the Mthinzima stream and ended up in Midmar Dam after flowing through a stream of degraded wetland. The first scenario of no intervention would be to retain the unused waste water treatment infrastructure as it is and continue to pump the waste water to the Howick WWTW. This scenario was not feasible as the capacity of the Howick WWTW was under severe pressure and additional waste water volumes were expected to be generated in the area due to potential population increase in Mpophomeni, development of the Khayalisha residential area, and a potential light industrial area (DEA, 2014). Therefore, there was an opportunity for intervention to reduce nutrient loads in the Mthinzima stream before the water reaches Midmar Dam.

Even with the only new WWTW in Mpophomeni (Scenario 2), it was expected that there may still be regular sewage spills into the Mthinzima because only the main sewer line was going to be refurbished. The regular spills meant that even with the new WWTW infrastructure (Scenario 4) some pollution would still enter the Mthinzima Stream through the informal settlement, surcharging manholes, broken pipes and storm water run-off; even with the new WWTW, there would be an opportunity for the rehabilitated wetland to provide its water treatment services. Ngubane, (2016) used the following equation to estimate load into the Mthinzima Stream:

Load = Flow x Concentration … (1)

$L = Q_{ave} \times C_{ave}$

L = Monthly load

Q_{ave} = Average daily Flow

C_{ave} = Chemical Concentration

The opportunity for the wetland with the new WWTW was estimated using historical load data (Ngubane, 2016) for when the old WWTW was functioning. The study used the average of nutrient loads from 1996 - 2000 (Ngubane, 2016). During this period the WWTW was functioning and was later decommissioned in 2001.
Mthinzima loads (Ngubane, 2016):

DIN ≈ 4.3 tons/ year (period 1996 to 2000)

4.3 tons ≈ 43000 kg (load into Mthinzima)

Removal rates by wetlands (Land, 2016):

Nitrogen removal = 69 kg/ha/year

Mthinzima degraded wetland (Nitrogen) = 55.44 ha x 69 kg/ha/year

= 3825.36 kg/year

Incremental change post rehabilitation = 10.78 ha x 69 kg/ha/year

= 743.82 kg/year

6.1.2 The second scenario

In the second scenario where only the WWTW intervention takes place, there was an opportunity for the rehabilitated wetland water treatment services. Even with the engineered infrastructure, the wetland has an opportunity to assimilate DIN of (4300 – 3825.36) 474.64kg/ year.

Average Total Phosphorus (TP) was an average of 1.7 tons during the period of 1996 – 2000.

Removal rates by wetlands (Land, 2016):

Phosphorus removal = 2.43 kg/ha/year

Mthinzima degraded wetland (Phosphorus) = 55.44 ha x 2.43kg/ha/year

= 134.72 kg/year

Incremental change post rehabilitation = 10.78 ha x 2.43 kg/ha/year

= 26.20 kg/year

Mthinzima loads (Ngubane, 2016):

TP ≈ 1.7 tons ≈ 1700kg/year (1996 – 2000)

The rehabilitated wetland has an opportunity to assimilate (1700 – 134.72) 1565.28 kg/year of phosphorus in a scenario with the WWTW.

There was opportunity for the rehabilitated wetland only (Scenario 3). The opportunity was identified using historical load data shown below (Ngubane, 2016).

Mthinzima loads (Ngubane, 2016):

DIN ≈ 11 tons/year (period 2010 to 2013)

11 tons ≈ 11 000 kg (load into Mthinzima)

Removal rates by wetlands (Land, 2016):

Nitrogen removal = 69 kg/ha/year

Mthinzima degraded wetland (Nitrogen) = 55.44 ha x 69 kg/ha/year

= 3825.36 kg/year

6.1.3 The third scenario

In the current situation where there was no intervention, there was an opportunity for the rehabilitated wetland water treatment service (Scenario 3).

Incremental change post rehabilitation = 10.78 ha x 69 kg/ha/year

= 743.82 kg/year

In this scenario, the average nitrogen into the Mthinzima stream per year is 11 000 kg. The wetland in its degraded state can assimilate 3825.36 kg/year. In this situation the wetland was going to be further degraded if no interventions were implemented to rehabilitate. There was an opportunity for the rehabilitated wetland to assimilate an additional Nitrogen of (11 000kg/year - 3825.36kg/year) 7174.64kg/year. Therefore, in scenario three there was also an opportunity for the wetland services to assimilate nitrogen and phosphorus loads. Similar results were gathered for phosphorus below.

Removal rates by wetlands (Land, 2016):

Phosphorus removal = 2.43 kg/ha/year

Mthinzima degraded wetland (Phosphorus) = 55.44 ha x 2.43kg/ha/year

= 134.72 kg/year

Incremental change post rehabilitation = 10.78 ha x 2.43 kg/ha/year

= 26.20 kg/year

Mthinzima loads (Ngubane, 2016):

TP ≈ 0.8 tons ≈ 800kg/year

The rehabilitated wetland had an opportunity to assimilate (800 – 134.72) 665.28 kg/year of phosphorus. Therefore, there was opportunity for the wetland to be rehabilitated, the system currently generates more nutrients loads than what can be removed by the degraded wetland.

Table 5.5 presents the expected change in the supply of ecosystem services with rehabilitation with the two main services being phosphate trapping and nitrate removal. Both of these services are expected to increase (Table 5.5) post rehabilitation. It was then assumed that the wetland can supply a water improvement service. A further assumption was that there is demand for the wetland to provide a water improvement service, since in South Africa, freshwater systems are under pressure and the population was expected to increase (van Deventer, 2012) which would result in a higher water demand in the future. The need for interventions to reduce the risk of and/or the delayed eutrophication of Midmar Dam (a primary water storage reservoir and recreation facility in KZN) was expressed by many of the stakeholders interviewed during this study.

The limitation of results presented was that the study could not measure some key variables with certainty; hence the lower bound estimate of incremental change in wetland services was based on the 10.78 ha of additional functional wetland area post rehabilitation predicted during the wetland assessments and rehabilitation planning (GroundTruth, 2015). The idea behind additional functional wetland area was that it captures the overall increase in functionality and expresses it as an area 'equivalent'. Post rehabilitation monitoring would be needed to improve the accuracy and certainty of the estimates.

6.2 Cost of rehabilitation

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 and commercial quotes). It is also important to note that all values for this analysis were used in real terms, they have been adjusted for inflation. Maintenance plan costs/data for the Mthinzima rehabilitation was only available for the first five years of rehabilitation. Maintenance cost per year were calculated to be R250 000, this is 2.08% of the infrastructure cost. For a more accurate maintenance cost, the study relied on literature for a suitable maintenance cost for the lifespan of a rehabilitated wetland. de Groot *et al.* (2013) investigated the benefits of ecosystem services. Their analysis involved studies in which the maximum and minimum cost values for each biome was identified which disclosed both total costs and analysis. de Groot *et al.* (2013) allowed for project maintenance of 2.5% of total investment cost for wetlands because wetlands are capital-intensive projects.

For this analysis 2.5% maintenance cost from year one was used since Mthinzima wetland has intensive communal grazing, wetland rehabilitation is capital intensive and it was a rate closer to the 2.08% for the first five years. The maintenance cost was estimated to be R1 250 000.00 (Felton, 2017) for a period of five years with an additional budget required for further maintenance such as alien plant clearing, reshaping, repair work and any other maintenance, therefore, the study assumes a 2.08% maintenance cost for the overall lifespan of the wetland rehabilitation.

From the above costs of different interventions of the Mthinzima wetland rehabilitation, the total cost of rehabilitation was estimated to be R12 000 000 (Table 1A – 4A, Appendices). The annual maintenance cost will be 2.08% of the total cost, therefore the calculated annual maintenance cost for the Mthinzima wetland was R250 000 for the analysis of this study.

6.3 Benefits of Wetland rehabilitation

The equivalent water treatment cost was used as the replacement cost to attribute value to the improved nutrient removal service associated with the wetland rehabilitation due to the lack of information on the other alternative methods. This analysis was limited by lack of data on the cost of nutrient removal and therefore, the study used unit costs of nutrient removal estimated by Turpie *et al*. (2010) for analysis. Equation 1 below was be used to adjust the figure for inflation so that it would be reflected in 2017 consumer price index (CPI).

The following formula was used to calculate the rate of inflation:

$$\text{Inflation rate} = \frac{CPIx+1-CPIx}{CPIx} \quad \dots (1)$$

CPIx = Initial Consumer Price Index

CPIx+1 = Current Consumer Price Index

The calculated increase in inflation in the seven years was found to be 45.8%, and therefore the inflated cost of removal of nitrogen was R37.90 per kg of N removed and was rounded off to R38. The amounts of nitrogen and phosphorus removed from treatment plants was found to be highly correlated and therefore, while water treatment works are designed mainly for the removal of P in mind (they are driven by the average cost per kg of P removed), if N was the targeted nutrient, the costs of treatment would not differ significantly from the average cost per kg of N removed that was achieved while P was being targeted (Turpie *et al*, 2010). Therefore, when targeting P, N is removed simultaneously, at no additional cost.

From the above, the value of treatment by wetlands can theoretically be determined as follows, following Turpie *et al*. (2010):

Value (R) = Max (kg N removed x C_N, kg P removed x C_P) … (2),

where:

C*i* = total cost of treatment / total kg of substance *i* removed

Mthinzima was not a well-researched area, therefore, there were a lot of unknowns and uncertainties. The main challenge in this research was a lack of data, thus, the study used some data from literature. From the initial comparison of nitrogen and phosphorus removal rates from the literature, it was evident that the range of rates reviewed is broad, both across the studies reviewed from Europe by Land *et al*. (2016) and within the South African study by Turpie *et al*. (2010). The studyused wetland removal rates from Land *et al*. (2016) as the values were more conservative and were based on measured data whereas the estimates from the Turpie *et al*. (2010) study were based on modelling. The removal rates used were 69 kg N/ha/year and 2.43 kg P/ha/year.

Therefore, the total value of the wetland using equation 2 is as follows:

$$\text{Value (R)} = \text{Max (kg N removed x } C_N\text{, kg P removed x } C_P\text{)}$$

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

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

$$= \text{R2622 ha}^{-1}\text{year}^{-1}$$

Turpie *et al*. (2010) used only the removal of ammonium nitrogen to avoid double counting and assumed that removal of total phosphorus is correlated to that of nitrogen. The maximum value was then used as the value of the wetlands nutrient removal service. The change in wetland value as a result of rehabilitation was calculated using the 10.78ha of functional wetland habitat that is gained as a result of the rehabilitation. The change in value as a result of the wetland rehabilitation investment is R28 265.16 year^{-1} and the overall wetland value post rehabilitation would be R 173 628.84 year^{-1}. These two values were obtained by multiplying the wetlands functional area by the value of the wetland nutrient removal service calculated above.

6.4 Economic Cost Benefit Analysis Results

This section presents the results of the economic cost benefit analysis (CBA) of the Mthinzima wetland rehabilitation. From the meetings with experts it was agreed that if everything was left unchanged, it would threaten the Midmar Dam water source and it would turn eutrophic in the near future hence, for the cost benefit analysis the scenario with wetland rehabilitation was investigated. This was to evaluate if investing in wetland rehabilitation would be worthwhile.

Table 6.1 represents the uniform series present values annuity discount factors (USPV) that would be used for the analysis. The USPV are used to discount the investments cash flows to today's value (net present value). This way, it may be determined whether the wetland rehabilitation was a worthwhile investment into the future.

Table 6.1 Uniform Series Present Values Annuity Discount Factors used for NPVs

USPV			
Years	20	30	40
3%	14,878	19,600	23,115
5%	12,462	15,372	17,159
8%	9,818	11,258	11,925

Given the above USPVs, Table 6.2 shows the results with the assumption that the NPV is equal to zero. A NPV that is equal to zero means that the investments cash flows (benefits) are equal to the investment costs. This illustrates the number of annual benefits that have to be accrued in order for the wetland rehabilitation investment to be worthwhile.

Table 6.2 Cost Benefit Analysis results when NPV=0

Annual net benefit required for NPV = 0		
20	30	40
R 806 587,13	R 612 244,90	R 519 143,41
R 962 911,85	R 780 640,12	R 699 341,45
R 1 222 232,41	R 1 065 908,69	R 1 006 289,31

The preceding table shows the annual benefits that were needed to justify the wetland rehabilitation investment. Table 6.3 shows the results of using the treatment costs as a replacement value of the improved water quality enhancement service of the rehabilitated wetland. The change in benefits were understated in the results reported in Table 6.3 as only treatment costs were considered, this is a small fraction of the overall cost of the WWTW. This does not hold true in reality because treatment costs are incurred but also the fixed costs of building the water treatment plant are incurred at the initial stage.

Table 6.3. NPV of Wetland rehabilitation assuming no fixed cost of WWTW

		N (life of WWTW in years)		
		20	30	40
Discount rate	3%	R -3 064 759,82	R -4 037 690,92	R -4 761 643,03
	5%	R -5 558 145,81	R -6 856 113,16	R -7 652 952,51
	8%	R -7 913 426,81	R -9 073 773,37	R -9 611 238,35

In order to overcome this bias, the fixed costs of the construction and annual running costs of the water treatment plant were considered. Table 6.4 shows the calculated annualised cost of the WWTW, followed by 6.5 which presents the present salvage value of the wetland rehabilitation. The study assumed that the wetland was going to be used sustainably, so the real value was to remain R12 000 000 in the future. Table 6.6 then presents the results assuming there would be a WWTW built to treat the water of the Mthinzima Stream before it reaches Midmar Dam (i.e. in the same location as the wetland). Running cost information was not available. Therefore, the analysis employed two different maintenance costs as a percentage of the fixed capital costs, 2.5% and 5% were used for comparison of the results.

Table 6.4 Annualised fixed Capital Cost of WWTW

		N (life of WWTW in years)		
		20	30	40
Discount rate	3%	R 1 008 235,61	R 765 288,89	R 648 935,67
	5%	R 1 203 638,81	R 975 771,53	R 874 172,42
	8%	R 1 527 783,13	R 1 332 411,50	R 1 257 902,42

Table 6.5 PSV of Wetland Rehabilitation

		N (life of WWTW in years)		
		20	30	40
Discount rate	3%	R 6 644 109,05	R 4 943 841,11	R 3 678 682,09
	5%	R 4 522 673,79	R 2 776 529,38	R 1 704 548,19
	8%	R 2 574 578,49	R 1 192 527,99	R 552 371,20

Table 6.6 NPV of Wetland Rehabilitation using 2.5% of maintenance cost

		N (life of WWTW in years)		
		20	30	40
Discount rate	3%	R 11 935 240,18	R 10 962 309,08	R 10 238 356,97
	5%	R 9 441 854,19	R 8 143 886,84	R 7 347 047,49
	8%	R 7 086 573,19	R 5 926 226,63	R 5 388 761,65

There was significant change in results after the inclusion of the fixed cost and its annual running/ maintenance costs of the WWTW. The results were all positive and therefore, investing in wetland rehabilitation for a period of 20 - 40 years was found to be worthwhile. The calculated costs and benefits in Table 6.6, show a set of three results using discount rates of 3%, 5% and 8%. The project is considered socially advantageous when the sum of discounted benefits is greater than the sum of discounted costs. For the Mthinzima rehabilitation program the investment turned out to be beneficial for society at all discount rates and for all periods. Table 6.7 below presents the NPV of wetland rehabilitation when the maintenance cost of the WWTW was assumed to be 5%.

Table 6.7. NPV of Wetland Rehabilitation using 5% maintenance cost

		N (life of WWTW in years)		
		20	30	40
Discount rate	3%	R 17 514 293,25	R 18 312 474,59	R 18 906 396,46
	5%	R 14 115 183,07	R 13 908 555,98	R 13 781 704,87
	8%	R 10 768 378,47	R 10 147 895,38	R 9 860 491,65

Even after accounting for the different maintenance costs of the wetlands replacement cost, the results showed that investing in wetland rehabilitation would be a worthwhile investment. The result were still positive after assuming a higher maintenance cost of the WWTW. This was because of the assumption that the wetland would offer the same benefits as those of a well maintained WWTW (replacement cost). So, the maintenance cost of the WWTW was part of the benefit, if it increases in this case the benefit increases. It can also be noted that the wetland net benefits from the economic cost benefit analysis (Table 6.6 and 6.7) are much greater than the minimum required benefit (Table 6.2) for the investment to be justified.

6.5 Summary

This chapter analysed wetland opportunities under different scenarios that were discussed in Table 5.2. Under all scenarios there was an opportunity for the wetlands water treatment services because even with the new WWTW, there could still be regular sewage spills into the Mthinzima wetland because only the main sewer line was going to be refurbished. Therefore, there was an opportunity for the Mthinzima wetland to provide its water treatment services.

Finally, the economic CBA technique was applied to assess if investing in the rehabilitation of Mthinzima wetland would yield net benefit. In South Africa, the social discount rate that is commonly used is 8% (Mullins, 2014), therefore, the results interpretation focused on the 8% discount rate. At an 8% discount rate, the net present values of the costs and benefits were positive at all periods at R7 086 573, R5 962 227 and R5 388 762 for 20, 30 and 40 years respectively, when maintenance costs were assumed to be 2.5% of the fixed capital cost. This outcome of the economic CBA showed that it was beneficial to invest in the rehabilitation of the Mthinzima wetland. The following chapter consists of the conclusion, study limitations and policy recommendations.

CHAPTER 7. CONCLUSION AND IMPLICATIONS FOR POLICY

7.1 Conclusion

This study was based on expected outcomes that aimed to compare costs of an investment in ecological infrastructure in the form of wetland rehabilitation against the value of ensuring incremental change in provision of wetland services. The wetland or ecological services that were targeted were those that related to improvement in water quality and therefore the overall benefit of the wetland was understated. The Mpophomeni settlement occupies less than 3% of the Midmar Dam's catchment area, it was identified as a point source pollution as it contributed 15% of the phosphorus load into the dam. Experts in focus group discussions, and past literature suggested that there should be an intervention to reduce loads to the Midmar Dam to minimise or reduce threats to the dam that may cause it to turn eutrophic in the near future. Therefore, the uMgungundlovu municipality took the decision to rehabilitate the Mthinzima wetland to gain from its water quality improvement services, and further build a new WWTW that would reduce direct sewage flows into the Dam. The main benefit of wetland rehabilitation would be improved water quality entering the Midmar Dam which would increase the lifespan of the dam before it turns eutrophic.

In the past most ecological infrastructure investments analysed the total economic value, and not the change in ecological infrastructure services as a result of investments. This study considered the demand, supply and opportunity for wetland services that would result from the Mthinzima wetland rehabilitation, and from that, measured the incremental change as a result of investment using economic evaluation methods. Demand focused on whether at least one individual demands the additional wetland water improvement services, while supply investigated the wetlands capacity to supply those services and the opportunity focused on the activities or circumstances that make it possible for the wetland services to be used.

A new general conceptual framework was also introduced to measure the impact of investments (or disinvestments) in ecological infrastructure and/or engineering infrastructure on the value of ecological infrastructure. From this study, it can be concluded that engineered infrastructure can be a substitute of ecological infrastructure as it may reduce opportunity for ecological infrastructure to provide ecological services. It is important to note that investments in engineering infrastructure may not always be a substitute for ecological infrastructure, however, it is possible for both investments to complement each other and the complementary may yield more benefit than the one of each individually. The study investigated if there was an opportunity for wetland services under four different scenarios. Under all scenarios there was an opportunity for the wetlands water treatment services because even the scenario that considered the wetland in its degraded state there was an opportunity for wetland services. Therefore, this opportunity justifies that there is a responsibility to conserve/ maintain existing ecological infrastructure and investments in ecological infrastructure.

Wetlands offer a range of services, and this study limited the wetland benefits to only the water treatment service due to a major problem in the study catchment area where sewage contaminated the stream water. Nitrogen and phosphorus nutrient loads were the focus of the study as these nutrients were a major threat to Midmar Dam. The economic cost benefit analysis method was used to value the costs and benefits of investing in the Mthinzima wetland rehabilitation. The focus was on the incremental change (or benefit) as a result of investment. A one mega litre WWTW cost was used as the replacement cost of the wetlands water treatment services. Experts agreed that a one mega litre WWTW would provide the same or similar level of service as the additional service provided through the wetland rehabilitation.

Initially, the economic CBA investigated the benefit that is required to justify the wetland rehabilitation investment. This was achieved by setting the NPV to be equal to zero; this is a break-even point where all net benefits are equal to costs. This gives an idea of the results of the CBA, if the benefit required to break even is less than the actual incremental benefit, it can be expected that the CBA results will be negative. The CBA results were negative at first due to the bias of only using the WWTW treatment costs to capture the incremental change in wetland services because a WWTW cost does not exist in isolation of WWTW fixed capital and maintenance cost. After the inclusion of the WWTW capital fixed cost and maintenance cost, the results of the CBA were positive at all different WWTW maintenance costs. Different WWTW maintenance costs were assumed as data on the exact maintenance cost of a one mega litre was unavailable.

The study then concluded that it was worthwhile to invest in the rehabilitation of the Mthinzima wetland as it yielded net benefits shown by positive net present values. The positive net present values show that investing in the wetland rehabilitation yields net benefits to society. It is important to note that the benefits of wetland services in this study were understated as only the water treatment service was considered, yet wetlands yield a variety of services. Post rehabilitation of the Mthinzima wetland, other positive changes in wetland services are expected to include toxicant removal, erosion control, stream flow regulation, water supply for human use and carbon storage. Furthermore, uMngeni Water would extract water for consumers and treat it at a lower cost relative to a situation where the water would be eutrophic and would be relatively more expensive to treat.

In conclusion, there are disagreements about the relevant social discount rate to use when conducting CBA. This is due to uncertainties associated with valuation of non-market ecological benefits. These uncertainties and disagreements imply that the results of a cost-benefit analysis should not be considered as the final answer. Future biophysical research in the Mthinzima wetland area would provide more information for economic valuation of investments in ecological infrastructure and more reliable results would be presented for decision makers. Given the available data, it was worthwhile to invest in the rehabilitation of the Mthinzima wetland.

7.2 Policy implications

Economic valuation of wetlands (and other ecological infrastructure) are important as it can justify and set priorities for programs, policies and actions that may protect and rehabilitate them (King and Mazzotta, 2000). Economic valuations give a basis for measuring and comparing the various benefits from wetlands against the costs associated with their conservation. Economic valuations assist in the understanding of user preferences and relative values placed on ecosystem services.

The results of the economic CBA showed that investing in ecological infrastructure may bring about incremental change to services they provide. Investing in the rehabilitation of Mthinzima yielded positive NPVs. At an 8% discount rate, the net present values of the costs and benefits were positive at all periods at R7 086 573, R5 926 227 and R5 388 7162 for 20, 30 and 40 years respectively, when the maintenance cost was assumed to be 2.5% of fixed capital cost. This outcome of the economic CBA showed that it was beneficial to invest in the rehabilitation of the Mthinzima wetland.

Consumers would benefit from paying relatively less for water when the water quality in Midmar Dam is of good quality. The wetland benefits also benefit Midmar Dam as it may result in maintained recreational potential from the dam for a longer period. It would be also beneficial to reduce the problem of increasing nutrient loads to Midmar Dam from its source which may be achieved by fixing or refurbishing all the sewer networks within Mpophomeni. This may result in less sewage flowing directly to Midmar Dam from Mpophomeni. Even though in scenario 4, where both interventions are implemented, the rehabilitated wetlands supply of services exceeds its opportunity, therefore, fixing the whole sewer line may play an important role in times of extreme weather which the study could not account for due to lack of available data.

The CBA results should not be used as a final answer, however the usefulness of CBA is in its ability to reduce complex clusters of effects to monetary value. Therefore, CBA does not control choices of decision makers, but it may be a useful tool for testing the robustness of a project to alternative assumptions concerning the magnitude of costs and benefits, and the various social demands with respect to the return on invested capital. From this, the outlined CBA indicated that the rehabilitation of the Mthinzima wetland was robust, as it yielded positive NPVs at all three discount rates in all periods.

7.3 Study limitations and future research directions

Focus group sessions with relevant experts recommended that there was consensus that the Mthinzima wetland rehabilitation was warranted. The study was limited by data shortages on the other alternative methods presented in the study and therefore, a one mega litre WWTW was used as an alternative that would treat water from Mpophomeni before it reached Midmar Dam. The replacement cost technique was used to value the incremental change in wetland services post rehabilitation. The replacement cost condition of willingness to pay for closest substitute was not met and experts only agreed that there had to be an intervention to reduce pollution loads from the Mthinzima stream but there was no one who was willing to pay for the intervention. The study was also not certain on whether the WWTW cost that was used as the replacement cost of the wetland was the lowest cost alternative and therefore this condition of the replacement cost method may have not been met. Another limitation was that there was no data available on the maintenance of Mthinzima wetland post rehabilitation, therefore the study relied on literature for a suitable maintenance cost for the lifespan of a rehabilitated wetland.

There was also no instrumental modelling of Midmar Dam to confidently predict the impact of nutrient load from the Mthinzima Stream on water quality of Midmar Dam. Economic valuation studies rely on biophysical studies to carry out valuations of ecological infrastructure and its services that may be used in decision making to justify their investments. Ideally, this study should have been done along with another biophysical/hydrological study.

The study assumed that the wetland rehabilitation investment was warranted in that treating polluted water before it reaches Midmar Dam was preferred so as to reduce the risk of eutrophication of the dam and avoid the associated consequences. Another limitation of the study was under-estimation of the benefits of investments in ecological infrastructure, the study only focused on those benefits that related to improvement in water quality. Future research may investigate the overall incremental benefit as a result of investment. Other incremental benefits include toxicant removal, erosion control, stream flow regulation, water supply for human use and carbon storage.

The researcher was not able to estimate how much it would cost to maintain the wetland in its current degraded state. Therefore, the baseline scenario assumed that the wetland was to remain in its current degraded condition, yet in reality, it may be further degraded over time. The study could not account for the stochasticity of the nutrient load data. Due to this limitation, the study used average flows and broad assumptions on the functions of the wetland, therefore, the study was unable to estimate the wetlands insurance value (benefit). As a result, the study concluded that economic studies rely on biophysical studies to obtain more reliable economic results. Future hydrology (biophysical) research could further investigate and measure what proportion of the nutrient loads data was associated with major events that may have resulted in peaks of nutrient loads in the data.

Due to data limitations the study relied on literature for data on the treatment cost of a WWTW and nutrient removal rates of wetlands. There are closer substitutes (technologies) that would have been almost perfect substitutes/alternatives for the rehabilitated wetland, but due to the unavailability of cost data the study could not employ them. The closer substitutes that may have been used are treatment wetlands and autotrophic denitrification as they both treat surface water and have similar characteristics to wetlands. Future research may also analyse the probability of the occurrence of the NPV= 0, this would help decision makers by informing them about the minimum annual benefits that are required for the investment to be worthwhile.

APPENDICES

Appendix A: Detailed rehabilitation costs

Table 1A: Concrete Buttress Weir Structures

BOQ INTERVENTION	EARTHWORKS (m^3)	CONCRETE (m^3)		MESH REINFORCEMENT (6m by 2.4m Sheets)	Cost (R)
U20C-02-001	204.13	107.21	7 X Ref 888	7 X Ref 943	448331.98
U20C-02-002	149.02	76.16	6 X Ref 888	8 X Ref 943	330151.12
U20C-02-003	104.19	51.78	5 X Ref 888	7 X Ref 655	225529.71
U20C-02-004	96.88	40.20	3 X Ref 888	4 X Ref 655	1753676.12
U20C-02-005	132.84	59.46	3 X Ref 888	4 X Ref 943	253128.56

Table 2A: Earthen Berm Structures

BOQ INTERVENTION	EXCAVATION (m^3)	EARTHEN MATERIAL (m^3)	ROCKPACK (m^3)	COSTS (R)
U20C-02-006	14.70	72.70	17.00	38930

U20C-02-007	22.05	90.64	0.00	32826.50
U20C-02-008	17.11	55.74	0.00	20364.50
U20C-02-009	9.00	39.56	0.00	14296
U20C-02-010	6.99	35.80	0.00	12879.50
U20C-02-011	4.96	34.19	14.00	22714.50
U20C-02-012	2.70	22.05	0.00	7852.5
U20C-02-013	1.78	21.18	0.00	7502
U20C-02-014	1.08	20.27	0.00	7148.50
U20C-02-015	0.80	15.45	0.00	5411.50
U20C-02-016	0.80	23.04	0.00	8068
U20C-02-017	1.08	17.10	0.00	6039
U20C-02-018	1.08	35.30	0.00	12409
U20C-02-019	6.99	29.86	10.00	18300

U20C-02-020	3.86	23.50	0.00	8418
U20C-02-021	6.10	26.09	0.00	9436.5
U20C-02-022	3.86	19.76	0.00	7109
U20C-02-023	1.78	15.68	0.00	5577
U20C-02-024	0.00	27.56	0.00	9646

Table 3A: Open Water Intervention

BOQ INTERVENTION	**SURFACE AREA (ha)**	**EXCAVATION (m^3)**	**COSTS (R)**
U20C_02_025	0.5	3890	194500

Table 4A: Reshaping Intervention

BOQ INTERVENTION	RESHAPING AREA (ha)	REPLANTING AREA (ha)	COSTS (R)
U20C_02_026	27.68	27.68	8304000

Appendix B: Turnitin report

Thesis

ORIGINALITY REPORT

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