AN EVIDENCE-BASED APPROACH TO MEASURING THE COSTS AND BENEFITS OF CHANGES IN AQUATIC ECOSYSTEM SERVICES

Dineo Maila; Joseph Mulders; Nuveshen Naidoo; Jackie Crafford; Steve Mitchell; Kyle Harris

WATER RESEARCH COMMISSION

TT 726/17

An Evidence-Based Approach to Measuring the Costs and Benefits of Changes in Aquatic Ecosystem Services

Prepared for the Water Research Commission

by

Dineo Maila; Joseph Mulders
Nuveshen Naidoo; Jackie Crafford; Steve Mitchell; Kyle Harris

Report No. TT 726/17
ISBN 978-1-4312-0907-1

August 2017

Obtainable from

orders@wrc.org.za
Water Research Commission
Publications
Private Bag X03
Gezina, Pretoria
0031 SOUTH AFRICA

This report emanates from the research project titled: Evidence-based analysis of environmental degradation: Impact of ecological degradation on water resources, ecosystems and socio-economic development (WRC Project No. K5/2272)

EXECUTIVE SUMMARY

Human well-being and ecosystems are intimately connected. Human understanding of the value of ecosystems has matured rapidly over the past two decades.

The Millennium Ecosystem Assessment's (MEA) concept of ecosystem services introduced a radical new framework for analysing the value of ecosystems, and this, combined with electronic data collection systems and rapidly increasing computing power has enabled us to improve both our understanding of the value of ecosystems as well as the accuracy of valuations.

Yet, despite our improved understanding and our improved valuation techniques, evidence of severe ecological degradation is evident all around us. This is especially evident in the developing economies of Africa, where government incomes are not sufficient to support the implementation of large scale command-and-control type environmental regulations.

Why is this, what are its consequences, and how can we stabilise this situation?

In this study, we focused on aquatic ecosystem services produced by urban river systems. These ecosystem services are especially relevant in South Africa where rapidly increasing urbanisation puts significant pressure on scarce water resources.

There exist, arguably, many drivers of ecosystem degradation. But fundamentally, South Africa has a large economic development need which results in migration to cities. Cities, in turn, have not been able to timeously provide the necessary urban infrastructure for sustainable city development. Of course, a full understanding of the resultant micro drivers of change is essential for an improved understanding of the consequences of ecological degradation, as well as to develop policies that mitigate or adapt to these risks. However, it is quite clear that ecological degradation in urban environments results from a set of large scale, and very complex cumulative effects.

The consequences of ecological degradation are severe. In this study, we provide evidence of loss of crucial informal economy income by people living in peri-urban areas; we demonstrate the significant increase in value on private property (subsequent municipal rates income) resulting from proximity to high quality ecosystems; we demonstrate the significant and practical value of wetlands in treating water pollution. We provide evidence that land use activities such as agriculture and wastewater treatment works (WWTW) negatively impact water quality.

How can we stabilise this situation? South Africa has legislation and policies in place that regulate activities that damage ecosystems. These include environmental impact assessments (EIAs), water use licenses and broad environmental damage regulations. These instruments are clearly inadequate. There may be many reasons for this, including, for instance, the exclusive focus on project-related and point-source ecological damage, and/or perhaps inadequate administration, and/or application of precautionary principles.

The problem is a complex one. Environmental degradation leads to loss of provisioning, regulating and cultural services provided by the ecological infrastructure. The interactions among these services are complex, for example, climate change will affect evapo-transpiration, rainfall, river flow, resilience to grazing and insects to mention a few. Constant pressure on the system resulting from point and non-point pollutants present a hazard to human well-being. Non-point source pollutants

which has cumulative impact are difficult to manage hence difficult to mitigate. The aggregate of past, present, and reasonably near future actions causes cumulative pollutants.

The point of departure for addressing this problem is to understand, in an evidence-based manner, the value, and interactions of ecosystem services. Only once these interactions are meaningfully understood, can suitable policy instruments be developed.

WRC project K5/1644 (Ginsburg *et al*. 2010) developed a set of guidelines and a manual for the evaluation of trade-offs in aquatic ecosystem services that may result from different water management scenarios. These guidelines combined water management practices; the MEA framework of ecosystem services, and best practices in environmental and resource economics (ERE) valuation into a four-phased approach. A key gap identified by this study related to both the methodology through which to analyse chains of causality and the burden of evidence required to specify and quantify chains of causality. Knowledge of, and data for, analysing chains of causality are often dispersed and poorly archived. Furthermore, limited guidance is available on how to make use of different types of available evidence. Thus, in a subsequent study, WRC Project K5/1978 (Ginsburg *et al.* 2012) explored the field of 'evidence-based analysis of socio-ecological systems' ("E-BASES"), with the purpose of identifying potentially feasible methodologies for finding evidence, both ecological and social, in support of analysing chains of causality in complex, water resource dependent, socio-ecological systems. The proposed E-BASES methodology was premised on the formulation of a review question based on a system of cause and effect relationships, involving multiple system components, which, together, comprise a chain of causality. In addition, the evidence-extraction is expanded to explicitly include five evidence-extraction methods, which included meta-analysis, scientific experimentation, database analysis, data mining and expert knowledge harvesting.

The current study aimed to address the need for a clear understanding and quantification (valuation) of the effects of environmental degradation on socio-economic systems. This to provide further evidence of the relationship between catchment degradation and the socio-economic status of communities as well as the cumulative effect of polluting activities on the provisioning of aquatic ecosystem services.

The specific aims of this study were therefore to:

1 Review the real challenges related to water resource and environmental management resulting from the impacts of environmental degradation on the health and integrity of water resources and the aquatic ecosystem services they provide.

2 Develop and refine approaches and tools needed to analyse the impacts of environmental degradation on socio-economic development in terms of the aquatic ecosystem services at risk due to environmental degradation.

3 Investigate the impacts of ecological degradation on the livelihoods and well-being of communities, specifically rural and peri-urban communities, who benefit directly from water resources and the associated aquatic ecosystem services they provide.

4 Apply the relationships between the degraded water resources and socio-economic development to the case study areas and critically analyse the results with specific

attention to the implications for policies, the opportunities presented for environmental and water resource management and the threats posed to dependent communities and the country as a whole.

5 Propose future research required in the study area for efficient water resource management and assistance in implementing the findings.

In order to achieve the above objectives, the project started with developing an understanding of the urban river system. Mapping of aquatic ecosystem services was fundamental to this systems analysis. This was especially important to define causal linkages between ecological infrastructure and beneficiaries of ecosystems services. Furthermore, in order to analyse pressures on ecosystems, the so-called DPSIR (Driving forces, Pressures, States, Impacts, Responses) causal framework for describing the interactions between society and the environment (as defined by the European Environment Agency) was used. According to the DPSIR framework there is a chain of causal links starting with 'driving forces' (economic sectors, human activities) through 'pressures' (emissions, waste) to 'states' (physical, chemical, and biological) and 'impacts' on ecosystems, human health and functions, eventually leading to political 'responses' (prioritisation, target setting, indicators). This resulted in the identification key indicators through which to evaluate and monitor aquatic ecosystem services.

The project included processes of acquiring data for ecosystem service valuation, using the methods identified in WRC project K5/1644. It specifically involved:

1. Gathering of new primary data (experimentation):
    a. Through SMART and affordable monitoring of river health through water quality;
    b. Conduct of household surveys reliance on aquatic ecosystem service
    c. Collection of property value data to estimate the aesthetic value of ecosystem services
2. Meta-analysis:
    a. Transfer Method (i.e. habitats for species).
3. Database analysis
    a. Geospatial analysis to classify and identify features and processes across a study area;
    b. Collection of current and historical land use and present ecological state data to determine trends in pressures and impacts; and
    c. Database retrieval of hydrological data sourced from trusted organisations
4. Data mining
    a. Hedonic pricing utilising CoT valuation roll to retrieve impact of aquatic infrastructure on property; and

b. The acquisition of proxies for use in ecosystem service valuation through:

    i. Market pricing;

    ii. Resource rent; and

    iii. Damage costs.

c. Retrieval of travel and recreational use of ecological infrastructure for a simplified Travel Cost Method (TCM).

5. Expert knowledge harvesting
    a. Interviewing of estate agents to estimate the aesthetic value of ecosystem services; and
    b. Consultations with local community members on the perceptions of associated aquatic infrastructure.

Ecosystem service valuation was performed and, thereafter, we constructed an integrated bio-economic model. This model demonstrated the relationships between the environment and the economy by using production functions where the environmental indicators are used as inputs into the production of ecosystem services. The model provided evidence of the magnitude and trajectory that various drivers have on the health of the ecosystem.

Two case studies, namely the Apies-Pienaar River system and Zaalklap Wetland in the Olifants River water management area (WMA) were used to demonstrate application on the relationships between the degraded water resources and socio-economic development.

The Apies-Pienaar River system was identified as a suitable case study area for testing the relationships between the impacts of environmental degradation (specifically on the socio-economic system) and the various catchment land uses and water uses that result in the degradation of aquatic ecosystems. The cumulative effect of urbanisation on an urban river system was analysed and a monitoring plan to provide data to be used in a socio-ecological systems model was developed.

An important consideration for the monitoring plan was for the techniques and approaches employed, to be technically realistic and practical for use by organisations such as municipalities.

The monitoring plan included monitoring river health through water quality, identification of the land and water uses that affect and are dependent on the river system, identification of ecosystem services that the river system provides and a measure of human well-being in the system. This study involved 12 months of monitoring and the results of these indicators are discussed below.

Between flow and concentration, using regression to estimate load from continuous flow and intermittent concentration data is highly effective. A regression relationship was developed between concentration and flow based on the days for which concentration data exist. The data was based on grab samples for concentration and mean daily flow for the sampling day. The load model indicated that inland use activities has a negative impact on water quality.

An Express-River Habitat Assessment method was developed with the premise of having a basic, yet insightful knowledge on the state of habitats in an urban river system. The catchment had a high heterogeneity of land uses and intensities spread across it and results showed that land transformation and increased population density are closely related to ecosystem damage.

Beneficiaries of water provisioning services included domestic, agricultural, and industrial land uses which use the water directly. A household survey was conducted to assess the relationship between households located within riverine system. The household survey considered a full range of provisioning services as well as the consumption of cultural services generated by the system. The survey indicated that many households utilise riparian vegetation from the riverine system as a source of fuel, collect raw material for use of construction and livestock grazing takes place on the banks of the riverine system.

Travel cost method was used for assessing recreational ecosystem services. The basic premise for this method is that the time and travel cost expenses that people incur to visit a site represent the "price" of access to the site. Thus, the method estimate the willingness to pay of consumers based on the number of travel trips that they make based on the quantity demanded at different prices. The method relates the number of trips people went fishing and the number of trips people went bird watching with a variety of environmental and economic indicators. The results indicated that the state of system has an impact on the number of fish caught and number of bird watching trips. This is because water in good condition will have a positive impact on the number of fish caught and improve tourism industry.

The value of the river system in terms of the aesthetic services that it provides was captured by estimating the impacts it has on property values. Data for a hedonic pricing analysis was collected from real estate agents operating within communities located within the study area. The analysis indicated that properties having a view of the river have a higher value.

These components were combined in a socio-ecological systems model, using ES production functions, to provide an evidence-based analysis of ecological degradation and its effects on the water resource, ecosystems, and socio-economic development. An Integrated Bio-Economic Model which is the output for this case study was developed. This model determines the relationship between the environment and the economy by using production functions where the environmental indicators are used as inputs into the production of ecosystem services. The production function approach allows the model to determine the marginal impact that certain changes in the environment will have on ecosystem services. The output of this model lend support to the position that land use activities negatively impact the health of natural systems.

In the case of the Zaalklap system, a mining and industrial impact on a wetland dominated system was analysed. Water quality results indicated that mines significantly impacted this wetland system negatively. Based on estimates done, the asset (or ecological infrastructure) value of the Zaalklap wetland ranges between R501-R763 million, of which the water purification and waste assimilation service contributes R130-R560 million. Thus, by rehabilitating the Zaalklap wetland at a cost of R1.7 million, we have been able to produce between R130-R560 million on the natural asset balance sheet of South Africa. This demonstrates that wetland rehabilitation form a very important part of wetland impact mitigation strategies.

It is a continuous challenge to balance economic development with maintenance of a healthy ecosystem as it requires recognition of the inter-dependencies between the natural environment, economic stability, and social well-being. Because ecosystem services are “free” or under-priced, their exploitation is not considered to constitute an economic or social cost which must be weighed against the economic benefits of the production and consumption they generate.

Two types of environmental impacts were analysed. In the case of the Apies-Pienaars system, the cumulative effects of urbanisation on an urban river system was analysed. In the case of the Zaalklap system, a mining and industrial impact on a wetland dominated system was analysed. These case studies managed to put value in ecological infrastructure and linking it to the economy.

We provided evidence of loss of crucial informal economy income by people living in Hammanskraal and surrounding areas; we demonstrated the significant increase in value on private property (subsequent municipal rates income) resulting from proximity to high quality ecosystems; we demonstrated the significant and practical value of wetlands in treating water pollution. Land use intensity was a major driver of ecological degradation, resulting in major impacts to ecosystem services. More specifically: roads, dams, agriculture, mining, power generation, manufacturing and urbanisation and associated land transformation. Data collection was possible through a range of sources which were either generally freely accessible or easily measured. Through a range of data sources and collection methodologies evidence required to quantify and assess the link between economic development and ecosystems was possible. The major institutional gap was shown to be the multidisciplinary nature of socio- ecological systems. Multidisciplinary nature of assessing the socio-ecological drivers, pressures and impacts can be packaged into a practical, straight forward and cost effective approach.

This study indeed provided evidence that if ecological infrastructure is valued, proper decisions or mitigations can be made when there are new developments so that the future generation can still benefit from these natural resources.

An informed approach to environmental management is key for sustainable development. Government and relevant regulators must adopt this informed approach. Governments are responsible for environmental regulation of users as well as are themselves users of the environment. The first approach would be to ensure efficient data is available to inform decisions and the second is to evaluate environmental policies to ensure that they are operating effectively.

Based on the evidence collected from this study, metropolitan municipalities should take a holistic and critical review of bylaws that relate to ecological degradation. Of course, these regulations need to be in harmony with crucially important economic development priorities. This study showed that ecosystem services of urban and mining systems are important and valuable to households, to business activities and to municipalities as a whole. The results described below are thus crucial to inform Business case(s) to be made towards preventing, mitigating, and rehabilitating ecological degradation.

Over the next 20 years we expect to see increasing urbanization, development of water services infrastructure, energy and electrification projects, transport infrastructure development and industrialisation. There is no doubt that the apparent conflict between economic development and environmental protection imperatives will increase.

Fortunately, the wonderful thing economic systems has taught us, is that they allow economic development to happen often in the most surprising ways. Thus, our challenge in South Africa will be to internalise ecological infrastructure and ecosystem services within the development potential of economic systems. Environmental risk is human well-being risk and thus economic risk. In the high inequality economy of South Africa, we face starkly different challenges to the economies of other continents, and we need a new risk management approach.

We need double dividend policy and financial instruments that simultaneously manage risk and enable development.

For example, market-based mechanisms could establish new markets in which pollution permits can be traded. This mechanism facilitates trade in the right to pollute within a predetermined safe pollution standard. Tradable pollution permits create an incentive for companies to reduce pollution relative to their entitlement, since it becomes possible to sell the difference to willing buyers. Such trading can lower the cost of compliance and enable development.

Towards improving and acting on the findings observed, various points of departure were proposed.

Firstly, the institutional data management gaps must be addressed. These relate to the challenges introduced due to the multi-disciplinary nature of socio-ecological studies. It has been shown here that data is readily available and can be practically collected. It is at this point, however, that this collection process should be standardised to allow for effective collaboration and communication between institutions regarding ecological degradation. Secondly, the accuracy of the ecology-economy linkages described in this study should be improved. This should focus on the refining and finalisation of the bio-economic model. The Bio-Economic model is a highly powerful asset that can potentially be used as a framework to enhance the effective collection of necessary data to inform current policy instruments and build confidence in decision making. Thirdly, the results should be further developed to inform future developments allowing for insight into the trade-offs between value provided and impacts received by the environment. Fourthly, monitoring and evaluation programmes will significantly reduce risks to ecological infrastructure by identifying red flags at which point in depth further investigations may take place. Finally, with the use of tools such as the bio-economic model, policy instruments should be developed and tested providing for additional regulatory, economic or suasion approaches toward ensuring economic development also results in environmental preservation.

ACKNOWLEDGEMENTS

The authors wish to acknowledge:

The WRC for funding this project, and Mr Bonani Madikizela (WRC) and Dr Stanley Liphadzi (WRC) for their guidance as research managers.

Dr Sebastian Jooste (Department of Water and Sanitation – Resource Quality Services) for his guidance and advice.

City of Tshwane citizens who took part in various parts of the study.

City of Tshwane staff and resources for their advice and support, especially Mr David Ntsowe, Mr Kerneels Esterhuyse and Mr Stephen van der Merwe.

Coaltech, SANBI and CSIR for providing data for one of the case studies conducted in this research.

Various members of the Reference Group, including:

Name	Organisation
• Mr M Braak	Department of Environmental Affairs: Natural Resource Management
• Dr NP Gola	SANBI
• Ms N Mohapi	Department of Water and Sanitation
• CG Pengelly	Green Cape
• Ms K Pringle	Institute of Natural Resources
• Dr F Tererai	Department of Environmental Affairs: Natural Resource Management
• Dr J Dikgang	University of Johannesburg

The authors also wish to acknowledge the tremendous contributions of our colleagues Darian Pearce, Wean Visser, Laura Danga and Thandi Magagula in various aspects of the earlier deliverables of this project.

TABLE OF CONTENTS

List of Tables

List of Figures

ACRONYMS AND ABBREVIATIONS

AMD	Acid Mine Drainage
CBA	Cost-benefit Analysis
CBD	Central Business District
CEE	Collaboration for Environmental Evidence
CMA	Catchment Management Agency
COD	Chemical Oxygen Demand
DEA	Department of Environmental Affairs
DO	Dissolved Oxygen
DWS[1]	Department of Water and Sanitation
E-BASES	Evidence-based analysis of socio-ecological systems
EIA	Environmental Impact Assessment
EIS	Ecological Integrity and Sensitivity
ERE	Environmental and Resource Economics
ES	Ecosystem Services
GDP	Gross Domestic Product
HVM	Hedonic Valuation Method
IBT	Inter Basin Transfer
IWMI	International Water Management Institute
IWRM	Integrated Water Resource Management
LSM	Living Standard Method
M&E	Monitoring and Evaluation
MAR	Mean Annual Runoff
MC	Management Class
MEA	Millennium Ecosystem Assessment
NCMP	National Chemical Monitoring Program
NEMP	National Eutrophication Monitoring Program
NMMP	National Microbiological Monitoring Program
NRMP	National Radioactivity Monitoring Program
NWA	National Water Act
ORP	Oxidation Reduction Potential
PES	Present Ecological State
RDM	Resource Directed Measures
RHP	River Health Program
RO	Reverse Osmosis
RQO	Resource Quality Objectives
SA	South Africa
SANBI	South African National Biodiversity Institute
SES	Socio-ecological System

[1] Department of Water and Sanitation (DWS) was known as Department of Water Affairs (DWA) until 2014. Therefore many publications still use DWA as their reference. We will, for simplicity's sake, consistently use DWS when referring to this department.

TCTA	Trans Caledon Tunnel Authority
TDS	Total Dissolved Solids
TEEB	The Economics of Ecosystems and Biodiversity
TEV	Total Economic Value
UN	United Nations
US EPA	United States Environmental Protection Agency
WMA	Water Management Area
WRC	Water Research Commission
WRCS	Water Resource Classification System
WRQMP	Water Quality Resource Monitoring Program
WSA	Water Service Authorities
WSP	Water Service Provider
WUA	Water User Association
WWTW	Waste Water Treatment Works

1 BACKGROUND

1.1 INTRODUCTION

The cumulative effect of catchment-wide aquatic environmental ecosystem degradation presents a hazard to human well-being. The degradation effects result from various water and land use practices, which impacts water resources and the aquatic ecosystem services they produce. Various economic sectors and humans bear the resulting risks directly, and especially poor communities who are reliant of aquatic ecosystem services for their livelihood.

These risks are often poorly understood and therefore also poorly managed. This is because the value of aquatic ecosystem services often lies in the “insurance value” provided by regulating services. Regulating services are intermediate services, in other words, are not consumed directly by humans. Therefore, people often have little conception of the role of regulating services and the ecosystem assets on which they depend.

Management of these risks requires a clear understanding of the relationships between human well-being, socio-economic development, ecological degradation, and evidence-based analysis thereof.

Water resources (i.e. aquatic ecosystems) form part of complex social-ecological systems within which the production of ecosystem services increasingly limits social and economic development. At a regional scale, there are no substitutes for these services, and thus resource users must learn to live within the limits of the capacity of the ecosystems to provide services that accommodate both efficiency and equity. Users must further manage use in ways that will offer better prospects for sustaining a future flow of benefits (Ginsburg *et al.*, 2011).

The aim of the project is to provide practical and affordable evidence-based analysis of the effects and impacts of environmental degradation on water resources, ecosystems, and socio-economic development and to use this evidence to secure aquatic ecosystem services.

1.2 PRIOR WORK

WRC project K5/1644 developed a set of guidelines and a manual for the evaluation of trade-offs in aquatic ecosystem services that may result from different water management scenarios. These guidelines combined water management practices; the MEA framework of ecosystem services, and best practices in environmental and resource economics (ERE) valuation into a four-phased approach. This four-phased approach contains a series of analysis methods through which to analyse and evaluate chains of causality and the trade-offs that result from different water resource management scenarios. It thus connects the social and ecological sub-systems such that we can consider in a structured and repeatable way, how they might respond to interventions we may choose to make or to naturally occurring changes.

However, a key gap identified relates to both the methodology through which to analyse chains of causality and the burden of evidence required to specify and quantify chains of causality. Knowledge of, and data for, analysing chains of causality are often dispersed and poorly archived. Furthermore, limited guidance is available on how to make use of different types of available evidence.

In a subsequent study, WRC Project K5/1978 explores the field of 'evidence-based analysis of socio-ecological systems' (which we have abbreviated "E-BASES"), with the purpose of identifying potentially feasible methodologies for finding evidence, both ecological and social, in support of analysing chains of causality in complex, water resource dependent, socio-ecological systems. This study defined E-BASES as follows:

- the systematic review and synthesis of primary and secondary data;
- the summary, appraisal and communication of the data and its implications to support decision-making with the best available evidence;
- to assess the likely outcomes of cause and effect relationships in complex socio-ecological systems.

The project proposed several guiding principles for E-BASES as a guide for extracting evidence and scientific inquiry:

- PRINCIPLE 1. Pose significant questions that can be investigated empirically
- PRINCIPLE 2. Link research to relevant theory
- PRINCIPLE 3. Use methods that permit direct investigation of the question
- PRINCIPLE 4. Provide a coherent and explicit chain of reasoning
- PRINCIPLE 5. Disclose research to encourage professional scrutiny and critique.

The proposed E-BASES methodology is premised on the formulation of a review question based on a system of cause and effect relationships, involving multiple system components, which, together, comprise a chain of causality. In addition, the evidence-extraction is expanded to explicitly include five evidence-extraction methods [2], which include meta-analysis, scientific experimentation, database analysis, data mining and expert knowledge harvesting.

1.3 MOTIVATION

The study aims to address the need for a clear understanding and quantification (valuation) of the effects of environmental degradation on socio-economic systems. This will provide further evidence of the relationship between catchment degradation and the socio-economic status of communities as well as the cumulative effect of polluting activities on the provisioning of aquatic ecosystem services.

Environmental management for sustainable socio-economic development necessitates the implementation and enforcement of policies. The implementation of the Water Resource Classification System and Resource Quality Objectives by DWS are important strategic policy initiatives. In addition, Environmental Authorisations and Water Use Licenses often have performance conditions attached. Monitoring of compliance to these strategic and other

2 The CEE guidelines allow for application of various evidence-extraction methods (personal communication – Prof Andrew Pullin). In this report, we explicitly identify five such methods that are of relevance to South African applications.

performance criteria would only be possible if the required data and evidence of the relationship between environmental degradation and the impacts on water resources and aquatic ecosystem services are available. Although sufficient anecdotal and other evidence exist that show the existence of ecological degradation impacts on the aquatic ecosystem services provided by water resources, the evidence-base is not yet of a standard required for monitoring the slow, cumulative degradation effects of multiple human impacts (personal communication with Nigel Adams (DWS), Mark Jardine (DEA) and Sebastian Jooste (RQS, DWS)).

During the consultations with DWS and DEA, both departments highlighted the need of a water resource management approach that addresses the specific needs of the management organisations, that quantifies the damage to an ecosystem due to human activities, that adds to the burden of proof required to intervene and enforce policies and that provides reliable and consistent results that can add to the knowledge base for skills development and subsequent regulation. Challenges faced by the departments include effective and reliable water quality monitoring, addressing the water quality data analysis backlog experienced, the interactions between departments on regional and national level and the subsequent difficulties in assigning ownership of problems and establishing a baseline of water resource health and integrity to measure the extent of the damage to the environment against. The necessity to determine a threshold of significance in order to manage impacts that cause serious harm, but not necessarily degradation, was also discussed (Mark Jardine (DEA)). Other concerns expressed by DWS and DEA include the need for an affordable early warning system that not only allows water management organisations to act pro-actively to occurring impacts, but which also prioritises impacts of significance that require immediate intervention. In consultation with Sebastian Jooste (RQS, DWS) approaches, tools, and models to address the needs and challenges of water resource management institutions and to solve the problems of environmental degradation were discussed.

1.4 Rationale

Poor communities especially depend directly on the aquatic ecosystem services provided by water resources. It is, therefore, of great importance to maintain the health and integrity of water resources to ensure the social and economic security of the dependent communities. Relationships between environmental degradation and their impacts on water resources, ecosystems and socio-economic development have been demonstrated in various studies. Very often a healthy ecosystem is viewed as a trade-off with economic development (Figure 1-1). This relationship however is more complex and contain various feedback loops and interconnected relationships.

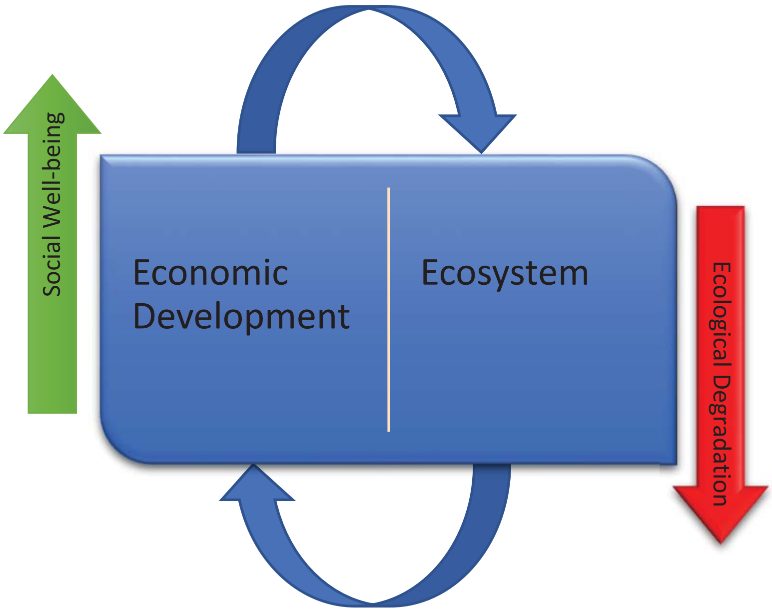


Figure 1-1: Relationship between ecosystem services and economic development

The management of environmental degradation from catchment land uses has thus become prominent for maintaining the provisioning of aquatic ecosystem services utilised by communities for their benefit.

Environmental management requires a clear understanding of the relationships and interactions between catchment land use practises[3], the associated impacts on the aquatic ecosystem due to the land uses and the risks to the aquatic ecosystem services provided by the water resource. DWS has various strategies in place to manage water resources. However, due to limited human resources and restricted water quality data, application and enforcement of the policies and approaches are constrained. Due to the water quality data-limited environment, comprehensive information regarding the sources and extent of pollution, the cumulative effect of pollution, the impacts associated with specific sources on water resources and the socio-economic system as well as the interaction between pollutants and the environment are lacking. Furthermore, conventional water quality models used as water resource management tools rely on the input of comprehensive and large data sets and an in-depth knowledge of the chemical and physical complexity of water resources (refer to previous WRC studies K5/1644 & K5/1978). Thus, the use and application of the conventional models are highly restricted and the reliability of the outputs is limited. However, a recent WRC consultancy study (Burger & Crafford, 2012) has shown that it is possible to develop water chemistry models that can provide reliable, accurate and rapid results within a data-limited environment. The challenges related to water resource management can, therefore, be addressed by a thorough investigation and consolidation of relevant study outputs, an in-depth examination of a catchment with associated catchment land uses, an analysis of the ecosystem services from which communities benefit and the determination of the ecosystem services at risk due to the

3 Poor land use practises include mining activities, agriculture, excessive abstraction, the discharge of partially treated or untreated wastewater effluents, deliberate pollution, catchment degradation and the harvesting of natural resources. These activities can be classified as point and non-point (diffuse) sources of pollution. Point sources of pollution have been studied extensively as compared to a limited understanding of the nature and impacts of diffuse sources. The significance of diffuse sources on environmental degradation, however, necessitates further investigation and quantification.

impacts of environmental degradation on the water resource, ecosystems and socio-economic development.

The findings of the investigation, together with the construction of a comprehensive water quality database will result in a framework for directed investigation and will enable the research team to elaborate on the relationships between environmental degradation and the associated impacts. The framework for assessing water resource degradation and the relationships developed between degradation and social well-being will be scientifically sound and statistically significant. These relationships can be used to effectively assess available data and maximise the information yield within a data-limited environment producing strong and sufficient evidence of the impacts of environmental degradation. From the refined relationships, production functions can be formulated to quantify the impacts of the degradation of natural assets on the socio-economic system. The full valuation of the impacts of environmental degradation and the internalisation of the natural capital into the greater economy will not only assist organisations and institutions in policy formulation and enforcement but will also prioritise impacts, direct further investigation into significant polluting activities and determine and motivate future research. The multidisciplinary nature of the project will also enable refinement and development of tools and approaches to build capacity for further research. The resultant greater understanding of the interactions within a catchment will facilitate management organisations to better manage water resources pro-actively with more directed water quality monitoring programs, better use of available human resources and optimum information yield within a data-limited environment. The implementation of principles and policies, to support environmental management and socio-economic development, will be made possible. All water users, especially poor communities that rely directly on water resources, will benefit from the outcomes of the project.

1.5 OBJECTIVES

The aim of the project was to develop appropriate approaches for assessing the casual effects of degraded water resources, resulting from catchment land uses, on socio-economic development.

AIMS:

1. Review the real challenges related to water resource and environmental management resulting from the impacts of environmental degradation on the health and integrity of water resources and the aquatic ecosystem services they provide.
2. Develop and refine approaches and tools needed to analyse the impacts of environmental degradation on socio-economic development in terms of the aquatic ecosystem services at risk due to environmental degradation.
3. Investigate the impacts of ecological degradation on the livelihoods and well-being of communities, specifically rural and peri-urban communities, who benefit directly from water resources and the associated aquatic ecosystem services they provide.
4. Apply the relationships between the degraded water resources and socio-economic development to the case study areas and critically analyse the results with specific attention to the implications for policies, the opportunities presented for environmental and water resource management and the threats posed to dependent communities and the country as a whole.

5 Propose future research required in the study area for efficient water resource management and assistance in implementing the findings.

The aims presented above were further interpreted by the project team into the following objectives:

- Identify and analyse the drivers with respect to ecosystem services, especially with respect to hydrology, water quality (nutrients and pollutants) and habitat.
- Source evidence from Literature, hydrological models, water quality databases of DWS and other relevant data sources (as per WRC K5/1978).
- Assess the quality of monitoring and evaluation databases, systems using the SMART method (Specific, Measurable, Attainable, Relevant, Time-bounded).
- Assess the sufficiency of the available evidence base against legal requirements of evidence with special attention to standards of evidence and burden of proof specifications
- Conduct an institutional gap analysis with respect to internalising ecological damage into the economy.
- Explore methods that have been developed for quantifying ecosystem damages causing loss of ecosystem service; including ecosystem service mapping, development of ecosystem structure production functions and ecosystem service valuation techniques.

The output of this task resulted in the study to follow Figure 1-2 process

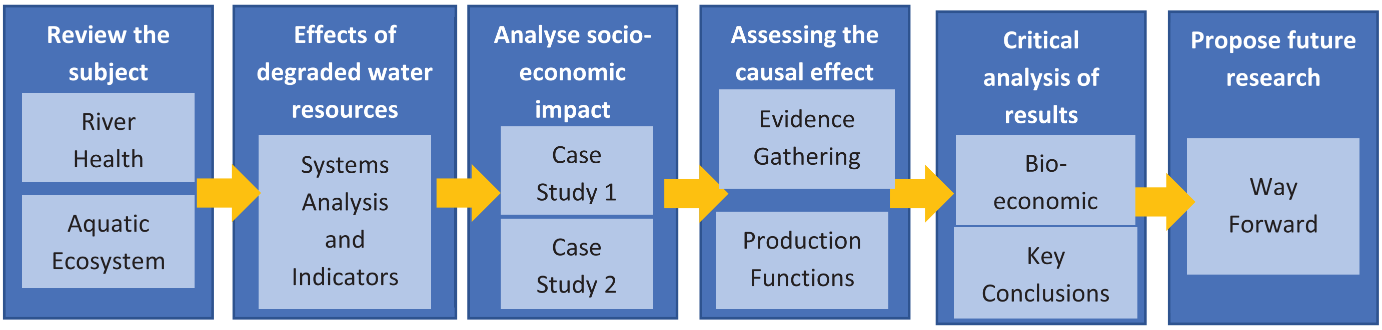


Figure 1-2: Approach to achieve the objectives

2 LITERATURE REVIEW

2.1 ECOSYSTEM SERVICES

The benefits produced by water resources are defined by the MEA as ecosystem services. This includes both fresh water of acceptable quality, and other aquatic ecosystem services.

Aquatic ecosystem services produce significant social and economic benefits. Households consume approximately 13% of South Africa's water for drinking, washing and other domestic purposes. Water is also a limiting input into production sectors such as agriculture, mining, manufacturing, and heavy industry. This means that, without a reliable water supply, these production activities are constrained and economic growth is restricted. South Africa's GDP in 2010 was R2, 664000 million, and our total water use approximately 14,147 million m^3. The economic sectors such as Agriculture, Forestry, Mining, Power generation and wet manufacturing industries require water as a significant production input. Together, these sectors contribute 8.4% to Gross Domestic Product (GDP). Another important public good component to water relates to other aquatic ecosystem services. These are the benefits provided to the households and economic sectors in South Africa. Although the total value of aquatic ecosystems in the South African economy has not yet been comprehensively assessed, it contributes significantly to the tourism sector, to recreation activities and to land values. In addition, it is estimated that aquatic ecosystem services externalities may be as much as 3% of GDP. These are benefits not accounted for in GDP such as benefits to the informal economy and to public health (Crafford, 2012).

A special category of ecosystem services are the regulating services. The regulating services are not consumed directly in the economy and can therefore not be measured through GDP and similar indicators. These services, are however, some of the most significant and important ones, as they regulate the production of other ecosystem services. They provide the economy with an insurance value.

2.1.1 INTRODUCTION TO ECOSYSTEM SERVICES

Ecosystem services are considered to incorporate assets (the natural capital) that yield a flow of services of benefit to people, much like other capital stocks. A change in the ecosystem (asset) would cause a change in the system and impact upon the delivery of ecosystem services in some way. By definition, then, the concept of ecosystem services is human-centric and explicitly links the well-being of people to ecosystems while, at the same time, recognising that there are many other factors which influence human well-being. Building on the MEA definition, Boyd and Banzhaf (2006) defined ecosystem services as 'components of nature, directly enjoyed, consumed or used to yield human well-being'.

The MEA classifies ecosystem services as **supporting** (basic ecosystem functions and processes that underpin all other services), **regulating** (covering the absorption of pollutants, storm buffering, erosion control and the like), **provisioning** services (covering the production of foods, fuels, fibre etc.), and **cultural** services (covering non-consumptive uses of the environment for recreation, amenity, spiritual renewal etc.). This is underpinned by the diversity of ecosystems, where biodiversity integrates ecosystem pattern or structure with the process or function. Biodiversity also links spatial and temporal patterns across scales, so providing a way to assess ecosystem health. Figure 2-1 illustrates this relationship from the viewpoint of the MEA (MEA, 2005).

Aquatic ecosystem services are an important subset of the suite of ecosystem services which are based on water in the environment.

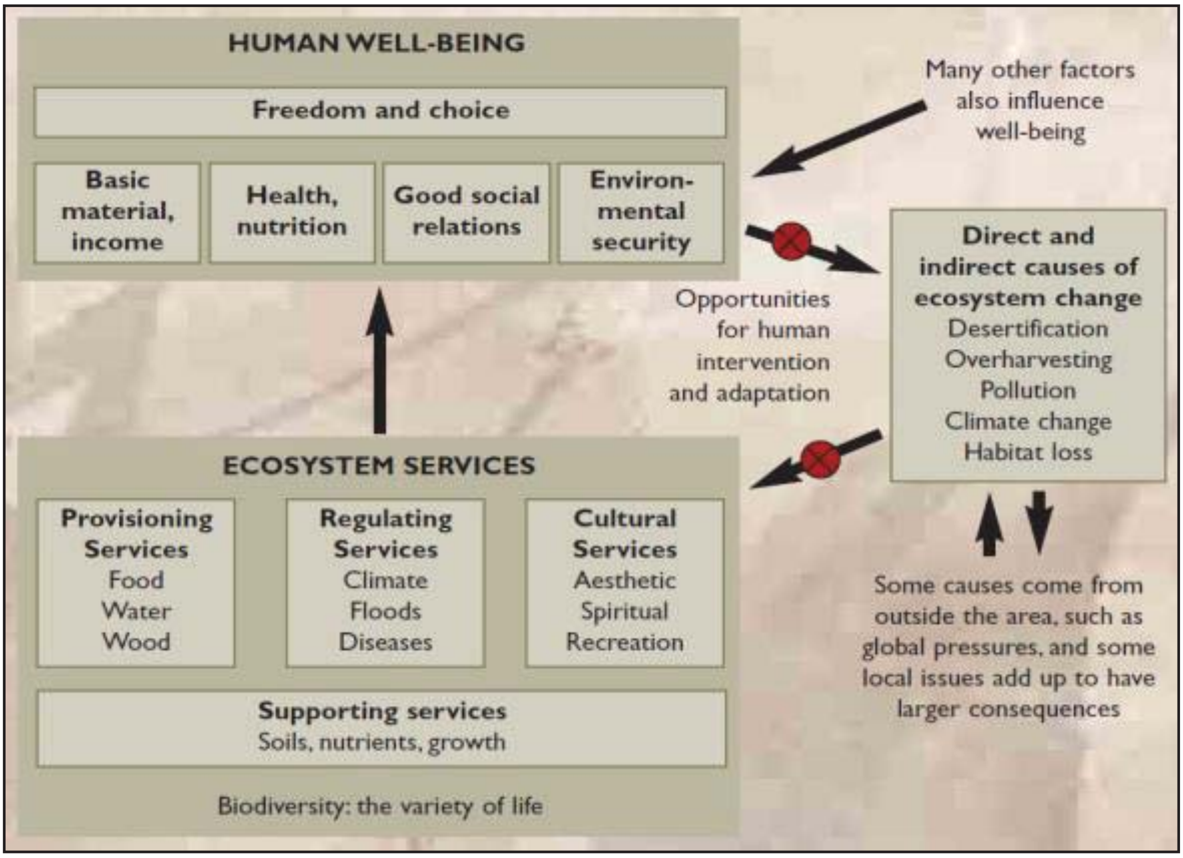


Figure 2-1: The relationship between ecosystem services and human well-being (Biggs et al. 2004)

The health of ecosystems is negatively impacted by many of man's activities while at the same time sustainable development together with human well-being are dependent on improving the management of ecosystems globally. There is an increasing demand for such ecosystem services as food and fresh water while at the same time our activities may be compromising the capacity of the ecosystem to provide these benefits. Sound policy and management interventions can reverse this trend but these interventions must be based on a good understanding of both the ecological and social systems involved.

Ginsburg *et al.,* (2009) developed the method to value the changes in ecosystem services resulting from changes in river flow resulting from decisions emanating from the implementation of the ecological reserve (as determined by the water resource classification system of the DWS). This study developed a set of guidelines and a manual for the evaluation of trade-offs in aquatic ecosystem services that may result from different RDM scenarios and indicates how the ecosystem services, and so the flow of benefits to society, will respond to water resource management decisions.

In the follow-up to Ginsburg *et al.,* (2009), Breen *et al.,* (2011), in investigating the applicability of production functions to analyse the chains of causality. They noted that existing methods tended to focus on a single dimension and ignore the complexity inherent in ecosystem processes and functionality. In addition, they point out that people often are not aware of environmental risk and have little conception of the role of ecosystem assets in the generation of ecosystem services and the generation of benefits. The production function approach was shown to adequately describe likely consequences of changes in multiple variables of complex systems, requiring a combination of expert knowledge and empirical evidence.

Recognition of the value provided by natural capital to the socio-economy combined with recognition that the current model of economic growth is socially, environmentally, and economically unsustainable The TEEB study which is an international initiative aimed at highlighting the economic benefits of biodiversity and the growing cost of biodiversity loss and ecosystem degradation. The value of natural capital is often overlooked or poorly understood, resulting in it rarely being considered in day-to-day decisions. And the global economy currently consumes the equivalent resources of 1.4 planets which tells us that we are no longer living off the ‘interest’ generated by the planet, but are ‘drawing down’ our natural capital (TEEB, 2009; Pauli et al., 2010a). To quote from TEEB (2010) *‘Applying economic thinking to the use of biodiversity and ecosystem services can help clarify two critical points: why prosperity and poverty reduction depend on maintaining the flow of benefits from ecosystems; and why successful environmental protection needs to be grounded in sound economics, including explicit recognition, efficient allocation, and fair distribution of the costs and benefits of conservation and sustainable use of natural resources’*. TEEB commissioned Trucost to produce a high-level perspective on the world’s biggest natural capital risks for business, investors and governments, it was found that the production and primary processing sectors which they analysed had unpriced natural capital costs of US$7.3 Trillion (13% of the global economic output in 2009). The costs were apportioned as follows: greenhouse gas emissions (38%), Water use (25%), land use (24%), air pollution (7%), land and water pollution (5%) and waste (1%). The analysis showed that no high impact region sectors generated sufficient profit to cover their environmental impacts. The contribution of natural capital to the economy is increasingly being recognised by business.

TEEB (2010) observes that linking biophysical aspects of ecosystems with human benefits through the concept of ecosystem services is essential to assess the trade-offs (ecological, socio-cultural, economic, and monetary) involved in the loss of ecosystems and biodiversity in a clear and consistent manner. The assessment of ecosystems needs to be spatially and temporally explicit at scales meaningful to policy formation and needs to provide solid underpinning to economic valuation. Assessments, within the context of contrasting scenarios, permit measurement of both the values of the ES and the costs of the actions, so allowing for decisions around trade-offs. When assessing trade-offs, the total bundle of ecosystem services should be included and assessments should include costs and integrate risks and uncertainties.

2.1.2 HAZARDS TO ECOSYSTEM SERVICES

A large range of anthropogenic activities impact on ecosystem services. The degradation effects result from various water and land use practices, which impacts water resources and the aquatic ecosystem services they produce. A clear distinction between point sources and non-point sources of pollution has been drawn by the DWS (Heath *et al*., 2003). Point sources include outfall pipes from any activity classified as a water use; storm water outfall pipe; irrigation point; run-off channels

and sub-surface drains; controlled-release dam and landfill leachate. Nonpoint sources include dams and water impoundments; landfill sites; irrigated agriculture; irrigation of waste; dry land agriculture; mine and industrial dumps and excavations; confined livestock enclosures; urban activities; general urban waste and spills. Point sources are easy to identify and measure, and it is theoretically possible to exercise a high degree of control over the quality of the final effluent discharged into the environment. Nonpoint sources, on the other hand, are often difficult to locate, difficult to measure and may be very difficult to control.
A detailed analysis on impacts is provided in Appendix B.

2.2 IWRM Policy considerations

The National Water Act (NWA) aims to ensure the sustainable use of water resources for the benefit of all users.

An integral component of ensuring the sustainable use of South Africa's water resources is the Water Resource Classification System (WRCS). The purpose of the WRCS is to facilitate a balance between protection and use of water resources in South Africa's Water Management Areas (WMA). A major outcome of the WRCS is assigning a Management Class (MC) to each of the sub-catchments within the WMA. In determining the class, it is important to recognise that different water resources will require different levels of protection. In addition to achieving ecological sustainability of the significant water resources through classification, the process will allow consideration of the social and economic needs of competing interests by all who rely on the water resources. The WRCS will be applied taking account of the local conditions, socio-economic imperatives, and system dynamics within the context of the South African situation. The process will also require a wide range of complex trade-offs to be assessed and evaluated at several levels.

One of the measures following from the WRCS is the so-called Resource Quality Objectives (RQOs). The RQOs form part of a family of water management measures which includes the:

- Water Resource Classification System (WRCS) which provides the vision and management class for the various sub-catchments within a river basin,
- Ecological Reserve provides for the ecological water requirements for the various sub-catchments within a river basin, and
- the Resource Quality Objectives provides management goals for the various sub-catchments within a river basin

The purpose of RQOs is thus to establish clear goals relating to the quality of the relevant water resources. These goals can be numerical and/or descriptive statements and may relate to the:

- Quantity (pattern and timing of flow),
- Water quality
- Character and condition of riparian habitat and
- Characteristics and condition of the aquatic biota.

The NWA also sets clear guidelines on prevention and remedying effects of water pollution, and the instrument of policy that reacts to these guidelines is the Waste Discharge Charge System (WDCS).

The purpose of this system is the internalisation of environmental costs by waste dischargers through use of water charges to ensure compliance with prescribed standards and water management practices per user pays and polluter pays principles. Thus, water use charges are to be used as a means of encouraging reduction in waste, and provision is made for incentives for effective and efficient water use (DWA, 2002).

South Africa thus clearly has sufficient policy measures in place to enable the implementation of IWRM. However, implementing IWRM has many additional challenges.

2.2.1 CHALLENGES TO IMPLEMENTING IWRM

IWRM implementation is hampered by several key constraints.

Firstly, the increased complexity of water management decisions requires new skills set and new and different institutional capacities. Thus, successful implementation of IWRM is conditional on having effective water law, water policy and effective water management organisations.

Secondly, multiple decision-makers are now involved in water management and thus it is often very difficult and time-consuming to find consensus in decision-making. The cost of collective decision-making increases with the fragmentation of water management decision-makers, and is an inherent feature of IWRM. Water management decision-makers in South Africa include DWS, its regional offices, CMAs, Water user associations (WUAs), ad hoc advisory committees, the TCTA, Water Boards, Water Service Authorities (WSAs), Water Service Providers (WSPs), other organs of state (e.g. National and Provincial Departments, SANBI, conservation agencies and others), local government and other interest groups including agricultural, commercial, industrial, labour, civic, community or environmental interest groups. Such institutional fragmentation creates transaction costs through weak integration and coordination and lack of clearly defined organisational mandates and strategies around governance of the water resource. In addition, associated power, and political interests impact transaction costs, and thus conflict (arising from inter-organisational competition) becomes an impediment to implementing water reforms. The key intervention proposed by the National Water Act is the establishment of Catchment Management Agencies (CMAs), for whom a key function is institutional engagement, dispute resolution and legal support. Increasing future water scarcity will increase incidence of disputes and conflicts. It is thus in the interests of DWS and water users that CMAs should develop management plans for shared river basins and derive workable protocols that can be used to minimize water-based conflicts (Aston, 2003).

Thirdly, revenue collection systems need to be extremely efficient to pay for the costs of IWRM. The operational costs of IWRM relate to the additional financial costs associated with IWRM, beyond the capital and operational costs of water supply. The key components of this include monitoring costs, enforcement and compliance, water use management, water resource protection and water allocation reform. These costs include not only water use charges (or catchment management charges) incurred by DWS, CMAs and WUAs, but also includes all costs incurred by all role-players during the decision-making and implementation process (e.g. research, professional fees, legal). It is imperative therefore that DWS implements an appropriate water tariff system, an appropriate water tariff collection system and an appropriate mechanism to regulate these.

Fourthly, the increased complexity of water management decisions requires improved management information systems. Increased complexity of water management decisions requires an appropriate set of Strategic Goals. It also requires a vastly improved management information system. IWRM governs water transactions with the purpose of integrating hydrological, ecological, and socio-economic systems. IWRM performance measurement is thus dependent on Strategic Goal indicators and information systems which provide timeous management information on relevant hydrological, ecological, and socio-economic indicators (Braid, & Görgens, 2010). DWS reports in its Annual Report performance against seven Strategic Goals and Objectives. DWS's performance against these is measured by several performance measures. In recent years, the Auditor General criticised the sufficiency of several DWS performance measures. Thus, although several excellent information systems are in place at DWS, such as rainfall, dam water levels and flow data; various water quality data; and the Blue and Green Drop initiatives; current DWS information systems are inadequate to measure IWRM performance. This makes measurement of the organisational efficiency of DWS and its state-owned enterprises, and their collective achievement of policy imperatives towards achieving IWRM difficult (Van Zyl, 2009). Moreover, it may delay the award of water use licences, the implementation of RQO's, or the implementation of polluter pays policies. Information scarcity may thus constrain economic development and growth. This results from delays in decision-making and the adoption of precautionary approaches. Thus, in an information poor environment, new ways of finding sufficient evidence for supporting decision-making are required.

Finally, we also need to highlight cumulative degradation effects in aquatic systems. The combined, incremental effects of human activity, referred to as cumulative impacts, pose a serious threat to the environment. While they may be insignificant by themselves, cumulative impacts accumulate over time, from one or more sources, and can result in the degradation of important resources (EPA 1999). Understanding the cumulative impacts of various development projects within the spatial context of a catchment scale has often been ignored. Assessment tools, such as the Environmental Impact Assessment (EIA) methodology, focus primarily on the direct environmental impacts of a single development thus ignoring cumulative impacts. In recent years, there has been a growing realisation that the processes of evaluating the negative environmental impacts of individual developments, which may be unobjectionable in themselves, does not adequately consider the accumulative nature of some effects (Court *et al.,* 1994). Within the context of IWRM and the sustainable use of water resources in South Africa, it is clear to see that the cumulative impacts of different land uses have not been considered. A case in point is the Upper Olifants Catchment, where years of the cumulative impacts of coal mining, agriculture and rural land use have led to the gradual deterioration of the Olifants River. Individually these activities may fall below the minimum requirements stipulated by environmental legislation, but their cumulative impacts have had a severe impact on the Olifants River.

For the sustainable and integrated management of water resources, water resource practitioners require a framework for sufficiently capturing the complexity of the system, and generating information at a catchment scale. One framework, which has been proposed, is the notion of the Socio-Ecological System and is described in section 2.3 below.

2.3 SOCIO-ECOLOGICAL SYSTEMS

2.3.1 SOCIO-ECOLOGICAL SYSTEMS DEFINED[4]

Aquatic ecosystems in southern Africa are complex social-ecological systems in which the supply of ecosystem services increasingly limits social and economic development. In response to this, the WRC has also been directing research effort to a Shared River Basins Research Program, with the purpose of integrating water resource science into the analyses of complex social-ecological systems (SES).

The theoretical point of departure for SES is the way in which river systems in South Africa are defined: namely 'the water resource'. This definition acknowledges that river systems produce a variety of ecosystem services of potential benefit. These ecosystem services vary in space (for example along the length of a river) and in time, as run-off varies or as we choose to modify river flow. And as we use these (water, for example) to produce other services such as food or electricity, we diversify the benefits and beneficiaries in time and space.

Resilience theory provides a mental model for the management of social-ecological systems. Resilience management assumes an uncertain and complex context for natural resource and social systems and strives to achieve sustainable long-term delivery of benefits (Breen *et al.,* 2010).

SES comprises of several key components including the Resource (river systems in this case); Resource users (those who use ecosystem services); Public infrastructure (the interventions that are made to gain access to or regulate use of); and Public infrastructure providers.

Social and ecological systems and their components are dynamically linked; changes in one elicit changes in the other and the effects are transmitted through both systems, sometimes with quite unexpected and undesirable outcomes.

In the resulting complex system, it is often difficult to identify and connect benefits and beneficiaries and to appreciate the consequences of decisions that are made around the allocation of access to ecosystem services. Every choice that is made alters the distribution of benefits and costs in both space and time.

2.3.2 THE SOCIO-ECOLOGICAL CONTEXT

South African water use patterns in several river basins have reached the point where there is little additional water available for new water uses (Ashton *et al.,* 2008). Population growth and new developments aggravate this situation. Rural situations in these basins have both a formal and informal water economy with those in the informal water economy the most vulnerable and least influential. Water shortages have different effects on urban and rural communities and shape the social resilience and adaptive coping capacity of these communities. The imbalance in social resilience between rural and urban communities must be accounted for when water resource managers make trade-offs between equity, efficiency, and sustainability objectives at different

4 This section has been developed based on the work done by Breen et al. 2010, for the WRC.

scales. Properly informed decisions need to be made and acted upon to sustain and strengthen social resilience in these river basins.

Breen *et al*., (2010) recognised that this understanding emphasises the need for adopting a systems approach to encourage the deeper reasoning that is necessary for informed collective decision-making around how the benefits derived from limiting water resources should be shared. The system is socially and ecologically complex; options emerge as the capacity of aquatic systems to supply benefits varies in time and space and in response to the choices stakeholders make as they strive to adapt and direct patterns of use toward equity and sustainability. Adaptive decision-making is made more difficult by uncertainty; as with all complex systems, knowledge and understanding is always imperfect and prediction is tenuous.

2.3.3 An improved evidence-base for managing rivers

Every SES is subject to disturbances that arise externally. A wetland based SES may experience biophysical disruption because flow is altered through abstraction or operation of an upstream impoundment; it may also experience social or economic disruption through policy changes that introduce new controls over access to resources such as grazing.

Thus, rivers in southern Africa are complex social-ecological systems in which the supply of ecosystem services increasingly limits social and economic development. As there are no substitutes for these services, resource users must learn to live within the limits of the capacity ecosystems to provide services, and to manage use in ways that will offer better prospects for sustaining a flow of benefits that accommodates both efficiency and equity.

Historically the ecological subsystem of shared river SES's has been drawn upon to meet expanding demands from the social subsystem. The most pressing challenge now is for the social subsystem to become more adaptive to the dynamics of both the ecological subsystem, and those of the social subsystem.

With this understanding it becomes evident that the focus of research on shared rivers has much to do with how people learn, adapt, and behave in complex social-ecological systems; and therefore, we need an improved evidence base for studying river systems.

2.4 Modelling socio-ecological systems

Prior to modelling social-economic systems, there are various factors that must be considered. These include the system itself, the drivers of change in the system and the relationships between the two.

2.4.1 Understanding systems

The most important aspect of understanding SESs, is the understanding of risks that result from disturbances in the system.

There exists a complex chain of causality between these disturbances and its consequences. Such a chain of causality provides for the identification and description of the effect-response function for each priority risk. Thus, systems models can be developed that allow the effects of the disturbances to be anticipated in terms of changes in ecosystem services, and hence the production functions required for valuation of ecosystem services.

Figure 2-2 provides a schematic of the causal relationships that require modelling in a production function. The linear illustration does not mean to mask the considerable complexities in the causal links and feedback loops that exist.

Evidence of relationships between the ecosystem components, which are driver variables namely hydrology, geomorphology, and physico-chemical variables and response variables namely fish, aquatic invertebrates, and riparian vegetation (as per Kleynhans and Louw 2007), is relatively good (illustrated by the numerous WRC and other reports, articles, and models).

However, comparatively little effort has gone into understanding the indirect linkages between ecological functioning, ecosystem services and the production and consumption of marketed goods and services" (Perrings 2007).

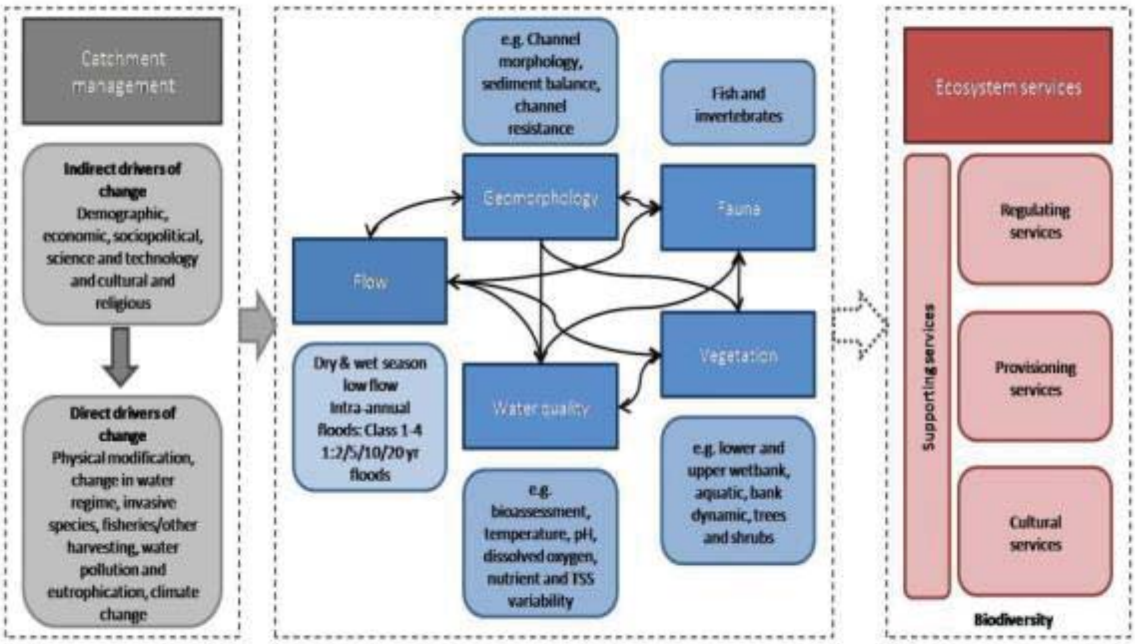


Figure 2-2: Schematic for the causal relationships that require modelling in the production function (Ginsburg *et al.*, 2010)

2.4.2 ENVIRONMENTAL INDICATORS

The most common weaknesses in environmental M&E systems are low availability and quality of data (i.e. evidence); the limited institutional capacity for data generation, storage, processing, analysis and reporting at all levels; limitations in availability of baselines and SMARTness (see section 3.1.2) of indicators; and a lack of strategic coordination of monitoring and evaluation between subsectors as well as between sectors.

Standardised data collection formats do not exist or are not readily accessible except for a few aspects such as land administration, which have received considerable national and external support, and there are no readily available time series data and no regular survey schedule.

Four categories of indicators are generally of importance:

- Poverty indicators - environment and natural resources often constitute the main direct livelihood source for poor populations, and poverty reduction is to a large extent dependent on the quality and access to natural resources by the population.
- Economic growth – aquatic ecosystem services are inputs into economic production, for instance in the case of water use licence activities.
- Management - performance targets which IWRM staff must meet. Data must be collected on specific activities undertaken or planned, as articulated in the action plans.
- Natural resource and green indicators - these indicators provide information on the health of the natural system.

2.4.3 MODELLING HUMAN WELL-BEING IN THE SES

Human well-being indicators will be used to measure the effects that the river system and its associated ecosystem services have on the population within the study area. Indicators will be divided into categories addressing well-being outcomes, with a focus on those that have relationships with the river system:

- Basic
    - Access to safe water
    - Daily calories available per person
    - Access to energy
    - Access to sanitation services
- Safety
    - Access to housing
    - Life expectancy
- Belonging
    - Telephone access
- Self esteem
    - Employment
    - Household income
    - LSM Band

2.4.3.1 IMPACT OF WATER POLLUTION ON HUMAN WELL-BEING

Information on waterborne diseases which are caused by variety of micro-organisms contaminants which leads to cholera and other gastrointestinal problems is an important component for understanding SES. Little information is available on water-borne diseases in South Africa. This is probably due to the absence of an infrastructure for the detection and recording of such infections WRC project No K5/1885 titled "Survey of Handwashing and Hygiene Behaviour" study the impact hygiene on transmission of water borne diseases. The study applied a triangulation approach, combining qualitative, quantitative, and microbiological information to determine the variables of hand hygiene. Triangulation allowed for the collection of information through a multitude of methods to ensure a comprehensive picture of the reality and at the same time, validation of the information being collected. The Framework was tested using data from three study sites in the Tshwane metro, namely an urban, peri-urban, and rural study setting.

The study managed to illustrate that hands are one of the chief vehicles of transmission of waterborne disease. Awareness of good hand hygiene thus plays a significant role in preventing and minimising these diseases.

2.4.4 VALUATION TECHNIQUES

The evolution of environmental goods and services valuation techniques is characterised by a historically increasing demand for precise quantification of the values of these goods and services, and driven by various incidences of environmental disasters (Brown 2000).

One widely used approach employed by economists for decision making support is the cost-benefit analysis (CBA). This approach was formalized in the United States of America with the purpose of justifying public expenditures for water construction projects. In the 1930s and 1940s, questions arose about social accounting and how to treat intangible cost and benefit factors such as saving lives, and dealing with recreation. CBA was formalized in 1958 with the publication of the “Green Book,” a document intended to provide federal agencies in the USA with a consistent conceptual framework for doing benefit-cost analysis. The Green Book advised on the treatment of National Income benefits and costs; how to measure them conceptually; how future prices should be treated; the importance of using a discount rate; the proper period of analysis; risk; taxes; and cost allocation procedures for multiple purpose projects. The Green Book was no doubt grounded in the “new welfare economics” thinking of the 1950s based on the works of Bergson (1938), Hicks (1940), Kaldor (1939) and others.

The Green Book (1958) recognised three types of benefits market goods, non-market goods and intangibles. It contained rigorous treatment of key economic concepts and an emphasis on developing measurable indices for valuing goods and services. Consumer and producer surplus as measures of value, and not price, began to be emphasized (drawing on Dupuit, 1844; and Hotelling, 1931). Moreover, non-market goods and intangibles were not measured, but rather treated qualitatively as no proven valuation methods for these existed.

In 1947 the US National Parks Service sent a letter to ten expert economists asking how to estimate the value of one or more national parks. Only Harold Hotelling responded, with the concept termed the travel cost method (TCM) (Brown, 2000). Subsequently, by 1962, recreation had become a primary purpose of federal water projects because it could be measured. The TCM relied indirectly on market values using observed behaviour, such as trips and their associated costs.

Ridker (1967) pioneered the hedonic valuation method (HVM) to estimate the marginal value of air quality in residential areas by regressing the value of residential properties on their characteristics. The estimated coefficient for each characteristic was considered to measure its marginal value. By 1970 hedonic valuation and the travel cost methods were the two indirect methods through which resource economists used prices generated by individual behaviour in the market to indirectly estimate the value of “non-market” goods such as air quality, scenic views, and recreation sites.

These methods however, were still inadequate to address a broader range of environmental goods and services leading to the development of the contingent valuation method (CVM). The CVM was intended to value public goods for which no behavioural activity could yield an economic value, direct or indirect. Krutilla (1967) laid out the vital relevance of these non-use values in making allocation decisions regarding natural resources. The work of S.V. Ciriacy-Wantrup (1947) provided a precursor for several studies of academic nature to follow. However, for many years thereafter, the CVM method was not regarded as a legitimate valuation technique, based on the so-called Ohio case (McManus, 1994; Brown 2000). This changed with the 1989 Exxon-Valdez oil spill, which occurred off the coast of Alaska damaging natural resources for which the trustees were the State of Alaska and the Federal Government. The level of injury to natural resources appeared to be very substantial. Exxon hired world famous economists to discredit non-market valuation techniques, arguing that they had no professional legitimacy. On the other hand, the lead federal agency (The National Oceanic and Atmospheric Administration - NOAA) appointed a panel comprised of two Nobel prize winners (K. Arrow and R. Solow), Paul Portney (Head of Resources for the Future), and three others to evaluate the legitimacy of non-use valuation methods. The said panel recommended a thorough set of procedures to follow if there was going to be litigation (Arrow *et. al.,* 1993).

Environmental and resource economists have since then applied these two approaches (stated and revealed preferences methods) to value ecosystem assets and their services. In the stated preference method, economists ask people to place a value on ecological resources. In the observed behaviour (revealed preferences) method, economists study the actual choices of people to infer the value people place on ecological resources (Freeman 2003, Pearce *et al.,* 2005, Dasgupta 2010). Both approaches however, have limitations. One of the limitations is that most valuation studies have focussed on a single dimension of a problem only, and has thus failed to adequately address the complexity inherent in ecosystem processes and functionality (Perrings 2006).

For many years, economists circumvented this problem by using the total economic value (TEV) framework (Pearce 2005). Whilst this framework provided an adequate categorisation of both market and non-market ecosystem services, it failed to address ecosystem complexity. The MEA's set of ecosystems services (MEA 2005) proposed a radical new valuation framework that significantly improved on the TEV framework through explicitly defining the linkages between ecosystems and human well-being.

Thus, through the MEA and TEEB, the approach to value of ecosystems has evolved to the understanding that the value of ecological assets is the discounted value of the ecosystem services which it produces. And ultimately, the shadow price of ecosystem assets could ideally be estimated through the human capital asset defined as "health" (Dasgupta 2010) or human well-being (MEA 2007), and specifically through valuing the marginal increase in life expectancy. This can be done either through estimating the social cost of a marginal increase in life expectancy, or through estimating the value of the increase in life expectancy. However, neither method has been particularly successful, for two reasons. First, the value of a statistical life is controversial when making cross-country comparisons, and secondly, both methods require perfect economies, whilst the economies of most countries are highly imperfect (Dasgupta 2010). At a project level, empirical data in support of such methods are also inadequate.

Moreover, not only are ecological assets' shadow prices functions of the stock of all assets, but in addition, they are functions of the degree to which various assets are substitutable for one another, for all time periods current and future (Dasguta 2010).

Several studies have employed the revealed and stated preference approaches to quantify the value of changes in ecosystem services to human societies in terrestrial (Daily et al 1997, Daily 1997), marine (Duarte 2000) and agro-ecosystems (Björklund *et al*., 1999).

Another limitation of several existing valuation methodologies has been that the people interviewed (stated preference method) or studied (revealed preference method) are often not aware of environmental risks (Perrings, 2006; Dasgupta, 2010). People often have little conception of the role of ecosystem assets in the generation of ecosystem services, or of the link between those services and the production of commodities (Winkler, 2006). This is because so many ecosystem services are intermediate inputs into the production of final goods and services (Perrings, 2006). This holds true not only for the supporting and regulating services, but also for some provisioning and cultural services, such as fresh water, genetic resources, or aesthetic services.

Understanding ecosystem responses to biodiversity and other ecological production factor change requires new theoretical and experimental work linking for instance nutrient cycling, biodiversity and ecosystem functioning in complex systems at different scales using spatially explicit models (Loreau *et al*, 2001).

Perrings (2006) described and analysed these weaknesses based on meta-analysis of publications in the Journal of Ecological Economics. Perrings (2006) found that most studies had focussed on a single dimension only, and ignored the multiple environmental goods and services effects of a shock introduced to a local system. Furthermore, most environmental economic studies had focussed primarily on the direct use values of the environment, and put comparatively little effort into understanding the indirect linkages between ecological functioning, ecosystem services and the production and consumption of marketed goods and services. Ecosystems and the goods and services they provide are, for the largest part, intermediate inputs into goods and services that are produced or consumed by economic agents. As with other intermediate inputs, their value derives from the value of those goods and services (Perrings 2006). This was aggravated by a dependence on stated preference studies (such as CVM) of sample populations who have insufficient knowledge of the role of ecosystem stocks in the generation of environmental goods and services, or of the link between those goods and services and the production of commodities (Winkler 2006a as quoted in Perrings 2006).

Another set of concerns related to the way in which valuation studies addressed the problems of risk and uncertainty (Winkler 2006b as quoted in Perrings 2006). Since the value of ecosystem stocks is the discounted stream of net benefits they provide, it is sensitive to uncertainty about the environmental and market conditions under which they will be exploited. Ecosystem cost and benefit relationships tend to be highly nonlinear and therefore, damage (or consequence) might be barely noticeable for low levels of hazard (e.g. pollution) but then becomes severe or even catastrophic once some (uncertain) threshold is reached. Furthermore, the precise shapes of the relationships are often unknown, which is of importance if there is a threshold at which the effect of a hazard becomes extremely severe Pindyck (2006).

Most valuation studies simply sidestepped the problem, whilst others addressed it indirectly through the discount rate. Where uncertainty about the future consequences of the use of the environment includes the likelihood of severe and irreversible consequences, this is not satisfactory. Since social-ecological systems are complex, coupled and adaptive, the capacity to predict the future consequences of current actions are limited at best (Perrings 2006). Closely associated with this was the problem that little effort also went into understanding the value of the role of the environment in either mitigating or exacerbating the risks we face (Perrings 2006).

An economic production function approach is best suited as a valuation method for intermediate ecosystem services and is therefore able to address these valuation weaknesses (Mäler 1991, Babier 2000 & 2003, Barbier *et al*., 2009). Appendix E expands the concept of production functions.

2.5 MONITORING CONSIDERATIONS

Historically, the goals of water resources quality monitoring programs were not emphatically emphasized in the ongoing decision-making process (DWAF, 2004). However, with the increasing scarcity of the resource coupled with cumulative demand from various water use sectors; the focus has lately been on a holistic assessment of water resources to support various, often competing, human needs and to ensure the sustainability of the environment. In this regard, the need to coordinate and integrate water resources monitoring is embedded in the national water legislation, i.e. Chapter 14 of the National Water Act (Act 36 of 1998) which mandates the Minister to "***ensure the continued and coordinated monitoring of water resources in its broadest sense…"*** the Act defines the purpose of National Monitoring Systems as:

***A mechanism to facilitate the continued and coordinated monitoring of various aspects of water resources by collecting relevant information and data through established procedures and mechanisms from a variety of sources, including organs of state, water management institutions and water users*.**

Additionally, it is further stipulated in National Water Act (Act 36 of 1998) Part 2: Classification of water resources and resource quality objectives "Under Part 2 (of the Act) the Minister is required to use the classification system established in Part 1 (of the Act) to determine the class and resource quality objectives of all or part of water resources considered to be significant. The purpose of the resource quality objectives is to establish clear goals relating to the quality of the relevant water resources. In determining RQOs a balance must be sought between the need to protect and sustain water resources on the one hand, and the need to develop and use them on the other. Provision is made for preliminary determinations of the class and resource quality objectives of water resources before the formal classification system is established. Once the class of a water resource and the resource quality objectives have been determined they are binding on all authorities and institutions when exercising any power or performing any duty under this Act." that monitoring is to be effectively implemented.

Therefore, the Policy and Regulation Branch of DWS has recognised the need to integrate water resource quality monitoring services through harmonising monitoring and analysis methods used by different monitoring programs and institutions. A ***Strategic Framework for National Water Resource Quality Monitoring*** document (DWAF, 2004) was developed to provide a basis for reviewing the current monitoring programs and designing new programs.

Existing resource quality monitoring programs are currently run in the department and monitoring is mainly for consider status and trends. These programs include the **Microbial Monitoring Program (NMMP), River Health Program (RHP), National Chemical Monitoring Program (NCMP), National Eutrophication Monitoring Program (NEMP) and National Radioactivity Monitoring Program (NRMP).** More recently, new programs have been introduced; though existing programs have largely focused on resource status and trends monitoring, whereas the new programs will be monitoring towards:

- assessing water and land-based impacts on the resource and
- managing impact (compliance monitoring).

This will be achieved through authorisations, policy changes, rehabilitation etc. This monitoring will mainly support resource management that will be delegated to lower levels; hence South Africa envisages an Integrated Monitoring Plan for each water management area also included is the Crocodile West and Marico catchments.

2.6 Designing a Monitoring Project

The overall purpose of monitoring is to determine the extent of change in the ecological character of water resources, based on a hypothesis and objective that are derived from an assessment of the major pressures or threats facing the water resources. In most instances the monitoring will be undertaken through measuring an indicator of change in the water resources. The WRQMP would be interested in obtaining information on “any changes that take place in South Africa’s waters” and in the causes of these changes. This would advocate for a more integrated approach to monitoring of the water resources.

A framework for assisting with the design of a monitoring program was designed by United States Environmental Protection Agency (USEPA) (Figure 2-3). The framework applies to all forms of monitoring (e.g. changes in a river, the ecological health of a river or the underlying reasons behind the loss of wetlands). As such it is not prescriptive and it does not provide a recipe for a particular ecosystem type. It presents a series of steps for designing a monitoring program which can be tailored to individual needs.

In presenting this framework it is stressed that not all monitoring programs are effective. For example, monitoring programs that are data rich and information poor are not likely to be effective. Effectiveness is further reduced if the program provides misleading information. At the outset, the likely outcomes of the monitoring program should be considered, including an assessment of the likely threshold of change that can be tolerated (both system and social tolerance), or the likely responses that may be needed.

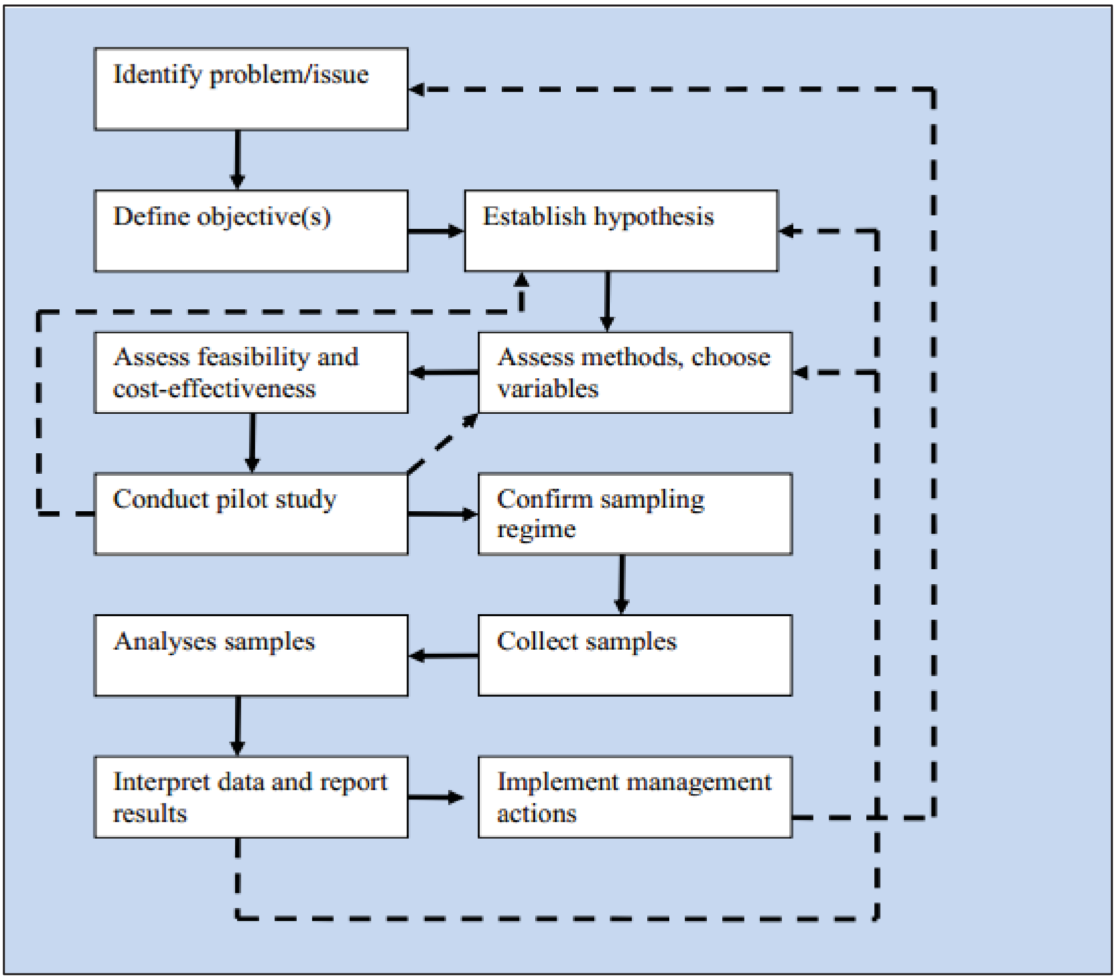


Figure 2-3. The recommended design for a monitoring program by USEPA. The solid arrows connect steps in the process, while dotted arrows are feedbacks to earlier steps.

3 SOCIO-ECOLOGICAL SYSTEM MONITORING APPROACH

"Measurement is the first step that leads to control and eventually to improvement. If you can't measure something, you understand it. If you can't understand it, you can't control it. If you can't control it, you can't improve it."

— H. James Harrington.

3.1 APPROACH TO MONITORING

As a point of departure, took an approach to monitoring based on existing challenges present in current monitoring programmes. Section 2.2.1 describes current challenges to the implementation of IWRM of which largely formed the basis of the approach taken to monitoring in this study.

An important consideration for the monitoring plan was for the techniques and approaches employed and proposed, to be technically realistic and practical for use by various organisations operating the plan. In this case, it was envisioned that the plan would be utilised by local municipalities. Typical approaches for gathering evidence are however often expensive and require a high level of expertise. This can form a key constraint for the success of a monitoring plan as resources and capacity are often major limiting factors.

The approach to collection of evidence was thus done with these limitations in mind. As far as possible the methodology for gathering of evidence was developed to include sources that were accessible, publicly available, inexpensive and do not require extensive training to perform. The methodology for data collection was developed in a way would not need extensive training to make observations on indicators nor would require complex expensive equipment.

The premise of the monitoring plan was to firstly, identify a set of practical and inexpensive set of indicators of ecological degradation that would allow for "a finger on the pulse" of the system and secondly, effectively identify any red flags or major degradation events or trends in degradation. Upon the identification of any concerning degradation, additional expertise and traditional extensive methods would then be employed for further investigation towards mitigation, rehabilitation and even policy evaluation.

Towards this goal the methodology followed frameworks which are discussed below.

3.1.1 DPSIR FRAMEWORK

Monitoring Framework used distinguished driving forces, pressures, states, impacts and responses that are exclusive to South Africa. This approach known as the DPSIR framework and has since been more widely adopted by the Department of Environmental Affairs (DEA), acting as an integrated approach for reporting, e.g. in the DEA's State of the Environment Report 2009. South Africa used the DPSIR framework for identifying core indicators for inland waters. The framework is giving a structure within which to present the indicators needed to enable feedback to policy makers on environmental quality and the resulting impact of the political choices made, or to be made in the future (Kirsten, 2004). Reference to the proposed Water Resource Quality Monitoring Framework, the DPSIR Framework will be used to report the state of the water, catering for the diverse needs.

According to the DPSIR framework there is a chain of causal links starting with 'driving forces' (economic sectors, human activities) through 'pressures' (emissions, waste) to 'states' (physical, chemical and biological) and 'impacts' on ecosystems, human health and functions, eventually leading to political 'responses' (prioritisation, target setting, indicators).

3.1.2 SMART Method

A major proponent of any monitoring plan is that the indicators must effectively allow for the goals to be reached. Towards this end the indicators must display a range of qualities necessary for achieving the ultimate goals. Therefore, indicators identified were judged against the SMART approach which allows for the assessment of the suitability of indicators chosen. The approach guides the comparison of indicators against five requirements. The requirements are that the indicator should be, specific, measurable, attainable, relevant, and timely (SMART). These requirements formed a crucial component of indicators chosen for the monitoring plan.

3.1.3 E-BASES Approach

The proposed E-BASES methodology is premised on the formulation of a review question based on a system of cause and effect relationships, involving multiple system components, which, together, comprise a chain of causality. In addition, the evidence-extraction is expanded to explicitly include five evidence-extraction methods, which include meta-analysis, scientific experimentation, database analysis, data mining and expert knowledge harvesting.

3.2 The Socio-Ecological System Monitoring Plan

Using the principles of socio-ecological monitoring discussed above, a monitoring plan to provide data to be used in a socio-ecological systems model was developed. The monitoring plan included monitoring river health through specific indicators, identification of the land and water uses that affect and are dependent on the river system, identification of ecosystem services that the river system provides and a measure of human well-being in the system (Figure 3-1). These components were combined in a socio-ecological systems model, using ES production functions, to provide an evidence-based analysis of ecological degradation and its effects on the water resource, ecosystems, and socio-economic development.

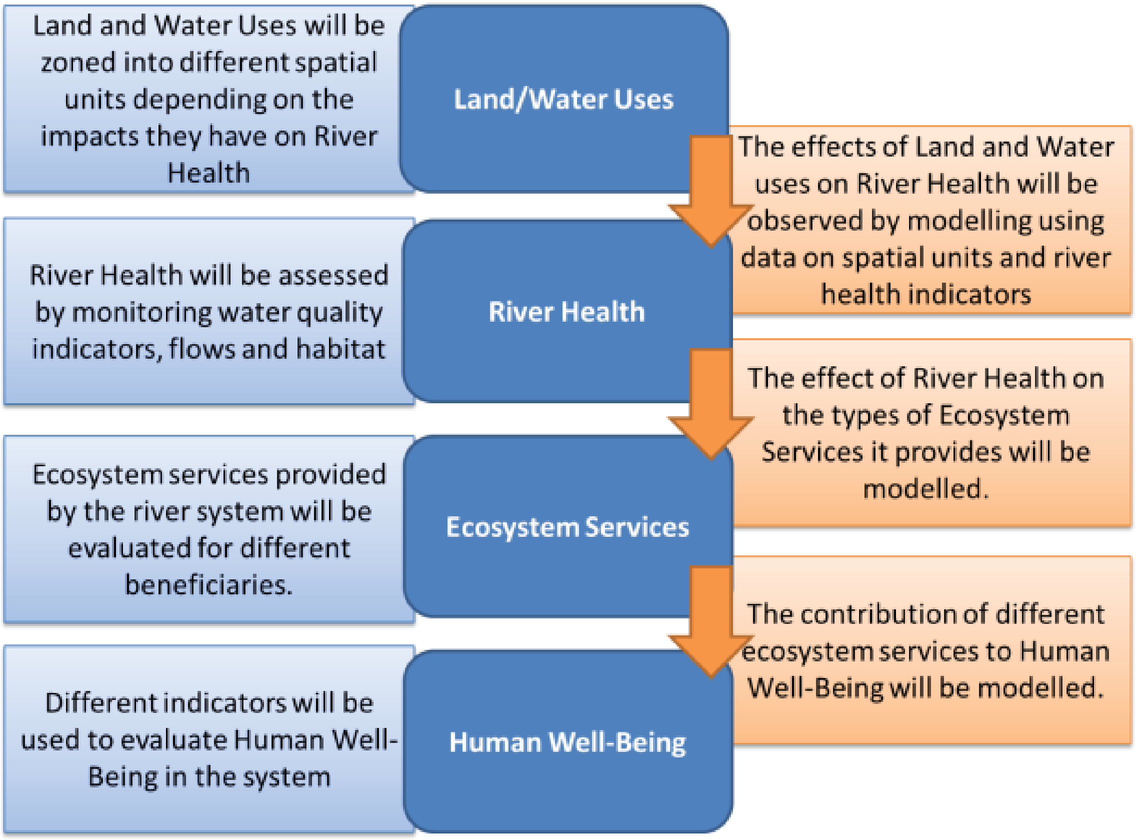


Figure 3-1: An overview of the monitoring and modelling of the socio-economic system

3.2.1 River Health Monitoring

Monitoring the health of the river system requires the identification of sites, indicators river health, a monitoring protocol and analysis; these are presented in the following sections. The data and model of the health of the river system will provide one component of the entire socio-ecological system model.

3.2.1.1 RIVER HEALTH INDICATORS

A multitude of factors determine the health of a river ecosystem: its geomorphological characteristics, hydrological and hydraulic regimes, chemical and physical water quality, and the nature of in-stream and riparian habitats (Figure 3-2). Each of these categories contains several different indicators that respond differently to different forms of human impact. **Error! Reference source not found.** recognises that the various components of the hydrological cycle are intimately linked to one another, each component being affected by changes in every other component.

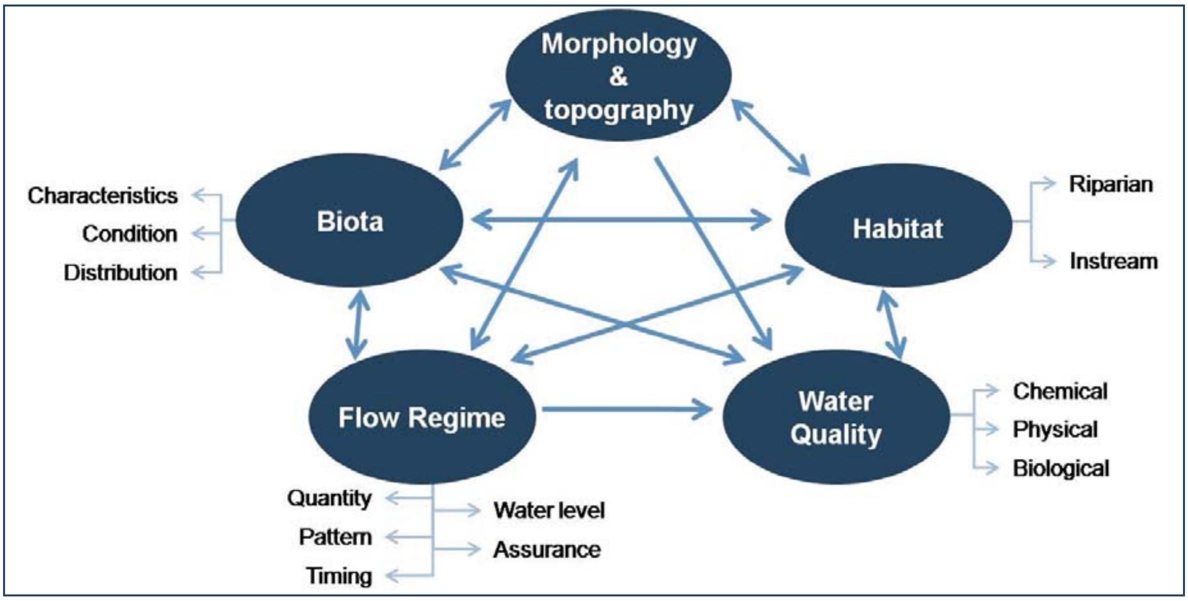


Figure 3-2: Interrelationship between river health indicators

3.2.1.2 TOPOGRAPHY AND MORPHOLOGY

The morphology and topography of the study area was classified using Geographic Information Systems (GIS). The software used was Quantum GIS V 2.8.2 which is freely available for download. The spatial investigation provided a first consider the study area identifying environmental, social and economic features in the landscape that potentially influence the state of the ecosystems or the wellbeing of communities. Furthermore, the approach was that indicators utilised needed to be sourced from publicly available sources or else needed to be acquired with relative ease. The various spatial layers utilised were sourced from the following locations:

- South African National Biodiversity Institute-SANBI (www.bgis.sanbi.org)
- Department of Environmental Affairs-DEA (www.egis.environment.gov.za)
- StatsSA (www.statssa.gov.za)
- Department of Water and Sanitation-DWS (http://www.dwaf.gov.za/iwqs/gisdata/river/rivs500k.aspx)
- Historical State of Rivers (www.soer.deat.gov.za)
- Chief Surveyor General (www.csg.dla.gov.za)
- Municipal Demarcation Board (www.demarcation.org.za)
- ENPAT (www.egis.environment.gov.za)

The DPSIR Framework was utilised to identify available spatial data which would give insight into the criteria playing a role in study area. Sources were mined for available data and criteria that was readily available and identified included the following:

- Socio-economic
    - Land cover (For the years 2000 and 2013/14);

- Major cities, towns and communities (all major towns and cities);
    - Waste water treatment works;
    - Population data (including demographics, education and income level).
- Environmental
    - Altitude and Precipitation;
    - Hydrological catchments (All hydrological catchments);
    - Geology;
    - Ecoregion (Kleynhans et al. 2005);
    - Rivers (NFEPA Rivers);
    - Wetlands (NFEPA Wetlands);
    - Dams and impoundments;
    - Vegetation cover (Mucina and Rutherford 2006); and
    - Present Ecological State (SOER/SOR).

Data was collated and processed to briefly classify the study area, providing an indication of the spatial nature of drivers and pressures in the system.

3.2.1.3 FLOW REGULATION

Flow is a major determinant of physical habitat in streams, which in turn is a major determinant of biotic composition- The movement of water across the landscape influences the ecology of rivers across a broad range of spatial and temporal scales. Flow regulation was used to develop a water quality load model

Data was collected from DWS monitoring sites close to the proposed sites.

3.2.1.4 WATER QUALITY INDICATOR SELECTION

An environmental indicator is a numerical value that helps provide insight into the state of the environment (US EPA, 2013b). Indicators, listed below Appendix A, were selected to specifically monitor human-induced changes based on the activities that are occurring in the study area and upstream. The purpose of water quality monitoring is to determine the physical and chemical properties of natural waters. The quality of a stream or river is often a good indication of the way of life within a community through which is flows. It is an indicator of the socio-economic conditions and environmental awareness and attitude of its users. Everything that happens in a catchment area is reflected in the quality of the water that flows through it, because the results of human activity and lifestyle ultimately end up in rivers, through runoff. Healthy streams, wetlands and rivers support a great variety of water life. Properties of water such as temperature, pH, dissolved oxygen, and the concentration of nitrates and phosphates are important indicators of water quality. These properties can change as a result of natural and human related processes. These properties can be used to determine the effects of groundwater and stream water on aquatic ecosystem health and can sometimes be used to identify sources of pollution in water. Changes in these parameters may be detrimental to the organisms in and around the water source. Many factors can affect the quality of the water in an ecosystem including discharges of industrial or agricultural wastes.

Historical DWS water quality monitoring data was used to analyses the extent of degradation on water quality. In-house laboratory was for analysis.

Table 3-1: Water quality parameters selected

Pollutants	Indicators	Testing location	Testing Equipment
Coliforms	E.Coli and total coliforms	Ex situ	Compact Dry EC Plates
Phosphorus	Total Phosphate	ex situ	Hach Kit and Colorimeter
Nitrogen	Total Nitrate	ex situ	Hach Kit and Colorimeter
Salts	Total dissolved solids (electrical conductivity)	in situ	YSI meter and EC probe
Dissolved Oxygen	Dissolved Oxygen (Galvanic)	in situ	YSI meter and DO probe
pH	pH	in situ	YSI meter and pH probe
Temperature	Stream temperature	in situ	YSI meter

3.2.1.5 HABITAT AND BIOTA INDICATOR SELECTION

The Prime Africa Express Habitat Assessment Method (E-HAM) was developed with the premise of having a basic, yet insightful, method for assessing the state of habitats in an urban river system. This allows for classification and the ultimate monitoring of systems without the need for extensive training in assessment methodology. The approach is to provide for an indicator of habitat health from which "red flags" in the system can be identified, at which point additional observations and river health experts would be deployed to undertake a full assessment. This method was based on approaches taken by:

The Rapid Habitat Assessment (DWAF 2009) and Index of Habitat Integrity (Kleynhans *et al.,* 2008) methods which are both used as tools in the Department of Water Affairs river eco-status determination.

The Wetland Classification and Risk Assessment method (Oberholster *et al.,* 2002) which is a field manual developed for Eskom used in the assessment of wetlands.

It must be noted that this assessment is a basic method for providing a glimpse into the general state of habitats and should not be used for any other purpose. This method allows for a comparative overview of ecosystems against changing influential variables. The method can be broken down into 5 steps. These include: site selection, site information, site description, physical characteristics of the site and finally classification of the site. The first four steps ensure that all the factors critical to assessments of this nature, are considered.

Please see Appendix D for a full description of the method.

3.2.2 CULTURAL SERVICES

3.2.2.1 HEDONIC PRICING

Data for the hedonic pricing analysis was collected from real estate agents operating within communities located within the study area. The real estate agents were asked to value a range of hypothetical properties, based on several characteristics possessed by the household. General characteristics (with sub characteristics) included:

- Property size;
- Structure size;
- View of ecological infrastructure; and
- Distance from ecological infrastructure.

Conjoint analysis was conducted on the data to identify the relationships between property characteristics and aquatic ecological infrastructure.

3.2.2.2 TRAVEL COST METHOD

The Travel Cost Method (TCM) was the approach used to assess the recreational ecosystem services of the system. The basic premise for this method was that the time and travel cost expenses that people incurred to visit a site represented the “price” of access to the site. Thus, the method estimated the willingness to pay of consumers based on the number of travel trips that they make based on the quantity demanded at different prices.

The TCM was used to estimate the economic benefits or costs resulting from the use of aquatic ecological infrastructure in the study area.

3.2.3 PROVISIONING SERVICES

3.2.3.1 HOUSEHOLD SURVEY

THE LIVING STANDARDS MEASUREMENT APPROACH

The Living Standards Method (LSM) approach is a method for inferring a household’s level of well-being using surveys that assess a range of non-monetary factors within a household that are highly indicative/correlated with the level of income and consumption. The LSM approach sidesteps the pitfalls of assessing household consumption by measuring household income. This is useful because the World Bank (2005) states that consumption is a more important determinant of economic well-being than income alone

Motivated by the need to measure poverty more accurately, the World Bank has taken a lead in the development of relatively standard, reliable household surveys, under its Living Standards Measurement (LSMS) project (World Bank. 2005). The World Bank initiated the project to explore ways of improving the type and quality of household data being sourced and used as a basis for policy and decision making. The LSMS surveys assess households on a wide range of topics including:

- Household consumption patterns including food and non-food items.
- Household assets, landholding, and other durables

- Socio-demographics variables including education, health

Within South Africa the LSM approach is widely used to classify income segments among households, and is widely used as a marketing tool by those looking at consumption patterns within segments of the South African population.

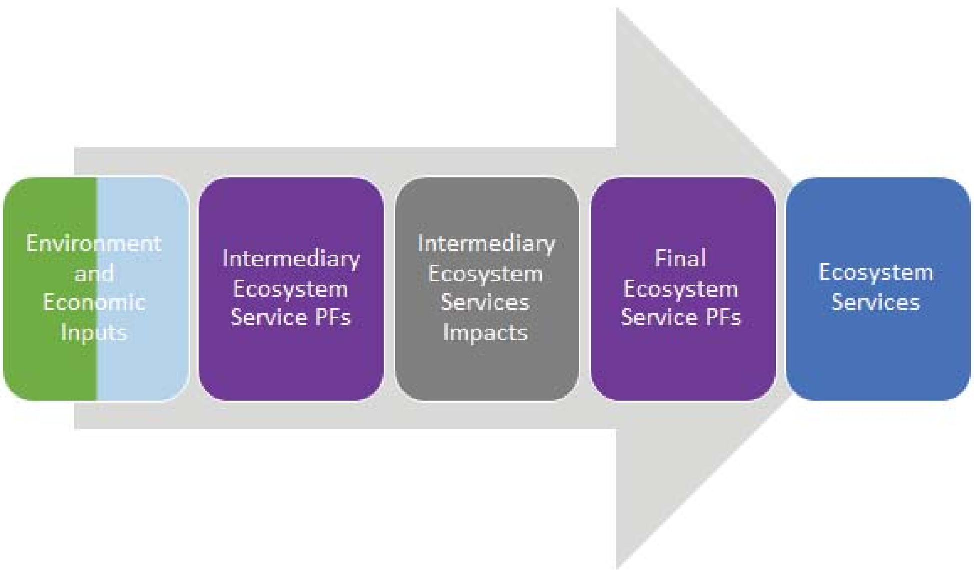
3.2.4 Integrated Bio-Economic Model

An Integrated Bio-Economic Model was developed to quantify the ecosystem services provided by system in relation to river health. The Integrated Bio-Economic Model brings together a wide range of multidisciplinary concepts and data. This allows the model to determine the relationship between the environment and the economy.

This model uses production functions where the environmental indicators are used as inputs into the production of ecosystem services. This approach differentiates it from most other bio-economic models and allows for marginal impact assessments to be performed.

3.2.4.1 MODEL USE

An overview of the structure of the model is presented below:



A screenshot of the impact assessment sheet of the model is presented below. On this sheet the user can input change in one, or many, of the input indicators of the model.

The inputs are firstly used in to calculate the impact, if any, on the intermediary ecosystem services and thereafter they are used in conjunction with the impacts on the intermediary services to determine the impact on final ecosystem services.

Production function approach studies quantify values for ecosystem services that contribute at least part of the shadow value of those resources. They apply knowledge of ecosystem functioning and processes to derive the value of supporting and regulating ecosystem services. They do this through deriving the value of ecosystems and the services they provide as intermediate inputs into goods and services that are produced or consumed by economic agents.

The production function approach allows the model to determine the marginal impact that certain changes in the environment will have on ecosystem services.

3.2.4.2 DATA COLLECTION AND HANDLING

The model used the following data sources:

- Prime Africa monitoring of water quality
- DWS data on water flow in the river system
- GIS data on land use
- Property values from City of Tshwane valuation roll
- GIS analysis to identify the properties in City of Tshwane valuation roll that are within ranging distances of the rivers
- Habitat assessment based on a number of in stream measures as well as the immediate surrounding riparian area
- Household survey
- Hedonic pricing on the property market w.r.t. environmental indicators
- Tourism activities from another study

The data sources above report data in various structures. In the table below we identify these different structures of the various datasets:

Table 3-2: Various structures of the data collected

Data	Structure
Water quality	Time series; Cross sectional
Water flow	Time series; Cross sectional (different cross sections than water quality)
Land use	Cross sectional
Property values	Cross sectional (limited to Tshwane)
Property shape files	GIS data
Habitat Assessment	Cross sectional
Household survey	Cross sectional (limited area coverage)
Hedonic pricing	Cross sectional (limited to residential areas within the catchment)
Tourism	Cross sectional (different area)

Due to the various structures in the following assumptions were made to complete the model. These assumptions were:

- Water flow data closest to our monitoring points are an accurate reflection of the flow at our monitoring points
- Land use did not change over the water quality sampling period
- Property values didn't change over the water quality sampling period

- Habitat assessment didn't change over the water quality sampling period
- Household survey results are an accurate representation for the entire area
- People's behaviour around fishing and bird watching aren't location specific and therefore it is acceptable to include tourism studies from other areas

The table below very briefly outlines the confidence in the data that was used in our model.

Table 3-3: Confidence level on the data used

Data	Confidence	Factors affecting confidence
Water quality	High	
Water flow	Very low	Different sites than water quality
Land use	Medium	Irregularities compared to official wetlands land cover map
Property values	High	
Property shape files	Low	Data irregularities compared to official Tshwane valuation roll
Habitat assessment	High	
Household survey	High	
Hedonic pricing	High	
Tourism	High	

4 CASE STUDY 1: URBAN SYSTEM

4.1 INTRODUCTION

The Apies-Pienaars River system was identified as a suitable case study area for testing the relationships between the impacts of environmental degradation (specifically on the socio-economic system) and the various catchment land uses and water uses that result in the degradation of aquatic ecosystems. The system was classified with a high ecological integrity and sensitivity (EIS) and needs to be maintained in a recommended management class (MC) II (WRCS). A high level, comprehensive systems description and understanding is, therefore required to preserve the system in its ecological sustainable base configuration.

Furthermore, a great floodplain wetland is found at the confluence of the Pienaars and Apies Rivers. Communities depend directly and indirectly on the aquatic ecosystem services provided by the Pienaars-Apies-Moretele River system. These services include provisioning services (clean water and wood), regulating services (pollution control, temperature regulation and flood attenuation), supporting services (food, biodiversity and habitat) and cultural services (recreation and education). Water quality monitoring and analysis can be done at various sites for a comprehensive systems description and to account for as many aquatic impacts as possible. In additional to the two-ecological water reserve (EWR) sites (EWR 4 and EWR 5) used in the WRCS to assess the water quality along the Pienaars-Apies-Moretele River system, other water quality monitoring points will be identified. EWR 4 is situated downstream of the Roodeplaat Dam in the Pienaars River in the A23B quaternary catchment. EWR 5 is downstream of the Klipvoor Dam in the Borakalalo National Park and quaternary catchment A23J. Additional monitoring points may include a monitoring point in the Apies River, before its confluence with the Pienaars River, a monitoring point downstream of the floodplain wetland in the Pienaars-Moretele system and a monitoring point in the Kutswane River before its discharge into the Klipvoor Dam.

The Pienaars River is one of the major tributaries of the Crocodile River. The Pienaars River comprises of:

1. Apies River which joins Pienaars River to the North of Hammanskraal;
2. Pienaars River which river joins Crocodile River just below the confluence of the Crocodile and Elands River;
3. Moretele River catchment area; and the
4. Tlholewe River catchment area.

The Pienaars River also forms the catchment basin for Mamelodi (situated at the foot of the Magaliesberg Range in the east of the Gauteng Province) with all tributaries flowing to the north and merging at the Magaliesberg and running through a ‘poort’ to the north where it spreads in the east-west direction and gets split into Mamelodi East and Mamelodi West.

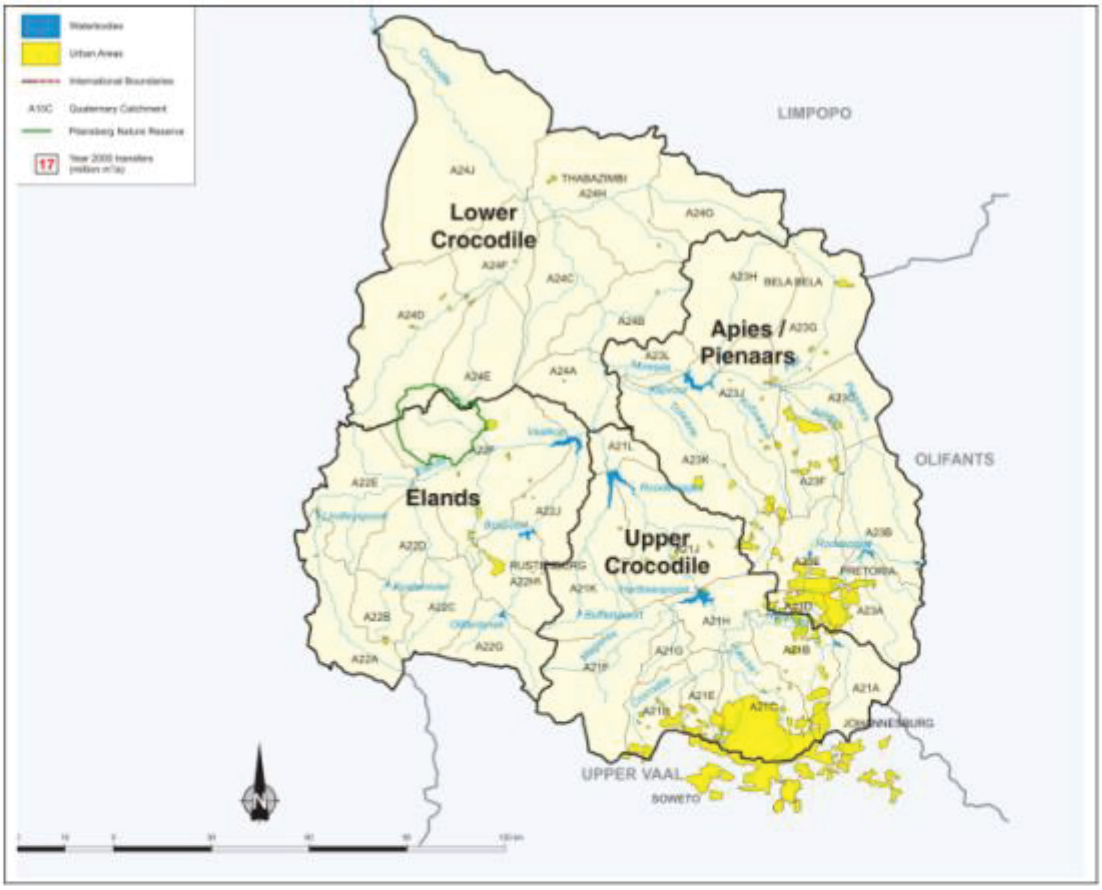


Figure 4-1: Apies / Pienaars River System (DWA, 2008)

A preliminary identification of ecosystem services present within the catchment is presented in Figure 4-2. For each service, there are various methods employed to acquire the necessary data to perform a valuation of the benefits provided by each. In addition, brief descriptions of beneficiaries are also provided.

Types of services in the category	Valuation methods	Beneficiaries
Water regulation and provisioning of good quality fresh water	Market pricing, Resource rent, Damage cost, Indirect through production functions Data: Database extraction	1. Agriculture activities within the CoT (~40,000ha) 2. CoT through water supply security and water-related revenue earned
Collection of natural products	Proxy household income method Data: Primary data collection	1. Residents of CoT, especially in lower reaches of the study area, have a large reliance on such products
Recreation, mental and physical health **Tourism**	Simplified travel cost method (TCM), revealing visitor's preference for the site Data: Database extraction	1. Residents of CoT who gain recreation benefits 2. CoT through gate fee revenue earned (where appropriate)
Habitats for species	Transfer method Data: "Meta-analysis"	1. Indirect benefits to residents and CoT
Aesthetic appreciation and inspiration for culture, art and design	Hedonic valuation, revealing from property valuations residents' preference for proximity of open spaces Data: Data mining	1. Residents of CoT 2. CoT through increased property rates

Figure 4-2: General Ecosystem Services Provided by Aquatic Ecological Infrastructure, Method for Data Collection and General Beneficiaries in the Apies Pienaar Catchment

4.2 CLASSIFICATION

The Apies-Pienaars tertiary catchment (A23) is highly developed, and is comprised of eight quaternary catchments which cover an area of 4,446,504 km^2 (Figure 4-3).

This includes the Apies, Pienaars, Moretele and Tshwane Rivers as well as their tributaries. It consists of the towns of Cullinan, Rosslyn, City of Tshwane (Pretoria), Hammanskraal, Ga-Motle, Pienaarsrivier, Dikebu and Makgabetlwane.

Mean annual temperatures range from 16-20 °C. The mean annual runoff is approximately 142 million m^3/annum. Mean annual precipitation ranges from 400-600mm/annum in the northern regions to 600-800mm/yr in the southern regions, coinciding with the Savanna and Grassland biomes respectively.

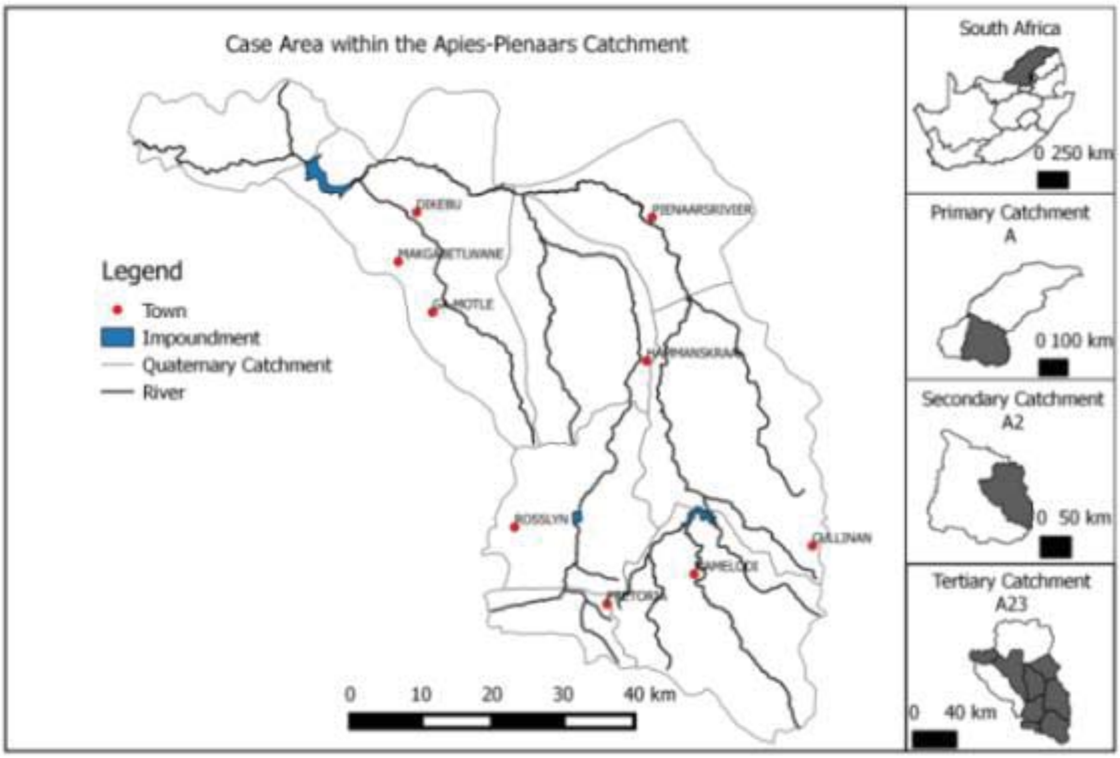


Figure 4-3: Locality map of the case area in the Apies-Pienaar tertiary catchment

4.2.1 GEOLOGY AND AQUIFERS

The geology of the case area is characteristic of the Pretoria group in the south and north-western boundary, with the Waterberg and Rooiberg groups moving up into the east of the case area. The west and north-west comprises of the Rustenburg layered, Rashoop granophyre and Lebowa granite suite which form part of the Bushveld complex. The Beaufort group of the Karoo sequence is characteristic of most of the northern and central regions of the catchment (Figure 4-4).

The geological formations have allowed for the presence of various aquifers throughout the catchment (DWA 2008). Granitic aquifers are present through quaternary catchments A23B, A23E, A23F and A23J. Dolomitic aquifers are present through catchments A23A and A23B. Quartzite and shale aquifers characteristic of the Pretoria group spread through A23A, A23D, A23F and A23L. Gabbro and Noritic aquifers of the Bushveld complex can be found in catchment A23E.

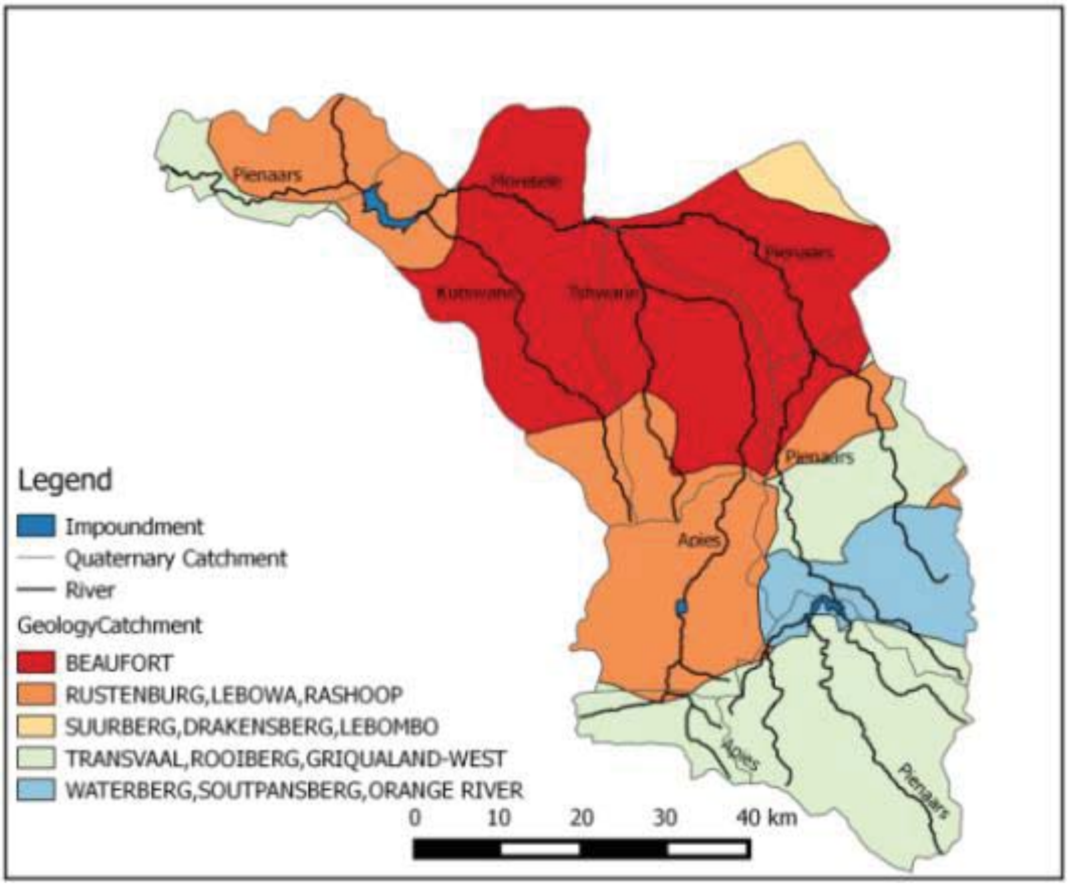


Figure 4-4: Geological lithology of the case area in the Apies-Pienaars tertiary catchment

4.2.2 Ecoregions

Eco-regions according to Kleynhans and others (2005) moving north from the southern regions are Highveld, Western Bankenveld and Eastern Bakenveld (Figure 4-45).

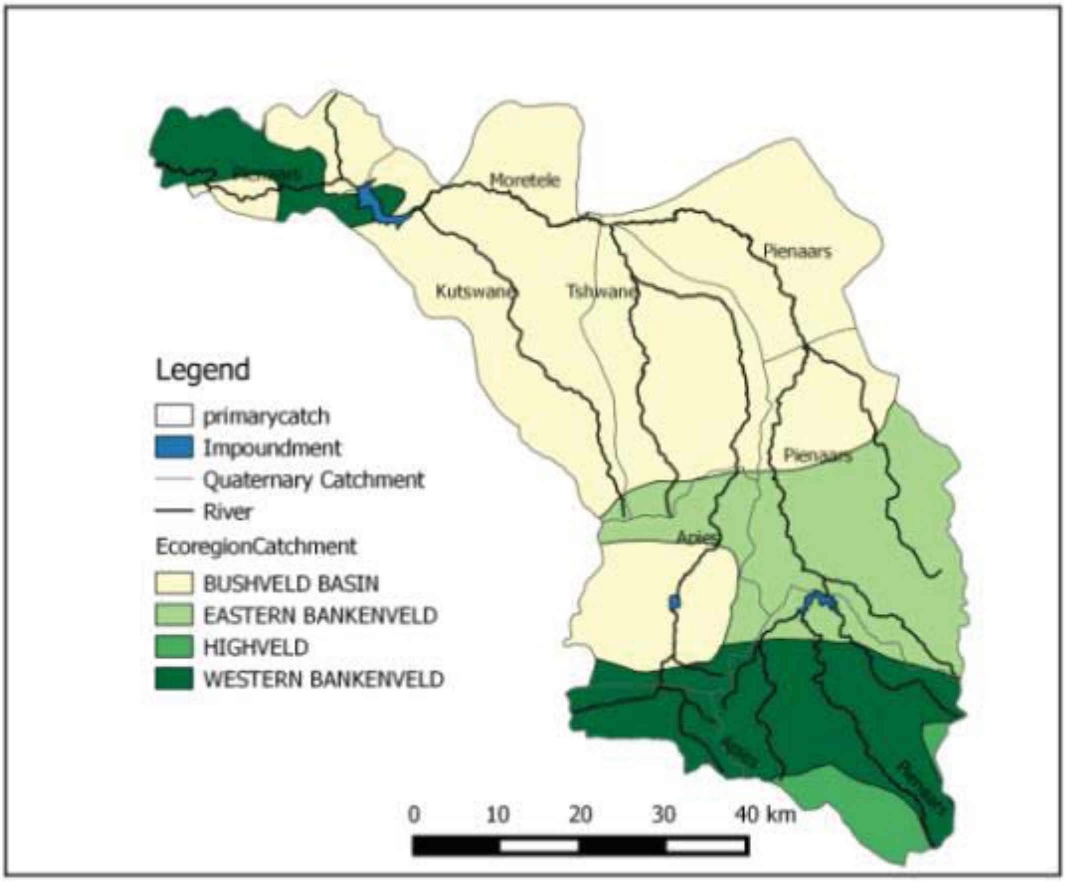


Figure 4-5: The eco-regions (Kleynhans *et al.,* 2005) of the case area in the Apies-Pienaars catchment

The catchment is predominantly the Bushveld Basin eco-region in the central and northern regions with Western Bankenveld in the north-western regions. These eco-regions are classified using a comprehensive approach based on attributes such as physiography, climate, rainfall and vegetation.

4.2.3 VEGETATION

Vegetation types according to Mucina and Rutherford (2006), range from predominantly Marikana Thornvelt in the south with scattered Bushvelt (Figure 4-6). Moving north through Central Sandy Bushvelt and Springbokvlakte Thornvelt in the north. The north-western regions are predominantly Western Sandy Bushvelt.

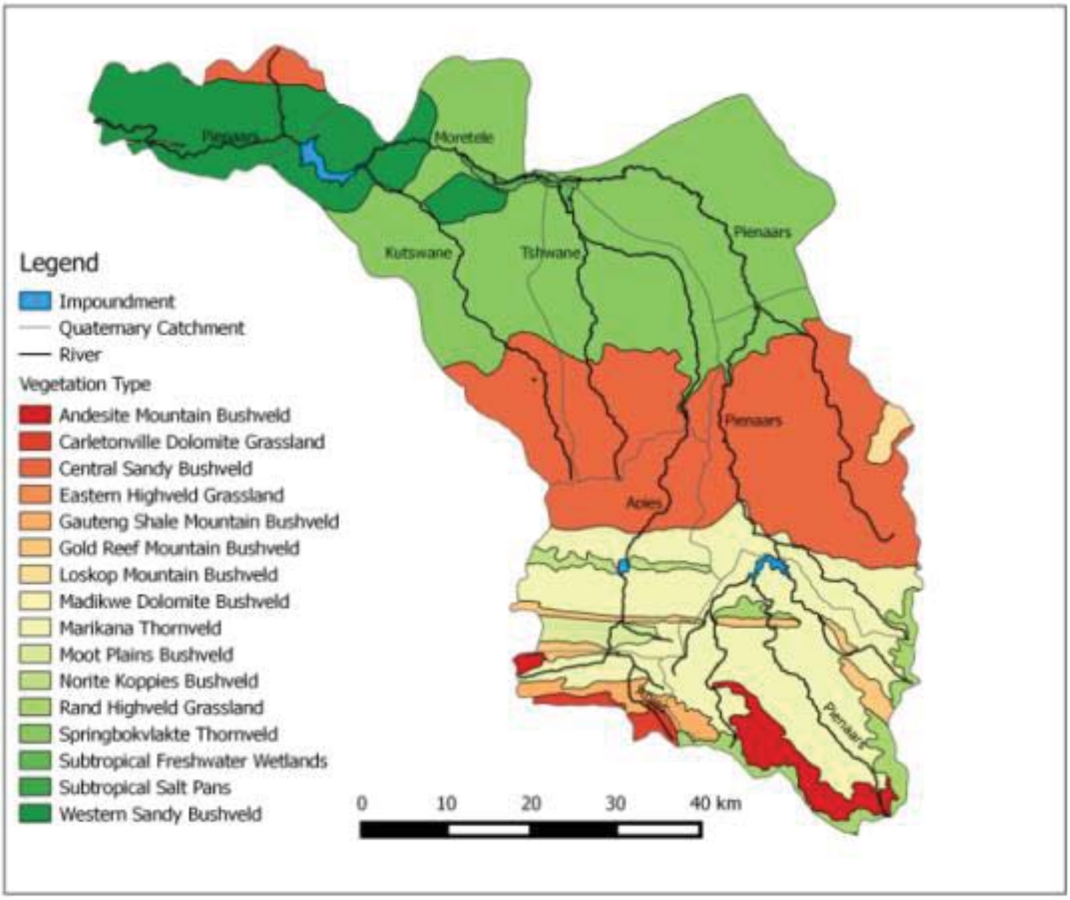


Figure 4-6: Vegetation types (Mucina and Rutherford 2006) of the case area in the Apies-Pienaars tertiary catchment

4.2.4 Locality and State of Rivers

Land use cover comprises of 19% urban, with the City of Tshwane (Pretoria,) being situated in the upper reaches of the catchment and stretching into the northern regions of the catchment with suburban communities (Figure 4-7). Ultimately, the source of the Apies and Pienaars Rivers are engulfed within an urban landscape. 8% land cover is agricultural with the majority being cultivated land in the northern regions. Three large dams are found within the area namely the Roodeplaat, Bon Accord and Klipvoor Dam as well as various scattered wetlands.

The catchment is further defined by scattered informal settlements, rural clusters, cultivated and degraded land towards the north.

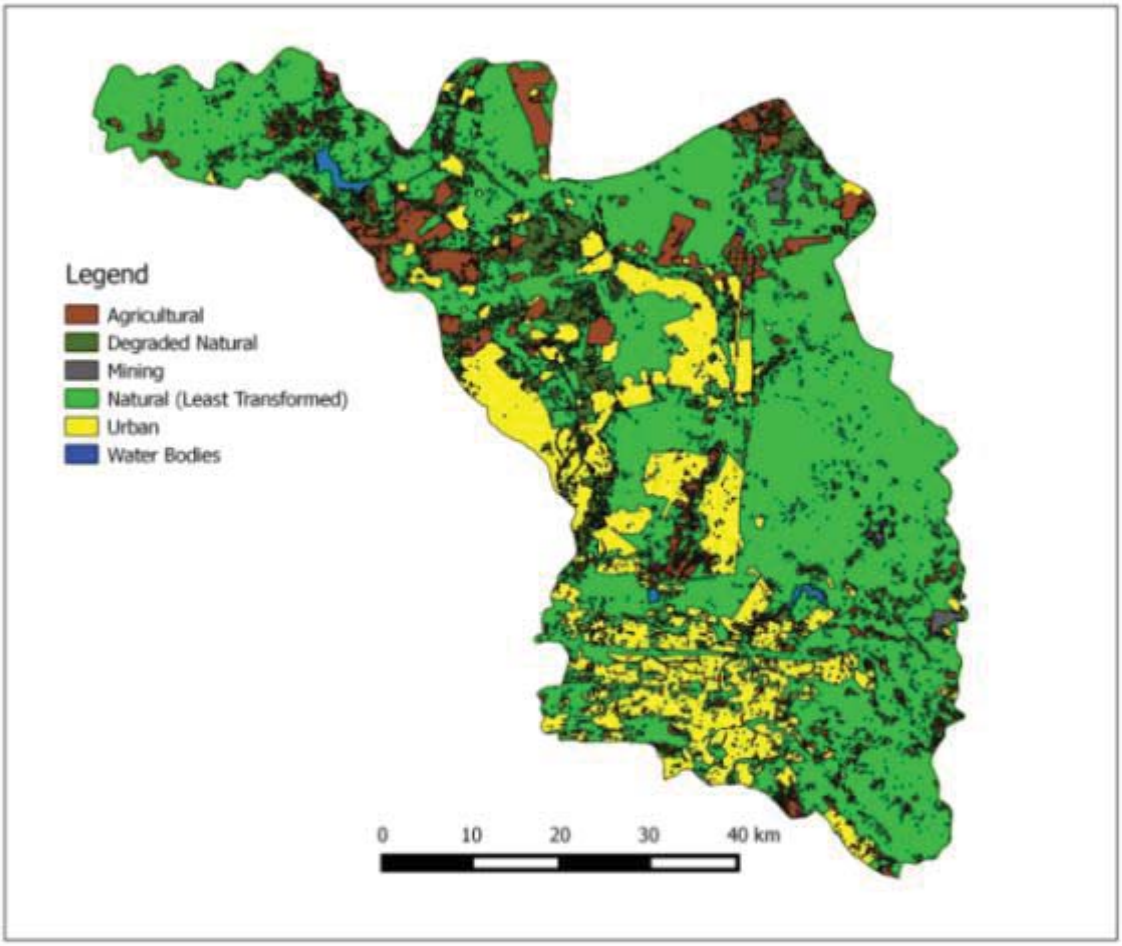


Figure 4-7: Land cover map of the case area in the Apies-Pienaar tertiary catchment

This high level of development has extensively impacted on the state of the riverine ecosystem within the catchment. This is illustrated by the present ecological state (PES) along the river system (Kotze *et al* 2012).

Three sub water management areas (SWMA) are defined based on the locality of rivers and tributaries in the case area (Figure 4-8). The Upper Pienaars SWMA covers the A23A quaternary catchment including the source of the Pienaars River. It includes the Moreletaspruit joining with the Hartbeesspruit in Pretoria East before flowing into Roodeplaat dam. Because of high urban pressures these tributaries are in poor condition with an ecological category of E in the order 1 branches and D in order 2. The Edendalespruit and Pienaars River which both flow through Mamelodi have category D and C states respectively as a result. They both flow into the Roodeplaat dam in the north of the SWMA. The Pienaars River flows out of Roodeplaat Dam into the Lower Pienaars SWMA. The Lower Pienaars SWMA includes the A23B, A23C, A23J and A23L quaternary catchments. The Pienaars River is joined by the Roodeplaatspruit tributary category D, in the south, and the Boekenhoutspruit tributary which is a category C in the north, which both originate close to Cullinan. The Pienaars River flows past Pienaarsrivier before joining the Tshwane River (Apies SWMA) and becoming the Moretele River close to Kgomo-Kgomo. Along this stretch the state of the Pienaars is a category C with the major impacts being from agriculture, irrigation abstraction, cannel alterations and alien riparian vegetation. The Moretele which is a category C flows west and joins the Kutswane tributary which is a category D flowing from the south and becomes the Pienaars River flowing into Klipvoor dam which is a category C. The Kutswane tributary originates in the vicinity of Mabopane. In the greater area land use impacts are typically agricultural. The Pienaars River continues west out of Klipvoor dam towards Assen and out of the catchment. The Apies SWMA includes the A23F, A23E and A23D quaternary catchments. The Apies River originates in the south in the Centurion region joining the Walkerspruit (Pretoria east), Skinnerspruit (Pretoria west) and Wonderboomspruit (Pretoria north). Flowing through such highly-developed areas, these systems are under high pressure with D categories and an F category for the Wonderboomspruit. Flowing north the Apies flows into Bon Accord dam. Further north past Hammanskraal and Leeukraal the Apies joins the Tshwane River at Makapanstad in the north of the SWMA before joining with the Pienaars River. The Tshwane River is a category D with abstraction, bed and channel disturbance and riparian vegetation removal being the main impacts.

The eco-status of each SWMA was found to be poor (River Health Program 2005) resulting from high levels of development within the catchment. High levels of discharge influencing water quality, loss of riparian vegetation, impoundments and canalisation influencing natural hydrological regimes were all seen to be major influences.

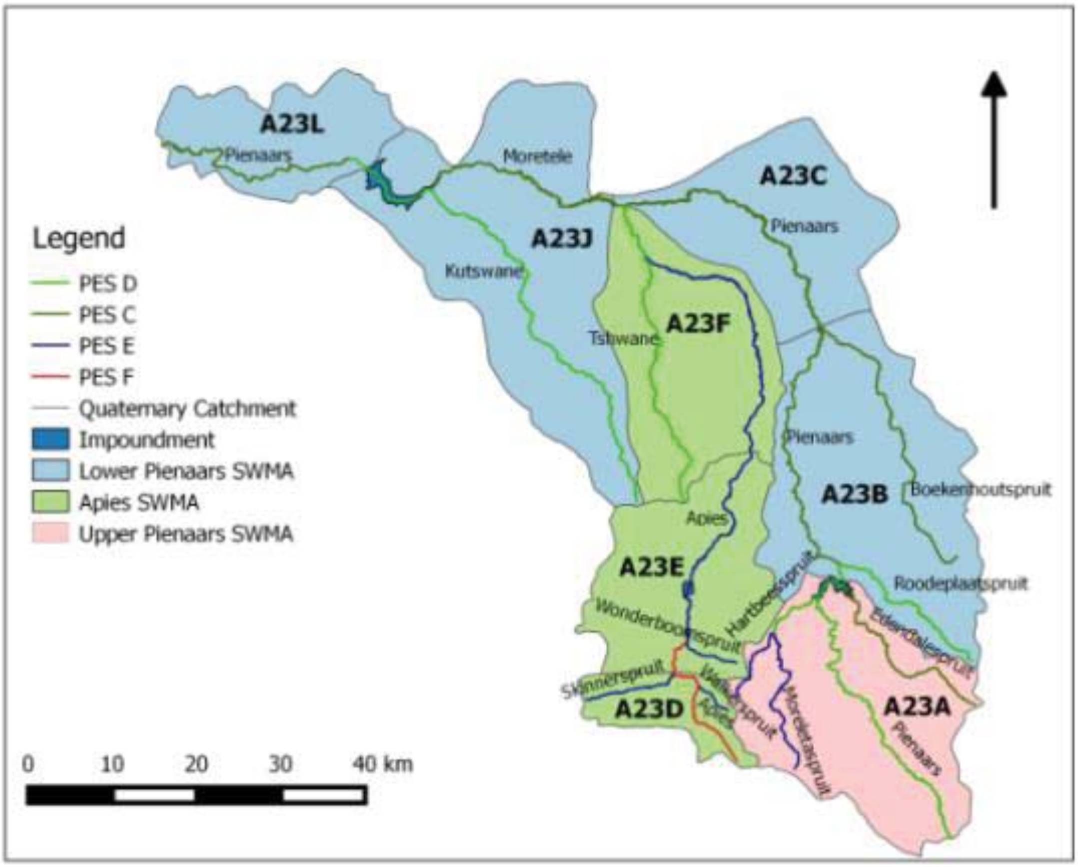


Figure 4-8: Locality map of the case area in the Apies-Pienaars tertiary catchment, containing quaternary catchments, sub water management areas and present ecological states of associated water bodies

Reduced ecosystem health results in a reduced ability to support biodiversity and provide ecosystem services. These services are irreplaceable and a loss thereof will result in reduced human well-being, illustrating the importance of sound catchment management to ensure the longevity of these complex ecosystems.

4.2.5 Water Use

The largest urban areas that use water in the Pienaars River catchment include:

1. City of Tshwane Metropolitan Municipality (Ga-Rankuwa, Mamelodi, Pretoria, Centurion, and Akasia);
2. Moretele Local Municipality (Babelegi, Temba);
3. Nokeng Tsa Taemane Local Municipality (Wallmansthal);
4. Bela Bela Local Municipality (Bela Bela)

Table 4-1 below shows the primary water suppliers and sources of water as listed in the Water Requirements Report of the Crocodile (West) River Return Flow Analysis Study (P WMA 03/000/00/0904).

Table 4-1: Primary Water Supply of the Pienaars Sub-area

Sub-catchment	Local Authority	Town	Water Supplier	Sources
Pienaars	City of Tshwane Metropolitan Council	Pretoria	Rand Water	Vaal River
			Own sources	Rietvlei Dam Fountains
		Ga-Rankuwa	Rand Water	Vaal River
		Mabopane		
	Moretele Local Municipality	Temba	Magalies Water	Apies River Pienaars River Roodeplaat Dam
		Babelegi		
	Nokeng Tsa Taemane Local Municipality	Wallmansthal	Magalies Water	Pienaars River Roodeplaat Dam
	Bela Local Municipality	Bela Bela	Magalies Water	Pienaars River Roodeplaat Dam
			Own sources	Plat River Boreholes

Source: Crocodile West River Return Flow Analysis Study, (Report number P WMA03/000/00/0904)

The bulk of the water requirements of the Pienaars sub-area, except for the City of Tshwane Metropolitan Municipality, is supplied by one of the two major water boards, Magalies Water and is sourced from the Pienaars River and Roodeplaat Dam. The City of Tshwane is supplied from the Rand Water Board and is sourced from the Vaal River. Significant quantities are also supplied from groundwater and from local sources (Boonzaaier, 2008).

Table 4-2: Water Requirements in the Pienaars River Sub-catchment area by sector

Sub-catchment	Total Local Yield (10^6m^3)	WATER REQUIREMENTS (10^6m^3)					Total Water Requirements
		Irrigation	Urban	Rural	Mining/Bulk	Power Generation	
Pienaars River	186	41	211	7	6	15	280

Source: National Water Resource Strategy, 2004

The firm yields of the dams in the Apies-Pienaars River Sub-area were determined as part of the System Analysis of the Pienaars River Sub-system Study and are listed in Table 4-3 below.

Table 4-3: Yield of Reservoirs in the Pienaars River sub-catchment

RESERVOIR	NET CAPACITY ($10^6 m^3$)	YIELD ($10^6 m^3$)	WATER USE
Bospoort	18	1.9	Domestic
Roodeplaat	43.5	21.3	Irrigation, Domestic
Bon Accord	4.5	18	Irrigation
Leeukraal	0.5		Domestic
Warmbaths Old	0.5	1	Domestic
Warmbaths New	8		Domestic
Nooitgedacht	1.5		Recreation
Klipvoor	47	53.3	Irrigation

Source: System Analysis of the Pienaars River Sub-system, Report No. PA200/00/1992

4.2.6 Water Re-use (Return Flows)

The water surplus in the Pienaars sub-catchment will be available in future as a result of increased return flows. For example, in the sub-catchment, the return flows became available and some of it has already been allocated to improve and expand water supply to the areas north of Tshwane. Table 4-4 below shows that urban return flows in the sub-catchment contribute 57% of the available yield, followed by 40% return flows for the surface and ground water. Both irrigation and mining contributes the small return flows to the total yield, less than 2% of the available yield. Riparian irrigators should not be allowed to utilise surplus return flow if the water can be used to supply other water users.

Table 4-4: Water Available for Re-use

Sub-catchment	Natural MAR ($10^6 m^3$)	YIELD ($10^6 m^3$)		RETURN FLOW ($10^6 m^3$)			Total Local Yield ($10^6 m^3$)
		Surface	Ground	Irrigation	Urban	Mining/Bulk	
Pienaars River	142	38	36	4	106	2	186

Source: National Water Resource Strategy, 2004

4.3 Socio-Economy of Study Area

The largest urban areas that use water in the Apies-Pienaars River sub-catchment include:

1. City of Tshwane Metropolitan;
2. Moretele Local Municipality;
3. Bela-Bela Local Municipality.

Table 4-5 summarises the 4 municipalities in the catchment area by showing the sizes of each of the municipalities. The sizes refer to area of land cover, population sizes, GDP and lastly the wealth of the people living in each municipality (GDP per capita). The GDP and GDP per capita are reported in constant 2005 prices to more accurately compare the different municipalities.

Table 4-5: Economic Overview (Source: StatsSA, Quantec and SARS used in own calculations)

Municipality	Area	Population	GDP (constant 2005)	GDP per capita (CONSTANT 2005)
Tshwane	6,368 km^2	2,921,488	R 261,251,664,600	R 89,424.18
Bela-Bela	3,406 km^2	66,500	R 3,640,730,676	R 49,044.42
Madibeng	3,839 km^2	477,381	R 25,537,240,156	R 53,494.46
Moretele	1,379 km^2	186,947	R 3,701,049,298	R 19,797.32

4.3.1 TSHWANE

Being one of 8 metropolitan municipalities in South Africa, Tshwane is the 5th largest municipality by population size. Also, not being one of the smallest municipalities, spanning an area of 6,368 km^2, it still has one of the highest population densities in the country at 459 people per km^2 which supports the argument of it being one of the highest populated areas. The main reason for the metro's high population would be due to its proximity to the biggest metro in the country, Johannesburg, which is the economical hub of southern Africa. Due to the proximity, many businesses have expanded / relocated head offices away from City of Johannesburg into the City of Tshwane metro. The recently completed Gautrain that connects suburbs in Pretoria and those in Johannesburg further links the growth and development of Tshwane to that of Johannesburg. It also is one of the largest contributors to national GDP (8.82% of national GDP) which means that impacts affecting the regional economy would have a substantial impact on the national economy.

Tshwane also has the biggest proportion, amongst the catchment area, of its population being employed at 42.24% and of the employed 38.28% are registered personal income tax payers to SARS.

The Apies-Pienaars River system supplies are largely populated City of Tshwane. The City of Tshwane Metropolitan Municipality has the total population of 2,921,488 and covers the area of 6,368km^2(Census, 2011). The Tshwane Metropolitan Municipality comprises of 7 regions, 105 wards, and 210 councillors; all which are made up of Pretoria Central Business District (CBD), parts of the central-eastern suburbs and most of the western Pretoria industrial and urban areas. Table 4-7 below defines these regions.

Table 4-6: Demographic summary of communities located within the study area.

Apies River						
Communities in the catchment	**Land area (km^2)**	**Population size (thousands)**	**No. of Households**	**Type of Settlement**	**Municipality**	**Land Uses**
Rosslyn	0.89	2,960	n/a	Industrial, suburbs, urban	City of Tshwane	Industrial, urban
Hammanskraal	7.60	21,345		Large Rural	City of Tshwane	Cattle grazing
Makapanstad	20.5	15,076		Large Rural	Moretele Local Municipality	Cattle grazing, Irrigation, Livestock farming, Degraded land
Pienaar River						
Communities in the catchment	**Land area (km^2)**	**Population size (thousands)**	**No. of Households**	**Type of Settlement**	**Municipality**	**Land Uses**
Potoane	0.81	433	105	Rural - Small Village	Moretele Local Municipality	Rural, Cattle grazing,
Pienaarsrivier	2.1	1,897	584	Peri-urban	Bela Bela Local Municipality	Peri-urban, Grasslands, Irrigated agriculture
Haakdoornbult		2,815	683	Farmstead	Bela Bela Local Municipality	Cattle grazing, Livestock farming
Moretele Village	30.4	4,933		Rural - Small, Traditional Villages, Farms	Moretele Local Municipality	Cattle grazing, Grasslands, Irrigated agriculture, Livestock farming

Ga-Habedi	1.3	597	216	Rural - Small Village	Moretele Local Municipality	Cattle grazing, Livestock farming
Borakalalo	130				Moretele Local Municipality	Nature Reserve, Grasslands
Roodeplaat	684			Recreational, Farm residents, Urban residents, Private Property	City of Tshwane	Irrigation, Nature Reserve,

The main economic sectors include: government, social and personal services (29.2%), finance and business services (23.28%), wholesale and retail trade (14.05%), manufacturing (13.04%), transport and communication (10.64%), construction (5.58%).

Table 4-7: Regions in the City of Tshwane Metropolitan Municipality:

Region 1 (North West)

Region 1 is situated in the north-western quadrant of the City of Tshwane with about 27.8% of the population which make up the highest concentration of residents of: (Akasia, Ga-Rankuwa, Rosslyn, Mabopane, Beirut, Soshanguve F and X, and Bodibeng) (Census, 2011). A significant number of the population have low levels of education, high unemployment, very low incomes, and poor living standards with limited job opportunities for unskilled labourers in the region.

Region 2 (Central Northern)

Region 2 is situated in the central northern sector of the City of Tshwane and covers total area of 1,062km^2 and consists of an estimated 115,882.35 households (Census, 2011). Region 2 is known for its tourist areas including the Tswaiing Crater, Dinokeng and Wonderboom Nature Reserves. Infrastructure differs across the region, from the well-developed south to areas in the north that need an upgrade. The region also characterised by low incomes, but unlike in the region 1, region 2 is a place that has many job opportunities, especially for young people.

Region 3 (Central)

Approximately 20% of the City of Tshwane population live in Region 3 and it makes up the third highest concentration of resident (Census, 2011). The south-eastern area of the Region accommodates middle and higher income groups and most of the low-income groups are in the west. The Region contains some of the oldest townships in the greater Tshwane indicating the heritage value of buildings and structures. Atteridgeville in the west of the Region is a low-income area and includes an expanding informal settlement. Predominant rural residential occupation and extensive land uses characterize the north-western area of the Region. The north-western area of the Region includes the undeveloped agricultural land, various residential townships and PPC cement manufacturer. Furthermore, the Crocodile River basin in the Region contributes water to this region.

Region 5 (North East)

Region 5 is characterised by informal settlements, primarily rural, with potential for agricultural development. Only 3.1% of the population of Tshwane resides in this region (Census, 2011). The majority of the residents of Region 5 are unemployed and those that are employed earn low incomes (City of Tshwane, 2012). Region 5 has two major towns, Rayton and Cullinan.

Region 6 (South East)

Approximately 20.73% of the City of Tshwane population live in Region 6 and it makes up the second highest concentration of residents (Census, 2011). It is made up of 24 wards and covers a large area of land. This region has the highest income per capital of all seven regions as a result of the high number of businesses and retailers in the area (city of Tshwane, 2013). It also contains the second most important industrialised area in Tshwane. However, the northern part of the region has fewer job opportunities and less development than the southern part.

Region 7 (East)

Region 7 is the easternmost part of the City of Tshwane, and forms the gateway to Gauteng from Mpumalanga (City of Tshwane, 2012). The area is primarily rural and has significant agricultural potential. In addition, there is an industrial zone (Ekandustria) and an urban area (Bronkhorstspruit). The economic contributions of region 7 includes manufacturing (29%), financial services, distribution services and trade (City of Tshwane, 2013).

4.3.2 MADIBENG

Madibeng covers 3,839 km^2 and accounts for 0.86% of national GDP. With a population density of 124 people per km^2 it is still one of the higher populated areas. Hartbeespoort is located within the municipality, which is seen as a large tourist attraction.

The second-largest municipality in this catchment area, behind Tshwane, boasts a population of 477,381.

Madibeng ranks third with its proportion of population being employed at 22.75% and of these employees 31.80% are registered at SARS.

4.3.3 MORETELE

Moretele is the smallest of the municipalities in the catchment area around the Pienaars River with area of only 1,379 km^2. Even though it's the smallest by area it's second smallest by population and because of that it contributes a little bit more to the national economy (0.12% of national GDP) than Bela-Bela. In our catchment are Moretele is the second most populated area w.r.t. population density which is 136 people per km^2.

Moretele has the worst proportion of population that is employed at only 10.23%. Registered tax payers make up 31.72% of the employed.

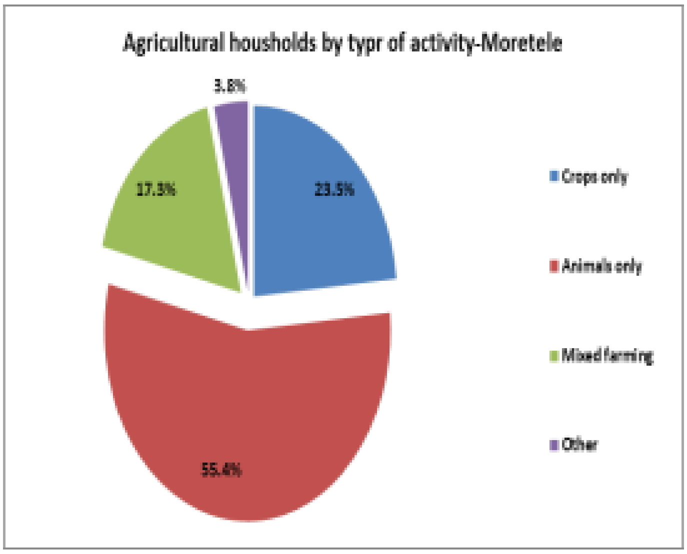
The Moretele Local Municipality has a total population of 186,947 and covers an area of 1,369km^2 (Census, 2011). In 2013, the total population increased to 209,291 (City of Tshwane, 2013). The Municipality is 100% rural with 58,779 households. There are 24 wards, which are made up of 66 villages and plots. Most of the villages are ruled by four traditional leaders, who are recognised by law and represent their respective tribes/communities in council.

The Municipality is highly rural with 88% of the population residing in traditional areas, 7.4% in urban areas and about 3% residing on plots. Black Africans constitute 99.4% of the Moretele Local Municipality's population (Census, 2011).

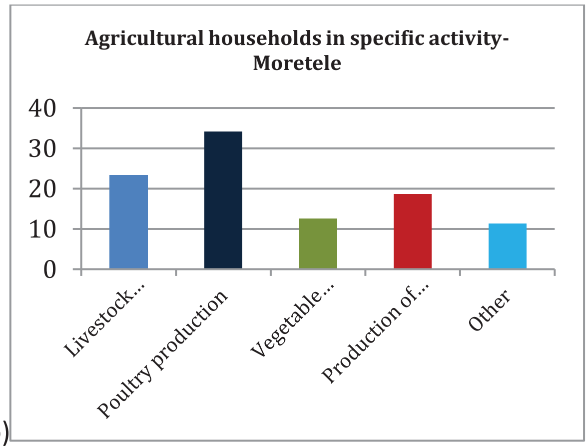
The overall broad land cover of Moretele Local Municipality is described as "degraded forest and woodland" which constitutes 41.1% (563 km^2) of the total area of the municipal area. Other important land cover categories include areas described as "forest and woodland" (29.8%), "subsistence farming activities" (14.6%) and "urban build-up areas" (representing just over 7% of the total municipal land area).

The municipality is shaped by the rich agricultural history characterising large pieces of land which can be used to harness economic development opportunities. Livestock farming is believed to be the main type of farming activity that is carried out in the local municipality. Trading Services are also key economic drivers but, agriculture has become a focal point in all economic development prospects for the municipality population.

a)



b)



c)

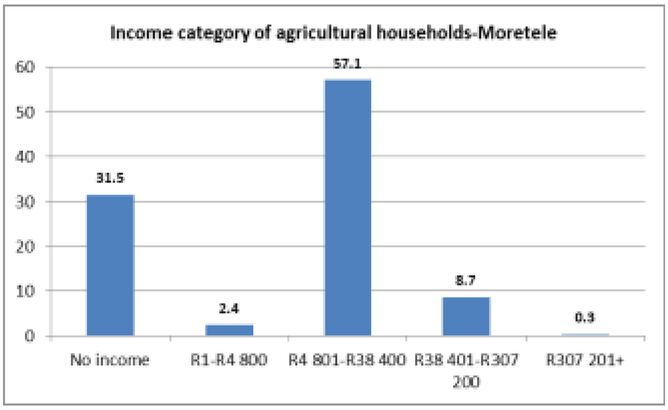


Figure 4-9: Agricultural Statistics of Moretele Local Municipality (StatSA, 2011)

4.4 CASE STUDY AREA DEFINITION AND ZONATION

The first phase in the description of a socio-economic system is the definition of the study area boundaries. Numerous reconnaissance visits as well as desktop studies of the catchment area, resulted in a study area that was large enough to encompass heterogeneous land and water uses, dependencies and catchment units. An area extending from the headwaters of the Apies, Pienaars, and Moretele rivers to the outfall of the Klipvoor Dam was selected (Figure 4-10).

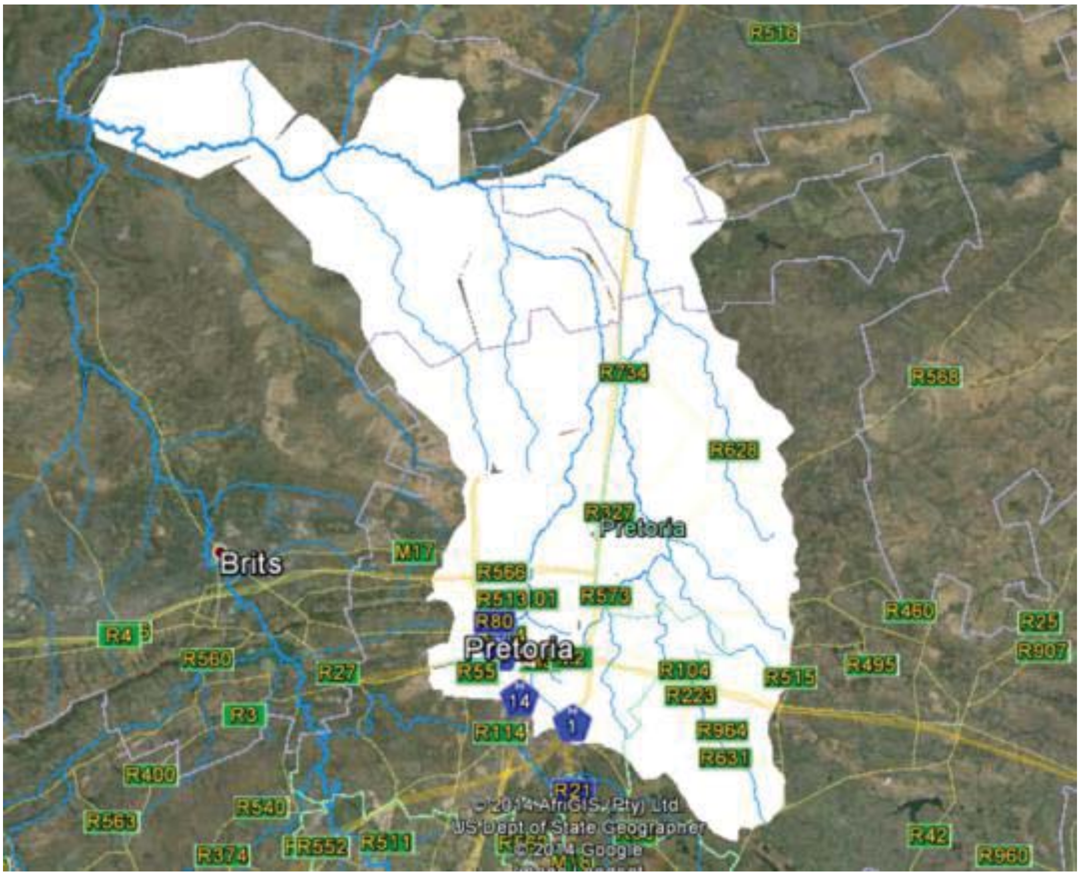


Figure 4-10: Study area for the modelling of the socio-economic system

The study area was then partitioned into eight different zones, largely delineated by quaternary catchments (

Figure 4-11). Because zone boundaries were largely determined by catchment areas, monitoring water quality at their boundaries can provide the consolidated effect on river health of all activities within the catchment.

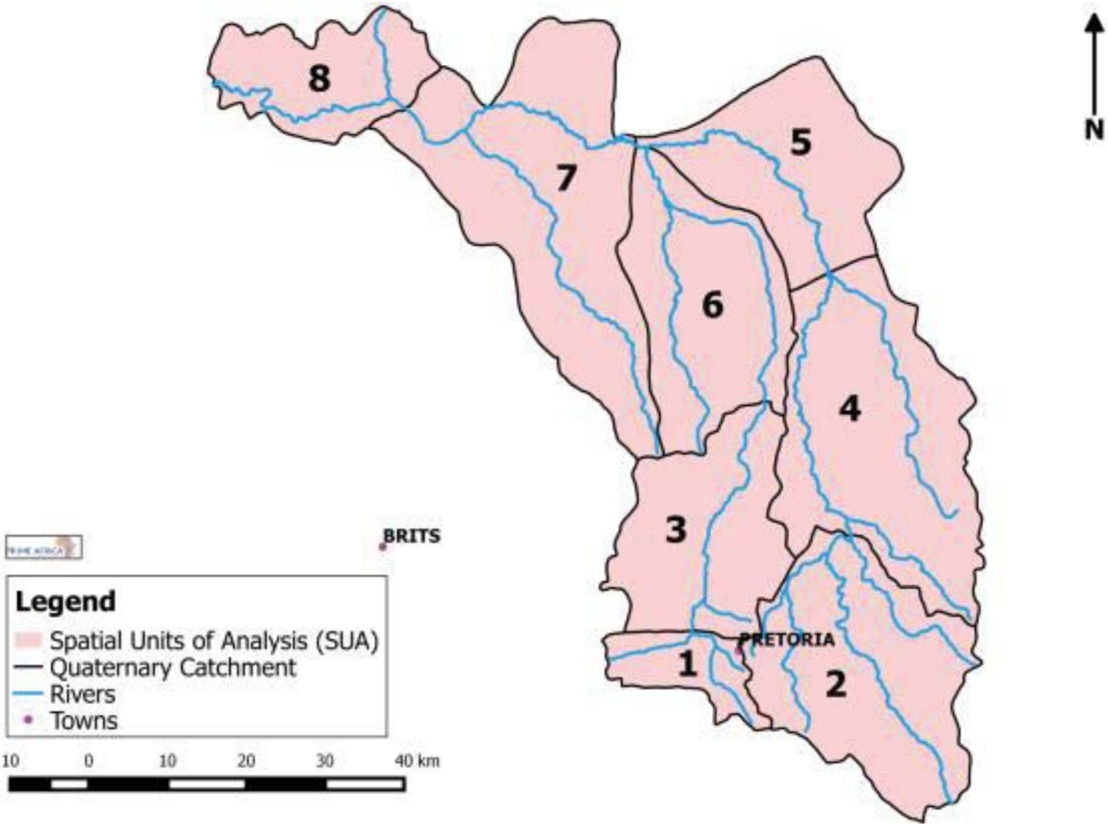


Figure 4-11: Spatial units of analysis in the study area

The spatial units were used to inform the selection of monitoring sites for river health indicators, as well as be further partitioned into spatial units to capture their heterogeneity in activities.

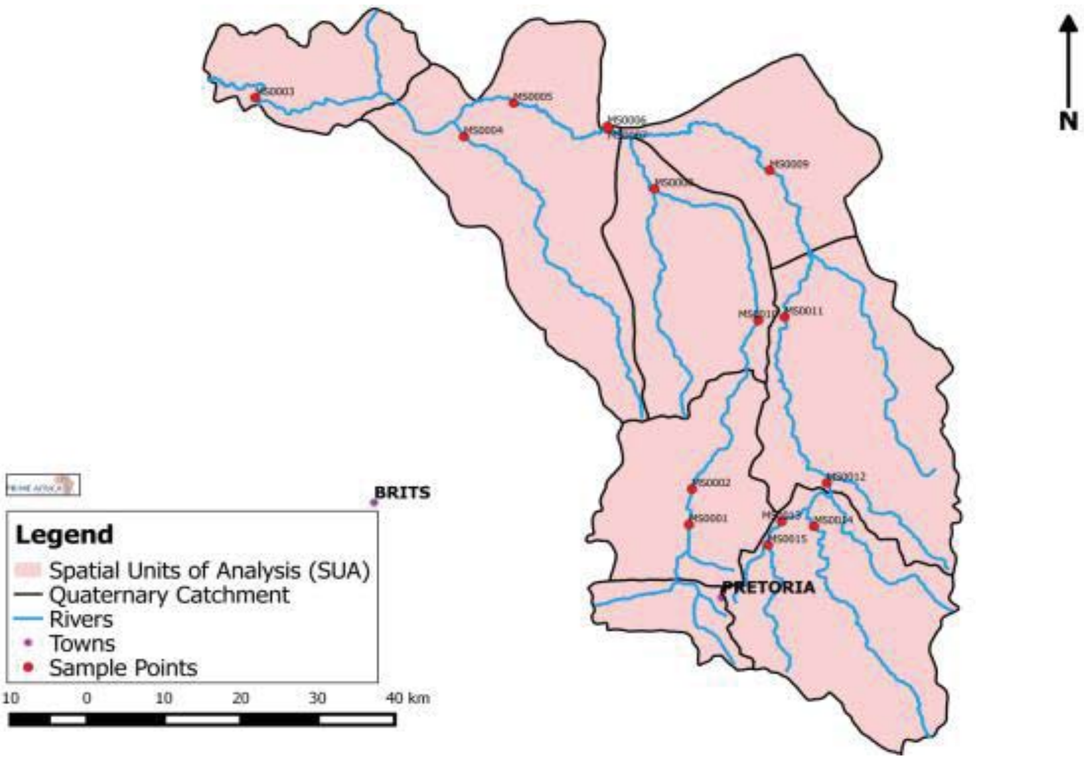


Figure 4-12: Monitoring sites within the study area

4.4.1 MONITORING PROTOCOL

With the monitoring sites and the indicators to be measured, determined, a monitoring protocol was developed. The monitoring protocol calls for a combination of *in situ* and *ex situ* sampling with probes and grab samples respectively (**FIGURE 4-13**). Furthermore, different indicators are measured at different intervals with the complete organics and metals tests only being conducted once (to assess any specific pollutants to the system), and all other indicators being assessed every two weeks, over a period on one year.

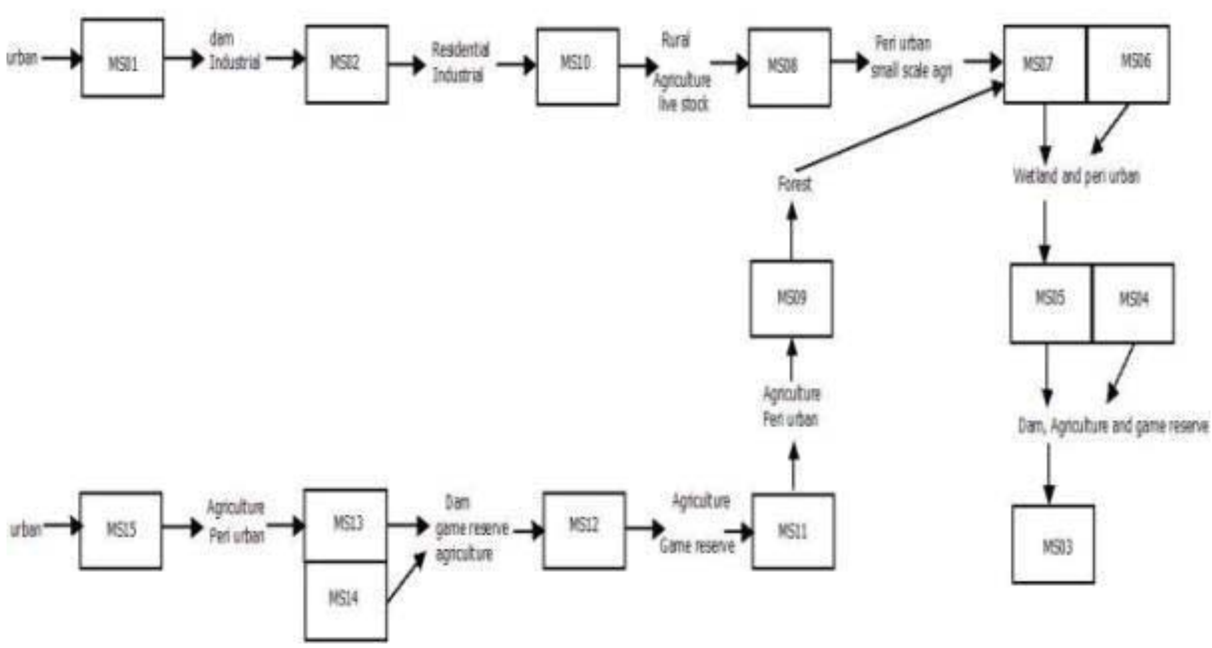


FIGURE 4-13: Factors contributing to change in water quality within the study area

Table 4-8: The water quality indicators monitored in the study area and the equipment used to measure them

Pollutant	Indicator (s)	Testing location	Testing Equipment
Faecal Bacteria	Faecal Coliforms	ex situ	Compact Dry EC plates
Phosphorous	Total Phosphate	ex situ	Hach Kit and Colorimeter
Nitrogen	Total Nitrate	ex situ	Hach Kit and Colorimeter
Salts	Total dissolved solids (electrical conductivity)	in situ	YSI meter and EC probe
Dissolved Oxygen	Dissolved Oxygen (Galvanic)	in situ	YSI meter and DO probe
ORP	Oxidation Reduction Potential	in situ	YSI meter and ORP probe
Other properties			
pH	pH	in situ	YSI meter and pH probe
Temperature	Stream temperature	in situ	

Major activities at each site can be used to predict the change in load at each site as shown on the table below.

Table 4-9: Expected change in the load on each sampling site – (Pos=Positive change; Neg=Negative change)

Sites	Area	Parameters					
		DO	TDS	Phosphates	Nitrates	COD	Coliforms
MS002	Onderstepoort	Pos	Neg	Pos	Pos	Pos	Pos
MS010	Hammanskraal	Neg	Neg	Neg	Neg	Neg	Neg
MS008	Makapanstad	Pos	No change	Pos	Pos	No change	Pos
MS013	Roodeplaat	Pos	Pos	Neg	Neg	Pos	Pos
MS012	Roodeplaat	Pos	Pos	Neg	Neg	Pos	Neg
MS011	Dinokeng game reserve	Pos	Pos	Pos	Pos	Pos	Neg
MS009	Pienaarsrivier	Pos	Pos	Neg	Neg	Pos	Neg
MS007	Haakdoornbult	Pos	Pos	Pos	Pos	Pos	Pos
MS005	Moretele	Pos	Pos	Pos	Pos	Pos	Pos
MS003	Borakalo	Pos	Pos	Neg	Neg	Pos	Pos

4.5 RESULTS AND DISCUSSION

4.5.1 RIVER HEALTH

The study of the surrounding area on the river system is important because it helps to understand the causes of change in the water quality. The quality of a stream or river is often a good indication of the way of life within a community through which it flows. It is an indicator of the socio-economic conditions and environmental awareness and attitude of its users. Everything that happens in a catchment area is reflected in the quality of the water that flows through it, because the results of human activity and lifestyle ultimately end up in rivers, through runoff. These properties can be used to determine the effects of groundwater and stream water on aquatic ecosystem health and can sometimes be used to identify sources of pollution in water.

The Apies-Pienaars River system had various catchment land uses and water uses that resulted in the degradation of aquatic ecosystems. Urban land use types displayed the highest impacts on ecosystem habitats primarily due to transformation extending into riparian zones and the increased prevalence of hardened surfaces which allow for greater levels of surface runoff and consequently greater introduction of contaminants into the system. An Integrated Bio-Economic Model was developed to quantify the relationship between the ecosystem services generated by the Apies-Pienaars river system and health of the riverine ecosystem.

4.5.1.1 RESOURCE QUALITY

WATER CHEMISTRY

The study generated useful data through the collection of water quality samples along the Apies-Pienaars river system. The data collected contributed to understanding the state of the river system and nature of various explanatory factors contributing to the water quality in the system. The specific conclusions related to various indicators are listed below:

- *Phosphates and Nitrates:* There is evidence to support the relationship between the relationship between high levels of nitrates and phosphates in the water and the proximity of the sampling points to areas of agricultural activity. Additionally, the presence of a WWTW near to a given sampling point also influenced the levels of nitrates and phosphates found in the water at that point. Conversely the presence of dams correlates with lower levels of nitrates and phosphates in the water, lending support to the argument that dams act as a sink for nutrients.

- *Dissolved Oxygen (DO) and Chemical Oxygen Demand*: The evidence collected indicates that DO and COD are not very effective explanatory factors for the water quality of the riverine system. This is since OD and COD are highly influenced by the other parameters (e.g. turbidity has a pronounced effect on the DO saturation percentage).

- *Coliforms*: The water quality data collected indicates that the coliform count present in the water is directly related to the presence of animals (either through game farming or livestock rearing) and to the presence of wastewater treatment plants.

- *Total Dissolved Solids* (TDS): The presence of industrial activity in proximity to the river correlates positively with the concentration of TDS. There was some anecdotal evidence to indicate that the presence of dams would reduce the concentration of TDS. Measurement before and after Roodeplaat Dam lend support to the position that dams reduce TDS. The measurements at Bon Accord Dam however were not as clear, though it is posited that the presence of industrial activity near Bon Accord Dam influenced these measurements, negating the effect that the dam has.

- *Turbidity:* There is no clear evidence (of the factors investigates) that factors contribute to the turbidity concentration in the water. However, there is evidence to show a relationship between turbidity and seasonality, indicating the turbidity is influenced by runoff.

HISTORICAL DATA

Historical data helps us to better understand and compare water quality data over years and to check the extended period in which the land use activities affect water quality. The data from sampling sites that was collected from 2014 to 2015 was compared with the closest historical DWS sampling sites from 1999 to 2011. For water quality results, the research team compared in-house water quality results with accredited laboratory results. In-house results were similar to that of accredited laboratory except for phosphate. For this reason, DWS phosphate historical data will not be compared with in-house data.

4.5.1.2 ECOLOGICAL STATE

The study catchment has a high heterogeneity of land uses and intensities spread across it. The effects of the impacts arising from this variable landscape on the riverine ecosystems are not fully understood. A full-scale ecological investigation into these systems was beyond the scope of this study; however, there is value in observing, on a comparative basis, the variation in the state of ecosystems due to the changing land use intensities (Figure 4-14). A river habitat assessment was thus done using the Prime Africa Express Habitat Assessment Method (E-HAM) (See appendix D). Past Present Ecological State Assessments were also included as to identify trends in ecological degradation (Figure 4-15; Figure 4-16). Note the overall degradation in state between PES done in 1999 compared to that of 2013 (Figure 4-15; Figure 4-16).

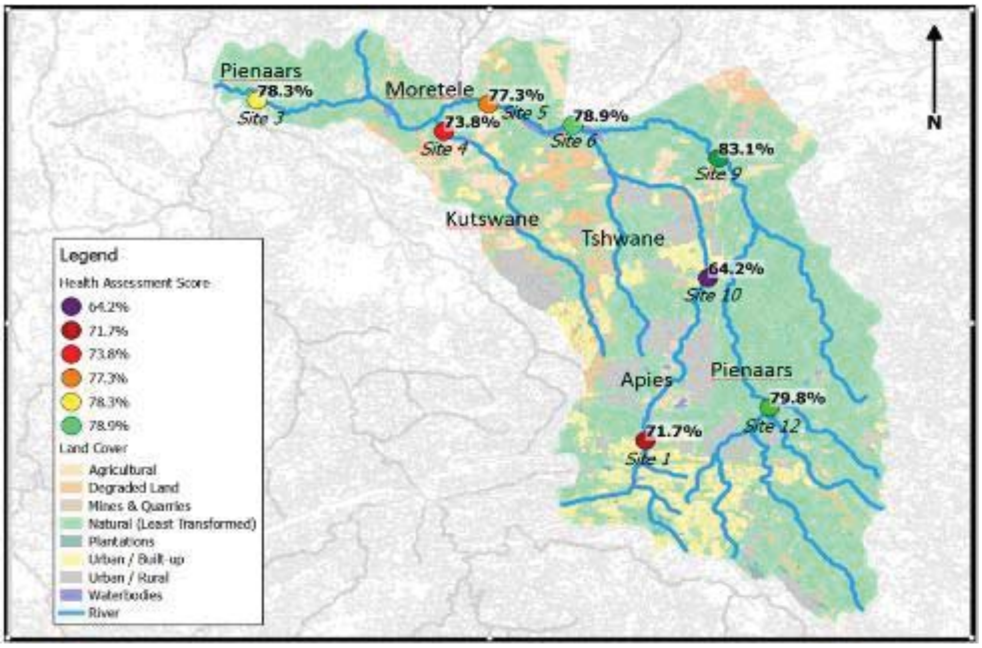


Figure 4-14: Results of the Express Habitat Assessment Method (E-HAM) for sites along the Apies-Pienaar Catchment

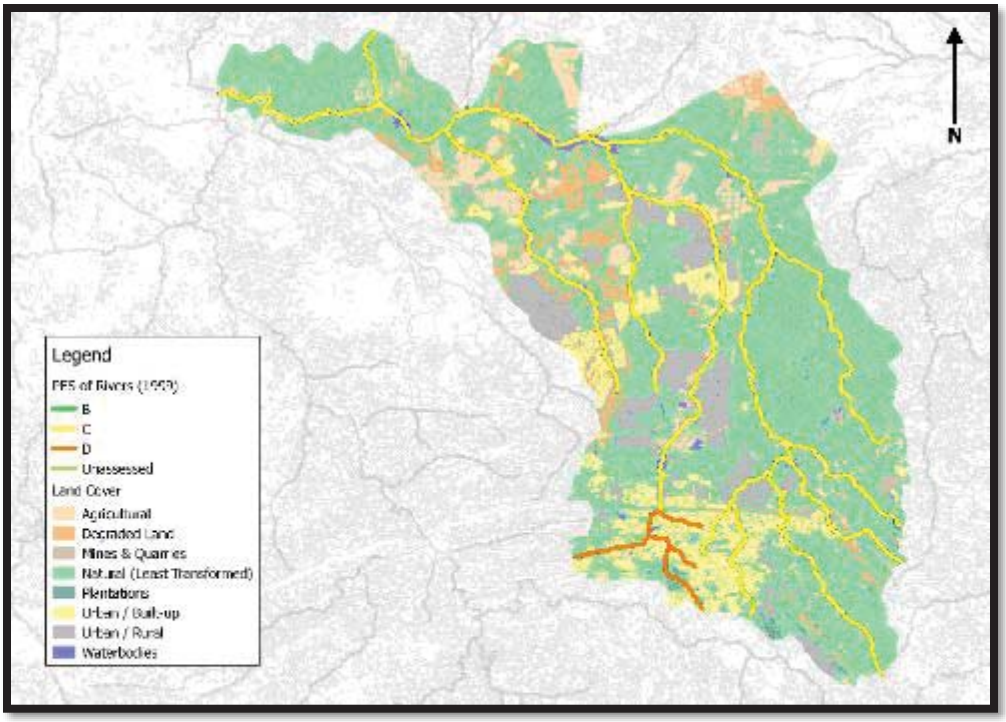


Figure 4-15: Results of PES 1999 along the Apies Pienaar Catchment

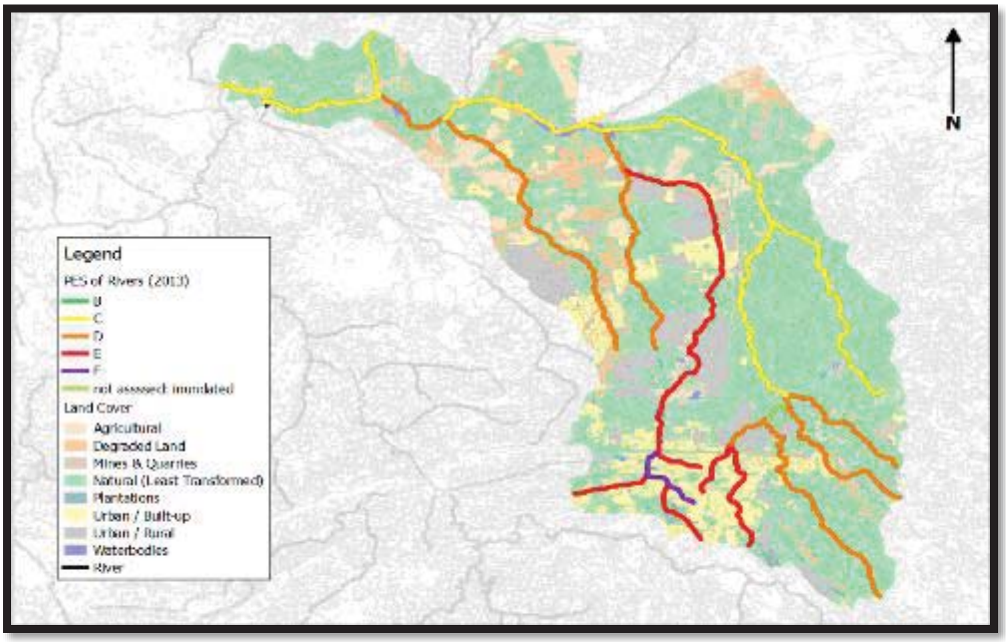


Figure 4-16: Results of PES 2013 along the Apies Pienaar Catchment

4.5.1.3 FLOW REGULATION

The hydrology of the Pienaars River system upstream of Klipvoor Dam no longer represents the natural flow. There are several contributing factors, some of which are variable, others may be more constant.

The ecosystem service contribution in the study area was highly dependent on the streamflow. In this study, information from the Water Resources of South Africa (WR2005), was used to describe the services at a quaternary catchment spatial scale (Figure4-17). Rainfall data was used to describe the study area in terms of a freshwater provisioning service (Figure 4-20), and rainfall runoff data to describe the study area in terms of the regulating service (Figure 4-19).

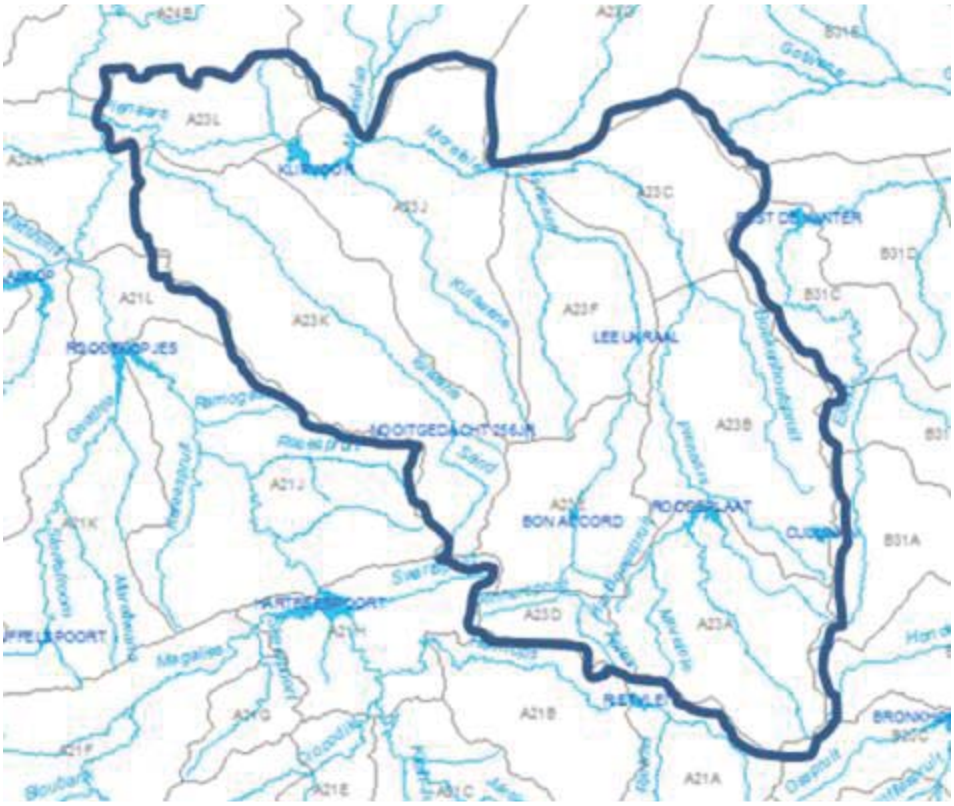


Figure4-17: Study area showing the primary and secondary rivers as well as dams in relation to quaternary catchments (WR2005)

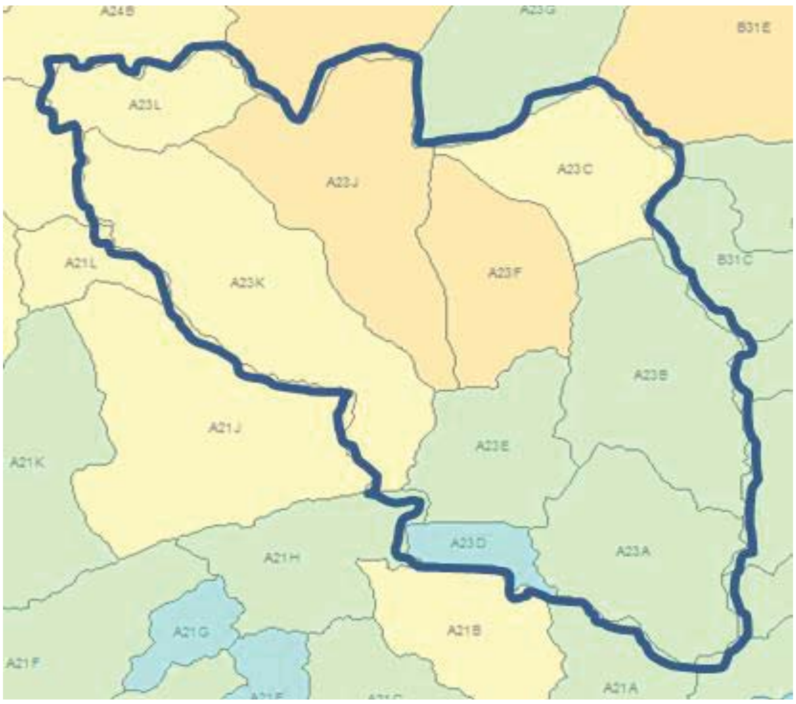


Figure 4-18: Study area showing the rainfall runoff in relation to quaternary catchments (WR2005)

Figure 4-19: Study area showing the rainfall in relation to quaternary catchments (WR2005)

The 'year round' factors will affect the base flow listed in Table 4-10

Table 4-10: Sources affecting the hydrology of the Pienaars River upstream of Klipvoor Dam.

Source	Variability
Rainfall • Runoff from hard surfaces	Seasonal Increases the flood peak
Urban situation • Interbasin transfer (IBT) from the Vaal • Wastewater treatment works (WWTW) • Non-revenue water[5] • Garden watering, swimming pool backwashing, etc.	 Year round Year round Year round Mainly summer
Groundwater • Dolomite • Other	 Year round
Abstraction • Treatment for potable use • Irrigation	 Year round Higher in summer

Each of the sources given above have an effect on the flow of the river and each of these effects influence both the water quality and the habitat in the river.

[5] Not all non-revenue water is lost through faulty infrastructure.

The water brought into the system by the IBT from the Vaal River is mainly discharged into the Pienaars River through the wastewater treatment works. This additional water will provide a higher and more stable base flow than would be the case if the river depended only on rainfall.

During times of high rainfall, however, the flood in the Pienaars is substantial. The photographs in Figure 4-20 show the floodplain upstream of Klipvoor Dam at low and high water. The Pienaars River at this point is a floodplain with a distinct channel. At low flow the floodplain will provide ecosystem services such as grazing for livestock but at high flow, when the floodplain is under water, the river may be expected to provide ecosystem services such as flood attenuation and nutrient sequestration.

The Pienaars system is eutrophic, as may be seen in Figure 4-20 which shows a substantial algal bloom in the Klipvoor Dam.

Picture of the floodplain taken from the Kgomo-Kgomo bridge at low water looking westwards (June 2014) (Photo: SA Mitchell)

Picture taken of the Kgomo-Kgomo bridge and floodplain looking eastwards (January 2008) (Photo: Marais and Peacock, 2008; Pg 110)

Figure 4-20: The bridge at Kgomo-Kgomo crosses the floodplain wetland on the Pienaars River at sampling station MS0007 (S25.16425° E28.08299°). The two photographs below were taken at low and high water respectively.

Figure 4-21: Klipvoor Dam showing an extensive algal bloom (Source: iPad maps).

The relationship between river flow and selected water quality variables was investigated at sampling stations MS003, MS010 and MS012. These are given in Figure 4-22 to Figure 4-25 below. MS003 is on the Pienaars River downstream of Klipvoor Dam, at the downstream end of the study area. MS010 is on the Apies River in Hammanskraal. MS012 is immediately downstream of Roodeplaat dam on the Pienaars River.

The variations in the correlation against flow of the variables measured between the 3 sampling stations in the following graphs underpin the complex mix of water sources and general activities that occur in the catchment.

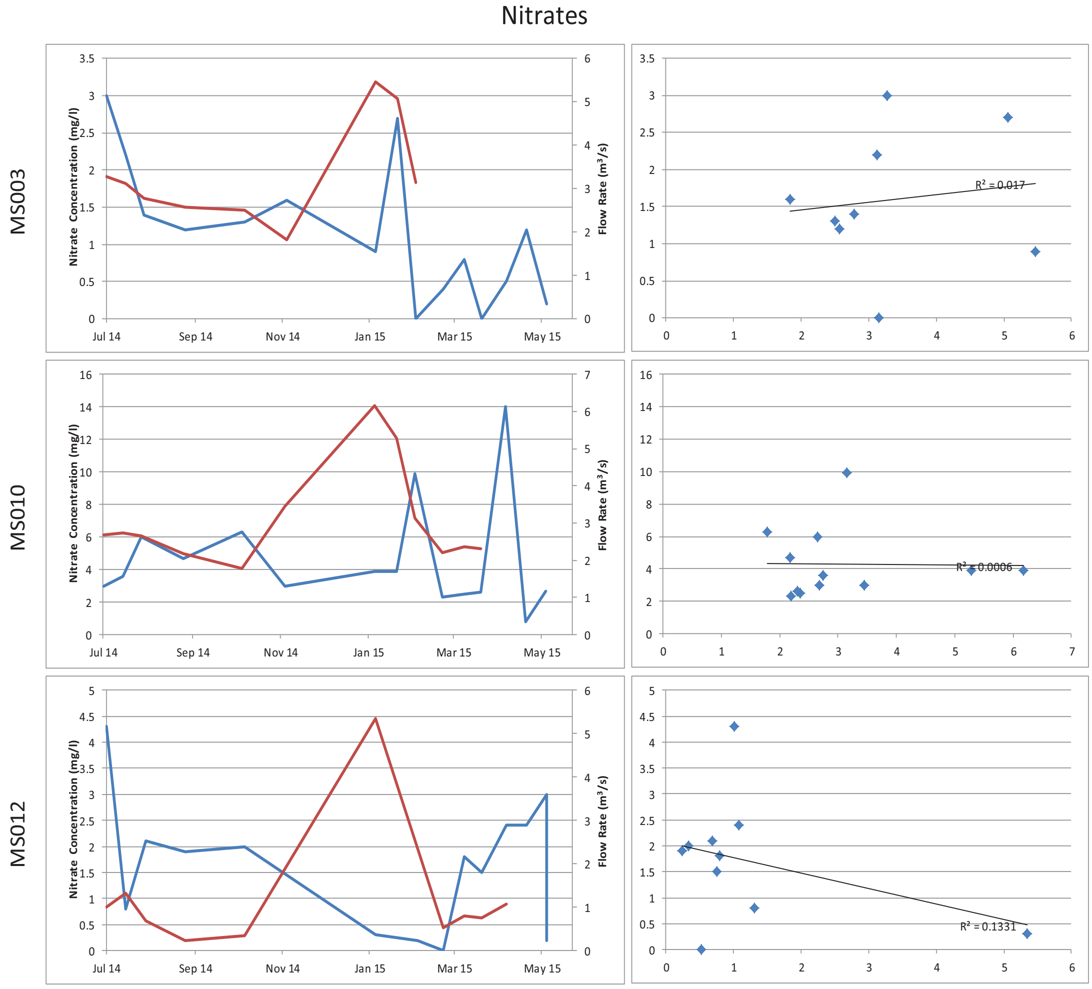


Figure 4-22: Nitrate concentration relative to river flow at selected sampling points.

Nitrate concentrations showed a slightly positive correlation with river flow at MS003. This may be due to runoff from irrigated areas. At MS010 and MS012 the correlation was negative. The difference in correlation may indicate that the NO_3 originates from different nutrient pools. For instance, there are two WWTWs discharging into Roodeplaat Dam and it is likely that the contribution of nutrients from these is greater than that from agriculture higher up the catchment.

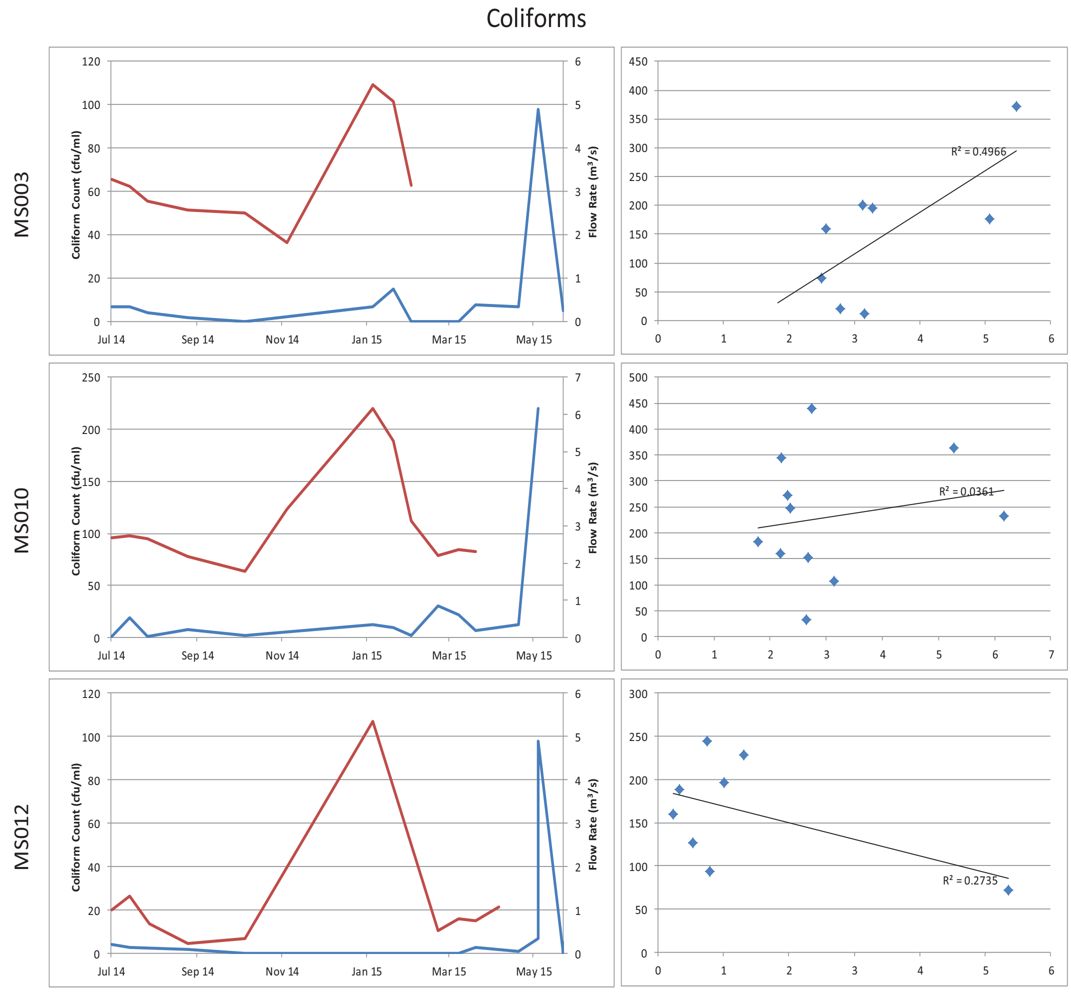


Figure 4-23: Coliform concentration relative to river flow at selected sampling points.

Coliform counts were not strongly correlated with flow.

Total Dissolved Solids

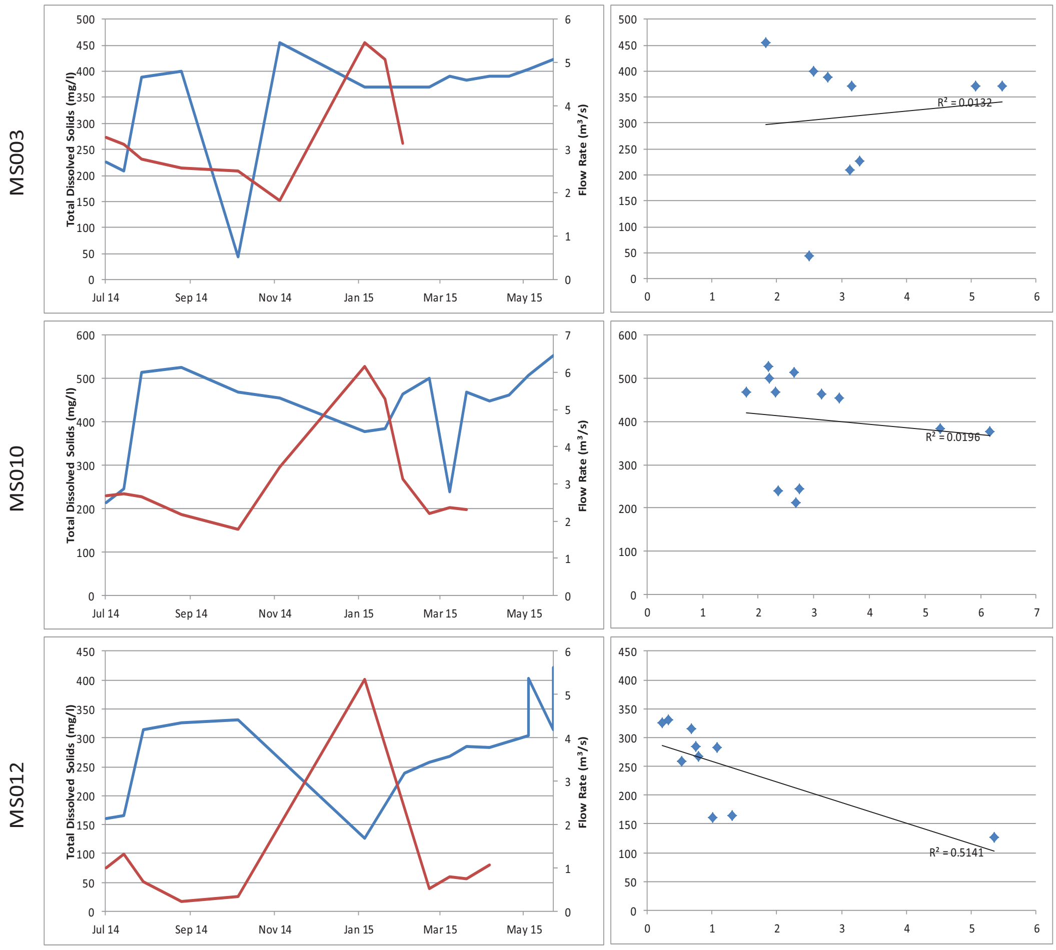


Figure 4-24: Total Dissolved Solids (TDS) concentration relative to river flow at selected sampling points.

The correlation between TDS and flow varies between sampling stations.

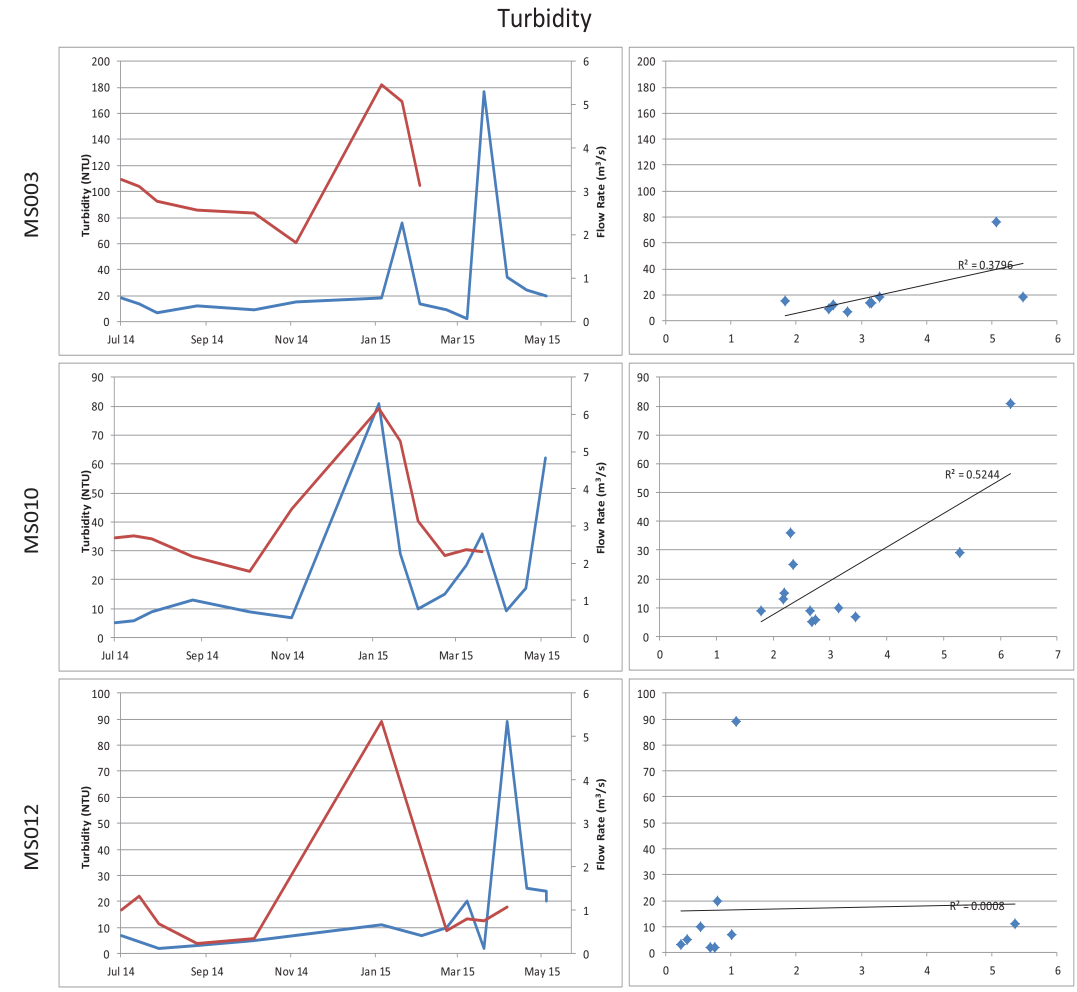


Figure 4-25: Turbidity relative to river flow at selected sampling points.

The correlation between flow and turbidity varies between stations but is generally higher than some of the other variables measured.

Production function

The water flow production function takes the following form:

$$flow = f(water\ quality; urban\ areas; waterbodies; wetlands; habitat\ assessment)$$

From our analysis, we found the following relationships:

- A positive, but statistically insignificant, relationship between water flow and water quality.
- A negative, but statistically insignificant, relationship between water flow and urban areas upstream and within 500m of the river.
- A negative, and statistically significant, relationship between water flow and waterbodies upstream and within 500m of the river. The interpretation could be that waterbodies dam up more water and release water at a lower but more consistent rate.

- A positive, but statistically insignificant, relationship between water flow and wetlands upstream of the river.
- A positive, but statistically insignificant, relationship between water flow and our habitat assessment.

4.5.1.4 SPATIAL UNIT ANALYSIS (SUA)

The Apies-Pienaars River system provides many land uses and water uses that impact on or depend on the health and integrity of the water resource. Various studies have also been conducted in the Crocodile (West) Water Management Area (WMA), including the implementation of the Water Resource Classification System (WRCS). The river system receives agricultural runoff, irrigation return flows, industrial effluents and partially treated or untreated wastewater effluents. The associated water quality impacts from the catchment land uses include nutrient enrichment, sedimentation, and the introduction of endocrine disrupting chemicals (EDC) and heavy metals into the water resource. The river system also flows through various settlements (both rural and peri-urban areas), commercial and subsistence farming land, an industrial area, and the Borakalalo National Park before its confluence with the Crocodile River.

The catchment has 8 spatial units. Each unit will be thoroughly discussed below to evaluate how the land use activities impact the quality of the river system.

SPATIAL UNIT 1

In this unit, the team had 2 sampling sites i.e. site MS001 and MS002. The unit A23D is situated in the upper catchment along the Apies River. This spatial unit is represented by site MS001. The site is situated in a shallow valley which is characteristic of a mosaic of mixed agricultural and suburban land uses which highly influenced the riparian composition as shown on Figure 4-26. The channel is a flat u shape with steep (in places) undercut banks. The sediment matrix displayed was mostly framework dilated with a low availability of interstitial spaces. A habitat quality score of 71,3% was observed at this site at site MS001 classifying it as a category C being moderately transformed.

Figure 4-26: Aerial view (Google Earth) of site MS001

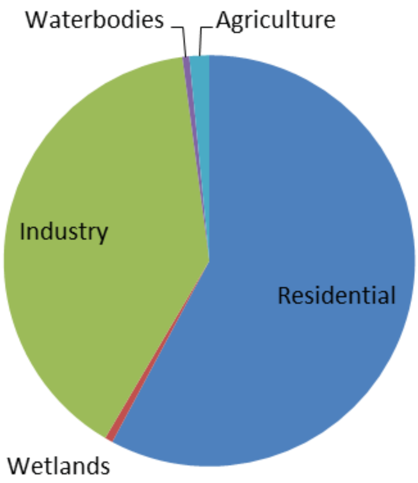


Figure4-27: Land use activities in spatial unit 1

Comparison between water quality data collected and historical data: Site A2H063Q01 (A DWS monitoring site) and site MS001 (a site selected in this study) were used to compare water quality in this spatial unit over the years by selecting certain indicators i.e. TDS and NO_3. The figure below show that total dissolved solids over the years has been reduced. Nitrate concentration has remained the same with varying values between 0.77-4.1 mg/l as shown on Figure 4-29.

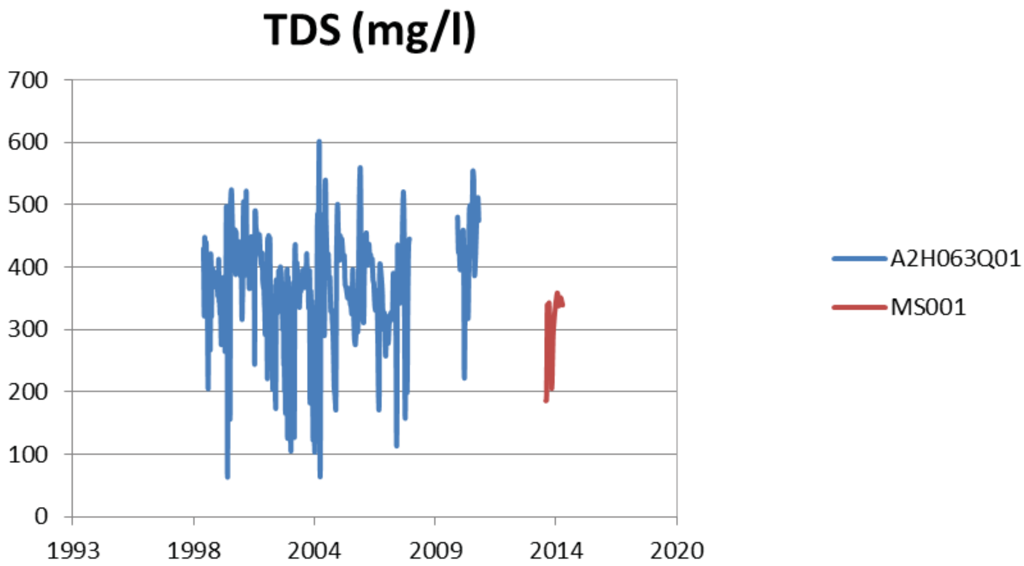


Figure 4-28: Comparison of TDS concentration between historical data (A2H063Q01) and water quality data collected (MS001)

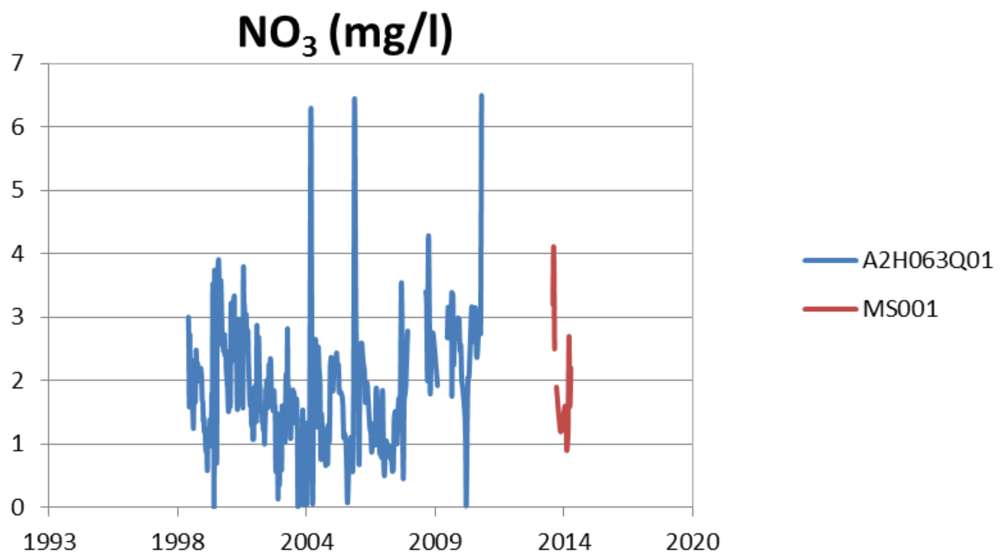


Figure 4-29: Comparison of nitrate concentration between historical data (A2H063Q01) and water quality data collected (MS001)

Bon Accord dam separates site MS001 and MS002 (downstream of the dam) and evidence portrayed by the figure below show the dam helps to reduced nitrate levels in the river system.

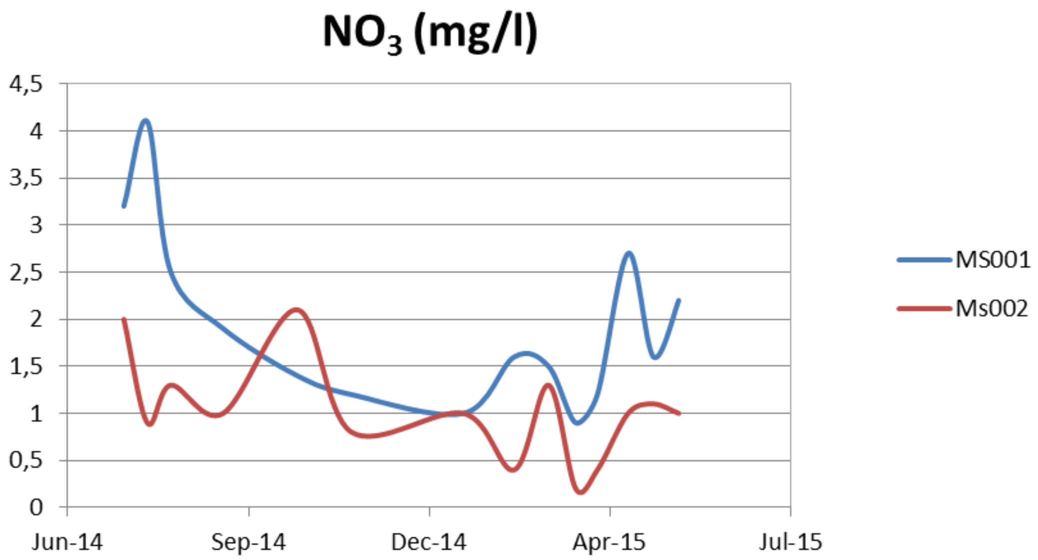


Figure4-30: Comparison of nitrate concentration between MS001 and MS002

Spatial Unit 2

In this unit, the project team had 2 sampling sites i.e. MS014 and MS015. Sites MS013 and MS015 are being situated near Mamelodi and Pretoria both on the Hartbeesspruit. High levels of urbanisation in these areas cause changes in the overall dynamics of the system reflecting in the ecological habitat states ranged between 70% and 73,9%. Urban rivers and streams are subjected to impacts arising from highly transformed landscapes which often stretch into the riparian zones. Site MS014 is similar area in terms of land use intensity. This site had a much lower score comparatively (60,9%) and over and above, the observed urban influence may have had an increased impact.

The unit A23E is represented by site MS012. The site is situated in a shallow valley approximately 2km downstream from the Roodeplaat dam. This area is characteristic of scattered agriculture, industry, smallholdings, and household plots as shown by the Figure 4-31 and Figure4-32. The channel is a flat u shape with steep banks consisting of highly vegetated riparian zones. The sediment matrix displayed was mostly open framework with a high availability of interstitial spaces. A habitat quality score of 79,8% was observed at this site classifying it as a category C being moderately transformed from pristine conditions

Figure 4-31: Aerial view (Google Earth) of site 12

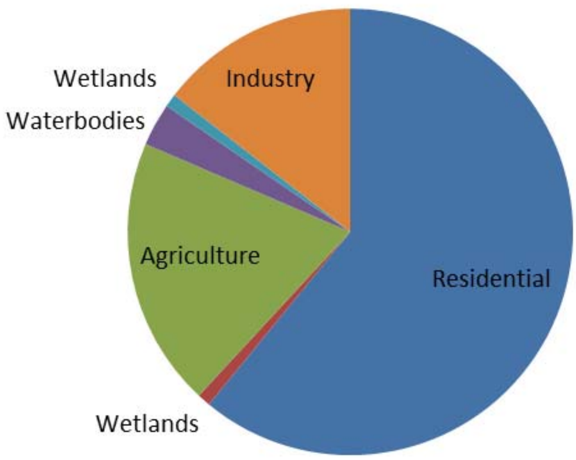


Figure4-32: Land use activities in spatial unit 2

Comparison between water quality data collected and historical data: Site A2H102Q01 (A DWS monitoring site) and site MS012 (a site selected in this study) were used to compare water quality in this spatial unit over the years by selecting certain indicators i.e. TDS and NO_3. Figures below indicate that the dissolved solids over the years have been reduced slightly. Nitrate concentration has remained the same with varying values between 0.082-2.72 mg/l.

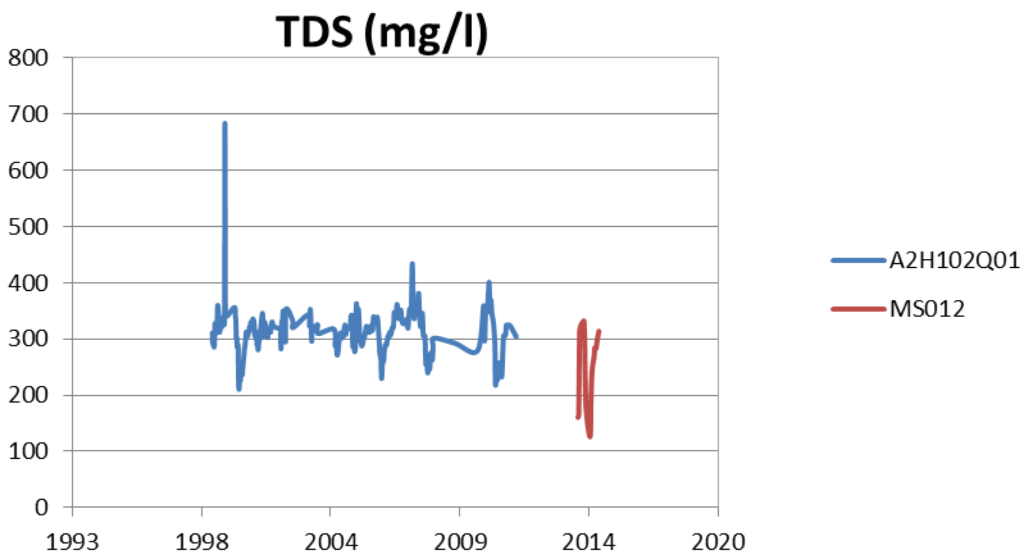


Figure 4-33: Comparison of TDS concentration between historical data (A2H102Q01) and water quality data collected (MS012)

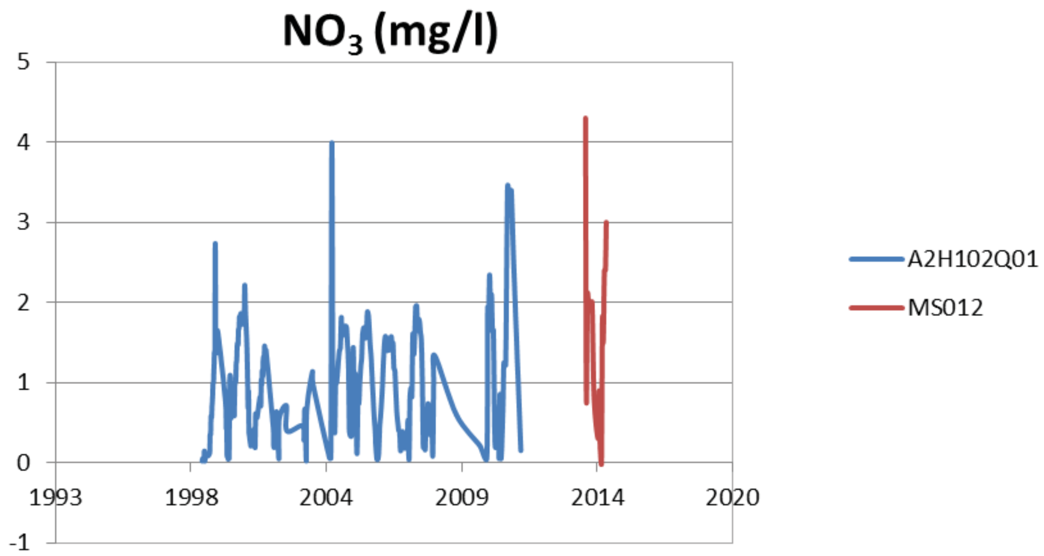


Figure 4-34: Comparison of nitrate concentration between historical data (A2H102Q01) and water quality data collected (MS012)

Coliforms are unacceptably high throughout the catchment. Discharge point of WWTW separates MS014 (downstream of the discharge point) and MS015.The figure below suggests that this point source pollution may contribute to the degradation of the water quality in the river system.

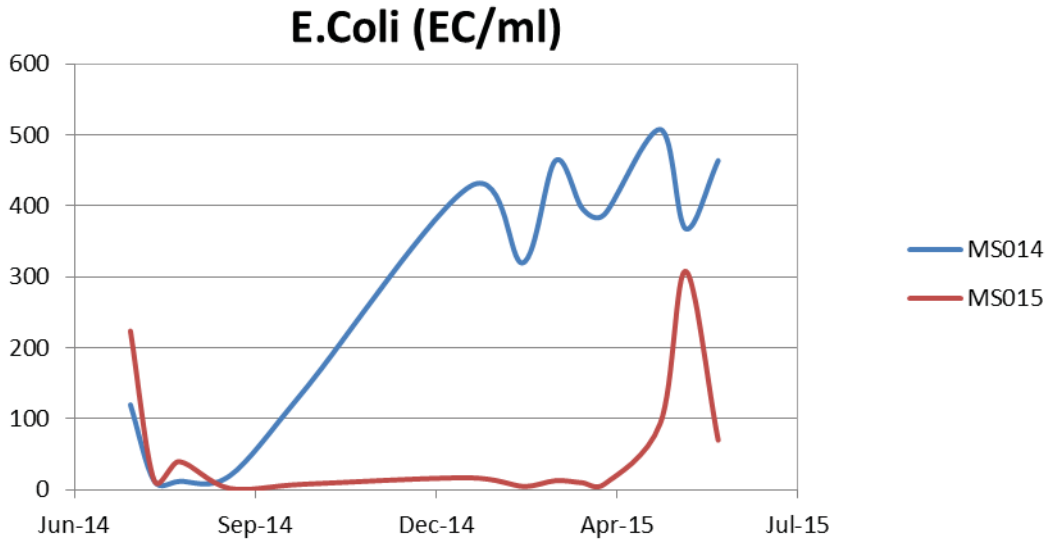


Figure4-35: Comparison of Coliforms (EC/ml) between MS014 and MS015

SPATIAL UNIT 3

The unit A23E is represented by Site MS010. This site is situated in a shallow valley which is characteristic of urban land use with natural to degraded land types being situated within Hammanskraal. There is a high level of accessibility to the system, however comparatively low intensity of urbanisation in the area likely aids in the maintenance of the system. The channel is a u shape with steep banks. The sediment matrix displayed was mostly matrix filled contact framework with a moderate availability of interstitial spaces. A habitat quality score of 64,2% was observed at this site classifying it as a category C being moderately transformed from pristine conditions.

Figure 4-36: Aerial view (Google Earth) of site 10

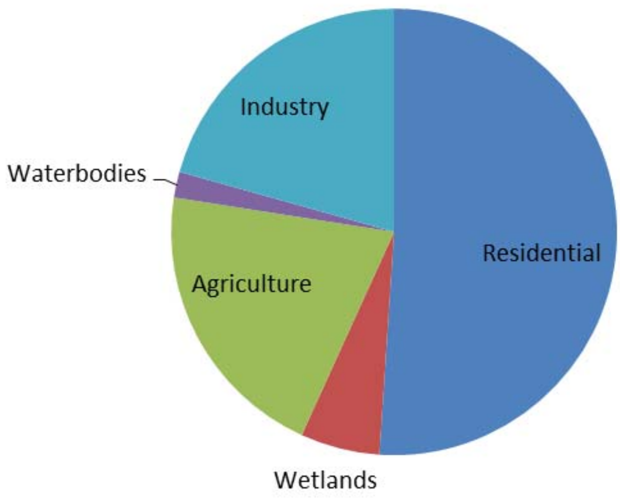


Figure4-37: Land use activities in spatial unit 3

Comparison between water quality data obtained and historical data: Site A2H061Q01 (A DWS monitoring site) and site MS010 (a site selected in this study) were used to compare water quality in this spatial unit over the years by selecting certain indicators i.e. TDS and NO_3. Figures below show that the dissolved solids over the years have been reduced with varying levels between 609-580 mg/l to 455-553 mg/l; and Nitrate concentration have been reduced slightly.

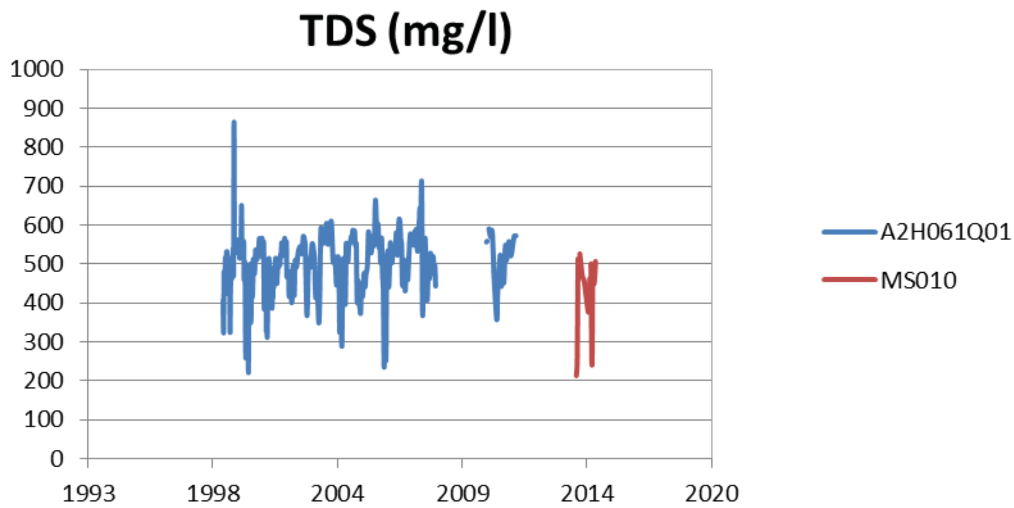


Figure 4-38: Comparison of TDS concentration between historical data (A2H061Q01) and water quality data collected (MS010)

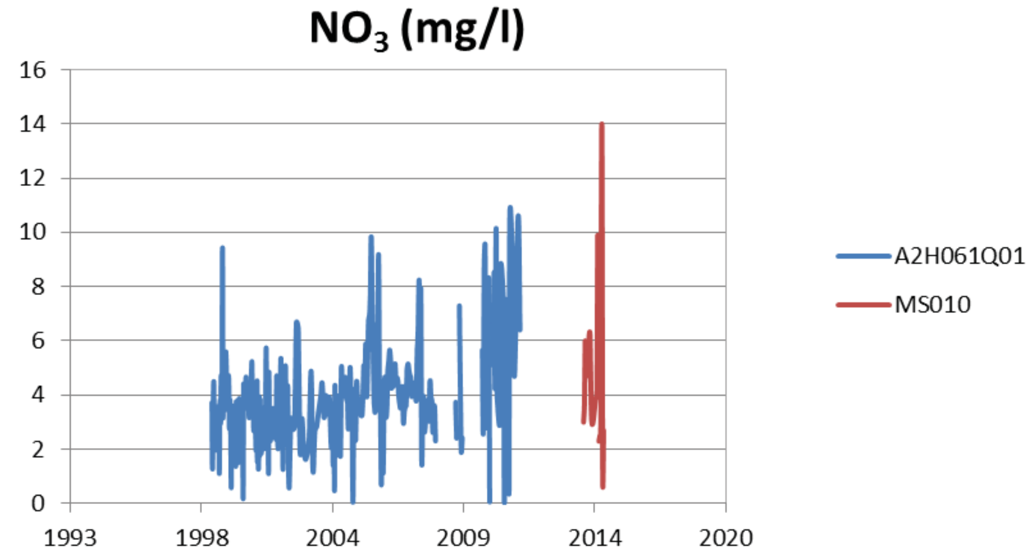


Figure 4-39: Comparison of nitrate concentration between historical data (A2H061Q01) and water quality data collected (MS010)

SPATIAL UNIT 4

In this unit, the research team had 2 sampling sites i.e. site MS011 and MS012. The land use intensity between site 12 and 11 reduce drastically, with site 11 being characteristic of mostly undeveloped landscape. Site 11 is located within the Dinokeng Nature Reserve thus having relatively undisturbed indigenous riparian zones and low evident direct disturbance.

The unit A23B is represented by Site MS009 as it is downstream of the unit. The site is situated in a shallow valley which is characteristic of mostly untransformed landscape with scattered agricultural and commercial as shown on Figure4-41. Riparian zones are thick with vegetation. The channel is a flat u shape with steep banks. The sediment matrix displayed was mostly framework dilated with a low availability of interstitial spaces. A habitat quality score of 83.1% was observed at this site classifying it as a category B being largely natural with few modifications from pristine conditions.

Figure 4-40: Aerial view (Google Earth) of site 9

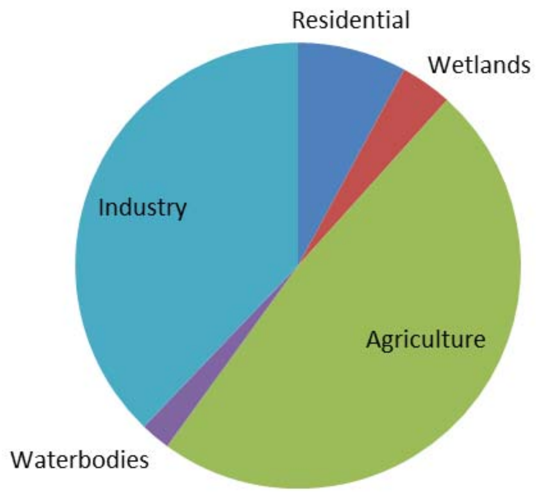


Figure4-41: Land use activities in spatial unit 4

Comparison of the water quality data obtained and historical data: Site A2H006Q01 (A DWS monitoring site) and site MS011 (a site selected in this study) were used to compare water quality in this spatial unit over the years by selecting certain indicators i.e. TDS and NO_3. Figures below show that the dissolved solids over the years have been increased slightly; Nitrate and phosphate concentration have been increased drastically.

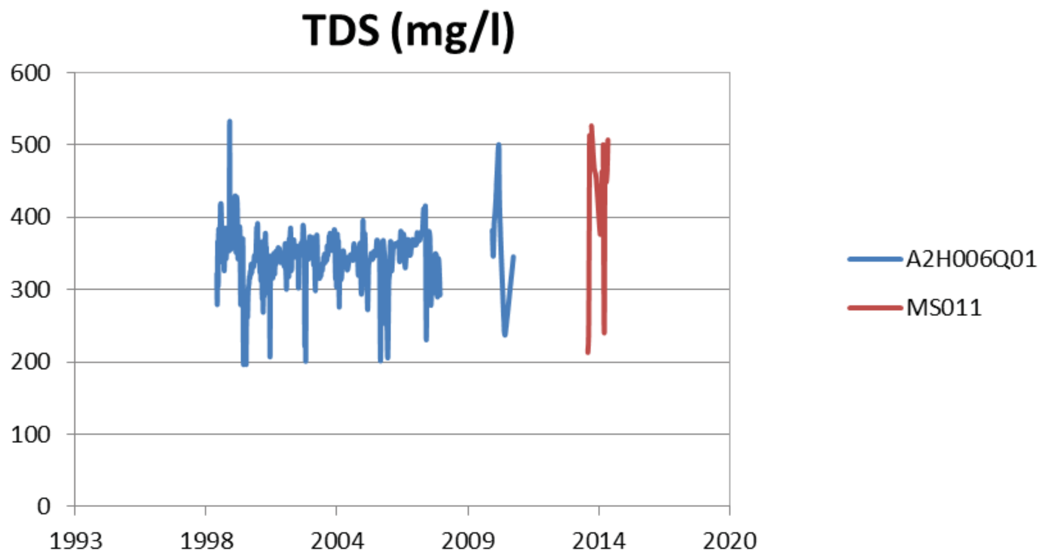


Figure 4-42: comparison of TDS concentration between historical data (A2H006Q01) and water quality data collected (MS011)

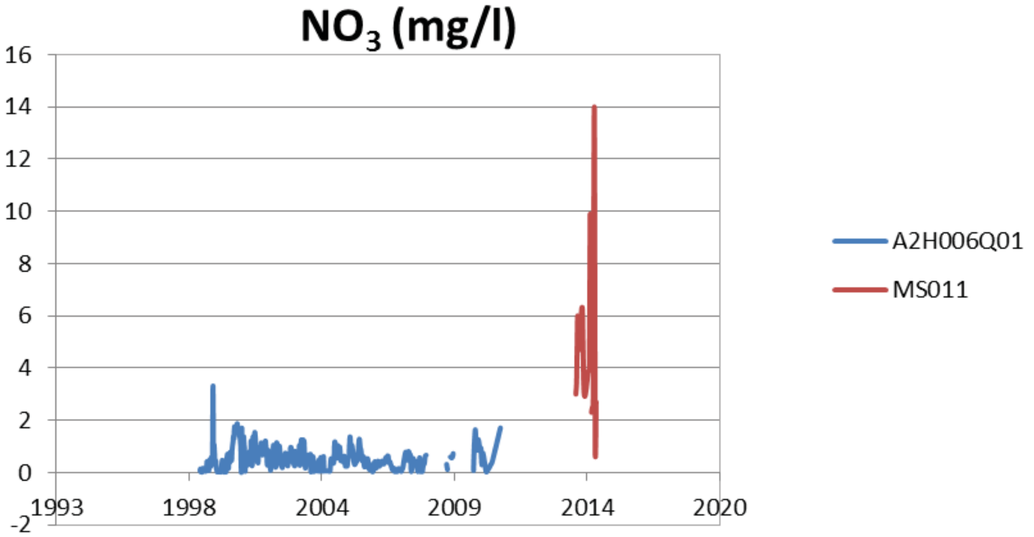


Figure 4-43: Comparison of nitrate concentration between historical data (A2H006Q01) and water quality data collected (MS011)

Irrigated activities occur in an agricultural land between site MS009 (downstream) and MS011 and the figure below shows an increase in phosphate concentration and most probably attributable to runoff from the fertiliser.

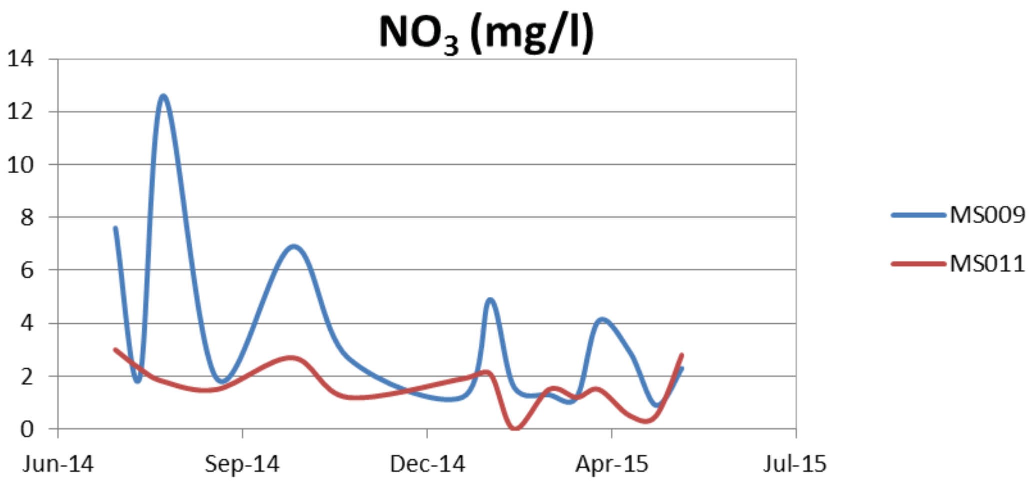


Figure 4-44: Comparison of Nitrate concentration between MS009 and MS011

SPATIAL UNIT 5

In this unit, the research team had 1 sampling sites i.e. site MS009. Unit A23C is represented by site MS007. The site is situated in a broad valley which is characteristic of a large wetland system with extensive livestock grazing by rural communities (Figure 4-45). The channel is a u shape with moderate banks. The sediment matrix displayed was mostly framework dilated with a low availability of interstitial spaces. A habitat quality score of 78,9% was observed at this site classifying it as a category C being moderately transformed from pristine conditions.

Figure 4-45: Aerial view (Google Earth) of site 7

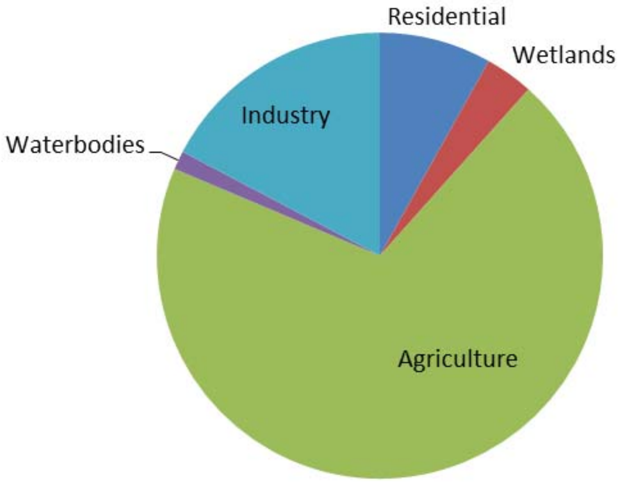


Figure4-46: land use activities in spatial unit 5

Comparison of the water quality data obtained and historical data: Site A2H106Q01 (A DWS monitoring site) and site MS007 (a site selected in this study) were used to compare water quality in this spatial unit over the years by selecting certain indicators i.e. TDS and NO_3. Figures below show that the dissolved solids over the years has remained the same; Nitrate concentration has increased drastically.

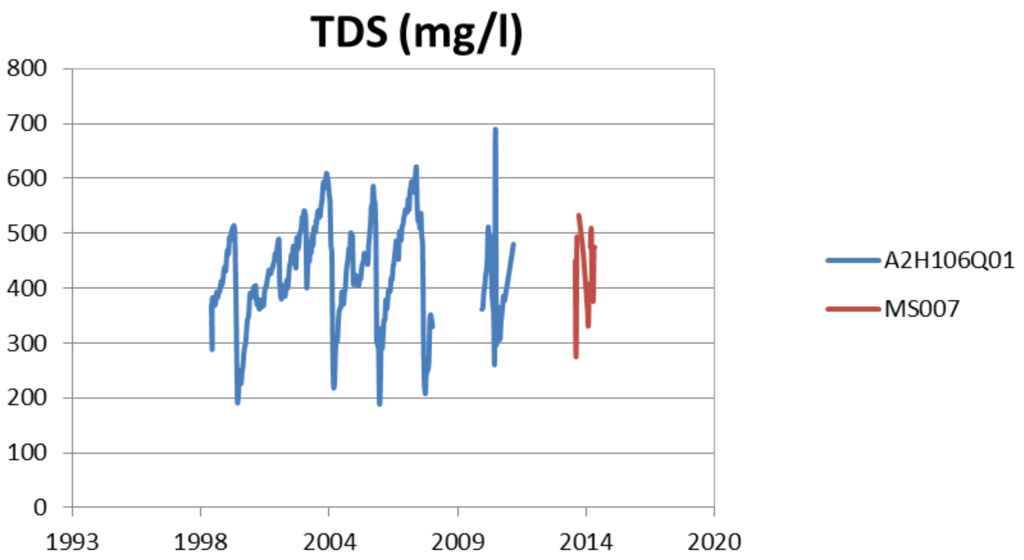


Figure 4-47: Comparison of TDS concentration between historical data (A2H106Q01) and water quality data collected (MS007)

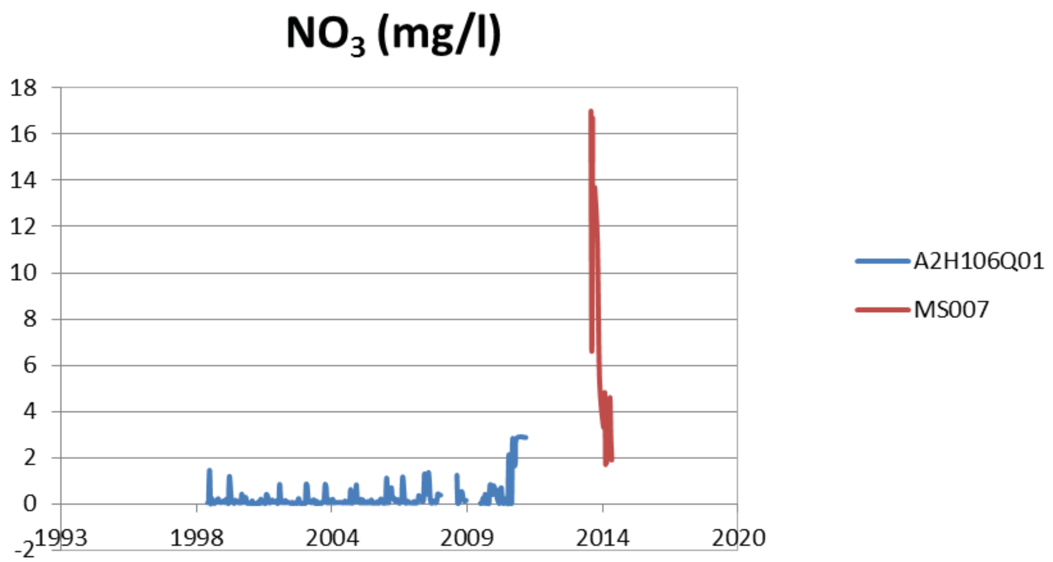


Figure 4-48: Comparison of nitrate concentration between historical data (A2H106Q01) and water quality data collected (MS007)

Coliforms are unacceptably high throughout the catchment. The was evidence of livestock grazing between site MS005 and MS007.The figure below suggests that livestock grazing may contribute to the degradation of the water quality in the river system.

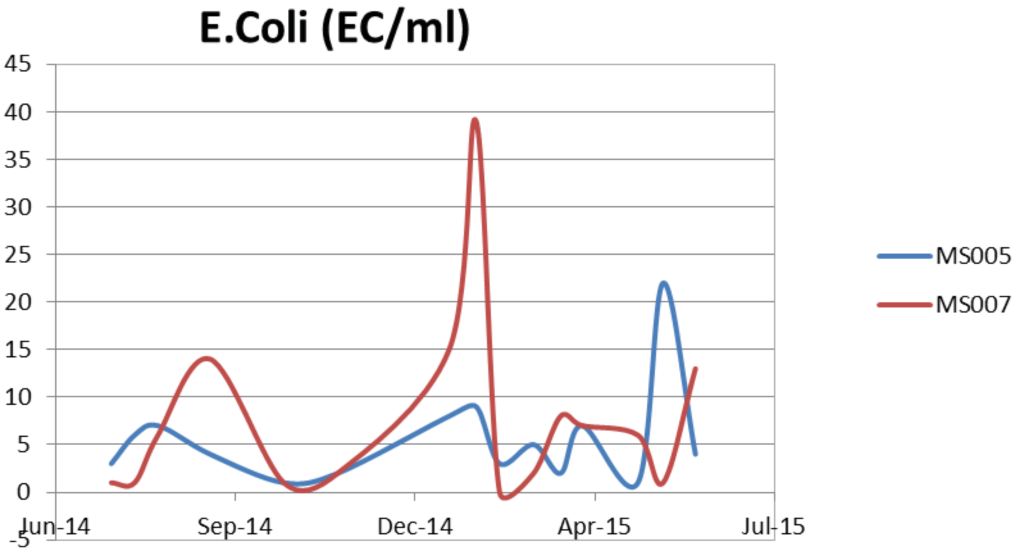


Figure 4-49: Comparison of coliforms (EC/ml) between MS005 and MS007

SPATIAL UNIT 6

In this unit, the project team had 2 sampling sites i.e. site MS008 andMS010. Site MS008 and MS010 downstream showed increases in states compared to upstream systems (Both reflecting 78,3%). The systems are situated within the relatively intense peri-urban landscape of Makapanstad and urban landscapes of Hammanskraal respectively. The result at site 10 is likely due to the increase in riparian zone intactness compared to previous sites, resulting in an overall increase in state. Site 8 however, was in relatively good condition considering the land use type. The likely explanation being localised access from livestock due to steep banks thus reducing the geographic range of impacts.

The unit A23F is represented by site MS008. The site is situated in a shallow valley which is characteristic of mixed rural land use activities such as small holdings and livestock grazing (Figure 4-50). Large portions of the landscape are untransformed with scattered tufts of vegetation however have clearly been degraded due to activities occurring in the area. The channel is a u shape with moderately steep banks. The sediment matrix displayed was mostly framework dilated with a low availability of interstitial spaces. A habitat quality score of 78,3% was observed at this site classifying it as a category C being moderately transformed from pristine conditions.

Figure 4-50: Aerial view (Google Earth) of site 8

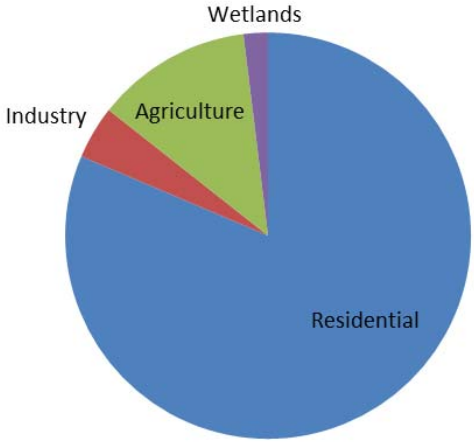


Figure 4-51: Land use activities in spatial unit 6

There is a WWTW between site MS008 (downstream of the discharge point) and MS010.The figure below suggests that this point source pollution may contribute to the degradation of the water quality in the river system.

SPATIAL UNIT 7

In this unit, the research team had 3 sampling sites i.e. site MS004, MS005 and MS007. Site 7 through 5 (Moretele) and 4 (Kutswane), the land use characteristic of the catchment is predominantly peri-urban, agricultural and extensive livestock grazing. Ecosystem habitat states observed in this area ranged from 71,7% at site 5 to 76,1% at site 6. Observed land use impacts in the areas were mostly livestock related impacts, such as extensive overgrazing, loss of bank integrity and introduction of nutrients from excretion. The absence of fences or restrictions to movement of livestock across the landscape, does not allow for effective management. As a result, the terrestrial landscapes around the river systems and especially the riparian zones are highly degraded.

The unit A23J is represented by Site MS004. The site is situated in a broad valley which is characteristic of mixed rural land use activities such as small holdings and livestock grazing. Large portions of the landscape are untransformed however have clearly been degraded due to activities occurring in the area. The channel is a u shape with moderate banks. The sediment matrix displayed was mostly matrix filled contact framework with a moderate availability of interstitial spaces. A habitat quality score of 73,8% was observed at this site classifying it as a category C being moderately transformed from pristine conditions.

Figure 4-52: Aerial view (Google Earth) of site 4

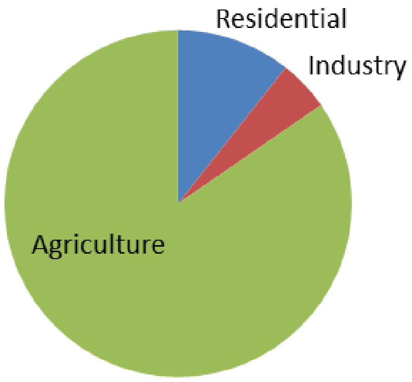


Figure4-53: Land use activities in spatial unit 7

SPATIAL UNIT 8

In this unit, the research team had 1 sampling sites i.e. site MS003. Site 3 which is the accumulation of the entire study area is characteristic of natural landscape and large scale agriculture. The observation was a relatively high state owing to a fully intact and untransformed riparian zone. This could also indicate the presence of regulatory services existing upstream along the catchment with an extensive wetland system occurring along the Moretele River.

The unit A23L is represented by Site MS003. Site MS003 is situated in a shallow valley which is characteristic of mixed agricultural but mostly undeveloped land ensuring riparian conditions remained intact (Figure 4-54). The channel is a wide box shape with steep banks. The sediment matrix displayed was mostly open framework with a high availability of interstitial spaces. A habitat quality score of 78,3% was observed at this site classifying it as a category C being moderately transformed from pristine conditions.

Figure 4-54: Aerial view (Google Earth) of site 3

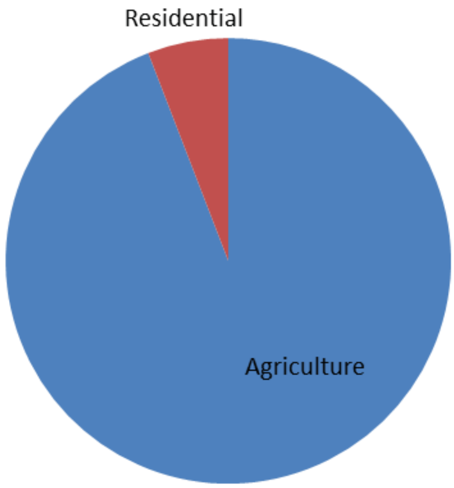


Figure 4-55: Land use activities in spatial unit 8

Comparison of the water quality data obtained and historical data: Site A2H021Q01 (A DWS monitoring site) and site MS003 (a site selected in this study) were used to compare water quality in this spatial unit over the years by selecting certain indicators i.e. TDS, PO_4 and NO_3. Figures below show that the dissolved solids over the years has been reduced; Nitrate and phosphate concentration have been increased.

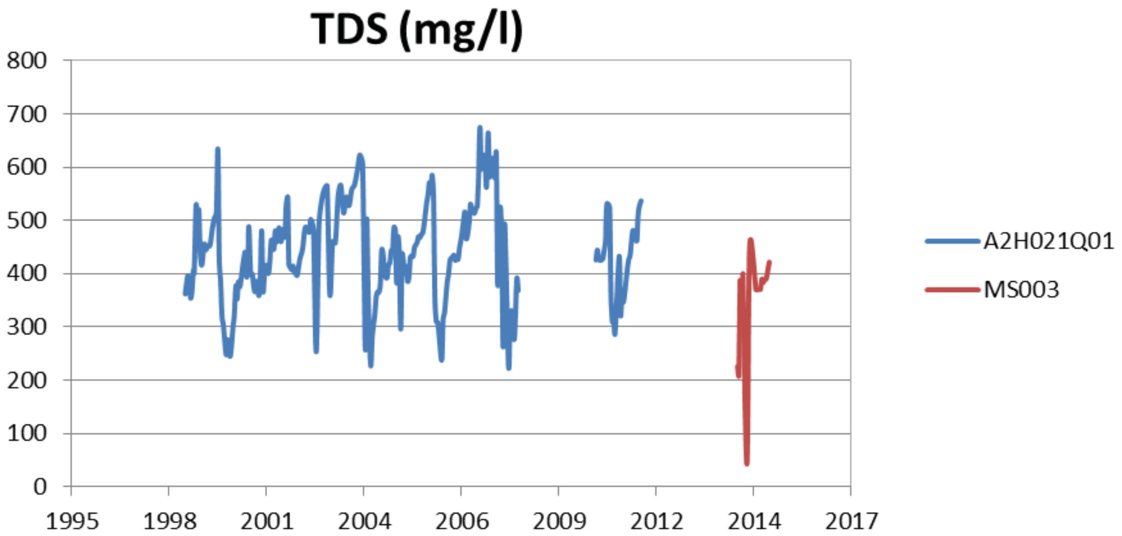


Figure 4-56: Comparison of TDS concentration between historical data (A2H021Q01) and water quality data collected (MS003)

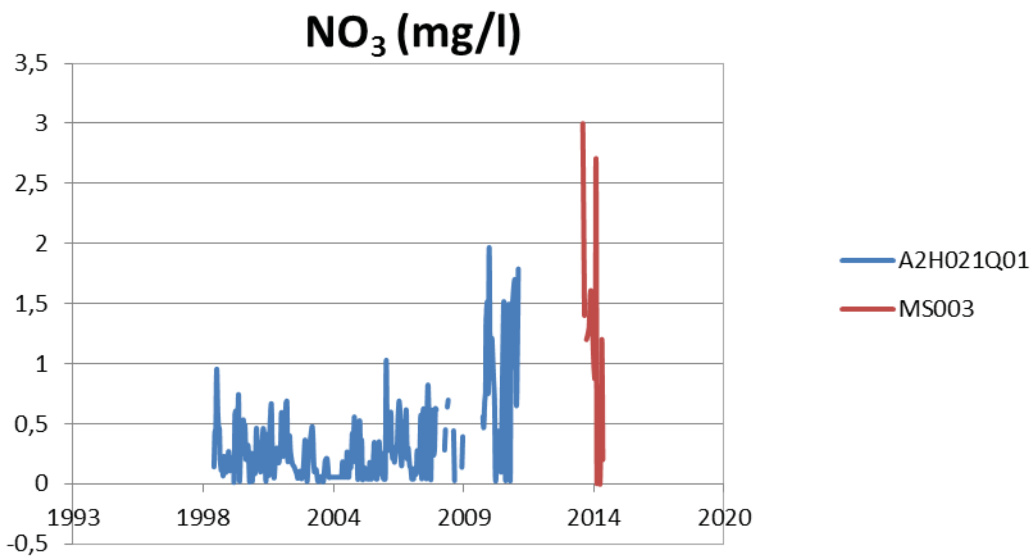


Figure 4-57: Comparison of nitrate concentration between historical data (A2H021Q01) and water quality data collected (MS003)

Irrigated activities occur in an agricultural land between site MS003 and MS004 and the figure below shows an increase in phosphate concentration and most probably attributable to runoff from the fertiliser.

4.5.1.5 LOAD MODEL RESULTS

The load is a function of concentration and flow rate. Table 4-11 describes change in load for all the sites. The results were then compared with expected results.

Table 4-11: Change in load on parameters for each sampling sites

Sites	Area	Parameters					
		DO	TDS	Phosphates	Nitrates	COD	Coliforms
MS002	Onderstepoort	Pos	Neg	Neg	Neg	Neg	Neg
MS010	Hammanskraal	Neg	Neg	Pos	Pos	Neg	Pos
MS008	Makapanstad	Pos	No change	Pos	Pos	Pos	Pos
MS013	Roodeplaat	Neg	Pos	Pos	Pos	Pos	Pos
MS012	Roodeplaat	Pos	Pos	Neg	Pos	Pos	Pos
MS011	Dinokeng game reserve	Pos	Neg	Pos	Neg	Neg	Neg
MS009	Pienaarsrivier	Pos	Neg	Neg	Neg	Pos	Pos
MS007	Haakdoornbult	Neg	Neg	Neg	Neg	Eg	Pos
MS005	Moretele	Pos	Pos	Pos	Pos	Pos	Pos
MS003	Borakalo	Neg	Pos	Pos	Pos	Pos	Pos

MS002: The presence of Bon Accord dam has a positive change in DO load. Discharge from WWTW can be the reason for the high nutrients and coliforms are present.

MS010: Hammanskraal area is a densely populated urban and that results in high coliforms load. Presence of irrigated agriculture and WWTW resulted in high nutrients.

MS005: The positive change in phosphate can be the results of wetland present.

MS003: This area has a game reserve which resulted in high coliforms because of faeces from animals. Irrigated agriculture resulted in high nutrients load.

MS013: Coliforms load in this area was reduced because the area is less populated as compared to MS015.

MS012: The presence of Roodeplaat dam assisted in reducing coliforms and nutrients load. This area is influenced by MS13 and MS14. The latter has high nutrients and coliforms load which can be the result of discharge from WWTW hence the load of coliforms and nutrients are more.

MS011: This point is inside Dinokeng game reserve. The coliforms load was high because of animal faeces. Phosphate load is reduced which can be resulted in presence of wetlands.

MS009. Agricultural activities in this area contributed in high nutrients load.

4.5.2 CULTURAL SERVICES

4.5.2.1 RECREATIONAL VALUE

The travel cost method is one approach assessing recreational ecosystem services. The basic premise for this method is that the time and travel cost expenses that people incur to visit a site represent the “price” of access to the site. Thus, the method estimate the willingness to pay of consumers based on the number of travel trips that they make based on the quantity demanded at different prices.

The first production function relates the number of trips people went fishing with a variety of environmental and economic indicators and takes the following form:

$$trips_{fishing} = f(number\ caught; average\ size; expenses; household\ income)$$

Analysing the production function for the number of trips people made to go fishing, the following relationships become apparent:

- A positive, and statistically significant, relationship between number of fishing trips and the number of fish caught. The interpretation of this is simply that the more fish people catch the more often they go fishing. Since number of trips in our model is an indicator of recreation we can deduce that the number of fish caught has a positive relationship with the recreational value of the river.

- A positive, but not statistically significant, relationship between the average size of fish caught and the number of fishing trips.
- A negative, and statistically significant, relationship between number of fishing trips and the average expenses / costs incurred by the tourist. The interpretation is that the higher the costs of a trip the less likely the tourists will be to go on the trip.
- A negative, but not statistically significant, relationship between number of fishing trips and the household income of the tourists.

The second production function we have relates the number of trips people went bird watching with a bunch of environmental and economic indicators and takes the following form:

$$trips_{birding} = f(expenses; safety/security;\ abundance; household\ income)$$

Analysing the production function for the number of trips made to go bird watching, the following relationships become apparent:

- A negative, and statistically significant, relationship between the number of bird watching trips and the average expenses / costs incurred by the tourist. The interpretation is that the higher the costs of a trip the less likely the tourists will be to go on the trip.
- A negative, but not statistically significant, relationship between number of bird watching trips and the safety / security in area.
- A negative, and statistically significant, relationship between the number of bird watching trips and the abundance of birds. This is likely a function of heterogeneous distribution being associated with low population density.
- A positive, and statistically significant, relationship between number of bird watching trips and the household income of tourists. The interpretation might be that bird watching is an expensive hobby that is more easily afforded by wealthier households.

4.5.2.2 AESTHETIC VALUE

The value of the river system in terms of the aesthetic services that it provides was captured by estimating the impacts it has on property values. Data for a hedonic pricing analysis was collected from real estate agents operating within communities located within the study area. The findings presented below were collected from 7 real estate agents and represent 2 areas, Hammanskraal and the Northern Pretoria Suburbs.

The real estate agents in question were asked to value a range of hypothetical properties, based on several characteristics possessed by the household. Regression analysis was conducted on the data, the outputs of that analysis are discussed below.

The first production function relates the value per m^2 to the distance the property is from the river as well as the type of property it is registered as:

$$value\ per\ m^2\ = f(distance\ from\ the\ river; dummy\ variables\ for\ the\ type\ of\ property)$$

From the analysis, we see the following relationships:

- A negative, and statistically significant, relationship between the value of the property and the distance between the river and the distance from the river.

The second production function relates the value per m^2 to various characteristics of the property:

$$value\ per\ m^2 = f(property\ size; reception; structure\ condition; view\ of\ river; adjacent\ to\ river)$$

Analysing the relationships we see the following:

- A positive, and statistically significant, relationship between the value of the property and the size of the property. The interpretation is that the value per m^2 of the structure will be higher if the size of the property is higher.

- A positive, and statistically significant, relationship between the value of the property and the dummy variable for a property having a reception area. The interpretation is that the value per m^2 will be higher if the property has a reception area.

- A positive, and statistically significant, relationship between the value of the property and the condition of the property. The interpretation is that properties in better condition have a higher value than properties in a bad condition.

- A positive, and statistically significant, relationship between the value of property and the dummy variable for a property having a view of the river. The interpretation is that properties having a view of the river have a higher value.

A negative, and statistically insignificant, relationship between the value of the property and the dummy variable for a property that is adjacent to the river

4.5.3 PROVISIONING SERVICES

4.5.3.1 AGRICULTURE

The ability for the ecosystem to provide water is due to the geomorphological characteristics within a catchment. It provides for a localized space where water accumulates and flows. The geomorphology further provides a platform whereby water quality and quantity may be maintained. The nature of the catchment ensures the collection of rainwater, which is typically naturally purified, into the system as well as groundwater which further supplies the system with water.

The accumulation of water allows for access to water as a resource. Accumulated water further acts as the material which further supports aquatic ecosystems and is a crucial component in supporting the overall biological riverine ecosystem. By providing for a system which ensures water quality and quantity is maintained it provides for a resource which can be utilized by various activities and processes.

Beneficiaries of water provisioning services include domestic, agricultural and industrial land uses which use the water directly. These uses include domestic use, crop and livestock irrigation and watering and various industrial processes needing water. Other beneficiaries include those benefiting from the broad range of ecosystem services provided.

The agricultural production function takes the following form

$$agriculture = f(flow; water\ quality; waterbodies; wetlands; habitat\ assessment)$$

From our analysis, we found the following relationships:

- There exists a positive relationship between the flow of the river and agricultural activities. Statistically this relationship isn't significant.
- Concentration of phosphates (which was our indicator used to illustrate water quality) and agricultural activity are positively related. The relationship wasn't statistically significant.
- Waterbodies, within 500m of the river has a positive relationship with agricultural activity within 500m of the river. This relationship is statistically significant and therefore the interpretation would be that as there are more waterbodies in the area the more agriculture takes place. This could potentially be explained by the fact that waterbodies are less susceptible to changes of the seasons and could provide a more constant availability of the desired quantity of water.
- Wetlands within the area has a negative relationship with agriculture. This relationship is statistically significant and the interpretation could be that wetlands have been drained to be converted into agricultural land and therefore the negative relationship.
- There is a positive relationship between the habitat assessment indicator and agricultural activity. This relationship is statistically significant and the interpretation would be that a healthier environment, derived from the habitat assessment, could lead to better yields from agriculture and therefore the healthier the environment the more agriculture is taking place.

4.5.3.2 FIBRE, FUEL AND FODDER

The timber, fuel and fibre category within the MEA Framework covers a wide range of ecosystem services provided by an equally wide range of ecosystems. For the purposes of this study the consideration given to the "Fibre, Fuel and Fodder" relates to the consumption of these ecosystem services by households existing in a certain proximity to the river system.

RAW MATERIALS (FIBRE)

The household survey investigated the collection of raw materials from the riparian area of the Apie-Pienaars river system for use in construction projects or for craft (i.e. baskets, hats, kraals, rudimentary buildings, etc.)

Data collected in the household survey showed that 67% of households responded stated that they were aware of people in the area who were involved in the process of collecting raw materials for the riparian area of the Apies-Pienaars river system. When respondents were asked to state whether this was a common practice among household in the area, the results were almost evenly split between those who stated that this practice was common (35%), those who stated that the practice was only undertaken by a few households (32%), and those who stated that they were not certain of how common the practice was (33%). Of the 100 households surveyed, 21% responded that they were (on an ongoing basis) involved in the collection of raw materials from the riverbanks.

Accounting for the sampling plan utilized by the household survey, there is evidence to indicate that there is a relationship between the proximity of a community to the specified riverine ecosystem and the consumption of the ecosystem services generated by that system. The collection of raw materials from the river bank is a common practice which is more prevalent in communities located relatively close to the river.

DOMESTIC ENERGY (FUEL)

Many households within the study area utilise riparian vegetation from the Apies-Pienaars river system as a source of fuel. The data collected in the household survey indicates that this practice is very common.

When asked whether they were aware of the collection of wood and bushed (from the riverbanks) for use as fuel in households, 82% of households responded that they were aware of the practice. Only 7% of households responded that were not aware of the practice and only 11% of households responded that they were not certain about the question.

The summary stats indicate that 43% of households perceive that practice as being undertaken by only a few households in their community whilst 39% of respondent indicated that the practice was very common in their community. Eighteen percent of households responded that they were not certain about the prevalence of the practice.

These stats are very similar to the number of households that are actively engaged in this process. OF the 100 households surveyed 36% indicated that they were involved in the on-going practice of collecting fuel sources from the riparian area of the Apies-Pienaars riparian areas. Fourteen percent of these households also stated that they collect and used cow-dung as a source of fuel.

LIVESTOCK GRAZING (FODDER)

The practice of keeping livestock is very common among rural households who can afford it. Eighty-seven percent of households surveyed indicated that they were aware of the practice taking place within their communities. Riparian habitats are often popular grazing areas as they usually have a greater year-round concentration of vegetation (due to the proximity to a supply of water) and they can doubly serve as a watering point for the cattle that are grazing.

Seventy-five percent of households surveyed indicated that livestock grazing takes place on the banks for the Apies-Pienaars river system. Open ended responses collected in the survey confirmed that the common practice is to take livestock to the river to be watered and that they would be allowed to graze on the riparian vegetation whilst down at the river.

The most prevalent form of livestock that is kept by households is cattle, but households reported that donkeys, goats, and sheep were also highly prevalent. Fourteen percent of the households surveyed reported that they have livestock in the area and they were involved in the practice of watering their livestock by the nearby river.

Production function

The domestic energy production function takes the following form:

$$domestic\ energy = f(recreation; dirty\ river)$$

Analysis of the relationship shows that there are:

- A positive, and statistical significant, relationship between the proportion of people collecting materials for domestic energy from the riparian area and the proportion of people using the river for recreational activities. The interpretation could be that people going to the river for recreation use their time down there to also collect domestic energy materials.

- A negative, but statistically insignificant, relationship between the proportion of people collecting domestic energy sources from the riparian area and how dirty the river looks.

4.5.4 INTEGRATED BIO ECONOMIC MODEL RESULTS

An Integrated Bio-Economic Model was developed to quantify the ecosystem services in relation to river health using production functions. The production functions allowed the marginal impact of inputs to be translated into impacts on output. Figure 4-58 illustrates the dashboard view of the Bio-Economic model.

The best approach to represent how various changes in inputs affect the various ecosystem services is to change the inputs, one at a time, by 1% and see which intermediary ecosystem services are affected as well as the magnitude of the impact on intermediary and final ecosystem services.

Listed below are some examples of the results that could be obtained from the model:

Example 1: A 1% increase in the area of waterbodies upstream and within 500m of the river

Intermediary impact: The flow of the river will decrease by 0.137%.

Final impact: Agricultural land upstream and within 500m of the river will increase by 0.165%. This increase is a result from the combined impact of an increase in waterbodies as well as a decrease in water flow.

Example 2: A 1% increase in the area of wetlands within the catchment upstream of the river

Intermediary impact: The flow of the river will increase by 0.039% whilst the level of phosphates in the water will decrease by 0.047%.

Final impact: Agricultural land upstream and within 500m of the river will decrease by 0.027%. This decrease is a result from the combined impact of an increase in wetlands, an increase in the river flow as well as the decrease in phosphates levels.

Example 3: A 1% increase in the urban areas upstream and within 500m of the river

Intermediary impact: The flow of the river will decrease by 0.124% whilst the level of phosphates in the water will decrease by 0.016%.

Final impact: Agricultural land upstream and within 500m of the river will decrease by 0.001%. This decrease is a result from the combined impact of an increase in urban areas, a decrease in the river flow as well as the decrease in phosphates levels.

Example 4: A 1% increase in the proportion of households that use the river for recreational activities

Intermediary impact: There will be no intermediary impact.

Final impact: The proportion of households that collect fibre, fuel and fodder from the riparian area will increase by 0.205%. Since there are no intermediary impact this increase is purely due to the increase in recreational activities.

Example 5: A 1% increase in the distance between the river and properties close to the river

Intermediary impact: There will be no intermediary impact.

Final impact: The value of these properties will decrease by 0.142%. Since there is no intermediary impact this increase is purely attributed to the increase in the distance between the river and the property.

Example 6: A 1% increase in the average cost of a fishing / bird watching trip

Intermediary impact: There will be no intermediary impact.

Final impact: The average number of trips to go fishing will decrease by 0.197% whilst the average number of bird watching trips will decrease by 0.387%. Since there is no intermediary impact these decreases are purely due to the increases of the average costs of these trips.

IMPACT ASSESSMENT

ToC

INPUTS	Units	% Δ	Nominal Δ
ΔDIRTY_R	*rating*	0%	-
ΔLNCATCHNU	*# fish caught*	0%	-
ΔLNAVESIZE	*kg*	0%	-
ΔWATER500	*ha*	0%	-
ΔWETLANDS	*ha*	0%	-
ΔHAB_ASS	*%*	0%	-
ΔWWTW	*# of plants*	0%	-
ΔURBAN500	*ha*	0%	-
ΔREC_HH_D	*proportion*	0%	-
ΔDIST	*m*	0%	-
ΔLNPEXP	*R per trip*	0%	-
ΔLNHHINC	*R per month*	0%	-
ΔLNSS	*rating*	0%	-
ΔLNABUN	*rating*	0%	-
Water Provisioning (ΔFLOW)	*m3/sec*	0.000%	
Water Quality (ΔPO4)	*mg/l*	0.000%	

IMPACT ON FINAL ECOSYSTEM SERVICES	Units	% Δ	Nominal Δ
Agriculture (ΔAGRIC500)	*ha*	0.000%	-
Fibre, Fuel and Fodder (ΔDOM_HH_D)	*proportion*	0.000%	-
Aesthetic (ΔVALUEM2)	*R per m2*	0.000%	-
Recreation (ΔLNTRIPS_f)	*Number of trips*	0.000%	
Recreation (ΔLNTRIPS_b)	*Number of trips*	0.000%	

Natural indicators
Human indicators
Ecosystem service production functions

Inputs
Endogenous
Outputs

Figure 4-58: Dashboard view of the Bio-economic model developed through evidence based approach to valuation of ecosystem services

4.6 Conclusion

The Integrated Bio-Economic Model was developed to quantify the relationship between the ecosystem services generated by the Apies-Pienaars river system and health of the riverine ecosystem. The model follows a production function approach to quantify values for ecosystem services that contribute at least part of the shadow value of those resources.

It applies knowledge of ecosystem functioning and processes to derive the value of supporting and regulating ecosystem services. The value of ecosystems and the services they provide as intermediate inputs into goods and services that are produced or consumed are derived. The production function approach allows the model to determine the marginal impact that certain changes in the environment will have on ecosystem services.

Overall the model provides evidence of the direct link between healthy river systems and improved ecosystem service delivery in economic terms. Some of the key findings included:

Increasing intensity of land transformation has negative impacts on the state of the Apies-Pienaars riverine ecosystem habitats.

Urban land use types displayed the highest impacts on ecosystem habitats primarily due to transformation extending into riparian zones and the increased prevalence of hardened surfaces which allow for greater levels of surface runoff and consequently greater introduction of contaminants into the system. Peri-urban and livestock agricultural land-use types were similarly distributed within the catchment. Livestock rearing was highly prevalent within peri-urban settlements. These areas, in terms of their impact on the riverine ecosystem habitats, were less than those observed in urban areas, but remain significant nonetheless. This is due to direct 1damage cause by livestock watering and overgrazing causing damage to river bank stability and inputs of nutrients and coliforms.

The least impacted riverine ecosystem habitats were those found in area that had been subjected to comparatively lower levels of transformation. The presence of intact riparian zones tended to improve the state of the riverine ecosystem.

Residential communities located within a reasonable proximity to the Apies-Pienaars river system actively engage in the consumption of provisioning ecosystem services generated by the riverine ecosystem.

The household survey conducted within the study area showed strong evidence of the active and ongoing consumption of provision and cultural ecosystem services generated by the riverine system.

Livestock rearing was highly prevalent within peri-urban communities located adjacent to the Apies-Pienaars river system. There was significant evidence to indicate that the communities actively use this riverine system to water their animals and graze them in the riparian zone of the river.

The riparian zone is also utilized as a source of raw material utilized in a range of construction and craft activities. The riparian zone is also a source of fuel wood/bush that is collected by households near to the river. The river is not commonly used as a source of water except in urban areas where informal settlements are located along certain stretches of the river. In many cases the informal settlements have been established along the banks of the river precisely to make use of the water that is available. These communities make use of the water for drinking, washing and ablutions.

Residential communities located within a reasonable proximity to the Apies-Pienaars river system actively engage in the consumption of cultural ecosystem services generated by the riverine ecosystem.

The household survey conducted within the study area showed strong evidence of the active and ongoing consumption of provision and cultural ecosystem services generated by the riverine system.

Fishing is a common recreational activity undertaken at various points along the river. The fish that are caught are consumed by those who catch them as well as sold to other households or passers-by. The data collected by the household survey also showed that use of the river for spiritual and cultural practices was commonplace along various points in the river.

The value of properties is impacted by aesthetic qualities of the Apies-Pienaars riverine ecosystem.

Data collected from real estate agents in the study area produced statistically significant evidence for the connection between the aesthetic qualities of the river and the value of properties. To be specific, it was proven that having a view of the river from a house has a positive impact on the value of that property, whilst being located adjacent to the river had a negative impact on the value of the property.

The model is very dependent on the quality, completeness and coverage of the data sources used in this exercise. While the results are indicative, they can be improved through smarter, more efficient, and integrated data collection:

- **Smart Indicators:** The model showed that just a few indicators can be used to evaluate the health of the river system and the ecosystem services that it provides. Having a basket of fewer indicators allows resources to be used more efficiently, and the savings can be invested in ensuring better coverage spatially and temporally.
- **Complete coverage:** Due to the expansive area investigated in this project, technologies such as the use of Geographical Information Systems, is essential to ensure full coverage. Even in situations where remote sensing might not provide the precision associated with traditional ground work, the objective and complete coverage of the system still makes remote sensing highly useful.
- **Resource sharing:** Due to the diverse nature of the indicators evaluated in the Integrated Bio-Economic Model, data is sourced from a wide variety of organisations. Greater integration is required between organisations collecting information on the system to ensure that the indicators measured can be related to each other.
- **Citizen science:** This project demonstrated many of the difficulties involved in sourcing data, particularly in terms of coverage and frequency. The involvement of

citizens in the data collection process can be used to remedy both these issues at a low cost.

The results of our investigations lend support to the position that land use activities impact the quality of the water in the Apies-Pienaars river system. The conclusions brought about in this study are as a result of the data that was available. Of the data, available only the water quality measurements taken at specific points were under the direct control of the research team. Other sources of data, which include flow rates, historic water quality trends (site specific) and other land use indicators were provided with the support of various institutions, but could not be tailored for the purposes of this study.

5 CASE STUDY 2: MINING AND INDUSTRIAL IMPACTED SYSTEM

5.1 INTRODUCTION

Coal is the major primary energy source for South Africa. More than 90% of the country's electricity, approximately 30% of the liquid fuel, and approximately 70% of its total energy needs are produced from coal (SANEDI 2011). Historically, the coal industry has not had a good reputation when it comes to environmental performance. Environmental impacts resulting from the coal industry range from water, air, biodiversity, and land use transformation. However, increasingly the industry is responding to these issues and challenges through careful planning, implementation of effective pollution control strategies, and increased monitoring and management of impacted areas (SANEDI 2011). According to Akcil and Koldas (2006) AMD is produced when sulphate bearing material is exposed to oxygen and water. Metal contamination associated with AMD depends on the type and amount of sulphate mineral oxidized and can be highly variable from site-to-site. Of particular concern to the coal sector, is the impact on wetlands. Wetlands, by virtue of their positions in the landscape and relationship to drainage networks, are frequently impacted by coal mining activities, especially opencast methods. As coal-mining activities are likely to continue in the future to support South Africa's developmental needs, impacts on wetland resources are likely to continue.

With focus on the regulating services a preliminary identification of ecosystem services delivered by the Zaalklap wetland is presented in **Error! Reference source not found.**. For each service type, there are various data requirements proposed to acquire the necessary data to perform a valuation of the benefits provided by each.

Table 5-1 General Ecosystem Services Provided by the Zaalklap Wetlands and Data Required for Valuation

Ecosystem Service Category		Ecosystem Service	Data requirements
Regulating Services		Erosion control, flood protection, habitat provisioning	WfW Database Mining
		Water regulation and supply	Comprises roughly 17% of the total area of the B20G quaternary catchment and would provide a significant component of the total flow
		Water purification	Experimentation and costs estimates
Provisioning and cultural ecosystem services		Various	DWS WRCS inference

5.2 Systems Description

5.2.1 Background

The Coaltech Research Organisation worked with SANBI and the CSIR from 2012 – 2014 to study the effects of mining and industrial pollution on the Zaalklap River and wetland system in Mpumalanga. The work also entailed the rehabilitation of a wetland to study the effect of wetlands as ecological infrastructure on water quality. Key data and insights from this study was kindly made available to this project as a case study and allowed for key E-BASES methods to be applied (Coaltech, 2014).

5.2.2 Location

The Zaalklap Wetland is situated 15 km east of Emalahleni in the Mpumalanga Province. The wetland is in the Olifants Water Management Area (WMA) located within the B20G Quaternary Catchment. The wetland is a moderate sized (135 ha) naturally unchannelled valley bottom wetland system located along the Grootspruit River (Figure 5-3).

Figure 5-1: Location of the Zaalklap Wetland as well as the location of the Highveld Steel Facility and the Anker Coal Elandsfontein Colliery

5.2.3 Impacts from Surrounding Land Uses

The Zaalklap Wetland is heavily impacted by a variety of sources and as a result many of the ecosystem services delivered by the wetland such as water purification and water provisioning have been compromised. The major sources of impact include:

- Pollution from the adjacent ash dumps of Highveld Steel;

- Pollution from the Adjacent Anker Coal Elandsfontein Colliery;
- Pollution from other upstream mining operations;
- Agricultural runoff form farming activities;
- Overgrazing from commercial cattle and dairy operations; and
- Modification and alteration of physical components of wetland i.e. stream and bank modification.

The wetland health assessment suggests that wetland hydrology is most severely impacted followed by wetland vegetation and wetland geomorphology (Figure 5-2). Given these changes, the current state of the wetland can be described as moderately modified as reflected by a **"C" Present Ecological State (PES) Category** (EcoPulse 2013).

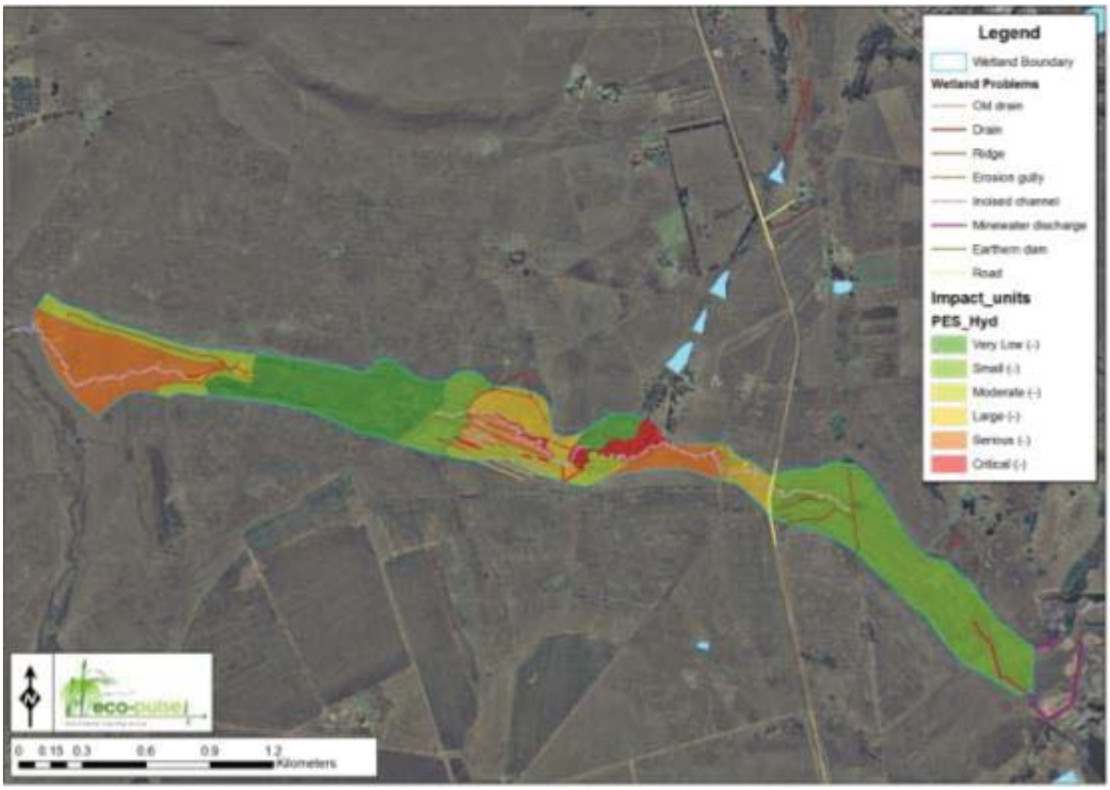


Figure 5-2: A map of Zaalklap wetland showing impacts to water distribution and retention patterns within assessment unit (Source: EcoPulse 2013)

5.2.4 THE IMPACT OF AMD ON THE WETLAND

Understanding the baseline water quality attributes of the Zaalklap Wetland is an important constituent of the resource economic component of the study. Baseline water quality sampling for the wetland measured the following water quality parameters: pH, electrical conductivity and dissolved oxygen, as well as the metals: aluminium (Al), copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn); at various sampling points (Figure 5-3).

Figure 5-3: The five sampling sites at the Zaalklap Wetland (Source: de Klerk et al. 2013)

From the results of the de Klerk study (2013) it is evident that the AMD impact observed at Site 2, significantly impacted the water quality of this wetland system. The tributary (Site 4), which flows into the Grootspruit Wetland, contributes little in terms of the dissolved metal loads and the cumulative effect thereof seen at Site 5 is more a function of the impact seen at Site 2 (de Klerk 2013).

5.3 Zaalklap Wetland Ecosystem Services

The ecosystem services delivered by the Zaalklap Wetland are defined in Table 5-2

Table 5-2: List of ecosystem services delivered by the Zaalklap Wetland

Ecosystem Service Category	Ecosystem Service	Relevance to Zaalklap Wetland
Regulating Services	Coastal protection	Not applicable
	Erosion control	It is possible that the wetland does contribute to maintenance of bank integrity, but this service would be fairly small.
	Flood protection	It is possible that the wetland would contribute to flood control during particularly high rainfall events. However, due to the fact that the wetland is highly channelized it is unlikely that the contribution would be significant. The contribution would likely increase after rehabilitation as the channelizing would be lessened.

	Water regulation and supply	Although the wetland catchment area is relatively small, it comprises roughly 17% of the total area of the B20G quaternary catchment and would provide a significant component of the total flow.
	Water purification	The wetland plays an extremely important role in treating water from the adjacent coalmines.
	Carbon sequestration	Due to the current ecological state and size of the wetland, it is unlikely to contribute significantly to carbon sequestration.
	Maintenance of temperature, precipitation	The size of the wetland would mean that it is unlikely to contribute to either temperature or rainfall maintenance.
Provisioning Services	Raw materials and food	There are no reports of local communities harvesting raw materials or food from this wetland.
	Maintains fishing, hunting and foraging activities	There are no reports of local communities hunting, fishing or foraging from this wetland.
	Grazing opportunities	The wetland is utilised by farmers in the area for grazing during winter months
Cultural Services	Tourism, recreation, education and research	There is no record of tourism activities on this wetland.
	Cultural, spiritual and religious benefits, bequest values	There is no record of spiritual or cultural use of this wetland.

5.3.1 Wetland importance in the Olifants WMA

The DWS recently concluded a large-scale valuation study of the aquatic ecosystem service value of the Olifants WMA. This study was an 18-month peer-reviewed study, conducted as part of the Olifants Water Resources Classification System project. This work is summarised in http://www.dwaf.gov.za/rdm/WRCS/.

The combined provisioning and cultural aquatic ecosystem services produced by water resources were valued at approximately R2,559 million in 2012. This represents more than 2% of the contribution to GDP generated within the catchment. Moreover, more than 55% of the GDP contributing sectors in the Olifants River Catchment are directly dependent on water use licences. The economy and people of the Olifants River Catchment are thus highly dependent upon the water resources of the catchment.

5.3.2 Value of Provisioning and Cultural Aquatic Services

The values for the directly used provisioning and cultural services delivered by wetlands in the Olifants WMA are given below in Table 5-3. It is important to note that the values given are based on the larger ecosystem service value calculated for the Olifants WMA and therefore some of the values may not be applicable i.e. the tourism and recreation values. The total value for the Provisioning and Cultural services were R2,559 million in 2012, which equates to R20,286/ha/annum for wetlands in the Olifants WMA.

Table 5-3Value of the wetland Provisioning and Cultural Services in the Olifants Water Management Area (2012)

Ecosystem Service	Value R'million
Provisioning services	
Harvested products	274
Resource-poor farmers	1,169
Resource rent to agriculture	332
Sub-total	**2,014**
Cultural services	
Aesthetic value	26
Recreation	70
Tourism	449
Sub-total	**545**
Grand-total	**2,559**
R/ha/annum	**20,286**

One way to analyse the value of aquatic ecosystem services in the Olifants WMA would be to estimate the values for the water flow, water purification and other regulating services delivered by wetlands and other aquatic ecological infrastructure in the Olifants WMA. Table 5-4 below attempts to do this, and the total value for the regulating services were R3,643 million in 2012, which equates to R28,880/ha/annum for wetlands in the Olifants WMA.

This does not represent the full value of aquatic ecological infrastructure as it is also known that approximately 55% of GDP in the Olifants WMA depend directly on water use licences of some form, and water use licences in turn depend on well-functioning aquatic ecosystem services. The GDP of economic sectors directly dependent upon Water Use Licenses in the Olifants WUA in 2010 was R72 billion (DWA 2012).

Table 5-4: Value of the wetland Regulating Services in the Olifants Water Management Area (2012)

Ecosystem Service	Value R' million
Regulating services	
Water flow regulation	2,733
Water purification / waste assimilation	876
Flood attenuation	23
Carbon sequestration	11
Grand-total	3,643
R/ha/annum	**28,880**

5.3.3 Ecosystem services and ecological infrastructure

It is clear from the above that it is not sufficient to express the value of wetlands as a single indicator, and that a basket of indicators is required to understand wetland value.

Of particular interest to wetland practitioners in South Africa are the following developments:

- **The National Water Act**: Wetlands form part of ecological infrastructure and deliver wetlands ecosystem services. Any form of wetlands impacts in South Africa is governed by the National Water Act section which, in section 21, defines wetlands as a component of a water course and which regards wetlands impacts as a water use activity, requiring a water use licence: "*21. For the purposes of this Act, water use includes - … (c) impeding or diverting the flow of water in a watercourse; … (i) altering the bed, banks, course or characteristics of a watercourse…*" In our experience, the Department of Water Affairs (DWA) is becoming increasingly strict on the awarding of Section 21 (c) and (i) water use licences.
- In 2010, an Environmental Assessment Practitioner was found guilty of **failing to disclose the presence of a wetland** at the site of the proposed Pan African Parliament in Midrand and received a sentence (North Gauteng Regional Court, Case number 14/1740/2010).
- **Ecological infrastructure**: In South Africa, SANBI published in November 2012, a discussion document on ecological infrastructure. Ecological infrastructure is defined to be the natural capital underlying the supply of ecosystem services to the economy (http://www.grasslands.org.za/document-archive/category/15-dialogue-on-ecological-infrastructure). This is a continuation of work by the Development Bank of Southern Africa (DBSA) (http://www.dbsa.org/Confr/Presentations/Ecological%20Infrastructure%20by%20J%20Manuel.pdf).
- **WET- *Management* Series**: DWA and the Water Research Commission (WRC) have, over the past 5 years, developed wetland assessment methodologies for delineation, classification and importance assessment and ecosystem services identification of wetland systems.
- **Wetlands Mitigation and Offset Guidelines**: SANBI and Working for Wetlands in 2012 published a draft Wetlands Offset Guideline, which categorises all wetlands in South Africa into different wetland infrastructure categories and assign scarcity indicators to them.

Underlying all the above initiatives is the understanding that wetlands are ecological infrastructure, which produces ecosystem services that have real benefits to people. In some cases, these ecosystem services benefits are highly tangible and large, and in other instances the benefits are indirect, intangible, or smaller. When thinking of these wetlands values, two economic concepts are of interest, commodities, and substitution.

An interesting phenomenon arising from the concept of ecological infrastructure is the emergence of ecological commodity properties of wetlands.

An early example of this is the Wetland Mitigation Banking system in the US (Robertson, 2004). The Clean Water Act gave the Corps of Engineers the power to issue developers with permits to allow the damage of wetlands in exchange to their commitment to create or restore larger wetlands elsewhere. From the system, it turned out that the average cost of wetland mitigation was approximately of $45,000 an acre, putting in practice a market price on preserved wetlands (Bayon, 2004).

In economics, a commodity can be defined as a basic good used in commerce that is interchangeable with other commodities of the same type. Commodities are most often used as inputs in the production of other goods and services. The quality of a given commodity may differ slightly, but it is essentially uniform across producers. Commodities often show the following characteristics:

- Clear demand and supply for a natural resource;
- Limited geographic distribution and supply;
- Global or regional market depends on it for providing benefits;
- Uniformity and fungibility - commodities are graded and classified as a specific type so that their characteristics are uniform; and
- Has a per unit value.

The above-mentioned characteristics identified, are applicable to wetlands, i.e. ecological commodities, to some extent. The unit value is especially difficult to quantify and as yet no all-encompassing value exists. The subsequent section shows a first attempt at developing a per unit value for wetlands.

Earlier in this section we demonstrated the increasing societal demand for wetlands and wetland ecosystem services. At the same time the proposed Wetlands Offset Guidelines of SANBI indicates a willingness to substitute between wetland ecosystems. All of this provides some level of evidence of an increasing demand for wetland ecosystem services. Furthermore, the work of Working for Wetlands (WfWet) provides evidence of a potential to supply wetland habitats. The rehabilitation work done by WfWet is captured in a series of wetland rehabilitation reports, which contain information regarding the size of the project, the cost of rehabilitation and several other ecological indictors such as the present ecological state (PES) of the wetland prior to rehabilitation and the projected PES after rehabilitation.

Using the WfWet database, we can use wetland rehabilitation costs as a proxy for estimating the commodity value of wetlands, which expresses a form of regulating service provided by wetland ecological infrastructure. The resulting supply curve for wetlands is given Figure 5-4 below.

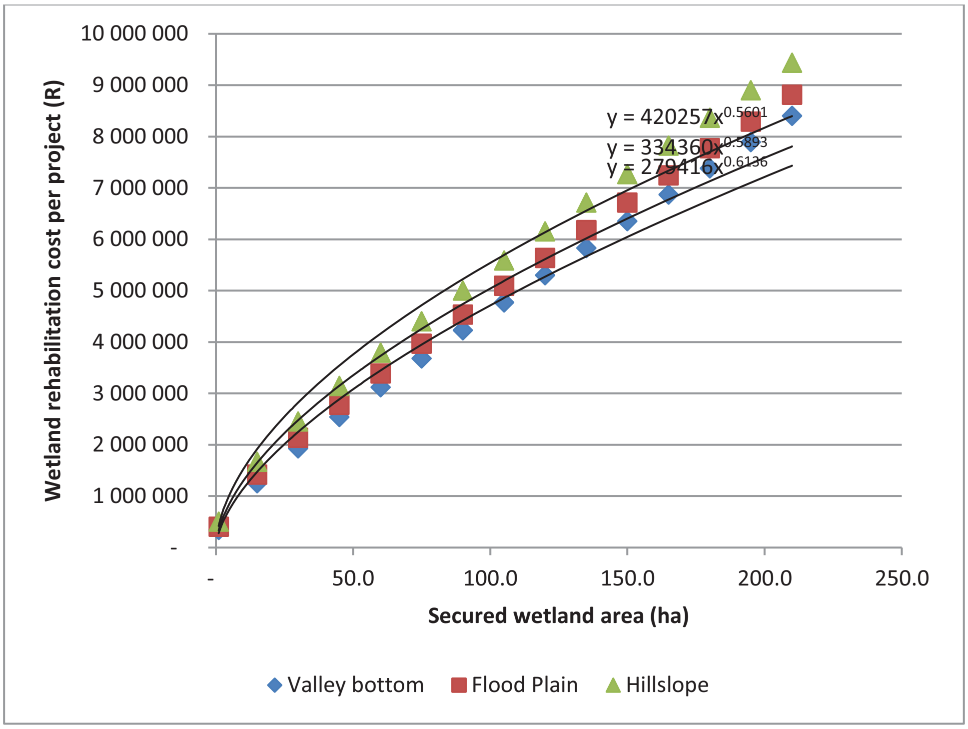


Figure 5-4: Supply curve for wetlands based on the rehabilitation costs provided by Working for Wetlands

5.3.4 The Zaalklap wetland's water purification and waste assimilation value

Sulphate and heavy metals, particularly Fe, Al and Mn are key water chemistry indicators of AMD. After rehabilitation of the Zaalklap wetland, sulphate levels decreased from levels varying between 509-662 mg/l to upstream of Zaalklap, to levels varying between 195 – 477 mg/l downstream of the wetland. The reduction in sulphate levels therefore potentially varied between 110-467 mg/l. TDS concentration after rehabilitation was reduced from levels varying between 820-1150 mg/l to levels between 348-549 mg/l downstream of Zaalklap wetland.

Thus, the Zaalklap wetlands have become, in a very short period after rehabilitation, a very effective sulphate and dissolved heavy metals treatment system. It is likely that the effectiveness of this system will further improve with time as the rehabilitated wetland system stabilises and matures.

The value of this water purification and waste assimilation service can be estimated through evaluating the alternative cost of reverse osmosis. The Olifants WMA WRCS of the DWS have identified reverse osmosis as a suitable technology for large scale and wide-spread treatment of AMD in the Olifants WMA, and have developed a future water management scenario based on reverse osmosis (RO). The cost of water treatment with RO was evaluated in the Olifants WRCS, based on analysis by Golder Associates. The marginal cost of RO treatment is presented in Figure 5-5 below.

No water flow data was measured and only Mean Annual Runoff (MAR) was available for estimating the load of sulphate removed by the wetland. The resultant load of sulphate was then converted to an equivalent RO plant treatment volume, upon which the cost of RO treatment was based. This cost, which is also the water purification and waste assimilation value of the Zaalklap, varied between R2.6 – R11.4 million per year for the data measured by the CSIR. This is equivalent to a wetland ecological infrastructure value ranging between R130 – R560 million, or an annual water purification and waste assimilation value ranging between R20,000-R85,000/ha.

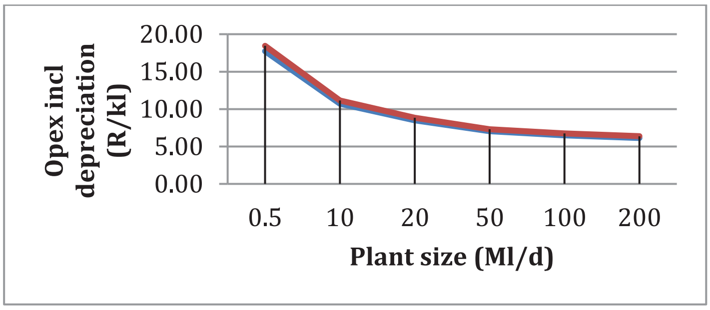


Figure 5-5: Marginal costs of reverse osmosis water treatment for AMD.

5.4 Conclusion

The Zaalklap wetland produces valuable wetland ecosystem services and, through these production activities, is a valuable component of ecological infrastructure.

The value of the provisioning and cultural services delivered by the Zaalklap wetland is estimated at R21,300/ha/annum (or R2.9 million per year for the 135 ha Zaalklap wetland); and the value of the regulating services delivered by the wetland, excluding water purification and waste assimilation, is R22,940/ha/annum (or R3.1 million per year).

The water purification and waste assimilation service of the Zaalklap wetland has a value ranging between R20,000 – R85,000/ha/annum or R2.6-R11.4 million per year. This is based on monitoring data of the CSIR taken within less than a season after rehabilitation and this value could therefore likely be expected to increase as the rehabilitated wetlands stabilise and mature.

This demonstrates that the Zaalklap wetlands' water purification and waste assimilation ecosystem service is possibly larger than the other wetland ecosystem services values based on the Olifants WRCS estimates of other wetland ecosystem services together.

The production of ecosystem services relates closely to wetlands' inherent 'asset' value, which is also referred to as "ecological infrastructure". Based on the estimates done in this study, the asset (or ecological infrastructure) value of the Zaalklap wetland ranges between R501-R763 million, of which the water purification and waste assimilation service contributes R130-R560 million. Thus, by rehabilitating the Zaalklap wetland at a cost of R1.7 million, we have been able to produce between R130-R560 million on the natural asset balance sheet of South Africa.

It must be noted that the value of wetland regulating services identified here, although represented in a financial currency, does not indicate the "Price" of the ecological infrastructure but rather indicates in a common currency the value it provides in economic terms. The price of ecological infrastructure would be a much larger number as the services provided are done so into perpetuity and there is an additional insurance value attached to that. Additionally, the value identified has been done so on a local level, identifying direct benefits provided by the study wetlands. This does not consider the cumulative benefits provided by the addition of the study wetlands at a regional or catchment scale. The interlinked nature of ecosystems results in the footprint of the study wetlands being far greater than just the direct surroundings and thus their value has likely been underestimated.

The results therefore very strongly support investment in wetland rehabilitation in general and for wetland rehabilitation in AMD affected areas specifically. It also demonstrates that wetland rehabilitation may form a very important part of wetland impact mitigation strategies.

6 KEY AREAS OF MANAGEMENT INTERVENTIONS AND RESEARCH NEEDED IN SOUTH AFRICA

Government has a responsibility to protect the aquatic ecosystems of the country. The NWA defines aquatic ecosystems as the water "resource". This water resource is a natural asset, which appears on the balance sheet of the green economy of South Africa, and which produces many aquatic ecosystem services. Both the water resource and the aquatic ecosystem services are public property. Thus, DWS and DEA must ensure that rights to the aquatic ecosystem services are allocated in a manner that is consistent with the NWA and NEMA requirements. For these purposes activities are regulated through legislation, strategies, policies, and policy instruments.

To understand key areas of management interventions and research needed in South Africa, South African's environment legislations and policies need to be unpacked and their shortfalls need to be understood.

6.1 LEGISLATIVE AND POLICY FRAMEWORK FOR ECOSYSTEM PROTECTION IN SOUTH AFRICA

There are many different policies, legislation and strategies in the South Africa that regulate the environment. In general, policies establish the vision, overall goals, and approach; legislation creates the enabling environment and strategies set out the detail of how the policies will be implemented to achieve the vision and goals.

6.1.1 CONSTITUTION OF SOUTH AFRICA

Section 24 of the Bill of Rights in the Constitution that states that everyone has the right to an environment that is not harmful to their health or well-being; and to have the environment protected for the benefit of present and future generations through reasonable legislative and other measures that: prevent pollution and ecological degradation; promote conservation; and secure ecologically sustainable development and use of natural resources while promoting justifiable economic and social development.

6.1.2 NATIONAL WATER ACT

The National Water Act legislates the way that the water resource (surface and ground water) is protected, used, developed, conserved, managed and controlled. The purpose of the National Water Act is to ensure that the nation's water resources are protected, used, developed, conserved, managed and controlled in an optimal manner. This requires consideration of factors such as meeting basic human rights, equity, efficiency, sustainability, conservation, and equality.

6.1.3 NATIONAL ENVIRONMENTAL MANAGEMENT ACT

Chapter 5 of the National Environmental Management Act 107 of 1998 ('NEMA') provides for integrated environmental management and promotes the application of appropriate environmental management tools in order to ensure the integrated environmental management of activities.

6.1.4 Policy instruments

UNEP describes policy as any course of action deliberately taken, or not taken, to manage human activities with the view to prevent, reduce or mitigate harmful effects on nature and natural resources and ensuring that the anthropogenic changes to the water resources and surrounding environment do not have harmful effects on humans (UNEP, 2004). Policy instruments" is the term used to describe some methods used by governments to achieve a desired effect. Broadly speaking, three types of policy instruments exist: regulatory instruments, suasion instruments and economic instruments.

Regulatory instruments are by far the most commonly used policy instruments internationally. A 'Command and control' approach is mostly exercised in conjunction with laws and regulations. 'Command' refers to standards or targets set and that is to be complied with; and 'Control' refers to the enforcement of compliance. Regulations and standards generally desire to achieve a uniform level of control but they can be an inflexible. Examples of these instruments includes water use licenses and EIAs.

6.1.4.1 WATER USE LICENCES AND GENERAL AUTHORISATION

Water supply in South Africa comprise three sources: surface water, return flows and groundwater. DWS regulates these water allocations principally through issuance water use licences. This process is governed by the NWA (1998). Water use licences (WUL) are akin to concessions given by DWS as custodian of the nation's water resources, to WUL applicants.

DWS's General Authorisation (GA) replaces the need for water users to apply for a licence in terms of the National Water Act for the abstraction or storage of water from a water resource, provided that the abstraction or storage is within the limits and conditions set by the GA (DWAF, 1998). The GA is thus a water equity mechanism that exempts small scale water users from applying for licences and paying for raw water.

6.1.4.2 ENVIRONMENT IMPACT ASSESSMENT (EIA)

An important component of ensuring a healthy environment is an understanding of the impact of human activities on the environment and the health and well-being of those who live in and depend on that environment. EIAs are a system of analysing and reporting on the impact of certain types of activities to enable decision makers to decide what sort of activities should and shouldn't take place and to determine what measures should be taken to mitigate and manage the impacts of the activity.

As a tool, EIAs are intended to facilitate informed and environmentally sound decision making. To be an effective tool in decision-making and environmental management, EIAs predict and evaluate the impact on not only the environment, but also socio-economic conditions and cultural heritage.

The need to incorporate environmental concerns into planning is one of the strongest tools when integrating environment and development in policy, planning, management decision-making as well as the legal and regulatory framework concerned. Reducing the burden of environmental impacts is necessary if development is to become sustainable. Policy instruments discussed above are generally regarded as key policy instruments to protect the state of ecosystem. However, on their own, they are not sufficient mechanisms for ensuring delivery of ecosystem services. There may be many reasons for this, including for instance its exclusive focus on project-related and point-source ecological damage, and/or perhaps inadequate administration, and/or application of precautionary principles. Therefore, additional policy instruments are required.

6.2 RESEARCH NEEDED

An informed approach to environmental management is key for sustainable development. Government and relevant regulators must adopt this informed approach. Governments are responsible for environmental regulation of users as well as are themselves users of the environment. The first approach would be to ensure efficient data is available to inform decisions and the second is to evaluate environmental policies to ensure that they are operating effectively.

6.2.1 DATA AVAILABILITY

The lack of an up-to-date national and regional data set of degradation makes it difficult to quantitatively determine the state of degradation. Databases describing physical, social and economic data in a consistent spatial and temporal dimension are extremely limited. These are essential for any robust investigative study into the causes and consequences of pollution induced environmental degradation.

The simple methods described above that can be utilised at a broad scale to monitor these systems, would allow for the creation of a database with data required to monitor trends in environmental degradation. This would act to highlight degradation on a broad scale which ultimately "keeps a finger on the pulse" of the state of ecosystems that are under pressure. The identification of rapid degradation or red flags would inform focal points for further investigation. This would effectively operate as a simplified monitoring program which identifies criteria necessary for the effective utilisation of the bio-economic model developed in this study.

It is crucial that data collected is appropriate to understand the influence of environmental degradation on human well-being within different socio-economic and political settings.

6.2.2 THE ROLE OF PROGRAM EVALUATION ON ENVIRONMENTAL POLICIES

Environmental policies are dynamic policies, it is thus essential to have program evaluation. Program evaluation can identify whether specific policies are serving their purposes or are having alternative effects, such as reducing environmental inequities, promoting or inhibiting technological change. Program evaluation should fit into the policy process and serves an important role in environmental decision making.

Program evaluation seek to determine the impact of a chosen policy or implementation strategy after it has been adopted. By assessing the performance of these policies in terms of various kinds of impacts, retrospective evaluation can inform policy deliberations as policy makes revisit regulatory standards periodically.

6.2.3 IMPLICATIONS FOR MUNICIPALITIES

Municipalities have a double role to play on the protection of the ecosystem. This is because when they discharge treated water from WWTW and this water that does not meet effluent standards, the surrounding industries will have a negative perception and that will put more pressure on the ecological infrastructure.

The wastewater sector in South Africa is part of South Africa's water sector, which due the scarcity of the resource, is a very prominent sector. Treated effluent is discharged into water resources, and is required to meet effluent standards. NWA aims to ensure the sustainable use of water resources for the benefit of all users. One of the measures for achieving this is RQOs. The RQOs would affect WWTW through the water quality conditions associated with effluent emanating from the WWTW.

Municipalities should take a holistic and critical review of bylaws that relate to ecological degradation. Of course, these regulations need to be in harmony with crucially important economic development priorities.

The study has shown that ecosystem services of urban and mining systems are important and valuable to households, to business activities and to municipalities. The results described above are thus crucial to inform Business case(s) to be made towards preventing, mitigating, and rehabilitating ecological degradation.

Over the next 20 years we expect to see increasing urbanization, development of water services infrastructure, energy and electrification projects, transport infrastructure development and industrialisation.

There is no doubt that the apparent conflict between economic development and environmental protection imperatives will increase. Fortunately, the wonderful thing economic systems has taught us, is that they allow economic development to happen often in the most surprising ways. Thus, our challenge in South Africa will be to internalise ecological infrastructure and ecosystem services within the development potential of economic systems. Environmental risk is human well-being risk and thus economic risk. In the high inequality economy of South Africa, we face starkly different challenges to the economies of other continents, and we need a new risk management approach. We need double dividend policy and financial instruments that simultaneously manage risk and enable development.

7 CONCLUSION AND RECOMMENDATIONS

The case studies have demonstrated how water resources and aquatic ecosystem services can be modelled, using the E-BASES approach. The case studies have applied combinations of evidence extraction including scientific experimentation, database analysis, data mining and expert knowledge harvesting.

Two types of environmental impacts have been analysed. In the case of the Apies-Pienaars system, the cumulative effects of urbanisation on an urban river system was analysed. In the case of the Zaalklap system, a mining and industrial impact on a wetland dominated system was analysed.

We have provided evidence of loss of crucial informal economy income by people living in Hammanskraal and surrounding areas; we demonstrated the significant increase in value on private property (subsequent municipal rates income) resulting from proximity to high quality ecosystems; we demonstrated the significant and practical value of wetlands in treating water pollution.

Land use intensity was a major driver of ecological degradation, resulting in major impacts to ecosystem services. More specifically: roads, dams, agriculture, mining, power generation, manufacturing and urbanisation and associated land transformation.

Data collection was possible through a range of sources which were either generally freely accessible or easily measured. Through a range of data sources and collection methodologies evidence required to quantify and assess the link between economic development and ecosystems was possible

The major institutional gap was shown to be the multidisciplinary nature of socio- ecological systems. Multidisciplinary nature of assessing the socio-ecological drivers, pressures and impacts can be packaged into a practical, straight forward and cost effective approach.

A bio-economic model has been shown to be used to quantify the ecosystem services and their losses in relation to river health. Production functions allow for statistically sound analysis.

From this study, various ways forward have been identified.

Firstly, the institutional data management gaps must be addressed. This relates to the challenges related to the multi-disciplinary nature of socio-ecological studies. It has been shown here that data is readily available and can be practically collected. It is at this point however that this collection process should be standardised to allow for effective collaboration and communication between institutions regarding ecological degradation.

Secondly, the accuracy of the ecology-economy linkages described in this study should be improved. This should focus on the refining and finalisation of the bio-economic model. The Bio-Economic model can be used as a framework to enhance the effective collection of necessary data to inform current policy instruments and build confidence in decision making. As it stands the model demonstrates an approach to linking these systems, however is not sufficient yet to provide robust results. The strengthening and finalisation of this model would form a basis of a business case to municipalities for additional resources through providing this linkage between the drivers of degradation.

Thirdly, the results should be further developed to inform future developments allowing for insight into the trade-offs between value provided and impacts received by the environment. This would include Social CBA (Cost-benefit analysis) of the investment into proposed developments and the ecological infrastructure required.

Fourthly, monitoring and evaluation programmes will significantly reduce risks to ecological infrastructure by identifying red flags at which point in depth further investigations may take place. This is especially necessary for urban rivers due to the high presence of potential impacts. Environmental use in these systems should be further investigated to fully understand the impacts. Additionally, the fact that wetlands have been shown to improve the resilience of ecosystems their protection and effective management is crucial. Wetland management plans should be put in place to ensure the services received are maximised.

Finally, with the use of tools such as the bio-economic model, policy instruments should be developed and tested providing for additional regulatory, economic or suasion approaches toward ensuring economic development also results in environmental preservation. This approach would provide for a double dividend where externalities of environmental use are internalised into economic development toward a net positive development scenario. Furthermore, it is crucial that existing and newly created instruments are evaluated through evaluation programmes. The ongoing monitoring of these systems would provide for indicators of performance toward assessing the effectiveness of the policies for reaching goals and targets.

The lack of understanding of regulating services has been the major reason for overexploitation and degradation of ecosystems assets and the ecosystem services they provide to humans. This study indeed provided evidence that if ecological infrastructure is valued, proper decisions or mitigations can be made when new there are new developments so that future generations can still benefit from these natural resources.

It is a continuous challenge to balance economic development with maintenance of a healthy ecosystem as it requires recognition of the inter-dependencies between the natural environment, economic stability, and social well-being. Because ecosystem services are “free” or under-priced, their exploitation is not considered to constitute an economic or social cost which must be weighed against the economic benefits of the production and consumption they generate. These case studies managed to put value in ecological infrastructure and linking it to the economy.

8 REFERENCES

Akcil, A., Koldas, S. 2006. Acid Mine Drainage (AMD); Causes, Treatment and Case Studies. Journal of Cleaner Production 14: 1139-1145.

Arrow,K., Solow,R., Potney, P., Learner, E., Radner, R. and Schuman, H. 1993. Report of the NOAA Panel on Contingent Valuation. Federal Register, 58 (10), 4602-4614.

Aston, P. 2003. Southern African Water Conflicts: Are They Inevitable or Preventable? The Water Wheel January/February 2003.

Barbier E.B., S. Baumgärtner, K. Chopra, C. Costello, A. Duraiappah, R.M. Hassan, A.P. Kinzig, Lehman M., Pascual U., Polasky S., Perrings C. 2009. The valuation of ecosystem services. Chapter 18. In: Biodiversity, Ecosystem Functioning, and Human well-being - An Ecological and Economic Perspective. Edited by: Shahid Naeem, Daniel E. Bunker, Andy Hector, Michel Loreau, and Charles Perrings. Oxford University Press.

Barbier, E., Hacker, S., Kennedy, C. Koch, E., Stier, A., and Silliman, B. 2011. The value of estuarine and coastal ecosystems services, Ecological Monographs, 81 (2):169-193.

Barbier, E.B. 2000. Valuing the environment sas input: review of application to mangrove-fishery linakges. Ecologcal Economics 35:47-61.

Barbier, E.B. 2003. ‘Habitat-fishery linkages and mangrove loss in Thailand’, Contemporary Economic Policy, 21(1), 59–77.

Barbier, E.B. 2003. Habitat- fishery linkages and mangrove loss in Thailand, Contemporary Economic Policy, 21:59-77.

Barbier, E.B. 2007. 'Valuing ecosystem services as productive inputs', Economic Policy, 177–229.

Bergson, A. 1938, “A Formulation of Certain Aspects of Welfare Economics”, Quarterly Journal of Economics, Vol. 52, No. 2, pp. 310-334.

Biggs, H.C. and K.H. Rogers. 2004. An adaptive system to link science, monitoring and management in practice. In: Du Toit, JT, KH Rogers and HC Biggs (eds), The Kruger Experience: ecology and management of savanna heterogeneity. Island Press. 520 pages.

Bjorklund, J., Limburg, K. E and Rydberg, T. 1999. Impact of production intensity on the ability of the agriculture landscape to generate ecosystem services: An example from Sweden. Ecological Economics, 20, 74-85.

Boyd and Banzhaf, 2006 James Boyd and Spencer Banzhaf, What Are Ecosystem Services, RFF Discussion Paper vol. 06-02, Resources for the Future, Washington, DC (2006).

Braid, S., Görgens, A. 2010. Towards the development of IWRM implementation indicators in South Africa. WRC Report No. 1839/1/10.

Breen, C; Crafford, J; Ginsburg, A; Harris, K; Mashimbye, D; Mwabutwa, C; Mitchell, S; Nyamabu, M; Pedzisa, T; Sang, L., 2011. Development of effective ways of extracting information from research to support decision making on social-ecological systems. WRC report no. 1978/11. Report to the Water Research Commission, Pretoria.

Brown, G. 2000. Personal Notes on the History of Non-Market Valuation in the United States. University of Washington. Draft. November 2000.

Cañedo-Argüelles M, BJ. Kefford, C Piscart, N Prat, RB. Schäfer and C-J Schulz, 2013. Salinisation of rivers: An urgent ecological issue. Environmental Pollution. 173: 157–167

Chalker-Scott, L, undated. The Myth of Phosphate Fertilizer. http://puyallup.wsu.edu/ ~linda%20chalkerscott/Horticultural%20Myths_files/Myths/Phosphate.pdf

Ciriacy-Wantrup, S (1947). Capital returns from soil conservation practices. Journal of Farm Economics 29, 1181.

City of Tshwane (2012) Tshwane Metropolitan Spatial Development Framework 2012. 26.

City of Tshwane (2013). Draft 2013/14 IDP Review 28 March 2013. 190.

City of Tshwane, Water Services Backlog Eradication Strategy December 2013

Coaltech. 2014. Limiting and mitigating the impact of coal mines on wetlands – Resource economic component. November 2014. Final Document

Costanza, R., R. D'Arge, R.S. de Groot, S. Farber, M. Grasso, M.B. Hannon, K. Limburg, S. Naeem, R.V. O'Neill, J. Paruelo, R.G. Raskin, P. Sutton and M. van den Belt. 1997. The value of the world's ecosystem services and natural capital. Nature 387: 253–260.

Court, J.D., Wright, C.J. and Guthrie, A.C. 1994. Assessment of Cumulative Impacts and Strategic Assessment in Environmental Impact Assessment, Document prepared for Commonwealth Environmental Protection Agency by J D Court and Associates Pty Ltd and Guthrie Consulting, Commonwealth of Australia.

Crafford, J. 2012. Water benefit Allocation Mechanisms, Water Tariffs, and DWA's Role in a Developmental State: An institutional Economic Analysis. WRC Report. K5-1002

Daily, G, c; Alexander, S., Ehrilich, P. R., Goulder, L, Lubchenco, J., Matson, P,A., Mooney, H. A. 1997. Ecosystem Services: Benefits supplied to human societies by natural ecosystems issues in ecology 1 (2);1-18

Daily, G.C., 1997. Nature's Services: Sicietal Dependence on Natural Ecosysytems. Island Press, Washingto, DC

Dasgupta, P.S. 2010. The Place of Nature in Economic Development. In: DRAFT: Handbook of Development Economics, 5. Doi 10.1016/B978-0-444-52944-2.00012-4. 2010 Elsevier B.V.

De Klerk, A.R., Oberholster, P.J., Cho, M., de Klerk, L.P., le Roux, W., Schaefer, L., Ndlela, L., Staebe, K. and van Deventer, H. 2013. Ecological integrity of the Grootspruit Wetland, Mpumalanga, South Africa. CSIR Report Number: CSIR/NRE/WR/ER/2013/0063/C

Department of Water Affairs and Forestry (DWAF), 2009. Orange River: Assessment of water quality data requirements for planning purposes. Resource Water Quality Objectives (RWQOs): Upper and Lower Orange Water Management Areas (WMAs 13 and 14). Report No. 5 (P RSA D000/00/8009/2). ISBN No. 978-0-621-38691-2, Pretoria, South Africa

Du Preez, H.H., Van der Merwe, M. and Van Vuren, J.H.J. 1997. Bio-accumulation of selected metals in African sharptooth catfish Clarias gariepinus from the lower Olifants River, Mpumalanga, South Africa. Koedoe. 40(l): 77-90.

Duarte C, M. 2000. Marine biodiversity and ecosystem services: an elusive link Journal of Experimental Marine Biology ad Ecology 250. :117-131

Dupuit, AJEJ. 1844. De la mesure de lutillite des travaux public, Annales des ponts et chaussees, Second series, 8. Translated by R.H. Barback as On the measurements of the utility of public works, International Economic Paper, 1952, 2, 83-110

DWA. 2008. The development of a reconciliation strategy for the Crocodile (West) water supply system: Summary of Previous and Current Studies. P WMA 03/000/00/3408. Department of Water Affairs.

DWA. 2009. Rapid Habitat Assessment Model Manual. Report no RDM/Nat/00/CON/0707. Authors: D Louw & CJ Kleynhans Submitted by Water for Africa

DWA. 2012. "Classification of Significant Water Resources in the Olifants Water Management Area: Ecological Sustainable Base Configuration Scenario Report".

EcoPulse. 2013. Wetland Assessment: Zaalklapspruit Wetland (B20G-01). Report No: EP60-03

Eggleton J and KV Thomas, 2004. A review of factors affecting the release and bioavailability of contaminants during sediment disturbance events. Environment International 30 (2004) 973 – 980.

EPA 2012. Wetland Compensatory Mitigation. US EPA-843-F-08-002.

Freeman AM. 2003. The measurement of environmental and resource values: theory and methods, RFF Press.

Frost and Sullivan, 2010. Eutrophication Research Impact Assessment. WRC Report No. TT 461/10. Water Research Commission, Pretoria.

Ginsburg AE, J. G. Crafford and K. R. Harris, 2009. Framework and Manual for the evaluation of aquatic ecosystems services for the Resource Directed Measures. Report No. TT 1644/09. Water Research Commission.

Ginsburg, A.E., J.G. Crafford and K.R. Harris. 2010. Framework and Manual for the evaluation of aquatic ecosystems services for the Resource Directed Measures. WRC Report TT 462/10. Water Research Commission, Pretoria.

Graham, M., Blignaut J., de Villiers L., Mostert D., Sibande X., Gebremedhin S., Harding W., Rossouw N., Freese S., Ferrer S. and M. Browne, 2012. Development of a generic model to assess the costs associated with eutrophication. Pretoria: Water Research Commission, 2012.

Green Book 1958. Proposed Practices for Economic Analysis of River Basin Projects. A report to the inter-Agency Committee on Water Resource by its Subcommittee on Evaluation Standards.

Hicks, J.R., 1940, 'The Valuation of the Social Income,' Economica, 7:26, 105-124.

Hotelling, H. 1931. The economics of Exhaustible Resources. J. Polit. Econ., Vol. 39:137-175.

Jarup L, 2003. Hazards of heavy metal contamination. British Medical Journal 68 (1) 167-182.

Jogo W, Hassan RM. 2010. Balancing the use of wetlands for economic well-being and ecological security: The case of the Limpopo wetland in southern Africa, Ecol. Econ. (2010).

Kaldor, N. 1939. Welfare Propositions of Economics and Interpersonal Comparisons of Utility. Economic Journal 49.195:549–52.

Kinzig A, Perrings C, Scholes RJ. 2007. Ecosystem Services and the Economics of Biodiversity Conservation, Arizona State University, http://www.public.asu.edu.

Kleynhans, C.J. and M.D. Louw. 2007. Module A: EcoClassification and EcoStatus determination in River EcoClassification: Manual for EcoStatus Determination (version 2). Joint Water Research Commission and Department of Water Affairs and Forestry report. WRC Report No.

Kleynhans, C.J., Louw, M.D., Graham, M. 2008. Module G: EcoClassification and EcoStatus determination in River EcoClassification: Index of Habitat Integrity (Section 1, Technical manual) Joint Water Research Commission and Department of Water Affairs and Forestry report. WRC Report No. TT 377-08.

Kotze, P.J., Mackenzie J.A., Deacon, A.R., Louw, M.D, and MacFadyan, S. 2012. Review and update of the desktop present ecological state (PES) and ecological importance (EI) - ecological sensitivity (ES) of South African Rivers according to sub-quaternary catchments: Limpopo WMA. WRC Project No. K5/2041.

Krutilla, John V. 1967, "Conservation reconsidered," American Economics Review, 71 (2): pp. 777-86

Loreau, M., S. Naeem, P. Inchausti, J. Bengtsson, J. P. Grime, A. Hector, D. U. Hooper, M. A. Huston, D. Raffaelli, B. Schmid, D. Tilman, and D. A. Wardle. 2001. Biodiversity and ecosystem functioning: current knowledge and future challenges. Science 294:806–808.

Mäler K-G., Vincent JR. 2005. Handbook of Environmental Economics: Valuing environmental changes. 2. Elsevier.

Mäler, K-G. 1991. The production function approach. In: Vincent, J.R. Crawford, E.W. and Hoehn, J.P. (Eds.). Valuing Environmental Benefits in Developing Countries. Special Report 29. Michigan State University, East Lansing, pp. 11–32.

Maler, K.G. 1991. The production function approach. I: Vincent, J. R, Crawford, E.W and Hoehn, J, P. (Eds).valuing Environmental Benefits in Developing Countries. Special Report 29. Michigan State University, East Lansing. 11-32.

McManus, R. J. (1994). Why the Ohio Case Shouldn't matter. Natural Resources Journal. Vol 34.

MEA. 2005. Ecosystems and human well-being: current state and trends, 1. Edited by R. Hassan, R. Scholes and N. Ash. World Resources Institute. Island Press, Washington.

MEA. 2007. Overview of the Millennium Ecosystem Assessment. http://www.millenniumassessment.org/en/About.aspx 16 May 2007

Mendelson, ER. 2006. Soil Formation and Quality. Pages 25-36 in Morhardt, J. Emil, (Ed). Roberts Environmental Center 2006 Guide to Ecosystem Services Research http://www.roberts.mckenna.edu/ecosystemservices.

Mucina, L., Rutherford, M. C. 2006. The Vegetation of Southern Africa, Lesotho and Swaziland. Strelitzia 19. South African National Biodiversity Institute, Pretoria.

Oberholster, P., McMillan, P., de Klerk, A., Durgapersad, K. 2002. Wetland Classification and Risk Assessment Index: Field Guide. Research, Testing and Development. Eskom Holdings SOC Limited.

Perrings C. 2006. Ecological Economics after the Millennium Assessment. International Journal of Ecological Economics & Statistics (IJEES). Fall 2006, Vol. 6, No. F06; Int. J. Ecol. Econ. Stat.; 8-22. ISSN 0973-1385; Copyright © 2006 IJEES, CESER.

Ridker, Ronald G. (1967), Economics Cost of air Pollution: Studies in Measurement. New Yrok: Praeger.

Robertson M.M (2004). The neoliberalization of ecosystem services: wetland mitigation banking and problems in environmental governance. *Geoforum*, Volume 35, 3: 361-373.

Rodwell, L, D., Barbier, E.B., Roberts, C.M., McClanahan , T, R. 2003. The importanceof habitat quality for marine reserve-fishery linkages. Can. J.Fish. Aquat. Sci. 60: 171-181

Russell, J.R.D., 2006. Forest Fires and Ecosystem Services. Pages 37-51 in Morhardt, J. Emil, (Ed). Roberts Environmental Center 2006 Guide to Ecosystem Services Research http://www.roberts.mckenna.edu/ecosystemservices2006.

SANEDI 2011. Overview of the South African Coal Value Chain. http://www.sanedi.org.za/archived/wp content/uploads/2013/08/sacrm%20value%20chain%20overview.pdf.

Sommers, Pacifica, 2006. Effects of Pesticides on Ecosystem Services. Pages 173-184 in Roberts Environmental Center 2006 Guide to Ecosystem Services http://www.roberts.mckenna.edu/ecosystemservices2006.

State of rivers report summary, Crocodile, Sabie-Sand & Olifants, undated. http://www.dwaf.gov.za/iwqs/rhp/state_of_rivers/state_of_crocsabieolif_01/summary.htm

TEEB. 2010. The Economic of Ecosystem and Biodiversity: Ecological and Economic Foundation. Edited by Pushpam Kumar. Earthscan, London and Washington.

Tshwane Metropolitan Spatial Development Framework 2012. Page 24. Research Unit | Tshwane General and Regional Overview 19.

US EPA. 2013b. Monitoring and Assessing Water Quality - Volunteer Monitoring. Environmental Protection Agency. http://water.epa.gov/type/rsl/monitoring.

Van Zyl, J.E. (2011). Introduction to Integrated Water Meter Management, Edition 1. Water Research Commission Report TT 490/11

worldUS EPA. 2013a. The National Rivers and Streams Assessment 2008-2009: A Collaborative Survey. U.S. Environmental Protection Agency.

WR2005. Water Resources of South Africa, 2005 Study. WRC Project No. K5/1491. Water Research Commission

Yadav SK, 2010. Heavy metals toxicity in plants: An overview on the role of glutathione and phytochelatins in heavy metal stress tolerance of plants.

9 APPENDIX A: THE IMPACT OF POLLUTANTS ON ECOSYSTEM SERVICES

In this section the impact of each of different pollutants is assessed against different ecosystem services.

Table 9-1: Faecal coliforms

Pollutant	Ecosystem Service	Impact
Faecal coliforms	**Provisioning services**	
	Food and fibre	
	Fuel	
	Genetic resources	
	Biochemicals, natural medicines, and pharmaceuticals	
	Ornamental resources	
	Fresh water	Indicator of faecal contamination Increases treatment costs Renders contact with the water risky (National Microbiological Water Quality Monitoring Program, DWA)
	Cultural services	
	Cultural diversity	
	Spiritual and religious values	Renders contact with water risky (National Microbiological Water Quality Monitoring Program, DWA)
	Knowledge systems	
	Educational values	
	Inspiration	
	Aesthetic values	Reduces the aesthetic value
	Social relations	
	Sense of place	
	Cultural heritage values	
	Recreation and ecotourism	Risk of infection through contact (National Microbiological Water Quality Monitoring Program, DWA)
	Regulating services	
	Air quality maintenance	In some instances aerosols, may prove infectious
	Climate regulation	
	Water regulation	
	Erosion control	
	Water purification and waste treatment	Renders water impure, so reducing the capacity of the water for purification
	Regulation of human diseases	Both a disease organism and an indicator of faecal contamination, so indicating risk in using the water without further treatment (National Microbiological Water Quality Monitoring Program, DWA)
	Biological control	
	Pollination	
	Storm protection	

Table 9-2: Heavy metals

Pollutant	Ecosystem Service	Impact
Heavy Metals	**Provisioning services**	
	Food and fibre	Heavy metals may be bio-accumulated by biota to be consumed by people, so exposing them to metal toxicity (Du Preez et al., 1997)
	Fuel	
	Genetic resources	Heavy metal toxicity, where it may occur, will reduce the health of the genetic resources, leading to the disappearance of some from the ecosystem (Yadav, 2010)
	Biochemicals, natural medicines, and pharmaceuticals	Bio-absorption / bio-accumulation of heavy metals will diminish the quality of natural products, making them toxic in extreme cases (Yadav, 2010)
	Ornamental resources	
	Fresh water	Low pH mobilises heavy metals into the water column, making them bio-available. There is then the risk that they will be bio-accumulated in the person's body. (Eggleton and Thomas, 2004)
	Cultural services	
	Cultural diversity	
	Spiritual and religious values	
	Knowledge systems	
	Educational values	
	Inspiration	
	Aesthetic values	Heavy metal toxicity can reduce plant growth, reducing the aesthetic quality (Yadav, 2010)
	Social relations	
	Sense of place	Heavy metal toxicity can reduce plant growth, reducing the aesthetic quality (Yadav, 2010)
	Cultural heritage values	
	Recreation and ecotourism	Heavy metals in the water column can bio-accumulate to harmful levels, making contact recreation risky or impacting on flora and fauna, reducing the value of the ecotourism experience (Du Preez et al., 1997)
	Regulating services	
	Air quality maintenance	
	Climate regulation	
	Water regulation	
	Erosion control	
	Water purification and waste treatment	Contamination by heavy metals can reduce the capacity of the organisms which purify the water or treat the waste
	Regulation of human diseases	People exposed to heavy metal contamination may become more prone to disease even before they begin to show symptoms of heavy metal toxicity (Jarup, 2003)
	Biological control	
	Pollination	
	Storm protection	

Table 9-3: Nutrients (phosphorous, nitrogen)

Pollutant	Ecosystem Service	Impact
Nutrients (phosphorous, nitrogen)	**Provisioning services**	
	Food and fibre	Stimulate plant growth, and in excess can cause a shift in the species of plants – specifically phytolanktonic algae (Mendelson, ER. 2006; Frost and Sullivan, 2010).
	Fuel	Stimulate plant growth (Chalker-Scott, undated)
	Genetic resources	Stimulate plant growth, and in excess can cause a shift in the species of plants.
	Biochemicals, natural medicines, and pharmaceuticals	Stimulate plant growth, and in excess can cause a shift in the species of plants – specifically phytolanktonic algae (Nitrates and Nitrites TEACH Chemical Summary ; Frost and Sullivan, 2010).
	Ornamental resources	Stimulate plant growth, and in excess can cause a shift in the species of plants – specifically phytolanktonic algae (Mendelson, ER. 2006; Frost and Sullivan, 2010).
	Fresh water	Will enhance the growth of plants, causing eutrophication at high levels. High levels of nitrates are dangerous for human consumption, especially in infants. Nitrate pollution in groundwater will persist. (Nitrates and Nitrites TEACH Chemical Summary; Mendelson, ER. 2006)
	Cultural services	
	Cultural diversity	
	Spiritual and religious values	Eutrophic systems are unattractive and may have bad odours or be toxic (Frost and Sullivan, 2010)
	Knowledge systems	
	Educational values	
	Inspiration	
	Aesthetic values	Eutrophic systems are unattractive and may have bad odours or be toxic (Frost and Sullivan, 2010)
	Social relations	
	Sense of place	Eutrophic systems are unattractive and may have bad odours or be toxic (Frost and Sullivan, 2010)
	Cultural heritage values	
	Recreation and ecotourism	Eutrophic systems are unattractive and may have bad odours or be toxic, making contact sports risky (Frost and Sullivan, 2010)
	Regulating services	
	Air quality maintenance	
	Climate regulation	
	Water regulation	
	Erosion control	
	Water purification and waste treatment	Algal blooms in eutrophic waters make treatment of water for potable use difficult and more expensive (Graham et al., 2012)
	Regulation of human diseases	At lower levels, will enhance the biological activity of organisms which will control disease micro-organisms
	Biological control	
	Pollination	
	Storm protection	May enhance the growth of the riparian fringe, assisting in erosion control

Table 9-4: Recalcitrant organic compounds e.g. Pesticides Herbicides PAHs, PCBs

Pollutant	Ecosystem Service	Impact
Recalcitrant organic compounds e.g. Pesticides Herbicides PAHs, PCBs	**Provisioning services**	
	Food and fibre	Some of these substances can bio-accumulate, leading to decreased vigour and ultimately death (Russell, 2006)
	Fuel	Some of the substances are not destroyed by normal temperatures of combustion, so will be in the smoke of burning plant material, a risk to inhalation (Sommers, 2006)
	Genetic resources	
	Biochemicals, natural medicines, and pharmaceuticals	Some of these substances can bio-accumulate, leading to decreased vigour and ultimately death – a risk to users (Sommers, 2006)
	Ornamental resources	
	Fresh water	Makes the water difficult and expensive to treat to potable standards. Contamination of groundwater will persist
	Cultural services	
	Cultural diversity	
	Spiritual and religious values	
	Knowledge systems	
	Educational values	
	Inspiration	
	Aesthetic values	
	Social relations	
	Sense of place	
	Cultural heritage values	
	Recreation and ecotourism	Risk for contact sports
	Regulating services	
	Air quality maintenance	
	Climate regulation	
	Water regulation	
	Erosion control	
	Water purification and waste treatment	The recalcitrant substances do not break down easily, and so are not removed through normal ecological process in an acceptable time
	Regulation of human diseases	Will reduce the vigour of people, making them more susceptible to disease
	Biological control	Will reduce the vigour and eventually poison biological control agents
	Pollination	Will reduce the vigour and eventually poison pollinating agents
	Storm protection	

Table 9-5: Salts (NOTE: chloride and sulphate have some different effects – not specifically differentiated in the table)

Pollutant	Ecosystem Service	Impact
	Provisioning services	
	Food and fibre	Reduction in growth and vigour of most plants used for food and fibre. Employed as a way to increase the sugar content of melons, so making them taste sweeter.
	Fuel	
	Genetic resources	Increasing concentrations will decrease biodiversity (Cañedo-Argüelles, 2013)
	Biochemicals, natural medicines, and pharmaceuticals	Reduction in growth and vigour of most plants used for biochemical etc. although the hormetic response at sub-lethal concentrations may stimulate production at certain stages (Cañedo-Argüelles, 2013)
	Ornamental resources	
	Fresh water	Makes water very difficult to treat and increasing concentrations make water less palatable. Low pH from sulphate mobilises heavy metals. (Eggleton and Thomas, 2004)
	Cultural services	
	Cultural diversity	
	Spiritual and religious values	
	Knowledge systems	
	Educational values	
	Inspiration	
	Aesthetic values	
	Social relations	
	Sense of place	
	Cultural heritage values	
	Recreation and ecotourism	
	Regulating services	
	Air quality maintenance	
	Climate regulation	
	Water regulation	
	Erosion control	Reduce the vigour of plants in wetlands and riparian zones, reducing the effectiveness of these to control erosion
	Water purification and waste treatment	Some organisms are able to perform in saline conditions, but this is not always the case (Cañedo-Argüelles, 2013).
	Regulation of human diseases	
	Biological control	
	Pollination	
Salts	Storm protection	

Table 9-6: Sediments

Pollutant	Ecosystem Service	Impact
Sediments	**Provisioning services**	
	Food and fibre	Will smother areas of deposition, killing seedlings and macro invertebrates and preventing food organisms that require firm substrates from growing, so will affect both productivity and biodiversity of the area (State of rivers report summary, Crocodile, Sabie-Sand & Olifants, undated Phosphate will adsorb onto clay particles (not or less so on quartz), so increasing the fertility of the sediment deposits and enhancing plant growth
	Fuel	
	Genetic resources	
	Biochemicals, natural medicines, and pharmaceuticals	Has the potential to smother areas where plants may be growing (e.g. wetlands) area (State of rivers report summary, Crocodile, Sabie-Sand & Olifants, undated
	Ornamental resources	
	Fresh water	Increases the cost of treatment and becomes expensive to dispose. Disease organisms may adsorb onto sediment particles
	Cultural services	
	Cultural diversity	
	Spiritual and religious values	Sediment-laden water is unattractive
	Knowledge systems	
	Educational values	
	Inspiration	
	Aesthetic values	Sediment-laden water is unattractive
	Social relations	
	Sense of place	Sediment-laden water is unattractive
	Cultural heritage values	
	Recreation and ecotourism	Sediment-laden water is unattractive
	Regulating services	
	Air quality maintenance	
	Climate regulation	
	Water regulation	
	Erosion control	Sediment-laden water has lower potential to further erode than does water that is not carrying a sediment load.
	Water purification and waste treatment	Increases the cost of treatment and becomes expensive to dispose. Disease organisms may adsorb onto sediment particles
	Regulation of human diseases	Disease organisms may adsorb onto sediment particles. Attenuates UV penetration into the water, thereby decreasing the natural disinfection qualities of sunlight
	Biological control	
	Pollination	
	Storm protection	

Table 9-7: Readily biodegradable organic compounds

Pollutant	Ecosystem Service	Impact
Readily biodegradable organic compounds	**Provisioning services**	
	Food and fibre	High levels will render water anoxic / anaerobic, preventing the growth of aquatic plants. Fish will die (Fish Kill undated) Phosphate in the sediment is solubilised under anoxic conditions, making it available for plant, usually algal, growth
	Fuel	
	Genetic resources	High levels will render water anoxic / anaerobic, preventing the growth of aquatic plants. Fish will die (Fish Kill undated)
	Biochemical, natural medicines, and pharmaceuticals	High levels will render water anoxic / anaerobic, preventing the growth of aquatic plants (Fish Kill undated)
	Ornamental resources	High levels will render water anoxic / anaerobic, preventing the growth of aquatic plants. Fish will die (Fish Kill undated)anoxic
	Fresh water	High levels will render water anoxic / anaerobic, causing bad odour and taste
	Cultural services	
	Cultural diversity	
	Spiritual and religious values	High levels will render water anoxic / anaerobic, causing bad odour and taste
	Knowledge systems	
	Educational values	
	Inspiration	
	Aesthetic values	High levels will render water anoxic / anaerobic, causing bad odour and taste
	Social relations	
	Sense of place	High levels will render water anoxic / anaerobic, causing bad odour and taste
	Cultural heritage values	
	Recreation and ecotourism	High levels will render water anoxic / anaerobic, causing bad odour and taste
	Regulating services	
	Air quality maintenance	
	Climate regulation	
	Water regulation	May change the plant species and so the capacity of the system to deliver the ecosystem services
	Erosion control	May change the plant species and so the capacity of the system to deliver the ecosystem services
	Water purification and waste treatment	
	Regulation of human diseases	
	Biological control	
	Pollination	
	Storm protection	

10 Appendix B: The effects of land-use on Ecosystem Services

In section 2.1.1 we defined ecosystem services. In the modelling of the system, ecosystem services will be used to measure the effects of ecological degradation of the river system on human well-being. In the study area we have identified and scored the impacts different land uses (consolidated into spatial units) have on the provision of ecosystem services.

10.1.1 Urban

This is the inner city area where most people lives in blocks of flats. There are office blocks and commercial enterprises. There are few open spaces and what exists is mainly city parks which are maintained by the municipality. See Table 10-1 for descriptions of ecosystem services present.

Table 10-1: Ecosystem Services in Urban Areas

Category	Service	Notes	Beneficiaries
Provisioning	Food	Few gardens, Very little opportunity to collect wild-grown food 0 / 4	Local poor people
	Fresh water	Runoff likely to be polluted 0 / 4	River health deterioration
	Fibre and fuel	Na 0 / 4	
	Biochemical / medicinal	Na 0 / 4	
	Genetic material	Na 0 / 4	
Regulating	Climate regulation	Paved areas could hold the heat of the day 0.5 / 4	
	Water regulation	Hard surfaces lead to more rapid runoff 0 / 4, mitigated to some extent by the open spaces – possibly 0.5 / 4	Lead to flash floods downstream
	Water purification and waste treatment	Minimal over most of the area with pollutants from the city, the open spaces will provide a little treatment 0.5 / 4	
	Erosion regulation	Increased runoff will lead to increase in erosion	Sedimentation in the stream and impoundments will cause deterioration
	Disease	Disease control minimal 0/4	
Cultural	Spiritual and inspirational	Waterways provide no effective ES 0/4	Mostly Flat dwellers
	Recreational	Parks on river banks & urban lakes would provide some, but absent from study area	Mostly Flat dwellers
	Aesthetic	Na	
	Educational	Na	

10.1.2 Suburban

The suburban residential areas vary from the large erven in suburbs the older suburbs of Pretoria to the much smaller erven of suburbs such as Mamelodi, Hammanskraal and others). See Table 10-2 for descriptions of ecosystem services present.

Table 10-2: Ecosystem Services in Suburban Areas

Category	Service	Notes	Beneficiaries
Provisioning	Food	Some marog (wild spinach) collected from the riparian Larger properties – some vegetables and fruit trees 1 / 4	Local poor people Suburbanites
	Fresh water	Runoff likely to be polluted 0 / 4	River health deterioration
	Fibre and fuel	Minimally used (such as tree prunings for firewood 0 / 4	
	Biochemical / medicinal	Probably Not used 0 / 4	
	Genetic material	Not used 0 / 4	
Regulating	Climate regulation	Minimal 0.5 (to 1) / 4	Those living adjacent to the waterways
	Water regulation	Rivers may be canalised. Hard surfaces lead to more rapid runoff 0 / 4, mitigated to some extent by the open spaces – possibly 0.5 / 4	
	Water purification and waste treatment	Minimal over most of the area with pollutants from the suburbs, unpaved hard surfaces will be the source of silt in runoff, the open spaces will provide some treatment 0.5 / 4	
	Erosion regulation	Increased runoff will lead to increase in erosion, unpaved hard surfaces (roads, bare roadsides and gardens) will be the source of silt in runoff	Sedimentation in the stream and impoundments will cause deterioration
	Disease	Disease control in this area is likely to be limited to the attenuation of E. coli through exposure to UV in sunlight	
Cultural	Spiritual and inspirational	Large properties provide quality of life and open spaces provide relaxation 3 / 4 Small properties in the high-density areas - Na	Suburbanites
	Recreational	Wealthier suburbs - Walkways and nature reserves provide opportunities for suburbanites to exercise of relax 3/4 Poorer suburbs – open areas are seen as areas prone to crime 0/4	Suburbanites, bird watchers Poorer suburbs
	Aesthetic	0.5 – 2.5/4	
	Educational	2/4 - there is potential for this activity to be increased	

10.1.3 Rural

People living in a rural environment where the suite of municipal services are reduced. They are self-sufficient to some extent at least. See Table 10-3 for descriptions of ecosystem services present.

Table 10-3: Ecosystem Services in Rural Areas

Category	Service	Notes	Beneficiaries
Provisioning	Food	These people will produce a certain amount of their own food; potential source of fish 2/4	Rural residents
	Fresh water	Water for irrigation and where not serviced by a water service provider the river will provide water for the house. 1.5/4	Rural residents
	Fibre and fuel	Not always widely available and tends to be over-exploited in populous areas.	Rural residents, especially poorer people
	Biochemical / medicinal	Harvested from the riparian	Rural residents
	Genetic material		
Regulating	Climate regulation	Ranges from 2/4 for larger wetlands to 0/4 for canalised stretches of rivers	Rural residents and downstream users
	Water regulation	Ranges from 2/4 for larger wetlands to 0/4 for canalised stretches of rivers	Rural residents and downstream users
	Water purification and waste treatment	Ranges from 2.5/4 for larger wetlands to 0/4 for canalised stretches of rivers	Rural residents and downstream users
	Erosion regulation	Ranges from 2.5 - 3/4 for areas where the riparian is in good condition to 0/4 where the riparian is in bad condition	Rural residents and downstream users
	Disease	Attenuation of pathogens and control of disease vectors – range from 2.5/4 (good condition) to 0.5/4 (poor condition)	Mainly rural residents
Cultural	Spiritual and inspirational	Areas in good, clean condition and safe from crime – 2/4, other areas as little as 0/4	Mainly rural residents;
	Recreational	Bird watching – the study area covers Highveld to bushveld and is home to many species of birds. 2.5/4	Visiting Bird watchers
	Aesthetic	Areas in good, clean condition and safe from crime – 2/4, other areas as little as 0/4	Mainly rural residents;
	Educational	Probably minimal at the moment	

10.1.4 Informal Settlements

Informal settlements, when first established, have no formal planning or municipal services and the inhabitants are generally indigent. This changes as the settlement matures when the municipality provides basic services and the population begin to find some form of employment. The third economy is most active in these communities. See Table 10-4 for descriptions of ecosystem services present.

Table 10-4: Ecosystem Services in Informal Settlements

Category	Service	Notes	Beneficiaries
Provisioning	Food	Indigent people will use what they can collect	Residents in Informal settlements
	Fresh water	Mostly rely on what can be sourced from the environment	Residents in Informal settlements
	Fibre and fuel	Will collect what is available	Residents in Informal settlements
	Biochemical / medicinal	Will collect what is available	Residents in Informal settlements
	Genetic material		
Regulating	Climate regulation	0/4	
	Water regulation	Little infiltration, runoff likely to carry silt and pollutants	
	Water purification and waste treatment	0/4	
	Erosion regulation	0/4	
	Disease	0/4	
Cultural	Spiritual and inspirational	0/4	
	Recreational	0/4	
	Aesthetic	0/4	
	Educational	0/4	

10.1.5 Irrigated Agriculture

Irrigated agriculture is mainly confined to commercial farmers in the study area. Centre pivot systems are prevalent in some of the schemes. In the study area these exist on the Apies and Pienaars River North of Pretoria. See Table 10-2Table 10-5 for descriptions of ecosystem services present.

Table 10-5: Ecosystem Services for Irrigated Agriculture

Category	Service	Notes	Beneficiaries
Provisioning	Food	Commercial agriculture with centre pivot irrigation where the land is suitable 2.5/4	Commercial landowners
	Fresh water	Riparian zone – narrow and invaded by alien vegetation – 1.5/4 Wide and in good condition – 2.5/4	Land owners and downstream users
	Fibre and fuel	Is available and probably only used from the reaches where the river passes close to high density suburbs 1/4	
	Biochemical / medicinal	Opportunity exists, but probably not extensively used. 1.5/4	Used where accessible – traditional healers
	Genetic material	Exists, but I assume minimally exploited 0/4	
Regulating	Climate regulation	Minimal where river channel and riparian narrow 1/4 ; where river	Local residents and adjacent areas

Category	Service	Notes	Beneficiaries
		channel and riparian wider – 1.5 – 2/4	
	Water regulation	The overgrown riparian will offer resistance to the passage of flood waters, reducing the velocity. The same characteristic will also increase the water use by the vegetation, so reducing water availability for other uses in times of drought.	downstream users;
	Water purification and waste treatment	Some water purification and waste treatment with greater attenuation at high flows when the riparian is under water 1.5/4	Downstream users
	Erosion regulation	Good 3/4	
	Disease	Good 3/4	
Cultural	Spiritual and inspirational	Large, quiet areas	Residents (2.5/4)
	Recreational	Depends on the individual, potential for bird watching, fishing, etc.	Residents and visitors
	Aesthetic	Varies with the state of the river 1.5 - 2/4	Residents and visitors
	Educational	Educational facilities exist; 1.5/4	Residents

10.1.6 Dry-land Agriculture

Dry land cultivation may occur adjacent to the rivers. Although the river is not used directly, runoff containing agricultural chemicals may enter the river systems. In the study area, this activity occurs on the Pienaars river upstream of Roodeplaat Dam as well as to the North of Greater Tshwane. See Table 10-6 for descriptions of ecosystem services present.

Table 10-6: Ecosystem Services for Dry-land Agriculture

Category	Service	Notes	Beneficiaries
Provisioning	Food	Food production 2/4	Commercial landowners and subsistence farmers
	Fresh water	Where there are no apparent polluting activities and fringing wetlands and riparian vegetation exist – 2.5/4, otherwise lower	Downstream users
	Fibre and fuel	Some production 1.5/4	Local use
	Biochemical / medicinal	likely	Probably local use
	Genetic material	likely	Possibly not used
Regulating	Climate regulation	Minimal 1 / 4	Mostly local area
	Water regulation	1.5 / 4	Downstream users
	Water purification and waste treatment	Possibly some agricultural pollution to purify 1 / 4	Downstream users
	Erosion regulation		Land owners, river ecosystem health and downstream users

Category	Service	Notes	Beneficiaries
	Disease	Depending on the health of the aquatic ecosystem, there are likely to be fish which will control disease vectors. Pathogens controlled to some extent by UV in sunlight	Local area residents
Cultural	Spiritual and inspirational	Rural environment provides peaceful atmosphere for residents 2.5 / 4	Local residents and visitors
	Recreational	Some angling and bird watching 1.5 / 4	Local residents and visitors
	Aesthetic	1 / 4	Local residents
	Educational	Potential for educational activities exists	

10.1.7 AGRICULTURAL GRAZING – PRIVATE OWNERSHIP

The grazing areas are fenced and the stocking rate controlled, although there may be instances of overgrazing. See **Table 10-7** for descriptions of ecosystem services present.

Table 10-7: Ecosystem Services for Agriculture Grazing – Private Ownership

Category	Service	Notes	Beneficiaries
Provisioning	Food	Some food production	Commercial and smallholder landowners
	Fresh water	Where there are no apparent polluting activities and fringing wetlands and riparian zone are intact – 2.5/4, otherwise lower	Downstream users
	Fibre and fuel	Some production	Local use
	Biochemical / medicinal	likely	Probably local use
	Genetic material	likely	Possibly not used
Regulating	Climate regulation	Minimal 1 / 4	Mostly local area
	Water regulation	1.5 / 4	Downstream users
	Water purification and waste treatment	Agricultural pollution likely to be minimal so the capacity of the environment to purify wastes is probably good 2.5 / 4	Downstream users
	Erosion regulation	Unregulated livestock access to rivers destroy the banks, leading to increased erosion 0/4	Land owners, river ecosystem health and downstream users
	Disease	Depending on the health of the aquatic ecosystem, there are likely to be fish which will control disease vectors.	Local area residents
Cultural	Spiritual and inspirational	Rural environment provides peaceful atmosphere for residents 2.5 / 4	Local residents and visitors
	Recreational	Some angling and bird watching 1.5 / 4	Local residents and visitors
	Aesthetic	1 / 4	Local residents
	Educational	Potential for educational activity	

10.1.8 AGRICULTURAL GRAZING – OPEN ACCESS

The grazing areas are unfenced and the stocking rate is not controlled. Livestock has access to the river and may compromise the integrity of the riparian zone, leading to erosion. The example of this in the study area is the Pienaars river between the town of Pienaarsrivier and Klipvoor Dam. See Table 10-8 for descriptions of ecosystem services present.

Table 10-8: Ecosystem Services for Agriculture Grazing – Open Access

Category	Service	Notes	Beneficiaries
Provisioning	Food	The wetland on the Apies provides grazing for livestock. There is also some flood-recession cultivation near the population centres; opportunity for angling. 3 / 4	Local residents
	Fresh water	Where there are wetlands in good condition water retention will be fairly good. Large wetland on the Pienaars River, with the numerous oxbows would suggest that the water passes through this area relatively slowly. 2.5/4	Local agriculture and downstream users
	Fibre and fuel	Fibre and fuel is certainly available and is likely to be used by those who cannot afford other forms of energy. 1.5/4	Local residents
	Biochemical / medicinal	Likely to be harvested by traditional healers. 1.5/4	Traditional healers
	Genetic material		
Regulating	Climate regulation	The wetlands will have a local influence 1/4	Adjacent areas
	Water regulation	The meandering nature of the river morphology through the wetlands will regulate the water flow and provide opportunity for the recharge of groundwater. When the river overflows its banks this ecosystem service will be enhanced. 2/4	Both local and downstream residents
	Water purification and waste treatment	This will be moderately effective given that the low flow through the wetland is confined to a channel, but that the velocity through the meandering channels is likely to be low, particularly during times of low flow. 2.5/4	Local users and livestock, downstream users
	Erosion regulation	Good where the riparian is intact and the velocity of stream flow is likely to be slow. 3.0/4 Where the riparian has been compromised the erosion will increase	The downstream impoundment will be protected from excessive silt deposition, prolonging its useful life.
	Disease	The low velocity of water passing through a wetland will suit disease	Residents adjacent to the river.

Category	Service	Notes	Beneficiaries
		vectors such as mosquitos, but it will also suit the predators of mosquitos. Assuming water quality suitable for the predators (mosquito larvae are air breathing so not affected by low oxygen concentrations) the mosquitos will be largely kept in check. 2.5/4	
Cultural	Spiritual and inspirational	The opportunity exists for spiritual activities, but the Pienaars River is remote from all villages except Moretele (South Bank) and Haakdoornbult (North Bank), so its use is probably limited to residents from these villages. 2/4	Residents of adjacent villages.
	Recreational	The opportunity exist for fishing and birding. 1.5/4	Residents of adjacent villages and visiting birders
	Aesthetic	Probably not very attractive 1.0/4	
	Educational	The opportunity exists but may not be actively developed. 1.0/4	

10.1.9 Industrial

Areas developed for industry in the study area include Silverton, Koedoespoort and Babalegi. There is no municipal open space in the area and the activities are heterogeneous which could lead to a variety of industrial chemicals in runoff which reaches the area. See Table 10-9 for descriptions of ecosystem services present.

Table 10-9: Ecosystem Services in Industrial Areas

Category	Service	Notes	Beneficiaries
Provisioning	Food	0/4	
	Fresh water	Likely to be a source of various pollutants	
	Fibre and fuel	0/4	
	Biochemical / medicinal	0/4	
	Genetic material	0/4	
Regulating	Climate regulation		
	Water regulation	Increased runoff	
	Water purification and waste treatment	0/4	
	Erosion regulation	Increased runoff will lead to increased erosion downstream	
	Disease	0/4	
Cultural	Spiritual and inspirational	0/4	
	Recreational	0/4	
	Aesthetic	0/4	
	Educational	1/4	Offers the opportunity for people to learn new skills

10.1.10 Wetlands

Wetlands provide a wealth of ecosystem services when in good condition. See Table 10-10for descriptions of ecosystem services present.

Table 10-10: Ecosystem Services in Wetlands

Category	Service	Notes	Beneficiaries
Provisioning	Food	Livestock grazing and riverbank agriculture are the main food-producing activities. The wetlands may also provide breeding and nursery habitat for fish 2/4	Local residents 2/4 – the cultivation around the densely populated areas could be used as a livelihood buffer in times of unemployment
	Fresh water	Where the riparian areas are intact, 2.5/4	Downstream users
	Fibre and fuel	Available in the riparian but supply limited in comparison with the number of people that may be resident in the area. Extent of use unknown, 1/4	Local residents
	Biochemical / medicinal	'Almost certainly' available and used 1/4	Traditional healers
	Genetic material		
Regulating	Climate regulation	Local, with some carbon sequestration 1.5/4	
	Water regulation	Intact riparian will regulate floods	
	Water purification and waste treatment	When the river overflows its banks, and runs on the floodplain there will be some treatment, but at times of low flow the ecosystem service will not be realised to any great extent 1.5/4	Downstream users
	Erosion regulation	Good where the riparian is intact 3/4	Local river health and downstream users
	Disease	There will be some attenuation of disease organisms (e.g. E. coli) and vectors. 2/4	Local residents
Cultural	Spiritual and inspirational	There are likely to be areas adjacent to the river where groups meet. 1.5/4	Local residents
	Recreational	Opportunity for fishing and bird watching exists 1/4	Local residents and visitors
	Aesthetic		
	Educational	The opportunity exists and could be developed	

10.1.11 Grasslands

This category includes nature reserves and urban open space in the study area. See Table 10-11 for descriptions of ecosystem services present.

Table 10-11: Ecosystem Services in Grasslands

Category	Service	Notes	Beneficiaries
Provisioning	Food	Production from natural and agricultural systems2.5/4	Commercial landowners and local residents
	Fresh water	Will attenuate pollutants, but less effectively than the riparian strip 1/4	
	Fibre and fuel	This is available and probably only used from the reaches where the river passes close to high density suburbs 1/4	
	Biochemical / medicinal	Opportunity exists, but probably not extensively used. 1.5/4	Used where accessible – traditional healers
	Genetic material	Exists, but I assume minimally exploited 0/4	
Regulating	Climate regulation	Minimal, 1/4	Dinokeng Game Reserve
	Water regulation	In good condition, will offer the opportunity for infiltration and will slow the runoff from the area. Nature reserves increase these opportunities	Dinokeng Game Reserve; downstream users;
	Water purification and waste treatment	Some water purification and waste treatment will occur, with greater attenuation in areas under good condition, but will be lower than that provided by a wetland 1.5/4	Downstream users
	Erosion regulation	Good when in good condition 3/4	
	Disease	n/a	
Cultural	Spiritual and inspirational	Nature Reserves offer substantial areas where people can commune with nature 3/4	Residents (3.5/4) and visitors
	Recreational	Nature reserves offer a variety of opportunities – nature, mountain biking, ultra-light flights, etc. 3.5/4	Residents and visitors
	Aesthetic	Not always very attractive to visitors 1.5/4	Residents and visitors
	Educational	Educational facilities exist in some of the nature reserves; these are available as short courses, educational outings and lectures for all ages ¾	Residents and visitors

10.1.12 VELDT

The category includes nature reserves. The largest in the study area is the Dinokeng Game Reserve. See Table 10-12 for descriptions of ecosystem services present.

Table 10-12: Ecosystem Services in Veldt

Category	Service	Notes	Beneficiaries
Provisioning	Food	Some food production from areas accessible to people	landowners

Category	Service	Notes	Beneficiaries
	Fresh water	Will attenuate pollutants, but less effectively than the riparian strip 1/4	Downstream users
	Fibre and fuel	Some production where the veldt is accessible to people	Local use
	Biochemical / medicinal	likely	Probably local use
	Genetic material	likely	Possibly not used
Regulating	Climate regulation	Minimal 1 / 4	Mostly local area
	Water regulation	1 / 4	Downstream users
	Water purification and waste treatment	Possibly some activity 1 / 4	Downstream users
	Erosion regulation	Where the veldt has not been overgrazed – good protection. Overgrazed veldt is prone to serious erosion	Land owners, river ecosystem health and downstream users
	Disease	Depending on the health of the aquatic ecosystem, there are likely to be fish which will control disease vectors.	Local area residents
Cultural	Spiritual and inspirational	Rural environment provides peaceful atmosphere for residents 2.5 / 4	Local residents and visitors
	Recreational	Some angling and bird watching 2 / 4	Local residents and visitors
	Aesthetic	1 / 4	Local residents
	Educational	Educational talks and outings are available in some of the areas.	

10.1.13 IMPOUNDMENTS

The main impoundments in the study area are the Roodeplaat Dam, the Bon Accord Dam and the Klipvoor Dam. There are smaller impoundments on the Pienaars and Apies Rivers as well as a number of small farm dams. See Table 10-13 for descriptions of ecosystem services present.

Table 10-13: Ecosystem Services in Impoundments

Category	Service	Notes	Beneficiaries
Provisioning	Food	Recreational anglers keep their catch from dams. 2/4	Recreational anglers
	Fresh water	Mostly, these dams have been constructed to supply water for unban or agricultural use. 3/4	City dwellers and irrigation farms
	Fibre and fuel	Fuel and fibre from dams to which rural people have access will be exploited. 1/4	Rural people
	Biochemical / medicinal		
	Genetic material		
Regulating	Climate regulation	Carbon sequestration: the larger dams (at least) are hypertrophic with heavy cyanobacterial blooms. This may not be permanent as mineralisation of the dead algae will release the carbon.	In the national interest

Category	Service	Notes	Beneficiaries
	Water regulation	Dams will retain a certain amount of flood water, depending on the size of the dam. There will be groundwater recharge from each of these dams. 1.5/4	Surrounding population and people dependant on the aquifer
	Water purification and waste treatment	Dams provide an environment in which suspended solids will settle, so improving the quality of the water downstream. A certain amount of phosphate is also sequestered by the algae that dies and settles to the bottom of the dam. However, the water leaving a dam is often sediment-deprived, so has higher erosive potential than before entering the dam. 2/4	River health
	Erosion regulation	Dams may reduce erosion but may also increase it (see above)	Downstream users
	Disease	Dams generally present a relatively stable environment in which the predators of both disease-causing microbes as well as disease vectors will be naturally controlled to a certain extent. 1.5/4	Residents adjacent to the dam and dam users
Cultural	Spiritual and inspirational	Dams provide spiritual and inspirational experience. 2.5/4	Residents adjacent to the dam and dam users
	Recreational	Provide opportunity for water sports, bird watching, and angling.	Water sports people, birders anglers
	Aesthetic	Open water has aesthetic appeal	Residents adjacent to the dam and visitors
	Educational	Dams provide opportunity for education	All ages through lectures and courses

11 Appendix C: Summary of sub-quaternaries (SQ's) within the Pienaars River Catchment

See Table 11-1 for sub-quaternaries (SQs) within the Pienaars River catchment showing natural land cover and descriptions of habitat diversity.

Table 11-1: Sub-quaternaries (SQs) within the Pienaars River catchment showing natural land cover and descriptions of habitat diversity.

SQ	SQ NAME	LENGTH (KM)	% NATURAL LCOVER (SQ CATCHMENT)	% NATURAL LCOVER (500 m)	% NATURAL LCOVER (1000 m)	HABITAT DIVERSITY COMMENTS
A23A-01049	Hartbeesspruit	8.39	36.17	9.60	17.12	Very disturbed. Increased flows, not diverse under present conditions and not sensitive to flow removal.
A23A-01072	Hartbeesspruit	10.93	16.09	27.16	22.94	Due to the level of disturbance, there is no sensitivity left and minimal functional habitat.
A23A-01074	Moretele	22.84	19.55	27.11	23.93	Very modified, incised, small - minimal habitat and not sensitive under present condition
A23A-01045	Edendalespruit	28.12	50.20	45.61	47.58	Low habitat diversity due to disturbance and therefore low sensitivity to flow change as well.
A23A-01056	Pienaars	45.97	43.44	40.14	42.66	Due to disturbance, habitat not as good as it could be. Many sections inundated. Only small area sensitive to flow changes.
A23B-0896	Pienaars	41.99	67.53	56.11	55.44	Large, one geomorphic zone
A23B-01012	Roodeplaatspruit	23.56	62.50	65.80	67.77	Disturbed, habitat diversity not as good as it can be and therefore not that sensitive.
A23B-01034	Pienaars	2.81	14.95	0.93	2.28	The rocky geozone (A) probably inundated by dam and weir.
A23B-0889	Boekenhoutspruit	43.57	66.08	63.03	63.59	Sections small, i.e. high sensitivity. Small riffles, important habitats. Varied habitat which, in places is reasonable instream.
A23C-0751	Pienaars	50.18	78.33	89.47	89.49	River not sensitive under low flows. However, for wetland to flood, the breaching point is very sensitive to change in flow levels. Habitat diversity low as mostly wetland and

SQ	SQ NAME	LENGTH (KM)	% NATURAL LCOVER (SQ CATCHMENT)	% NATURAL LCOVER (500 m)	% NATURAL LCOVER (1000 m)	HABITAT DIVERSITY COMMENTS
						meandering run type of river.
A23D-01104	Skinner spruit	11.78	38.16	44.56	37.30	Very disturbed, mostly wetland feature, even if habitat diversity still intact, would not be sensitive.
A23D-01105	Apies	4.02	10.46	15.09	11.59	No habitat diversity of sensitive as essentially not a river anymore.
A23D-01110	Walker spruit	4.90	9.60	6.20	7.85	Habitat diversity definitely not a 2 under present conditions as consist only of a canal. Size sensitivity also not relevant.
A23D-01117	Apies	12.46	46.21	39.89	42.93	Size sensitivity not relevant as no river, but a canal.
A23E-01080	Wonderboom spruit	7.13	11.30	20.52	13.46	River is canalised or extremely disturbed. Habitat diversity and sensitivity not relevant.
A23E-01071	Apies	5.40	32.41	27.47	22.27	No habitat diversity or sensitivity due to extreme modification.
A23F-0801	Tshwane	8.52	84.75	98.46	94.63	Artificially incised channel within the wetland. Main channel meandering and a run and not sensitive to flow changes. Habitat diversity low as habitat dominated by wetland.
A23F-0827	Apies	71.69	40.97	44.43	39.67	Some areas maintain some habitat although extremely disturbed by increased flows and the water quality situation.
A23F-0828	Tshwane	38.72	68.72	76.76	73.43	Diversity rating as well as size sensitivity should be lower due to the extent of the disturbance.
A23J-0710	Moretele	26.38	79.86	97.54	96.07	Very insensitive and monotone especially as so incised.
A23J-0736	Moretele	4.68	99.81	97.69	98.46	Habitat diversity should be higher as the few but critical areas of rocky habitat provides crucial habitat and, apart from water quality, is in reasonable condition.
A23J-0793	Pienaars	6.37	90.35	98.27	98.17	Lowland, U-shaped, run - not sensitive or diverse.

SQ	SQ NAME	LENGTH (KM)	% NATURAL LCOVER (SQ CATCHMENT)	% NATURAL LCOVER (500 m)	% NATURAL LCOVER (1000 m)	HABITAT DIVERSITY COMMENTS
A23J-0717	Pienaars	12.89	85.55	46.49	63.92	

12 APPENDIX D: THE PRIME AFRICA "EXPRESS HABITAT ASSESSMENT METHOD"

The Prime Africa Express Habitat Assessment Method (E-HAM) was developed with the premise of having a basic, yet insightful, method for assessing the state of habitats in an urban river system. This allows for classification and the ultimate monitoring of systems without the need for extensive training in assessment methodology.

This method was based on approaches taken by:

- The Rapid Habitat Assessment (DWAF 2009) and Index of Habitat Integrity (Kleynhans *et al* 2008) methods which are both used as tools in the Department of Water Affairs river eco-status determination.

- The Wetland Classification and Risk Assessment method (Oberholster *et al* 2002) which is a field manual developed for Eskom used in the assessment of wetlands.

It must be noted that this assessment is a basic method for providing a glimpse into the general state of habitats and should not be used for any other purpose. This method allows for a comparative overview of ecosystems against changing influential variables.

12.1.1 METHODOLOGY

The method can be broken down into 5 steps. These include: site selection, site information, site description, physical characteristics of the site and finally classification of the site. The first four steps ensure that all the factors critical to assessments of this nature, are taken into account.

Step 1

Management units are selected based on the large-scale characteristics of the river system. Variables such as geology, hydrology, topography, eco-region, and vegetation type must be kept at a minimum when separating the river system into these management units. Geographic information systems assist in classifying the management unit in terms of land uses and potential impacts to the system. Sites to be investigated fall within these management units and must be a representative sample in terms of state of the ecosystem (as far as possible) of the entire management unit.

Criteria of habitat presence must be met within each site chosen. The in-stream zone must include at least 4 of the microhabitat types identified in the South African Scoring System which is used in river state investigations (Dickens and Graham 2002). The presence of these criteria determines the length of each site.

Step 2

Site information is noted for each site in terms of geology, hydrology, topography, eco-region and vegetation type. The location, date and time and weather conditions on and prior to the day of sampling must be noted (Table 12-1).

Table 12-1: Site information.

Site Name		
Location	S	E
Date		
Time		
Assessor		
Weather Description		

Step 3

Sites are described in terms of valley shape, channel shape, connectivity, types of bars in-stream, bank shape, bank slope, bed compaction and sediment matrix (Table 12-2).

Table 12-2: Site description.

Site Description	
Valley Shape	
Channel Shape	
Connectivity	
Types of Bars In-stream	
Bank Shape	
Bank Slope	
Bed Compaction	
Sediment Matrix	

Step 4

Sites are separated into the in-stream zone and the riparian zone which are then further separated into the various microhabitats and the marginal and non-marginal areas respectively. Physical characteristics of each zone are determined.

The in-stream zone characteristics are identified by determining the mean characteristics within each microhabitat. These characteristic measures include physio-chemical parameters, algae growth, odour, colour and surface water quality. Other in-stream characteristics include marginal bank modification, connectivity (Table 12-3) and in-stream invader native and alien flora

Table 12-3: Physio-chemical characteristics of each habitat unit.

Physical Characteristics for each Habitat Unit							
	1	2	3	4	5	6	Average
Habitat Unit Description							
pH							
Conductivity							
Dissolved Oxygen							
Algae Growth							
Colour	Type:						
Odour	Type:						
Surface Quality	Type:						

The percentage change from a natural state in the riparian zone is determined by observing the transformed cover type, invader native and alien flora and erosion. The guideline found in Braid (2014) should be used as a starting point for the identification of invader native and alien flora. A map of transformed areas such as impervious surfaces, paths, grazing damage and other transformation within a 50m by 50m area is made (Figure 12-1). This map together with aerial photographs (Google Earth) and GIS are then used to determine the proportion (%) of transformed cover in the area. This indicates the level of transformation from natural conditions. For the invader native and alien faunal and erosion assessment the same riparian zone must be observed and a general distributional characteristic description must be made (Table 12-4; Table 12-5). Floral species identified as significant must be listed. Again, these observations must be used with aerial photographs to obtain the proportion of invader native and alien flora and erosion in the riparian zone. Additional observations include marginal vegetation, biotic response (with descriptions), in-stream and riparian connectivity, erosion and bank transformation (Table 12-6).

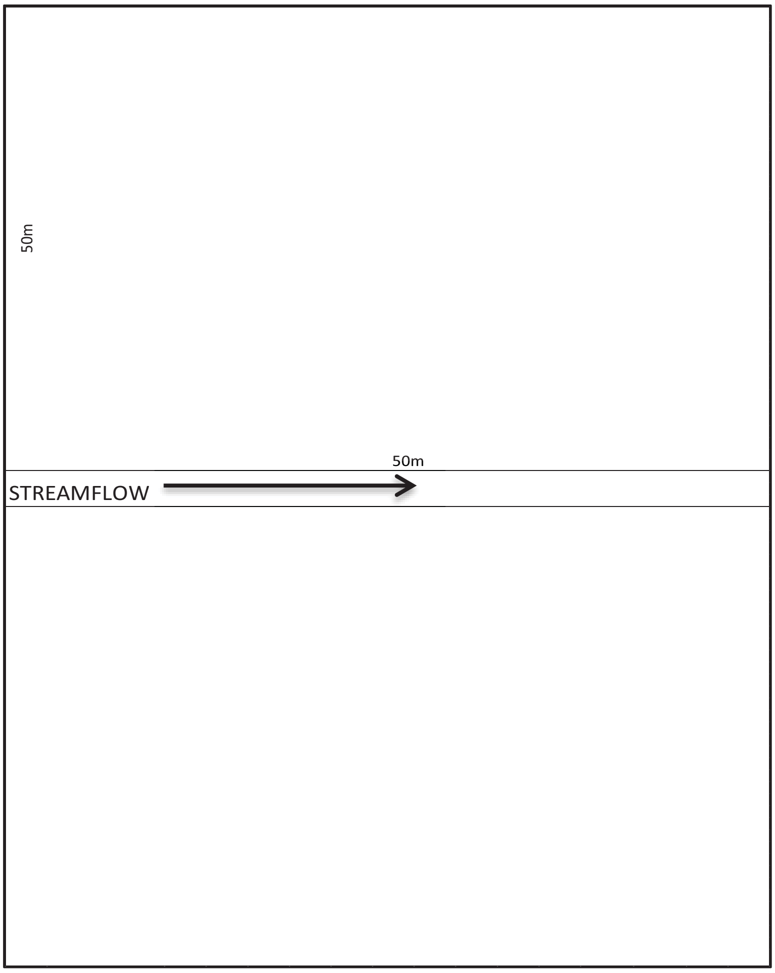


Figure 12-1: Riparian zone cover type.

Table 12-4: Erosional characteristics of site

	Erosional Cover Extent				
LEFT ZONE (facing downstream)	**=>70%**	**>30;<70%**	**>10;<30%**	**>10%**	**None**
Present					
Reference					
RIGHT ZONE (facing downstream)	**=>70%**	**>30;<70%**	**>10;<30%**	**>10%**	**None**
Present					
Reference					

Table 12-5: Invasion native or alien characteristics of site

	Invasion Native and Alien Cover Extent				
IN-STREAM/ MARGINAL	**=>70%**	**>30;<70%**	**>10;<30%**	**>10%**	**None**
Present					

LEFT ZONE (facing downstream)	**=>70%**	**>30;<70%**	**>10;<30%**	**>10%**	**None**
Present					
RIGHT ZONE (facing downstream)	**=>70%**	**>30;<70%**	**>10;<30%**	**>10%**	**None**
Present					

Table 12-6: Physical characteristics of site

Overall Physical Characteristics	
Marginal Vegetation	100 / 75 / 50 / 15 / 0
In-stream Connectivity	None/Moderate/ Extensive
Bank Transformation/ Straightening	None/Moderate/ Extensive
Riparian Connectivity	None/Moderate/ Extensive
Biotic response: Description:	None/Moderate/ Extensive

Step 5

Characteristic measures for both the in-stream and riparian zones are rated in terms of change from preferred conditions and given a score (Table 12-7). The scores are summed and an overall percentage of state of the river habitats is calculated which allows for river classification (Table 12-8).

Table 12-7: Habitat integrity index formulation table.

	Physical Characteristics	**Weight**	**Score Range**					**Score**
			4	**3**	**2**	**1**	**0**	
In-Stream Zone	**pH**	0.85	7.01-7.5	6.61-7.0	6.21-6.6 7.51-8.0	6.0-6.2	>6 or >8	
	Conductivity (micro Siemens)	0.85	0-418	419-2450	2451-7832	7833-11600	>11600	
	Dissolved Oxygen	0.85	>7	5.01-7.0	2.01-5.0	1.5-2.0	<1.5	
	Algae Growth (Nutrients)	0.8	Minimal patches	Small Patches	Moderat e Patches	Large Patches	Extrem e Patches	
	Colour	0.85	No impact	Small	Moderat e	Large	Extrem e	
	Odour	0.85	No impact	Small	Moderat e	Large	Extrem e	

	Surface Quality	0.85	No impact	Small	Moderate	Large	Extreme	
	Biotic Response	1	No		Moderate		Yes	
	Marginal vegetation	0.45	100% veg	15/75 Veg	50/50 Veg	75/15 Veg	No Veg	
	Invasion Native or Alien Fauna	0.45	None	=<10%	>10;<30	>30;<70	=>70%	
	Connectivity	0.65	No		Moderate		Yes	
Riparian Zone	**Concrete/tar/roads /bare earth/ paths/grazing damage/Transformed natural**	1	None	=<10%	>10;<30	>30;<70	=>70%	
	Invasion Native or Alien Fauna	1	None	=<10%	>10;<30	>30;<70	=>70%	
	Erosion	1	None	=<10%	>10;<30	>30;<70	=>70%	
	Bank transformation	1	No		Moderate		Yes	
	Connectivity	0.5	No		Moderate		Yes	
Total Score out of 51.8								
Percentage								

Table 12-8: Transformation chart with corresponding state categories (Kleynhans et al. 2008)

Habitat State Category	Description	State (%)
A	Untransformed natural habitat.	90-100
B	Largely natural with minor transformations from pristine conditions	80-89
C	Moderately transformed from pristine conditions.	60-79
D	Largely transformed with major losses in the natural habitat.	40-59
E	Extensively transformed from natural conditions.	20-39
F	Critically transformed from natural conditions with extreme loss in ecosystem functions	0-19

The classification method assists in monitoring and doing a comparative analysis into the state of habitats within river systems. By taking a comparative approach, this method provides a rapid yet valuable tool in indicating the state of an ecosystem, in terms of habitat integrity, due to changing land use impacts.

13 APPENDIX E: ENVIRONMENTAL VALUATION TECHNIQUES

13.1 THE PRODUCTION FUNCTION VALUATION APPROACH

Production function approach studies quantify values for ecosystem services that contribute at least part of the shadow value of those resources. They apply knowledge of ecosystem functioning and processes to derive the value of supporting and regulating ecosystem services (Mäler 1991, Perrings 2006, Barbier 2000, Barbier 2003, Barbier et al 2009). They do this through deriving the value of ecosystems and the services they provide as intermediate inputs into goods and services that are produced or consumed by economic agents.

In its simplest form, such a production function would have, as dependent variable (or response variable) an ecosystem service, and as independent variables (or influencing factors/determining variables) one or more ecosystem component and/or process attributes:

Ei(t) = f (Sij(t); Xij(t))

Where Ei(t) is a vector of ecosystem services at time t

Sij(t) is a vector of the stock of ecosystem assets and other assets

X(t) is a vector of ecosystem processes and other processes.

The theoretical foundations for the production function approach were pioneered by Mäler (1991). Several production function studies exist in the literature. Barbier (2000, 2006,), focusing on applications of production functions to coastal wetland ecosystems, demonstrated how to value mangrove habitat area as an input into a fisheries production model, both for static and dynamic cases. While this work succeeds in integrating habitat, as a component of an ecosystem, into a fisheries production model, it does not integrate any variables that explain habitat quality. Few production function studies investigate the value of regulating services. Barbier and co-workers (2009) propose a damage function approach to deal with the "natural hazard regulation" function as defined in the MEA, but concludes that much work is required to develop this field.

Building on Barbier's early work Rodwell et al (2003) inserted a habitat quality function into a dynamic fisheries production model for Kenyan off-shore fisheries. Rodwell's work is significant because it demonstrates the application of a system of production functions, as opposed to a single function. This system of functions consists of a catch model, a production model, a recruit transfer model, and a habitat quality model. However, Rodwell et al. (2003) failed to find empirical data to confirm the exact relationship between habitat quality and fish biomass or natural mortality rates, but rather applied simulations to implement the system of production functions.

Chopra and Adhikari (2004) investigated the link between ecological parameters and tourism through studying a wetland in the Keoladeo National Park in Northern India. They use empirical data captured between 1984 and 1988 to model a series of production functions that relate various attributes of ecological parameters to tourist visitation numbers. The resultant production function analyses show that tourist visitation elasticity is high with respect to an ecological health indicator, whereas conflictingly, the results of a conventional TCM study showed that tourists have inelastic demand for ecosystem services. The authors conclude that the conflicting study outputs result from economic valuation typically focussing on short run use values, whereas conservation biologists are more concerned with the underlying long-run conservation value of the system being studied. This is however a spurious conclusion, as the TCM was inadequately specified and did not include appropriate attributes of ecological health as independent variables.

Although the production function approach is theoretically sound, we have a poor understanding of the linkages between management actions and ecosystem functioning; their linkages to the supply of ecosystem services and linkages to the value of these services to humans (Barbier *et al*., 2009). It follows from the above that the formulation of production functions that adequately describe likely consequences of changes in multiple variables of complex systems, requires a combination of expert knowledge and empirical data. This research intends to extend the production function approach to explicitly integrate effects of changes in biological diversity and other ecological factors.

Conclusion

A production function approach to the valuation of supporting and regulating ecosystem services has been proposed by many economists (Perrings 2006, Barbier et al 2009, Dasgupta 2010) as the only valuation methodology through which would address the existing weaknesses in ecosystems service valuation. A production function approach would allow for multiple component or variable inputs into the production functions and thus would better capture key aspects of ecosystems complexity. In addition, it would allow for analysis of marginal impact of a change in the service on the second (or higher) moments of the distribution of output, and therefore improve our understanding of the stabilization effects of regulating services and the underlying importance of biodiversity.

The methodology required for this research therefore needs to extend existing economic production function formulations to internalise ecosystem parameters. This will be achieved through establishing an explicit link between biodiversity and the supply of provisioning and cultural ecosystem services used as final or intermediate products, to be econometrically specified as biodiversity supply functions.

9781431209071