The net economic benefits from eradication of invasive alien vegetation: The case of the Inkomati Catchment, Mpumalanga Province in South Africa

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The net economic benefits from eradication of invasive alien vegetation: The case of the Inkomati Catchment, Mpumalanga Province in South Africa

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DECLARATION

I, Siphokuhle Mahlathi declare that this dissertation, which I hereby submit for the degree of Master of Science in Agriculture, Agricultural Economics at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at another university. Where secondary material is used, this has been carefully acknowledged and referenced in accordance with university requirements. I am aware of university policy and implications regarding plagiarism.

(Ms.) Mahlathi, S.	30 November 2018
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(Tittle) Surname, Initials	**Date**

DEDICATION

This dissertation is dedicated to my son, my mother, my sisters and the rest of the family. Your support is much appreciated.

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Foremost, I thank the loving God who always strengthens me and grants my desires in times of need.

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ABSTRACT

Invasive alien plants (IAPS) in South Africa threaten the functioning of natural ecosystems. In 1995, the national government established a programme called Working for Water Programme (WFW) aimed at eradicating invasive alien plants and their impacts on the economy and society at large. Investment decisions regarding the programme are predominantly based on the societal costs and benefits emanating from the programme, as well as the rate of returns from every R1 invested into the programme. In order to promote sustainable investment and also to curtail widespread invasion by IAPS in the country, it is essential to close the knowledge gap about these costs and to support research aimed at ascertaining the true monetary values of all the benefits.

The specific objectives of the study included applying improved methods and data analysis to measure and value the impacts of IAPS on non-water ecosystem services, particularly carbon sequestration and timber values. The costing structure was also adjusted to account for the opportunity cost of invested capital funds and to consider the social benefit derived from employment opportunities created through the programme.

The study employed several models and quantitative methods to assess costs and benefits associated with eradicating IAPS. The Le Maitre et al. (1996) hydrological model was employed to estimate water benefits (savings) from IAPS removal. The study employed direct and indirect market and non-market valuation methods to assign values to the biophysical impacts of IAPS and their removal on the considered ecosystem services. IAPS clearing cost structures have been adjusted to separate capital investment costs and expenditure on labour wages from other components. The estimated values of costs and benefits of IAPS removal were then used to evaluate the net social and economic worth of the WFW programme investments.

Results of the study indicate that investing in the eradication of alien vegetation in the study area is economically and socially viable, with benefits due to water savings steadily growing, over time, to constitute 100% of total project benefits after completion of eradication activities. Overall, the IAPS eradication project in the study area generates positive Net Present Value (NPV) and greater than one BCR under all tested project funding scenarios. These results suggest that the WFW programme represents a socially worthwhile investment of the country's resources.

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ACRONYMS

ACRU	Agricultural Catchments Research Unit
ARC	Agricultural Research Council
BCR	Benefit-Cost Ratio
CBA	Cost Benefit Analysis
CSIR	Council for Scientific and Industrial Research
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
DAFF	Department of Agriculture Forestry and Fisheries
DWS	Department of Water and Sanitation
FV	Future Value
IAPS	Invasive Alien Plant Species
IAS	Invasive Alien Species
IWMA	Inkomati Water Management Area
IUCMA	Inkomati-Usuthu Catchment Management Area
IPCC	Intergovernmental Panel on Climate Change
IRR	Internal Rate of Return
MAR	Mean Annual Runoff
MP	Mpumalanga Province
MPC	Marginal Private Costs
MSC	Marginal Social Costs
NPV	Net Present Value
PV	Present Value
OECD	Organisation for Economic Co-operation and Development
PBP	Pay Back Period

UNEP	United Nations Environment Programme
WFW	Working for Water

CHAPTER ONE: INTRODUCTION

1.1 BACKGROUND TO THE STUDY

Invasive alien plants (IAPS) in their many forms have severe, unfavourable ecological and economic effects. Invasions by alien plants tend to alter ecosystems as well as important natural processes, including nutrient cycling, soil formation, hydrologic cycles, fire frequency and sediment deposition, resulting in substantial negative environmental and socioeconomic impacts for both current and future generations (Ahimbisibwe, 2009).

Where they invade arable lands, invasive alien plants negatively impact on agricultural productivity as they reduce the availability of soil nutrients. IAPS intensify flooding and soil erosion, leading to increased siltation of dams and estuaries, reduced availability of water, and deterioration in water quality (DWA, 2014; 2015). The problem of IAPS has accelerated in South Africa over the past few decades, with rising human interventions, rapid increase in afforestation and changes in land use (Richardson, 1997). Such invasions inflict high costs on South Africa annually in lost agricultural productivity and resources spent on their removal and control, as well as costs of damages to ecosystems, human health and biodiversity (Chapman *et al*., 2002). At the same time, IAPS have positive impacts on the economy, as in some cases they provide useful products such as firewood to rural communities and services to commercial forestry (Cock, 2003). It is therefore important to consider the various opportunity costs of clearing IAPS when evaluating net benefits derived from their control.

The recognition of the importance of these invasions in South Africa led to the establishment of a national programme called ‘Working for Water’ (WFW) in 1995 to address the problem (DWA, 2015). The South African WFW programme has the reputation of being the world’s most comprehensive initiative to clear IAPS. The main aim of the programme is to eradicate IAPS in order to restore ecosystem services such as water and biodiversity (DWA, 2014). About 750 000 hectares have been cleared of IAPS each year in South Africa over the past 20 years (Versfeld et al., 1998). However, the cost of doing so is huge, estimated at a minimum of R600 million per annum (DWA, 2012), and therefore a great deal of financial investment is needed to achieve the objectives of the programme.

Of particular importance to South Africa is the impact of IAPS on streamflow and hence the country's scarce water resources, as it is a semi-arid country with an average annual precipitation of 480 mm (which is almost half of the world's average annual rainfall of 800 mm) (DWA, 2012). In addition to the reduced availability of water for downstream economic uses, the reduction of runoff by IAPS has important negative impacts on the water reserve for ecosystems' health (Hassan, 2002). The country's most affected areas are the fynbos (shrubland) and grassland biomes (Van Wilgen et al., 2011). Most of the country's surface water originates from these ecosystems, which implies that water resources are particularly prone to these invasions. An equivalent of over 7% (3 300 million m3) of the mean annual surface runoff in South Africa has been claimed by IAPS (excluding their severe impacts on groundwater reserves) (Le Maitre et al., 2000). A recent study by Van Wilgen (2012) estimated the current loss of usable water to IAPS at a much lower figure of 695 million m3, which is equivalent to 4% of registered water use. These invasions, therefore, impose serious economic costs on the country in terms of the value of lost volumes of water, which translates into higher water prices for agricultural and urban users and reduced recreational services (Hosking and du Preez, 2004), as well as costs of required additional water treatment and purification (De Lange and Van Wilgen, 2010).

A number of studies have been conducted on quantifying the impacts of IAPS on surface water runoff and water quantity gains associated with the IAPS control programme in South Africa (Scott and Smith, 1997; Kaiser, 1999; Van Wilgen et al., 2001). Research has also been done on the costs and benefits of the WFW IAPS clearing programme (Hosking and du Preez, 2004; Versfeld et al., 1998; Le Maitre et al., 1996). These studies, however, have generated a very wide range of estimates of streamflow reduction impacts due to large variations in the methods employed for estimating the hydrological losses caused by IAPS infestations (Mallory and Hughes, 2011). In addition to the water saving gains, many other benefits are realised from the removal of IAPS, such as values of conserved biodiversity and other regulating, intangible ecosystem services, and improved productivity and grazing potential of the land. The current study aims to contribute to bridging some of these gaps and improve on the available estimates of the costs and benefits of clearing IAPS.

1.2 PROBLEM STATEMENT AND MOTIVATION OF THE STUDY

IAPS pose a direct threat to the South African environment and water resources by diverting enormous amounts of water from productive uses such as agriculture, fisheries, recreation and other economic use sectors. It is estimated that IAPS cover about 10% of the land area in the country, which is almost equivalent to the size of Gauteng Province, and the problem is growing at an exponential rate (DWS, 2017). The removal of these plants frees up water resources for both human use and the environment. The South African Government has accordingly invested substantial resources in controlling IAPS, at an estimated cost of R600 million annually over a 20-year period since 1995 (DWS, 2017). Further research on the costs and benefits of the programme is, therefore, needed to help policymakers make informed decisions for the efficient allocation of public funds between competing uses. A number of studies have been carried in South Africa to evaluate the economic impact of the WFW programme. The common finding of all studies carried out so far is that the IAPS clearing programme has resulted in a significant increase in streamflow and generated positive economic returns on investment, i.e. benefits of the programme exceeded its costs (Van Wilgen et al., 1997; Marais, 2007; Gillham and Haynes, 2001; Prinsloo and Scott, 2009).

The bulk of previous studies, however, did not account for the impacts on many important ecosystem services (e.g. non-water and non-timber benefits such as biodiversity preservation), and costs (e.g. carbon storage services of trees lost). Another weakness common to these studies relates to their treatment of clearing costs. All the studies, for instance, utilised estimates of total clearing costs, and did not attempt to separate and explicitly include in the analysis expenditure on labour wages as a potential social benefit of these programmes. Similarly, none of the reviewed studies has accounted for the opportunity cost of funds invested (i.e. the capital component), which is a standard benefit–cost analysis (BCA) practice. Secondly, while some consistency is observed in the methods used to quantify water savings from clearing IAPS across these studies, they have significantly diverged in approaches employed to value and measure impacts on water and other ecosystem services. Thirdly, there has been a clear bias in the focus on the Western Cape region, and particularly the fynbos biome. This suggests that large gaps and biases remain in the available empirical knowledge on the net social and economic worth of removing IAPS.

The current study aims to contribute to bridging some of these gaps and improve on the available estimates of the costs and benefits of clearing IAPS. This is achieved by accounting for the opportunity cost of invested funds and the social benefit derived from employment opportunities created, and utilising better measures of the value of other ecosystem services, particularly the timber and carbon sequestration values. The study was carried out in Mpumalanga Province, which is another region covered by the WFW programme operations where no such BCA has been undertaken yet. The Inkomati River catchment has been chosen as the case study area for conducting the intended analysis, as it is one of the catchments most severely affected by alien vegetation infestation in the Mpumalanga Province. Through the above-mentioned contributions, it is hoped that this study will provide a better basis for an enabling policy environment and a sound framework for sustainable eradication and management of IAPS in the country.

1.3 RESEARCH QUESTIONS

This study intends to address the following questions:

1. What difference will accounting for the value of non-water and non-timber ecosystem services make for judging the net economic worth of the WFW programme of removing IAPS?

2. How will adjusting the structure of clearing costs, to reflect the opportunity cost of invested funds and the social benefit derived from created employment opportunities, alter the results of the BCA of IAPS eradication programmes?

1.4 OBJECTIVES OF THE STUDY

The overall objective of this study is to apply improved criteria and methods for measuring the costs and benefits of investing in the WFW programme in the Inkomati River Catchment Area to evaluate its net economic worth in using the country's resources.

To achieve the above-stated main objective, the following specific objectives will be pursued:

1. Apply improved methods and data to measure and value the impacts of IAPS on non-water ecosystem services, particularly carbon sequestration and timber values

2. Adjust IAPS removal programme costing structure to account for the opportunity cost of invested capital funds and consider the social benefit derived from employment opportunities created under the programme

3. Incorporate the improved estimates of costs and benefits of the IAPS eradication (WFW) programme in the intended BCA to evaluate the net social and economic worth of the programme in the Inkomati River Catchment case study area
4. Derive key messages and implications of the results of the BCA for improved policy and management practice for the eradication of IAPS in South Africa.

1.5 HYPOTHESES OF THE STUDY

1. Accounting for the values of non-water ecosystem services of IAPS removal will significantly alter current conclusions on the net economic and social worth of the WFW programme
2. Adjusting the treatment of the various costing components of IAPS removal operations will have a significant impact on results of the intended BCA.

1.6 APPROACH AND METHODS OF THE STUDY

This study will employ several quantitative and qualitative methods to assess costs and benefits associated with eradicating IAPS, as well as to evaluate the social and economic net worth of the IAPS eradication (WFW) programme in the Inkomati River catchment case study area. The study will first adapt the Le Maitre et al. (1996) hydrological model to estimate water benefits (savings) derived from removal of IAPS. Timber benefits from the volumes of removed IAPS will be estimated, based on which, the value of carbon storage services lost as a result will then be derived using a forest ecology approach. The study will employ direct and indirect market and non-market valuation methods to assign values to the biophysical impacts of IAPS and their removal on the considered ecosystem services. IAPS clearing cost structures will be adjusted to separate capital investment costs and expenditure on labour wages from other components. The estimated values of costs and benefits of IAPS removal will then be used to evaluate the net social and economic worth of the WFW programme investments. Widely used project evaluation techniques, such as benefit-cost analysis (BCA) and internal rate of return (IRR), are employed to implement the study. The upper reaches of the Inkomati catchment in Mpumalanga Province have been chosen for implementing this study, for a number reasons explained later, including IAPS infestation levels and relative importance. The study is based primarily on secondary data from various sources, as well as key informant field surveys, including interviews with relevant WFW programme managers. A detailed description of the employed approach and empirical methods will be given in Chapter 3.

1.7 ORGANIZATION OF THE STUDY

This dissertation is organised in 5 chapters. Following the introduction and background to the study given above, the next chapter (Chapter Two) reviews the relevant literature. Chapter Three presents the analytical approaches and empirical methods employed to implement the study, including a brief discussion on key attributes of the case study area, together with sources and methods of data collection. The results of the empirical analyses are presented and discussed in Chapter Four. Chapter Five concludes with a summary of the key findings and implications of the study.

CHAPTER TWO: REVIEW OF RELEVANT LITERATURE ON THE IMPACT OF INVASIVE ALIEN SPECIES

2.1 INVASIVE ALIEN SPECIES AND THEIR IMPACT

The term ‘invasive alien species’ refer to plants, animals, and microbes that are introduced into non-native countries and compete with the indigenous species, and whose introduction results in economic and environmental harm (Department of Environmental Affairs and Tourism, 2004). IAPS by definition are non-indigenous plant species that have been introduced to a new area, have become naturalised, and are able to spread and establish over large areas (Cooper, 2001). These species may not necessarily be damaging in their native habitats; however, when introduced into a new set of climatic and environmental conditions, the characteristics and survival strategies of invasive plant species may result in them having a competitive advantage over indigenous biota. If left uncontrolled, IAPS increase and have a potential to threaten biodiversity by disturbing ecosystem processes while displacing indigenous species.

The invasion of ecosystems by IAPS has gained recognition as an alarming global problem (Ahimbisibwe, 2009). Large areas of the globe have been transformed because of these invasions, leading to many negative impacts on sectors such as health, agriculture, fresh water supply, biodiversity and tourism (Richardson, 1997). Invasive species may alter hydrology, nutrient accumulation, and cycling, as well as carbon sequestration on grasslands (Polley et al., 1997). IAPS can also change the natural landscape by destabilising catchments and thereby increasing soil erosion, changing fire regimes and altering the chemical and physical composition of the soil (Le Maitre et al., 1996). Furthermore, the United Nations Environment Programme (UNEP, 2005) reported that the Millennium Ecosystems Assessment confirmed IAPS as being the primary driver of diversity loss across the globe over the last 50 to 100 years. For these reasons, alien vegetation is considered to be a major threat to global biodiversity (Cooper, 2001).

Less obvious is the impact of alien vegetation on human food security, livelihood security, and general welfare. These pests have spread to almost every human habitation in the world and exist on numerous uninhabited islands as well. This, in turn, has resulted in increased public spending on human health. The control of these species is therefore considered a global public good problem, which calls for action from national governments to protect their citizens and environment from IAPS (Perman et al., 2003). In addition, several rangelands for animal grazing and cultivated systems have declined in terms of productivity due to alien vegetation (Turpie et al., 2016). Of particular importance is the impact of IAPS on water resources, the research on which is reviewed hereunder.

2.2 STUDIES MEASURING IMPACTS OF IAPS ON STREAMFLOW

Although there is a growing body of literature on the biophysical and socio-economic impacts of land invasions by IAPS (Richardson, 1997; Pysek, 1995), the hydrological impacts of these invasions, such as the impacts on surface runoff, groundwater recharge, particularly at stand or catchment scale, have received comparatively little attention in the world (Le Maitre et al., 2014). Exceptions include some studies on the impact of riparian invasions in the United States of America (Doody et al., 2011; Hultine and Bush, 2011), and Salix invasions in Australia (Doody and Benyon, 2011; Doody et al., 2014). Doody and Benyon (2011) quantified water savings derived from removing an invasive plant species known as the willow from Australian streams. The Doody and Benyon (2011) study estimated that, on average, water savings of 5.5 millimetres per hectare annually are potentially achievable through the removal of the willow plant. However, their research highlighted the point that this is only the case when willows are situated instream, implying that water savings are potentially achievable if willows with permanent access to water were to be removed.

Other international studies carried out include those of Hultine and Bush (2011) and Doody et al. (2014). Hultine and Bush (2011) used exploratory research methods to evaluate the impacts of non-native riparian vegetation on water resources in the Southern United States. The Hultine and Bush (2011) study developed a framework that focuses on assessing where and to what extent the establishment of introduced alien species, at varying scales, potentially alters the hydrologic cycle, from individual plants to small river reaches, to entire river basins. The analysis of plant–water relations in the Hultine and Bush (2011) study suggested that many non-native plant species have the potential to establish, or outperform indigenous vegetation along drier regions of riparian floodplains. As a result, the water intake by non-native plants will increase the potential to reduce total basin discharge, particularly along relatively small rivers with low annual streamflow rates.

Because of the country's arid climate and stressed water resources, strong emphasis has been placed in South Africa on the hydrological impacts of IAPS, attracting considerable attention to studying the impacts of IAPS on streamflow reduction (La Maitre et al., 1996; Scott and Smith, 1997; Kaiser, 1999; Van Wilgen et al., 1997; 2001). The cited studies have provided sufficient scientific and empirical evidence indicating that IAPS invasion has resulted in significant reduction in streamflow, especially in mountain catchment areas (Dye and Jarmain, 2004; Prinsloo and Scott, 2009). For example, studies have shown that 695 million cubic meters of water are being claimed by these invasions in South Africa, exacerbating the pressure on an already-stressed state of water security (Van Wilgen et al., 1997). The preliminary results reported in the latter research study comprised a key motivation for the establishment of the government-funded WFW programme (van Wilgen et al., 2001). The results have also been used in setting priorities for investments in control measures so that resources are deployed effectively (Forsyth et al., 2012). Some time ago, Görgens and van Wilgen (2004) reviewed the state of knowledge of the hydrological impacts of IAPS in South Africa. Since then, several additional studies have been undertaken that have advanced the understanding of invasive alien plant water-use and how this affects hydrological processes and river flows.

Three main methods have been used to estimate water gains derivable from controlling invasive alien plants in South Africa. These models have been used to estimate streamflow reduction in the presence of IAPS, after which the water saving is quantified by comparing the streamflow reduction with and without IAPS.

Le Maitre et al. (1996) developed a biomass model to estimate streamflow reduction from the knowledge of forestry water use associated with biomass of invasive plants, relative to the biomass of indigenous plants replaced by IAPS. In this model, biomass is a function of age and vegetation type, and it distinguishes between three categories of biomass, namely biomass of tall alien shrubs, medium alien trees, and tall alien trees.

A second method used to model streamflow reduction due to afforestation is known as the Agricultural Catchments Research Unit (ACRU) model (Smithers and Schulze, 1995). Latterly, the ACRU model has been extensively used to model the hydrological impacts of IAPS (Jewitt et al., 2009). The use of this method is largely applicable to those IAPS that are not situated in riparian zones and consist of medium-tall trees (Mallory and Hughes, 2011). Its disadvantage is that it represents the lower limit of streamflow reduction attributable to

IAPS, since it assumes a fixed rotation period in forestry simulations (Mallory and Hughes, 2011). In terms of streamflow reductions attributable to IAPS, this is a shortfall in the model since IAPS reach maturity and therefore could remain in place, resulting in higher streamflow reduction than afforestation does.

The Pitman model (the water resources simulation model-WRSM (2000)) which uses the above biomass model of Le Maitre et al. (1996), but allows for both riparian and upland alien vegetation, represents a third method employed for estimating the impacts of IAPS on streamflow in South Africa. This method has been criticised on the grounds that it is not clear how it distinguishes between these two categories of vegetation types. The main disadvantage of the model is that it models IAPS as only having access to water from the quaternary catchment in which they are situated, while in reality, IAPS located on the main stem of a river will also have access to water from upstream catchments. An assessment of the streamflow reduction associated with IAPS estimated using this model has shown that this model underestimates streamflow reduction attributable to riparian IAPS, at least when compared with other estimates (Mallory and Hughes, 2011).

2.3 GLOBAL STUDIES ESTIMATING THE ECONOMIC BURDEN OF IAPS

Several studies on the economic impacts of invasive species have emerged since the 1990s (examples include Pysek, 1995; Sandlund et al., 1996; Richardson, 1997; and Scott and Smith, 1997). These studies have reported that the invasion of ecological systems by non-indigenous species is alarming as a growing global problem, and it is therefore necessary to control such species. The increase of invasive species is argued to have become the second biggest threat to biodiversity, after habitat transformation (Pysek, 1995, Sandlund et al., 1996; Richardson, 1997).

The Office of Technology Assessment (OTA, 2012) of the United States of America has estimated damage and control costs of IAPS for the US at more than US$ 257.8 million, annually. Wise et al. (2012) estimated expenditure on research and control of IAPS in Great Britain to be about GBP 17.4 million (US$ 29.7 million) per annum. In Canada, economic losses amounting to US$ 213.5 million per year in fisheries, agriculture and forestry production due to IAPS were estimated, using direct and indirect costs (including control costs, reduced yield, reduced land value, tourism and health care costs) (OTA, 2012). In

2003, New Zealand had a bio-safety annual budget of US$ 44 million, while China allocated a budget of US$ 3,231.4 million for IAPS eradication in 2004 (Xu et al., 2004). Although the impact of IAPS has been defined slightly different by the above-cited studies, these studies all concur that IAPS have caused significant economic losses.

The economic impacts of IAPS discussed above include damage costs on production, biodiversity loss or habitat change, and the costs of their control. Given that the damage costs are difficult to compute, the measure of effort committed to the control of IAPS has been used as a good indicator of adaptation costs (Ahimbisibwe, 2009). Some economic studies, however, have attempted to include biodiversity values in their analyses, reporting substantial economic costs of biodiversity loss (Turpie and Heydenrych, 2000; Higgins et al., 1997). Other studies have estimated damage costs of IAPS in a number of African countries, excluding the costs to biodiversity (Doody et al., 2011). There have also been a number of studies undertaken that incorporate estimates of both impacts and control costs to inform benefit–cost analyses (BCA) of a given eradication programme, as well as to inform future management strategies (Wise et al., 2012; van Wilgen, 2012).

2.4 STUDIES ON THE ECONOMIC IMPACTS OF IAPS IN SOUTH AFRICA

As noted above, substantial research has been conducted on quantifying the impacts of IAPS in South Africa, particularly on surface water runoff. Because of the county’s climate, the literature on the economic impacts of IAPS on water resources in South Africa has grown, leading to series of studies being conducted on the economic impacts of the WFW IAPS control programme, as indicated below.

In Table 2.1 below, we separate research on the economics of IAPS removal in South Africa into two main groups. The first set of studies focused on clearing costs only, without assigning economic values to the benefits arising from such programmes (e.g. value of water saved). The second group of studies attempted to value and compare both benefits from, and costs of, IAPS clearing efforts. The cost-based assessments derived estimates of costs of increasing water supply by removal of IAPS at catchment and national levels (La Maitre et al., 1996, 2000; Versfeld, 1993). The bulk of cost-based studies, however, attempted to evaluate cost effectiveness of the WFW programmes, compared with alternative water supply options (van Wilgen et al., 1997), as well as in terms of the effectiveness of various clearing operations and strategies (Le Maitre et al., 2000; Marais and Wannenburgh, 2008; van Wilgen et al., 2010, 2012). The cost of controlling IAPS in South Africa was estimated to have been R60 million annually, over a 20-year period since 1995 (DWA, 2015). In addition, South Africa spent over R41.1 million (US$ 1.6 million per annum in 2012 values) on biological control research (van Wilgen et al., 2011). Most cost effectiveness studies, however, concluded that current IAPS removal operations and programmes have achieved only partial success and need to change strategy by targeting priority species and locations on the basis of density of infestation and ecological sensitivity (van Wilgen et al., 2012, 2011).

The second group of studies employed the BCA framework to assess the economic net worth of investments in IAPS clearing programmes (see Table 2.1). Almost all the studies listed in Table 2.1 concluded that the benefits of IAPS removal programmes have exceeded their costs. Where IAPS clearing investments showed inefficiency (i.e. negative present value of net benefits (NPV), the authors warned against not accounting for IAPS impacts on the flows of many other ecosystem services (e.g. nutrient cycling, protection against fire damages and biodiversity loss, and carbon sequestration values) (Gillham and Haynes, 2001; Du Plessis, 2002; Hosking and du Preez, 2004; Marais and Wannenburgh, 2008; Mudavanhu et al., 2017).

As Table 2.1 shows, some studies attempted to include values other than water yield benefits in their analyses, such as lower agricultural productivity and land values, downstream timber processing benefits, biodiversity values and lost products and services of the original vegetation replaced by IAPS, and carbon values[1] (Higgins et al., 1997; Turpie and Heydenrych, 2000 and van Wilgen et al., 2011; Mudavanhu et al., 2017). None of these studies, however, combined all costs and benefits of IAPS in one comprehensive assessment.

A number of gaps have been identified when reviewing the above literature. Firstly, one weakness common to studies evaluating the economic net-worth of IAPS eradication (WFW) programmes relates to their treatment of clearing costs. All the studies, for instance, utilised estimates of total clearing costs, and none of them attempted to separate and explicitly include in the analysis expenditure on labour wages as a potential social benefit of these programmes[2]. Similarly, none of the reviewed studies has accounted for the opportunity cost of funds invested (i.e. the capital component), which is a standard BCA practice. Secondly,

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1 Other studies that accounted for carbon values in SA analysed the environmental values of, primarily, plantation forestry and did not focus on IAPS vegetation (see Hassan, 2002; De Wit et al., 2001).

2 Some authors have evaluated the social benefits of the WFW program separately in terms of number of jobs created, capacity building, and health benefits, among others (DWAF, 1997; Marais, 2007).

while some consistency is observed in the methods used to quantify water savings achieved from clearing IAPS across these studies, they have significantly diverged in the approaches employed to value and measure the impacts on water and other ecosystem services. Most of the studies that attempted to account for non-water values relied on hypothetical scenarios on potential streams of costs and benefits considered in simulation modelling exercises, including rates of removal and regrowth of IAPS, and rehabilitation of cleared areas (Gaertner et al., 2012; Turpie and Heydenrych, 2000; van Wilgen et al., 2008; Mudavanhu et al., 2017). Thirdly, the bias in the focus on the Western Cape region, and particularly the fynbos biome, is clearly evident from Table 2.1. The current study aims to contribute to bridging some of these gaps and improve on the available estimates of the costs and benefits of clearing IAPS by accounting for the opportunity cost of invested funds and the social benefit derivable from employment opportunities created, and by utilising better measures of the value of other ecosystem services, particularly the timber and carbon sequestration values. The study was carried out in the Inkomati River Catchment in Mpumalanga Province, which is another region covered by the WFW programme operations and where no such BCA has been undertaken yet.

The following table shows a number of studies carried out on the economic impacts of IAPS eradication in South Africa.

Table 2.1: Studies on the economic impacts of IAPS clearing in South Africa

Purpose / methods used	Values estimated & compared		Indicators/measures (case study area)	Sources (studies)
	Programme costs	Programme benefits		
Cost of water supply	Direct clearing costs (ZAR)	Amount of water saved/supplied (m^3)	ZAR/m^3 (costs of clearing IAPS in ZAR & amount of water lost due to streamflow reduction in m^3- Western Cape/National)	Le Maitre et al. (1996 & 2000) Versfeld et al. (1998)
Cost effectiveness of water supply & clearing operations	Direct clearing costs (ZAR)	Amount of water saved/supplied (m^3)	ZAR/m^3 (comparison with costs of alternative water supply options-Western Cape/Eastern Cape)	van Wilgen et al. (1997) Hosking & Du Preez (1999)
	Direct clearing costs (ZAR)	Amount of water saved/supplied (m^3)	ZAR/m^3 (comparison with a scenario of delayed clearing of IAPS-National)	Le Maitre et al. (2000)
	Direct clearing costs (ZAR)	Effectiveness of control (area in ha)	ZAR/ha to clear IAPS by species, extent and density of infestation/cover (National)	Marais (2007)
	Direct clearing costs (ZAR)	Effectiveness of control (area in ha)	ZAR/ha to clear IAPS by species, extent & density of infestation/cover (National/Eastern Cape/Kruger National Park)	Van Wilgen et al. (2012a) Van Wilgen et al. (2012b) Van Wilgen et al. (2012)
	Clearing costs (ZAR) & years to clear	Effectiveness of control (area in ha)	ZAR/ha & years to clear IAPS by species, extent and density of infestation/cover (Western Cape)	Van Wilgen et al (2016)
	Clearing & restoration costs (ZAR)	Effectiveness of control & rehabilitation (ha)	ZAR/ha to clear IAPS & restore original vegetation by spp. & extent of infestation/cover (Western Cape)	Fill et al. (2017)
Benefit-cost analysis (BCA)	Direct clearing costs (ZAR)	Value of water saved from IAPS removal (ZAR)	Unit Reference Value-URV (ratio) & NPV in ZAR (KwaZulu-Natal/National)	Gillham & Haynes (2001) Marais & Wannenburgh (2008)
	Clearing & restoration	Value of flower harvests of	NPV in ZAR from alternative options for	Gaertner et al. (2012)

	costs (ZAR)	native fynbos *spp*. (ZAR)	restoring native fynbos *spp.* compared (W. Cape)	
	Direct clearing costs (ZAR)	Value of water & value of extra agric. yield (ZAR)	NPV in ZAR, IRR & BCR ratios (Eastern/Southern Cape)	Hosking & du Preez (2004)
	Direct clearing costs (ZAR)	Values of water, extra yield & fire protection (ZAR)	NPV in ZAR, IRR & BCR ratios (Eastern/Southern Cape)	Du Plessis (2002)
	Direct clearing costs (ZAR)	Simulated values of water, fynbos flowers, & tourism (ZAR)	BC ratio of clearing IAPS from hypothetical area compared to total cost of clearing (Western Cape)	Higgins et al. (1997)
	Direct clearing costs (ZAR)	Values of water, grazing, fynbos wildflower, & tourism (ZAR)	BCR-ratio of the benefits from clearing IAPS to the total cost of clearing (Western Cape)	Turpie & Heydenrych (2000)
	Direct clearing costs (ZAR)	Values of water, fynbos flower, & recreation services (ZAR)	BCR-ratio of the benefits from clearing IAPS to the total cost of clearing (Western Cape)	Turpie & Heydenrych (2000)
	Direct clearing costs (ZAR)	Values of water & ecosystem services of fynbos (ZAR)	BCR-ratio of the benefits from clearing IAPS to the total cost of clearing (National)	van Wilgen et al. (2008)
	Cost of research biocontrol (ZAR)	Values of water & ecosystem services of fynbos (ZAR)	BCR-ratio of the benefits from clearing IAPS to the total cost of clearing (National)	van Wilgen et al. (2004), de Lange & van Wilgen (2010)
	Clearing costs & carbon values (ZAR)	Values of water & products of timber processing activities (ZAR)	NPV in ZAR & URV in R/ m^3 (Western Cape)	Mudavanhu et al. (2017)

CHAPTER THREE: ANALYTICAL APPROACH AND EMPIRICAL METHODS OF THE STUDY

3.1 INTRODUCTION

This study employs the BCA tools to evaluate the social net worth of the IAPS eradication programme in South Africa (i.e. the WFW project). To conduct the intended social BCA, the study not only accounts for the direct financial and economic costs and benefits of the project, but also considers values of indirect non-market environmental impacts of the programme. In addition to the increased streamflow (water savings) benefits, the study estimates other timber and non-timber costs and benefits associated with removal of IAPS. The social BCA framework and empirical methods employed to carry out the investigation and pursue the testing of hypotheses of the study are described in the subsequent sections.

3.2 THE BENEFIT-COST ANALYSIS (BCA) FRAMEWORK AND EVALUATION CRITERIA

The BCA approach is widely used to evaluate and compare the net worth of alternative projects. Projects typically considered cover alternative investment plans for private or public funds, economic policy and environmental management actions, programmes and social choice strategies, among others. BCA approaches were initially applied to appraise public-sector projects, where the social costs and benefits from the generation of (or impacts on) public goods had to be recognised and added to the stream of costs and benefits to be compared. This has distinguished social BCA from financial (commercial) evaluations of alternative private investment plans, which only consider direct financial implications on the decision maker. Social BCA, accordingly, is applicable to situations where environmental externalities (positive and negative) are among the consequences of the projects being evaluated (Perman et al., 2003). As it is the case in this study that the evaluated project has environmental impacts that are non-private, we apply the social BCA approach principles.

The outcomes/impacts of the evaluated alternative investment plans and actions are typically realised over several years to come (project cycle). Therefore, BCA employs the concept of net present value (NPV) to compare the stream of future costs and benefits arising from the projects under consideration. As illustrated on *equation 1,* the length of the project cycle (evaluation period) and the rate at which future flows of expenditures and gains are discounted to the present (discount rate) are the two key arguments in the specification to compute the NPV of a project.

$$\text{NPV} = \sum_{t=0}^{T}(B_t - C_t)/(1+r)^t = \sum_{t=0}^{T}[B_t/(1+r)^t] - \sum_{t=0}^{T}[C_t/(1+r)^t] \quad (1)$$

Source: DEAT (2009)

As Equation 1 shows, the NPV of any project is calculated as the sum of the stream of benefits (B_t) it generates over its cycle of T years, net of costs (C_t), where net benefits (B_t - C_t) from the project at time t (t = 0, 1, …, T) are discounted to the present at the discount rate r. In general, if the NPV of a project is positive (NPV > 0), then the project is considered to be worth undertaking. However, when a choice is to be made between alternative project options, one needs to compare the magnitude of NPVs generated by considered alternatives, with the one generating the greatest value getting the top rank. However, the project with the greatest NPV is not necessarily the most efficient user of scarce resources (Marais et al., 2005). Based on the present value concept described above, a number of techniques have been developed to evaluate and compare alternative project plans, as described below.

3.2.1 The Benefit–Cost Ratio (BCR)

This technique simply rearranges Equation 1 to define the benefit–cost ratio BCR as follows:

$$\text{BCR} = \sum_{t=0}^{T}[B_t/(1+r)^t] \,/\, \sum_{t=0}^{T}[C_t/(1+r)^t] \quad (2)$$

Source: DEAT (2009)

The rule then becomes that projects with BCR > 1 (i.e. generates present value benefits in excess of project costs) are worth undertaking, and the project with the highest BCR is ranked as most important. The main advantage of this criterion is seen in the allocation of a budget across a range of projects or where efficiency is crucial (Marais, 2007). When comparing mutually exclusive projects, however, this method is ineffective (DEAT, 2004).

3.2.2 The Internal Rate of Return (IRR)

The internal rate of return (IRR) index is computed by again redefining Equation 1 above to compute the rate at which the stream of future net benefits should be discounted to produce a NPV of zero, i.e. present values of the stream of benefits and costs are equal.

$$0 = \quad \sum_{t=0}^{T}[B_t/(1+r)^t] \,/\, \sum_{t=0}^{T}[C_t/(1+r)^t] \qquad (3)$$

Source: DEA (2016/2017)

In this specification, one needs to solve for the value of r (instead of computing NPV from Equation 1). The computed value of r is then compared with the chosen social discount rate, and projects that generate an IRR higher than the social discount rate are considered worth undertaking, and the one with the highest IRR ranks top. One weakness of this criterion, however, is the fact that it assumes that cash flows are reinvested at the IRR and it also does not distinguish between projects that differ in size (DEAT, 2004).

3.2.3 Payback period (PBP)

This technique computes the time it will take a project to pay back the initial resources invested. This is another alternative to the IRR, in which one solves for T in Equation 3, instead of r. The projects that recover the initial investment outlays faster (i.e. over shorter T horizons) are ranked higher.

It has been largely established that projects that are environmentally related are prone to risk and uncertainty. The values of some environmental factors cannot be estimated precisely. The costs of major projects, for instance, can sometimes be overstated or understated. This is usually called cost optimism or pessimism (Ackerman, 2008). When the measurement of costs and benefits becomes more complex, the future outcomes are likely to be more uncertain (Cooper, 2001). Faced with such risks and uncertainties, it is effectively impossible to provide a precise measurement of the benefits of a project. This is mainly the case when dealing with environmental-related projects which are characterised by large degrees of uncertainties. Estimating the social costs of carbon, for example, specifically depends on the expected values of various uncertainties about precisely how much more rapidly the climate will change. It is therefore important that these shortfalls of a BCA are kept in mind when interpreting and using the results of the analysis of this study. Conducting sensitivity analysis on key determinants of the stream of benefits and costs will be important for determining how the final net benefit figure varies if costs or benefits are increased or decreased by a certain percentage.

3.3 EMPIRICAL METHODS FOR ESTIMATING THE BENEFITS FROM AND COSTS OF REMOVING IAPS

This study considered the following benefits derivable from eradicating IAPS[3]:

1. The value of water saved from lower streamflow reductions attributable to IAPS
2. The value of the timber of harvested IAPS
3. WFW project employment benefits. This is considered in a separate scenario for computing the stream of benefits from the project to include expenditure on labour wages as a social benefit of employment creation.

The above benefits have been compared with the following costs of removing IAPS:

1. Direct costs of IAPS control. These include operating expenditures as well as the opportunity cost of invested capital funds
2. Value of the carbon sequestration services of IAPS foregone.

3.3.1 Estimation of the water quantity benefits derived from removal of IAPS

This study employed a hydrological model to estimate water yield gains achieved from clearing IAPS. Estimates of water yield gains generated by the hydrological model were then used in the social BCA. Data and methods used to estimate water yields and their values are described hereunder. The biomass-based regression model developed by Le Maitre et al. (1996) is adopted in this study to estimate the reduction in streamflow attributable to IAPS, relative to the natural vegetation they replaced, based on total above-ground biomass of the exotic vegetation. The hydrological impact model is specified as follows:

$$\text{Streamflow reduction (mm)} = 0.0238 * \text{biomass } (g/m^2) \qquad (4)$$

Source: Le Maitre et al. (1996)

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[3]Other benefits emanating from alien vegetation control include biodiversity conservation, fire protection, higher land productivity, among other ecosystem services, which have not been included in this analysis due to time and financial limitations.

This equation converts estimates of biomass into estimates of streamflow reduction in millimetre (mm) rainfall equivalents. The biomass is measured in terms of mass of vegetation structure per square meter (volume) (g/m^2).

When calculating water use using this model, each invading tree and shrub species was assigned to one of three biomass categories, namely tall shrubs, medium trees, and tall trees, based on their size when mature, as given in Table 3.1 below.

Table 3.1: Biomass equations of the Le Maitre et al. (1996) model

Vegetation class	**Vegetation structure**	**Biomass equation (gm/m^3)[1]**
1	Tall alien shrubs	$b = 5240 \log_{10}(a) – 415$
2	Medium alien trees	$b = 9610 \log_{10}(a) – 636$
3	Tall alien trees	$b = 20\ 000 \log_{10}(a) - 7060$

Note: a and b in the equations refer to age and biomass, respectively (Le Maitre et al., 1996)

From table 3.1, the streamflow reduction due to alien vegetation can be established, and then the quantity of water that would be saved in the future is calculated.

This study considered streamflow reductions attributable to IAPS that are in excess of those of the original natural vegetative cover to be an environmental externality of exotic plantations. Therefore, the increased streamflow achieved as a result of removing IAPS is considered to be a social benefit. In this study, the social value of this externality is measured as the opportunity cost of water lost to downstream users. Several economic sectors in the study area are affected by the reduction in streamflow due to these IAPS, including the ecosystem reserve. The quantity of water saved is accordingly divided among the various downstream use sectors according to current industry allocations. Finally, to determine the value of the saved water, water quantities made available are valued at the current water tariffs charged in receiving sectors.

The following data is needed to calculate the above values for the study area: (1) Total area invaded by each of the above IAPS vegetation types and their location with respect to the riparian zone, e.g. inside or outside the riparian zone, and (2) Current allocation of available water between users and water tariffs charged for each sector.

3.3.2 Estimation of the timber benefit from clearing IAPS

IAPS provide timber benefits for different purposes, either for commercial or firewood use by surrounding communities. While the removal of IAPS deprives communities of the harvesting firewood benefits from IAPS vegetation, the volume of timber harvested from clearing IAPS provides direct benefits to the society. Because of the difficulty in quantifying the value of firewood used by the surrounding communities in the study area[4], our analysis has only taken into account the value of harvested timber in determining the timber benefit.

Harvested IAPS can be used for different purposes, depending on a number of factors, which include the type of species harvested, the age at which it is harvested, and the extent of the infestation. Each alien species has unique characteristics that allow for the making of certain secondary industry products. Our key-informant interviews with the WFW programme area management revealed that timber harvested from clearing IAPS is given to an eco-furniture company, which processes it into various secondary industry products (e.g. pulp, paper, and furniture). Since the timber derived from cleared IAPS vegetation is given as a donation to the eco-furniture company, the project does not receive revenue from their harvest. Nevertheless, this is considered a benefit indirectly accruing to the society at large, and hence is included in our social BCA.

Timber benefits were calculated by multiplying harvested volumes of different IAPS vegetation type (species) that are utilisable (pine, acacia, and eucalyptus) by the market price received for each of these species. Accordingly, the study required data on areas infested, densities, and prices of the different IAPS vegetation types.

3.3.3 Estimation of employment benefits of the IAPS eradication project

This category of benefits is included in a separate scenario of the NPV calculations where expenditure on labour wages was left out of project costs, as this is considered to represent an employment benefit to the society at large. According to the annual reports (DEA, 2016/17) the alien plant clearing programme provides jobs for disadvantaged people in the surrounding communities. These jobs vary from timber processing into school furniture as well as

[4] Communities also harvest non-timber products from IAPS vegetation (e.g. wild foods, medicinal products, etc.), the value of which have similarly not been included in this study. The value of such timber and non-timber benefits of IAPS to communities represents an opportunity cost of IAPS removal.

harvesting of this timber. It is therefore safe to assume that labour wages are more of a benefit than cost to the society.

Estimation of costs associated with IAPS removal

The WFW programme uses the integrated clearing approach, whereby a mixture of eradication methods are applied in a given area, including mechanical control and chemical and biological control. Eradication techniques applied differ, depending on the type of species being removed and the species' density. Alien vegetation control costs depend on the control method used (mechanical, biological or chemical control). Since the focus of our study is solely on clearing woody species (Pinus, Acacia mearnsii, and Eucalyptus spp.), the mechanical and complimentary chemical control methods usually applied for clearing such tree plants are considered to be the only relevant methods in this study. Although biological control is expected to play a significant role in controlling invasive vegetation in the future, it has not been adopted yet in our study area (as noted in key-informant survey interviews with the WFW programme area manager).

The spread of alien plants is controlled through intensive efforts, commencing with initial clearing, and subsequently followed by a series of follow-up procedures. Initial clearing is the first stage of IAPS control where alien vegetation is removed, while the follow up stages entail the removal of the re-growth of IAPS in an area previously cleared.

The costs associated with the mechanical and chemical control methods include capital costs (i.e. upfront cost of initial clearing), annual operations, and maintenance costs (which include labour, land, herbicides, and other resource management costs), as well as the costs of subsequent follow-up operations. As mentioned above, follow-up costs are costs incurred to avoid regeneration/regrowth of alien vegetation.

This study also estimated the opportunity cost of funds invested in the IAPS clearing programme. Since its start, almost all funding for the WFW programme operations came from public sources. Contributions from other sources, including private entities (i.e. landowners) and some non-governmental organisations (NGOs) have seen a slow growth over the years (Turpie et al., 2016). Regardless of the sources of funding, typical BCA evaluations consider any project to be one option for using financial resources, competing with other available investment opportunities in the economy. This study accordingly attempted to account for this real economic opportunity cost in deriving the various BCA measures.

3.3.4 Estimation of carbon sequestration benefits foregone with the removal of IAPS

Carbon sequestration effected by vegetation, such as trees in forests, contributes to climate mitigation by reducing the negative impacts of higher concentrations of carbon in the atmosphere. The carbon storage benefit is measured as a change in the carbon stock, as carbon in the atmosphere is absorbed by plants in the form of stored carbon. Consequently, the removal of IAPS may impose costs on the environment in terms of reduced carbon sequestering stocks, as trees have higher carbon storage densities than the natural vegetation they replace does. It was, therefore, necessary to consider the value of this ecosystem service in our social BCA.

Different methods have been employed to calculate carbon-storage densities (Harmon et al., 1990; Schroeder, 1992; IPPC/OECD, 1994). These methods range from static to dynamic models. The end results of these models are similar, however, and the only difference is that the dynamic models allow for variability in carbon density of forest biomass among different age groups (Hassan, 2002). In this study, the net change in the stock of carbon stored in the forest is measured using standing timber volumes. Following Christie and Scholes (1995), this study employed the formula set out below to convert timber volumes to carbon-storage densities:

$$C = V_s * D_w * F_c / F_s \qquad (5)$$

Source: Christie and Scholes (1995)

where:

C is tree biomass carbon density in MgC/ ha

V_s is stem wood volume in m^3/ha

D_w is density of wood in Mg/m^3

F_c is the fraction oven-dried mass that is carbon

F_s is the fraction of whole tree biomass per hectare in stem wood.

Carbon lost due to the removal of IAPS was then calculated as the difference between carbon sequestration levels with and without IAPS, i.e. between IAPS and the natural vegetation they replaced. The carbon density parameters for all three species in the study are shown in Appendix III.

3.4 TYPES AND SOURCES OF DATA

All the items of data required for this study relate to the impacts associated with the eradication of IAPS. Data was collected from various secondary sources, including books, annual reports, journals, and departmental websites, as well as policy documents. In addition, formal in-depth interviews were conducted with key informants, especially the WFW project managers and experts. The main purpose of the initial interviews with project managers and experts was to acquire a deeper understanding of the eradication process. In the follow-up interviews with the relevant stakeholders, further insights into more specific WFW programme activities and data were gained.

The types of data collected to allow the application of the empirical methods outlined above include:

1. The area invaded by IAPS and the types of species existing in the study area,

2. Project costs covering expenditure on labour (number of days required to clear one hectare), running costs incurred during the course of the project, and overheads.

   Our key-informant survey in the study area revealed that IAPS clearing activities are funded through annual budget allocations used by each programme/project to contract the services of clearing agents. This implies that the programme does not make initial capital investments in buying equipment and other fixed assets, but rather pays rental on hiring the clearing services required from contractors. Nevertheless, expenditures in hiring labour and other capital services (e.g. mechanical clearing, etc.) are also considered to have an opportunity cost of foregone returns on investing such funds in other alternative income-generating opportunities, including interest on depositing these funds in a bank savings account. Accordingly, this study included the opportunity cost of financial resources invested in funding IAPS clearing activities, at the ruling commercial banks' savings (lending)[5] interest rate.

Data details on the extent, costs, and impact of clearing IAPS were collected directly from interviews with the area project manager and/or extracted from the WFW project Information Management System.

3. Quantities of timber harvested and the market prices of timber. Market prices of commercial timber in South Africa were gathered from the Department of Agriculture, Forestry and Fisheries (DAFF) database for forestry products,

4. Data on the value of water. Values of water were estimated using data on water tariffs imposed on different sectors of water use by the Department of Water and Sanitation (DWS). The hydrological data for the study was obtained from the Department of Environmental Affairs (DEA).

5. The study used a recent estimate of a tax proposed on carbon emissions in South Africa, the implementation of which is under consideration by the government (National Treasury, 2013).

3.5 THE STUDY AREA

This study was conducted in the Inkomati Water Management Area (IWMA), which is situated in the north-eastern part of South Africa, in Mpumalanga Province. The IWMA covers an area of 28 757 km^2, and consists of three main rivers, namely the Komati River, the Crocodile River and the Sabie River. The Komati River rises in South Africa, flows into Swaziland and then re-enters South Africa, where it is joined by the Crocodile River at the border with Mozambique.

5 Based on the assumption that funds used to sponsor clearing activities may be borrowed from commercial banks.

3.5.1 Attributes of the physical climate

Rainfall in the study area is strongly seasonal and occurs mainly in summer (October to April) (DWA, 2012). The mean annual rainfall is 767 mm, ranging from 400 mm to 1000 mm over most of the water management area, reaching close to 1500 mm in the mountainous areas along the cliff (DWA, 2016). The mean annual temperature is 17 °C and maximum temperatures are experienced in January (with an average of 21 °C). Minimum temperatures occur in June, with an average of 11.5 °C. Heavy frost takes place from June to early August, and only the far-eastern parts are generally frost-free.

The mean annual runoff (MAR) from the entire IWMA is estimated at 3 539 million m3/annum (DWAF, 2004). The Komati, Crocodile and the Sabie catchments all encompass areas of high rainfall and steep topography, and most of the surface runoff originates from these areas. There are no natural lakes in the catchment area. Isolated wetlands are found, together with small pan areas in the south-western boundary of the water management area. Reduction in natural runoff is mainly caused by vast commercial plantations and invasive alien vegetation (which covers an equivalent of about 132 000 ha). The impacts of afforestation and alien vegetation on runoff reduction are approximately 53 million m^3 and 38 million m^3, respectively (DWAF, 2004). A total volume of 91 million m^3/annum of water is taken up by alien vegetation in the IWMA, as estimated by DWAF (2004) and distributed as follows:

- Komati West: 7 million m^3/annum

- Lower Komati: 0 million m^3/annum

- Crocodile: 57 million m^3/annum

- Sabie: 24 million m^3/annum

- Sand: 3 million m^3/annum.

3.5.2 Geographical sites selected for the study

The present study is based on four quaternary catchments in the study area, namely the Injaka Dam (X31E), Blyde River/Graskop (X31F), Crocodile (X21C), and Sabie (X31A). The selection of the above catchments in the study area was based on various factors. Firstly, a benchmark was done to ensure that there is reliable cost and water-yield data available on the selected catchments. Secondly, the relative importance of these catchments was assessed to identify priority catchments in Mpumalanga Province. Priority catchments are those that contain important diversity, and have species with significant impacts on water yield and other ecosystem services (Van Wilgen et al., 2011). To ensure variation in observed climatic conditions, two catchments from summer rainfall areas (Komati west and lower Komati) and two from winter rainfall areas (Crocodile and Sabie) were selected.

Injaka Dam is located on the Monte River, a branch of the Sabie River in Mpumalanga Province. This quaternary catchment was constructed as part of the initial phase of the Sabie River government water scheme. The main purpose of the Injaka Dam was to supply water for irrigation and domestic uses in the surrounding communities. It was constructed between 1995 and 2002. Table 3.2 below displays the main characteristics of the selected study sites and the map in Figure 3.1 shows their location.

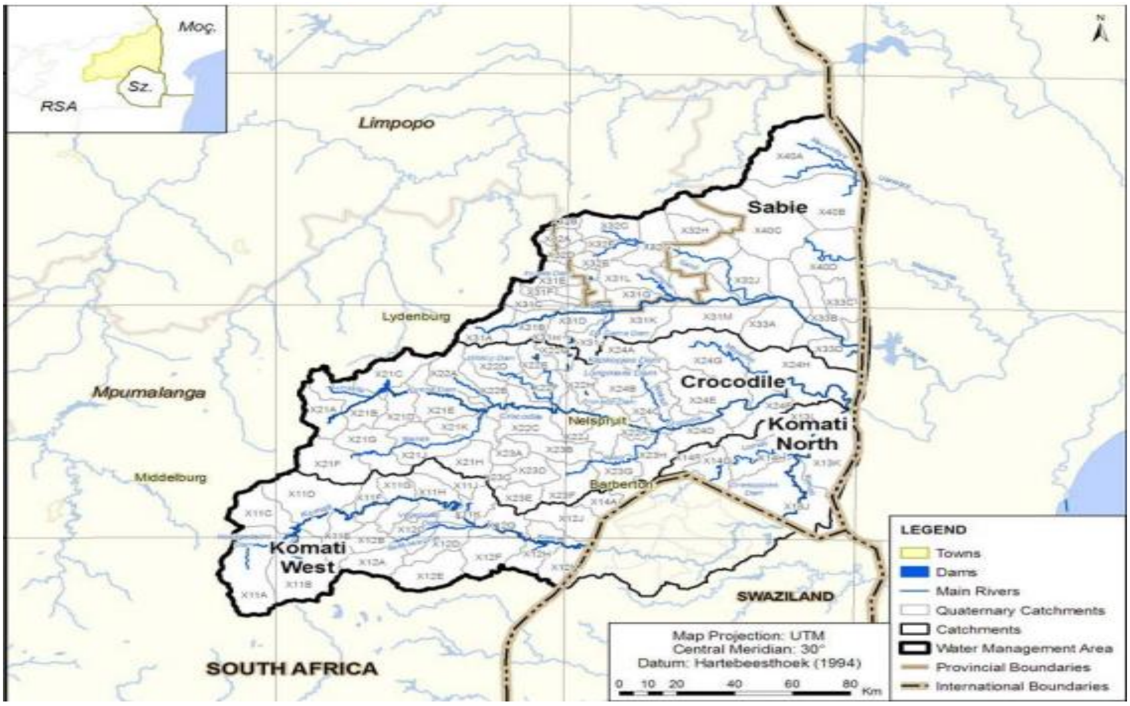

Figure 3.1: Location map of the selected catchments in the study area

Table 3.2: Summary of the main characteristics of the selected study sites

1. Injaka Dam Catchment (X31E)	
Main users	Irrigation/ Domestic
Storage Information	
Estimated storage capacity in million M^3	120 000 000
Live storage volume in million M^3	123 700 000
Mean annual Runoff	
Natural catchment (M^3)	101 000 000
Constructed catchment (M^3)	78 947 000
Yield	**41 200 000**
Area (square Km)	**209**
2. Blyde River Catchment (X31F)	
Main users	Irrigation/ Domestic/ Industrial
Storage Information	
Estimated storage capacity in millionm^3	54.36 000 000 M^3
Live storage volume in million m^3	7.2.1 000 000 M^3
Mean annual Runoff	
Natural catchment (m^3)	378.55 000 000 M^3
Constructed catchment (m^3)	64 345 000 M^3
Yield	**80 200 000**
Area (square Km)	**2000km^2**
3. Crocodile Catchment (X21C)	
Main users	Irrigation/ Domestic
Storage Information	
Estimated storage capacity in million m^3	130 000 000
Live storage volume in million m^3	156 700 000

Mean annual Runoff	
Natural catchment (m^3)	115 000 000
Constructed catchment (m^3)	82 126 000
Yield	**55 300 000**
Area (square Km)	**409**
4. Sabie Catchment (X31A)	
Main users	Irrigation agriculture and forestry
Storage Information	
Estimated storage capacity in millionm^3	172 000 000
Live storage volume in million m^3	180 000 000
Mean annual Runoff	
Natural catchment (m^3)	190 000 000
Constructed catchment (m^3)	101 162 000
Yield	**60 000 000**
Area (square Km)	**502**

Source: DWS (2017)

Although land ownership in the study area is shared among the private and public sectors, it was established from the programme managers that only the public sector, through the WFW programme, is entirely engaged in the eradication of alien vegetation. Only a few private landowners in the study area have been willing to participate in alien vegetation control. For example, in the Crocodile quaternary catchment, only 42 hectares out of the privately owned 860 hectares have been cleared at the farmers' expense. Information on infestation levels in the study area was sought from the local project manager and the research officer, as presented in Table 3.3 below. For the purposes of this study, however, areas of both state and privately owned land were considered in assessing the impact of IAPS eradication in the study area.

Table 3.3: IAPS infestation by type of land ownership in the study area

Landowner	Total area owned (ha)	Area infested by IAPS (ha)
Private Farm Land	37123 (68%)	5 766 (83%)
State land	17470(32%)	1 181 (17%)
Total	**54593**	**6 947**

**Note: Total area invaded = 6 947, 3821 ha of this was cleared between 2008 and 2017, while 2 432 ha were cleared prior 2008. 694 ha are still remaining.*

Source: Project management data (DEA, 2016/2017).

3.5.3 Economic activities in the study area

Economic activities in the IWMA are mainly centred on irrigation and afforestation (commercial plantations) with related industries, and also include a strong eco-tourism industry. A key feature of this water management area is the renowned Kruger National Park, with the Crocodile River forming the park's southern boundary. Due to its well-watered nature, the IWMA groundwater utilisation is relatively small. Most of the current yield from the Komati River is transferred to the Olifants Water Management Area for power generation.

Various crops are grown in the area, including banana, avocado, macadamia, vegetables, sugarcane, maize, and citrus. Sugarcane is the dominant crop in the area in terms of contribution to the GDP, business output, employment and household income. The impact of any of these crops depends on the hectares planted, coupled with adequate or high water volumes being available for irrigation. The pie chart in Figure 3.2 below shows the irrigation hectares required for each of the above-mentioned commodities in the study area.

Table 3.4: Water requirements in IWMA for the year 2016 (million m3/a)

Sector/ Sub-area	Irrigation	Urban	Rural	Mining & bulk industrial	Power generation	Afforestation	Total local requirements
Komati (W)	21	2	4	0	0	38	**65**
Swaziland	35	1	6	0	0	25	**67**
Komati (N)	215	3	6	1	0	7	**232**
Crocodile	257	35	7	23	0	42	**364**
Sabie	65	22	4	0	0	26	**117**
Total	**593**	**63**	**27**	**24**	**0**	**138**	**845**

Source: DWA (2016)

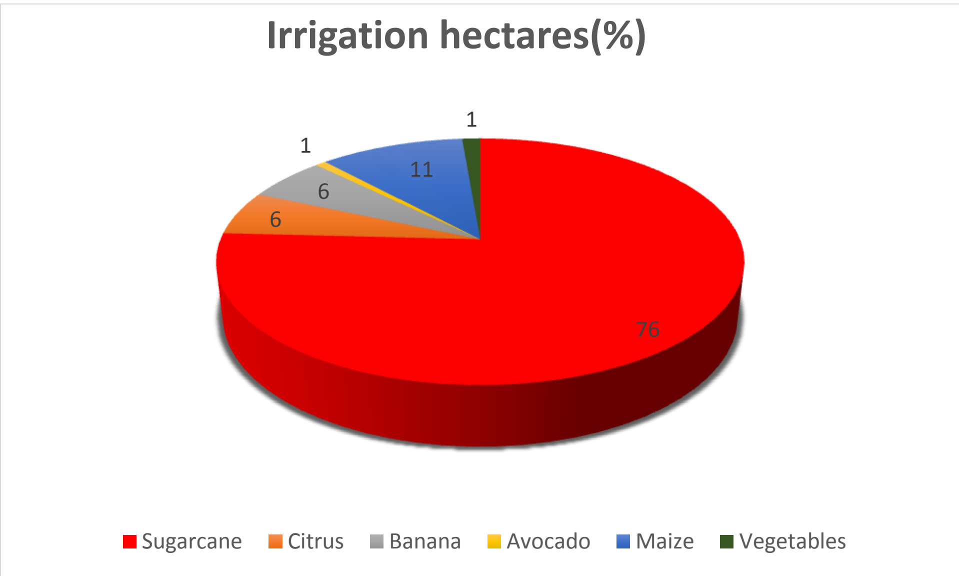

Figure 3.2: Irrigation hectares for different commodities planted in the study area

Source: DWS, 2017

As shown in Figure 3.2, sugarcane takes up the largest area planted in the study area, equivalent to 28 850 ha (76%) followed by maize occupying an area of 4000 hectares (11%) (DAFF, 2016). Citrus and banana both take an area of 2200 (6%) hectares each. Avocado is the least-planted crop, occupying an area of 300 ha (1%), with vegetables ranking just above that, with an area of 500 hectares (1%) (DAFF, 2016).Commercial plantation forestry is practised extensively in the high rainfall areas at the upper reaches of the IWMA. Streamflow reduction by forestry operations constitutes the second highest use of water in the study area. A number of zones in the area have sizeable hectares under both pine and gum tree plantations. Most of these plantations are concentrated in the rural areas where unemployment is high, with scarce alternative economic activities.

A sugar mill in Komati and sawmills for the commercial forestry operations (paper and pulp) comprise the two major industrial operations in the study area. The Ngodwana pulp and paper mill is one of the largest mills in the southern hemisphere (DAFF, 2016). It is worth noting that the pulp and paper and sugar industries are large water users in the study area.

Figure 3.3: Komati River before clearing

Source: DWA, 2012

CHAPTER FOUR: RESULTS OF THE EMPIRICAL ANALYSES

4.1 INTRODUCTION

This chapter presents and discusses results of the social BCA of the economic impacts of IAPS and the net worth of investments in the WFW programme for their eradication in the upper parts of the IWMA. The study covered a total area of 54 593 hectares, of which 12.7% or 6947 hectares, are densely infested with IAPS. Little information was available on IAPS clearing activities in the study area for periods prior to 2008, with major gaps in key elements of the data that is required to implement the intended BCA. However, the WFW project managers in the study area have better records on IAPS clearing activities conducted after 2008. We were able to get access to information on the various project operations for the period from 2008 to 2017. This study therefore implemented the analysis for the period following 2008.

4.2 COSTS OF CLEARING IAPS IN THE IWMA

4.2.1 Direct costs of removal

The spread of alien plants is controlled through intensive efforts, from initial clearing followed by a series of follow-up procedures as shown in table 4.1 below. Initial clearing is the first stage of IAPS control, while follow-up stages entail the removal of the re-growth of IAPS in an area previously cleared. It has also been noted that this study solely focused on woody species (Pinus spp., Acacia mearnsii, and Eucalyptus spp.), and hence the mechanical control approach is the only relevant method in clearing these plants in the study area.

Information on the costs of alien vegetation control in the study area, at 2017 prices, was obtained from the project management team and was averaged for a nine-year cycle (of the available data), covering the initial stage and the typical seven subsequent follow-up clearing stages[6], plus a final maintenance year (see Table 4.1 below).

In the initial phase of the clearing, the total costs are high due to the cost of hiring mechanical clearing equipment. The initial phase is also very labour intensive due to the relative difficulty of managing invasive vegetation characterised by a high density of growth. In this phase, labour costs amount to R1680/ha, comprising both wages and salaries, which is equivalent to 37 person days at R45.00 per person day per hectare. The major activities at this stage include felling of trees, and moving and packing of wood to a cleared place. Other associated costs such as herbicide applications and hired equipment amount to R1120 in this phase. For the purposes of this study, such costs were not separated according to specific activities.

In the first follow-up treatment, the total clearing costs fell drastically, since at this stage the density of invasion is lower. As the follow-up treatment operations continue, the overall cost of IAPS clearing diminishes, and the average rate of clearing becomes quicker. The quantity of labour required per hectare also declines in a similar fashion until the final maintenance stage is reached, when clearing costs reach their lowest. In the maintenance stage, a very low density of invasion prevails, which is mainly made up of weed seedlings sprouting in the areas previously cleared. Small invasions due to re-growth in new areas are also cleared in this phase. There is a negligible difference in costs incurred between the 7th (final) follow-up stage and the maintenance phase.

[6] In some instances, this is not the case as clearing operations are often delayed for lack of funds, and therefore, cost estimates used in this study may be less accurate as total eradication costs will increase if IAPS are left to re-establish for long. It is also worth noting that, in some quaternary catchments the follow-up treatments go beyond the 7th phase. Since costs incurred in these stages are insignificant, this study considered only 7 follow up treatments.

Table 4.1: Costs associated with eradicating IAPS in the different clearing stages (2017)

Phases of eradication	Labour costs (R/ ha)	Other costs (e.g. equipment costs, chemical cost) (R/ha)	Total Cost (R/ha)
Initial stage	1680	1120	2800
1st follow-up	540	360	900
2ndfollow-up	372	248	620
3rdfollow-up	250	172	430
4thfollow-up	168	112	280
5th up to 7th follow-up	120	80	200
Maintenance stage	114	76	190

Source: All information was provided by the WFW programme area project manager. The figures given represent average costs for all density classes in 2017 ZAR values. Management costs are included in these figures.

The total costs are inclusive of all species selected, although it is necessary to point out that each species contributes disproportionately to the total cost of eradication. As mentioned earlier, this study also accounted for the opportunity cost of funds invested in IAPS clearing activities.

4.2.2 Carbon storage benefits lost with removal of IAPS

Carbon storage is one of the benefits accruing from the presence of IAPS, which becomes a loss upon their clearance. Therefore, this indirect environmental cost of removing IAPS is accounted for as a social cost of the IAPS eradication programme. Carbon lost due to the removal of IAPS was calculated by working out carbon sequestration levels with and without IAPS. Carbon storage densities vary among different vegetation types (e.g. depending on total biomass – see Table 4.2 for details). The proposed tax of R120 per ton of carbon emission in South Africa (National Treasury, 2013) is used to estimate the price of carbon sequestration benefits lost. Carbon values included in the analysis represent two components. The first is the loss of carbon densities stored in the removed IAPS timber stocks. This value is assumed to cease upon completion of clearing activities. A second carbon sequestration benefit lost is the annual capacity of standing IAPS stocks to regenerate if the vegetation is allowed to continue growing, i.e. not removed. This second value is assumed to continue indefinitely into the future at the right measure of tree biomass growth, such as the mean annual increment (refer to Table 4.2 for more details).

4.3 BENEFITS FROM CLEARING OF IAPS IN IWMA

As indicated above, this study accounted for only two benefits derived from clearing IAPS, namely the water saving benefits from lower reductions in streamflow, and the timber benefits from harvested IAPS vegetation. The employment benefits of the project are considered in a separate scenario for calculating NPV, as presented and discussed below.

4.3.1 Benefits from increased streamflow

As indicated in Chapter Three, this study adapted a biomass-based regression model developed by Le Maitre et al. (1996) to estimate the incremental impact of IAPS on streamflow, relative to the original natural vegetation it has replaced (i.e. net change in streamflow reduction). To implement this model, one needs data on: (1) total invaded area and its distribution between the dominant types of IAPS species and age classes, and (2) location of the IAPS vegetation within and outside the riparian area. Data obtained on these attributes are presented in Appendix IV. From the data in Appendix IV, it is shown that the medium alien trees (age structure 2) are the dominant trees, occupying 75% of the total invaded area in the IWMA. The vegetation structure with the highest average age class comprises the tall alien trees at 16 years. According to the literature, streamflow reduction is positively related to the age of the alien plants, and hence rates of streamflow reductions are proportional to the age of alien vegetation (e.g. plant growth) (Le Maitre et al., 2000). Figure 4.1 below depicts the general relationship between alien vegetation growth and consequent streamflow reduction. The curvature of the graph shown in Figure 4.1 indicates a non-linear relationship between IAPS biomass and the amount of water reduced that is concave, i.e. with rapid streamflow reduction initially, and then decelerating towards an asymptote (Hansen, 2000).

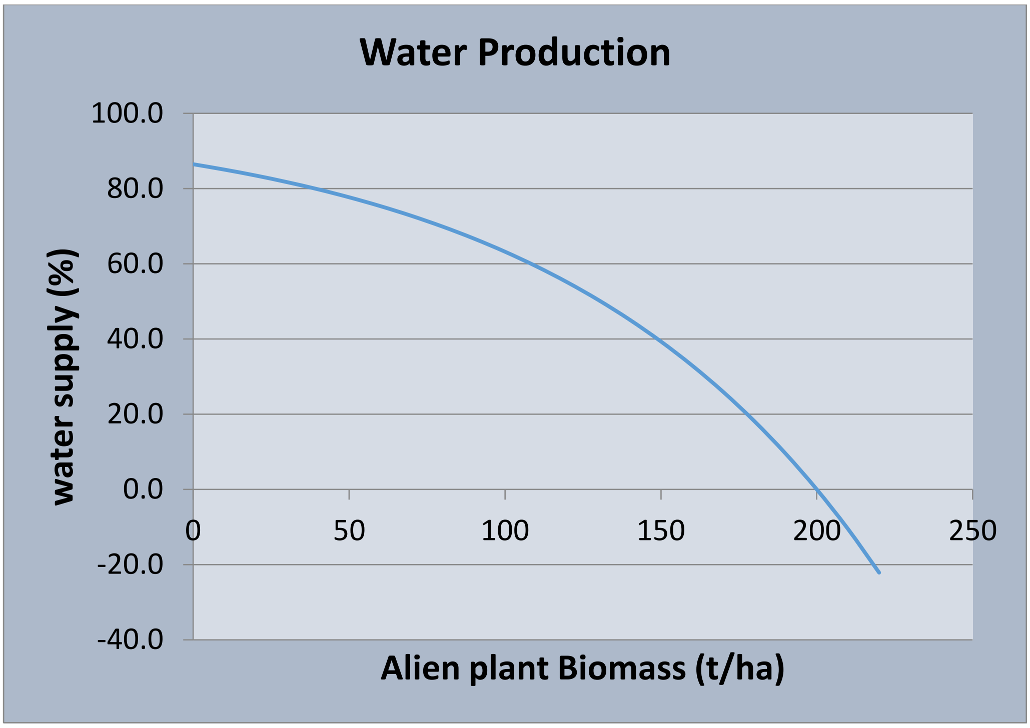

Figure 4.1: Water production in the presence of IAPS

Source: (Hansen, 2000)

The information presented in Appendix IV was used to calculate streamflow reduction associated with the alien vegetation in the study area, details of which are shown in Appendix V. The results of the calculations presented in Appendix V were used to construct the bar graph shown in Figure 4.2 below, depicting streamflow reductions in the study area for the different alien vegetation types.

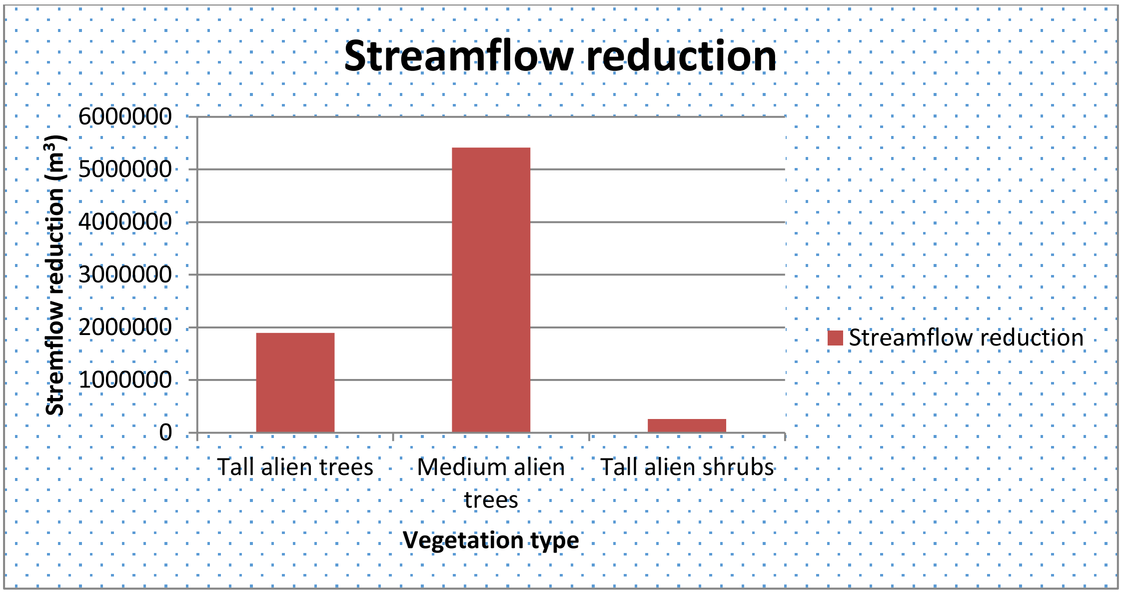

Figure 4.2: Total streamflow reduction (in m3) associated with each alien vegetation structure in the study area

The above graph shows that streamflow reduction effected by medium alien trees is the highest, amounting to about 5,3 million cubic meters, compared with streamflow reduction by tall alien trees (1,8 million m^3) and tall alien shrubs (0.25 million m^3). Total streamflow reduction in the 3821 ha area considered in our BCA is therefore estimated to be about 7, 57 million cubic metres. It is therefore expected that eradicating all IAPS in the said area will increase streamflow by an equivalent magnitude. The yearly increase in streamflow attributable to alien vegetation control depends, however, on the rate of recovery over time and the type of natural vegetation that is re-established (Cooper, 2001). Therefore, the following assumptions were made in order to establish the amount of water which would be saved for utilisation by downstream users.

- In the long run, indigenous vegetation will replace the removed exotic vegetation. The indigenous vegetation will also continue to use water, although at far less rates than was taken up by streamflow reduction caused by exotic vegetation.
- Not all the water saved from eradicating alien vegetation will be readily available for use by downstream economic users of water resources
- The estimated streamflow increase upon removal of IAPS in the study area is thus assumed to proceed as follows: 100% in the first year, 90%, 80%, 70%, 65%, 60%, 55% and 50% for each subsequent year (Cooper, 2011).

Thus, only portions of the 7, 57 million m^3 streamflow reduction due to IAPS in the 3821 ha area will be available for downstream use after eradication of IAPS, following the above ratios, until savings in water flow stabilise at 50% of the increase in streamflow in the long run after full eradication (Le Maitre et al., 2000; Van Wilgen et al., 1997). This amounts to approximately 3,785 million m^3 per annum for use by downstream users in the study area. The above-described pattern of gradual change in water savings has been used to calculate the value of water benefits over the years, based on actual areas cleared annually (see Table 4.2).

The next challenge in determining water benefits is to decide on a monetary unit value of water. The economic value of water differs across different economic uses. Principles of economics suggest that, if water is allocated according to economic efficiency (directed to the use generating highest returns), an efficient market price, equated across use sectors, will be established. Unfortunately, water in the study area is not allocated on the basis of economic efficiency, and accordingly no market mechanism exists to allocate water among competing sectors and to drive the establishment of an equilibrium point where the marginal value of water (efficient price) is equated across sectors. Alternative methods have been applied in such situations, depending on the availability of the data needed (Hassan and Mungatana, 2006). In South Africa in general, water is administratively allocated among use sectors by respective catchment management agencies, according to requirements established on technical bases and strategic considerations.

This study has accordingly followed the simple assumption that the additional water made available as a result of IAPS removal would be similarly allocated. The study assumed that water saved through the eradication programme would be used according to the current water allocation across the different water use sectors in the study area (see Figure 4.3 below). Based on this, the study used the water tariffs charged by the Department of Water and Sanitation (DWS) as at July 2017 across the different sectors as the value of water in the respective use sectors. One should note, however, that this water pricing regime provides a lower bound on water values, as water tariffs in general do not reflect economic prices, and typically contain an implicit subsidy, particularly on major water-use sectors, such as agriculture (Lange and Hassan, 2006).

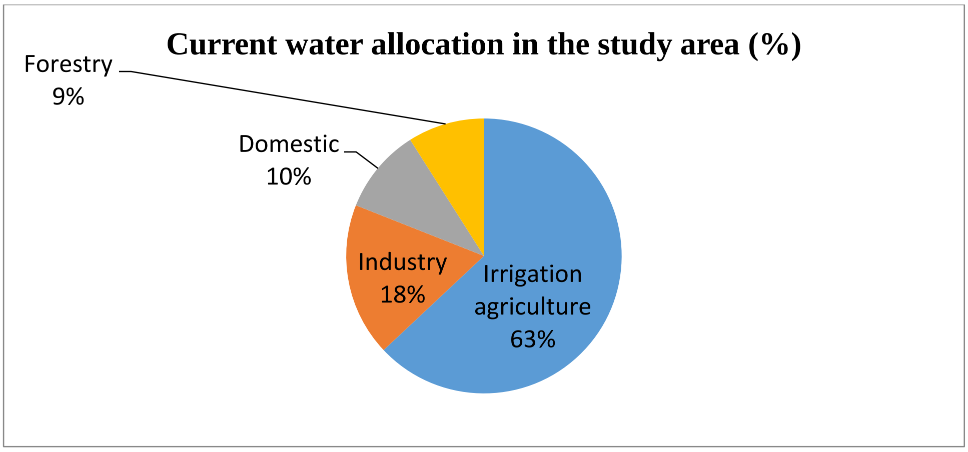

Figure 4.3: Current water allocation in the study area

Source: DWS (2017)

Based on the assumptions made on this study (*Please see detailed explanation on section 4.3.1*), the estimated amount of water available for utilisation (3,785 million m^3) is allocated among use sectors, following the current water allocations shown in Figure 4.3, with irrigation taking the largest share of the total available water (63%), followed by industry (18%), domestic (10%), and forestry (9%)[7]. This is in line with the existing literature on the demand of water resources in the area, with Agriculture recognised as the biggest user of water in the study area.

4.3.2 Benefits from Harvestable Timber

Data obtained from the WFW programme area management on the extent of IAPS in the study area indicate that the most dominant species is Acacia mearnsii, which makes up to 52% (2001 hectare) of the infested area. In calculating the value of timber in monetary terms, it is necessary to highlight the fact that each species is priced differently according to its value; hence, the average prices per tonne for the different timber species were used for this analysis.

According to the interview with the project manager, it was estimated that an average of 20 to 35 tonnes of timber per hectare in a densely invaded area could be extracted in the initial

7 One should note that forest plantations are typically situated upstream; hence, this assumes (theoretically) that such additional allocations of water to these activities can only be effected through some mechanism of licencing or other enabling policy regimes. However, the allocation of their share to industry or domestic uses will not alter the total value, as the same tariff rates are charged on these.

stage of eradication. The amount of timber extracted at any given time depends on various factors. These include the condition and location of the timber. The quality of timber is also an important factor since it is not financially viable to harvest timber that cannot be processed because it does not meet the required specifications. In those cases where timber of poor quality cannot be extracted because it is not financially viable to do so, the surrounding communities were allowed to use it for firewood. Moreover, it is necessary to mention that certain alien woody species have become a valuable source of firewood in the surrounding communities of the study area, especially where they occur in dense stands. The most important species used for firewood in the study area was the Acacia Cyclops (DEA, 2016/2017). However, this species has not been used for commercial exploitation and therefore this benefit will not be taken into account. Although it is difficult to quantify the value of timber used for firewood by these communities, it is clearly one positive externality that is not usually included in analyses.

Based on these facts and assessments by project management (*from project management data*), a more accurate average rate of extraction in the initial stage of clearing is estimated to be 25 tonnes per invaded hectare. The tonnages of timber harvested in subsequent follow-up and maintenance phases are derived according to the proportion of costs in those phases, relative to the initial clearing stage.

Table 4.2 presents estimates of the volumes of timber harvested, water saved, and carbon stocks lost over a 20-years cycle as a result of IAPS eradication activities conducted in the study area since 2008 using Net Present Value. Information obtained from project management in the study area indicates that a total of 3821 ha had received initial clearing treatment between 2008 and 2017. The volumes of IAPS timber harvested in the initial and subsequent clearing stages have accordingly been computed over the 20-year cycle. The consequent impacts of IAPS removal on streamflow and carbon stocks were then calculated by employing the above-mentioned assumptions and scenarios, as explained in respective appendices. As Table 4.2 shows, no timber benefits are expected to be realised (i.e. zero harvests) after 2025, as the area initially cleared in 2017 completes its final (maintenance stage) by the year 2025, since clearing activities continue for 8 years after the initial phase, as discussed above. However, the water saving benefits will continue infinitely after all IAPS are cleared by 2025, at the 50% level of streamflow reduction estimate of 3, 78 million m^3.

While no instantaneous carbon cost is considered after the removal of all IAPS, this study estimated an infinite impact of a long-term opportunity cost of carbon sequestration services lost due to the removal of standing timber stocks. This is based on the assumption that if the IAPS vegetation on the 3821 ha had not been cleared, it would have continued to grow, thereby adding new volumes to the standing timber stocks. Following the estimates used by Hassan (2002) for a similar situation in South Africa, we used an estimate of a mean annual increment (MAE) of 0.014 m3 per ha to compute the annual growth of timber stocks foregone. The estimate of annual timber growth was then converted to incremental (i.e. in excess of the natural vegetation growth potential) carbon mass of 34 MgC ton, as shown in Table 4.2 below.

Table 4.2: Volumes of timber harvested, water saved and carbon stock removed due to IAPS clearing activities in the study area during the 2008–2017 period

Year	Area received initial clearing treatment (ha)	IAPS timber harvested (1000 m3)	Water saved (Million m3)	Carbon mass (1000MgC) ton)
2008	208	7.12	0.41	4.53
2009	210	9.48	0.79	6.02
2010	274	13.27	1.25	8.43
2011	538	24.11	2.18	15.32
2012	667	32.64	3.27	20.74
2013	484	30.64	3.90	19.47
2014	290	25.06	4.07	15.92
2015	**558**	**32.95**	**4.77**	**20.94**
2016	**422**	**30.56**	**5.17**	**19.42**
2017	**170**	**22.53**	**5.06**	**14.31**
2018	0	14.29	4.64	9.08
2019	0	10.91	4.32	6.93
2020	0	8.61	4.12	5.47
2021	0	6.64	3.97	4.22
2022	0	4.81	3.86	3.06
2023	0	3.54	3.80	2.25
2024	0	2.93	3.78	1.86
2025	0	1.55	3.78	0.99
2026	**0**	**0.00**	**3.78**	**0.03**
2027	0	0.00	3.78	0.03
TOTAL	**3821.00**	**281.65**	**70.72**	**179.01**

Note: above estimated over a 20-year project cycle

Source: Authors' calculations

4.4 RESULTS OF THE SOCIAL BENEFIT–COST ANALYSIS

The above-mentioned estimated flows on table 4.2 were used to implement the social BCA for this case study. The first step in conducting any BCA is to specify the planning horizon over which costs and benefits count. Another important determinant of the net worth of any investment project is the choice of the rate at which future streams of costs and benefits are discounted to the present, i.e. the social discount rate. The choices of these two factors are therefore made first, before the various BCA evaluation criteria are derived in subsequent sections.

4.4.1 Selection of the project evaluation period

In the case of a project that involves streams of costs and benefits that continue for some time into the future, a question arises as to how far into the future these financial flows would be likely to persist. Two factors determined the choice of the project cycle length for this study. The first is the period for which sufficient information is available on the IAPS eradication activities in the study area. It is noted above that the WFW project management in the study area provided reliable data on IAPS clearing operations for the period between 2008 and 2017. The second factor relates to the strategy followed for the eradication of IAPS. Regarding the current study, we have knowledge that the IAPS eradication programme needs 9 years to complete it (starting with the initial year of intensive clearing, 7 years of follow-up stages, and a final year for maintenance operations – see Table 4.1). This implies that the last IAPS clearing operation that we had information on in 2017 will complete its final clearing phase by 2025 (after 8 years). Accordingly, a project cycle continuing up to 2025 and beyond has been chosen, as displayed in Table 4.2.

4.4.2 Selection of the discount rate

As the costs and benefits of public projects/policies are often not incurred and accrued simultaneously, BCA follows the standard economic practice of discounting future values to their equivalent value today, referred to as "present value" (Ackerman, 2008). Different discount rates have been used in the literature for project evaluations, ranging from 4% to 8% (Hosking and Du Preez, 1999). However, major disagreements exist among economists as to which rate is appropriate to use, with strong views arguing for the use of lower rates when evaluating projects that take very long to realise benefits (such as investing in climate mitigation), than when evaluating short-term projects (Stern, 2007; Dasgupta, 2008).

The average real interest rate on long-term bonds in South Africa over the last 10 years (2006–2016) was used to discount future values in this study. This rate was chosen in order to obtain an accurate reflection of the rate of return on investments which are low risk and longer term as it applies in the current study. Nominal interest rates on 10-year bonds and rates of increase in consumer prices (inflation) were obtained from the South African Reserve Bank (SARB) to compute an average real interest rate of 8% for the 2006–2016 period. The 8% rate is used to discount future values in this study. However, sensitivity analyses were carried to evaluate the impacts of lower discount rates on the results of the social BCA.

4.4.3 Results of the benefit-cost analysis

This study compared the benefits and costs associated with IAPS eradication activities in the study area over a 20-year project cycle under the following scenarios:

1. In the first scenario, it is assumed that the capital funds used by the project are provided at no cost and that expenses paid as compensation for the services of the labour employed by the project are project costs. Other direct costs and the value of carbon sequestration services are included in the stream of project costs, while the values of both timber harvested and water saved constituted the stream of the social benefits of the project.
2. Scenario two applied all the assumptions of the first scenario, but accounted for the opportunity cost of capital funds invested in the IAPS eradication activities.
3. The third scenario adopted all assumptions of scenario 2, but considered compensation paid for labour services as being a social benefit of employment (job creation) and not a direct financial cost to the IAPS eradication operations.

Table 4.3 below presents the results of the BCA under the first scenario of free capital funding. As explained above, the project under evaluation here represents IAPS eradication activities in the study area, which commenced after 2008 and will continue up to the year 2025. Accordingly, all direct costs (labour & other) and benefits from harvested IAPS timber will cease by completion of all clearing operations in 2025. However, the benefits of mitigating streamflow reduction (saved water) and the potential losses of carbon sequestration services resulting from the eradication of IAPS vegetation will continue beyond

2025. The stream of costs and benefits displayed in Table 4.3 below clearly shows how the water benefits steadily grow over time to constitute 100% of the project benefits by completion of IAPS eradication, while carbon benefits seem to fluctuate at around 30% of total costs over the project cycle.

The results of the BCA under the three scenarios are summarised in Table 4.4 below, with further details being given in Appendix VI. The IAPS eradication project in the study area generates a positive NPV and a BCR larger than 1 under all scenarios, suggesting a socially worthwhile investment of the country's resources. Although the results indicate low sensitivity to discount rates, the fact that the project net worth measures (i.e. NPV & BCR) improve under lower rates of discounting future values reflects the higher returns to investment in IAPS eradication, in terms of the larger water savings benefits, realised at later stages in the project cycle. This also confirms the long-term positive net worth of the WFW programme, as the stream of benefits from water savings, going into the distant future beyond completion of IAPS eradication, is significantly larger than the only opportunity cost of lost carbon sequestration service values is (Table 4.3).

Table 4.3: Results of the benefit–cost analysis excluding capital costs (values in R 000)

Year	STREAM OF COSTS								STREAM OF BENEFITS						NET SOCIAL BENEFITS					
															Including cost of labour			Excluding labour costs		
	Labour	Other	Total direct	Carbon loss	Total social	PV 2008	FV 2027	Carbon % of	Timber	Water	Total benefits	PV 2008	FV 2027	Water % of	Net benefits	PV	FV	Net	PV	FV
2008	269	179	448	418	867	867	3740	48.3	1145	73	1218	1218	5254	6	351	351	1514	620	620	2675
2009	353	177	531	549	1080	1000	4316	50.9	1504	138	1641	1520	6558	8	561	520	2243	915	847	3655
2010	586	279	865	911	1776	1523	6571	51.3	2493	258	2751	2358	10178	9	975	836	3607	1561	1338	5775
2011	875	321	1196	1360	2556	2029	8757	53.2	3722	370	4093	3249	14022	9	1537	1220	5265	2411	1914	8261
2012	1216	600	1816	1891	3707	2725	11761	51.0	5176	572	5748	4225	18235	10	2041	1500	6475	3257	2394	10333
2013	1202	854	2056	1869	3925	2671	11529	47.6	5115	717	5832	3969	17130	12	1907	1298	5601	3109	2116	9131
2014	1043	852	1896	1624	3520	2218	9572	46.1	4444	796	5240	3302	14250	15	1720	1084	4678	2763	1741	7515
2015	1437	731	2167	2236	4404	2569	11089	50.8	6119	976	7095	4140	17867	14	2692	1571	6779	4129	2409	10396
2016	1423	1026	2448	2214	4662	2519	10870	47.5	6058	1130	7188	3884	16761	16	2526	1365	5890	3949	2134	9208
2017	1076	1001	2077	1718	3795	1898	8193	45.3	4701	1165	5866	2934	12664	20	2071	1036	4471	3147	1574	6794
2018	686	736	1422	1115	2536	1175	5070	43.9	3050	1092	4142	1919	8280	26	1605	744	3209	2292	1062	4581
2019	520	471	991	870	1861	798	3445	46.8	2381	1041	3422	1468	6334	30	1561	670	2889	2081	892	3852
2020	1342	958	2300	702	3002	1192	5146	23.4	1922	1014	2936	1166	5032	35	-66	-26	-113	1275	507	2186
2021	259	256	515	555	1069	393	1697	51.9	1518	1001	2519	926	3997	40	1450	533	2301	1708	628	2711
2022	192	176	368	411	779	265	1145	52.8	1125	995	2120	722	3115	47	1341	457	1970	1533	522	2252
2023	154	131	285	309	594	187	809	52.0	847	1002	1849	583	2515	54	1255	395	1707	1409	444	1917
2024	652	486	1138	262	1399	408	1763	18.7	716	1021	1737	507	2188	59	337	98	425	989	289	1246
2025	23	55	78	142	220	59	257	64.5	388	1044	1433	387	1671	73	1213	328	1415	1236	334	1442
2026	0	0	0	5	5	1	5	100	0	1068	1068	267	1154	100	1063	266	1148	1063	266	1148
2027	0	0	0	5	5	1	5	100	0	1093	1093	253	1093	100	1088	252	1088	1088	252	1088
8% Discount rate results																				
Total in R million			22.6	19.2	41.8	24.5	105.7		52.4	16.6	69.0	39.0	168.3		27.2	14.5	62.6	40.5	22.3	96.2
Benefit-cost ratio (BCR)																**1.6**	**1.6**		**2.3**	**2.3**
5% Discount rate results																				
Total in R million			22.6	19.2	41.8	29.5	74.5		52.4	16.6	69.0	47.5	120.0		27.2	18.0	45.4	40.5	27.4	69.1
Benefit-cost ratio (BCR)																**1.6**	**1.6**		**2.4**	**2.4**
2% Discount rate results																				
Total in R million			22.6	19.2	41.8	36.1	52.6		52.4	16.6	69.0	59.0	85.9		27.2	22.9	33.3	40.5	34.3	50.0
Benefit-cost ratio (BCR)																**1.6**	**1.6**		**2.4**	**2.4**

The above results stand as presented in table 4.3, even under the stricter project funding scenario (i.e. capital not free), which requires repayment of the principal amount of funds invested, plus 4% interest on the borrowed funds at the end of every year of operations. The results also indicate how the social net worth of the Working for Water programme increases when expenditure on labour was considered a social benefit, rather than a direct financial cost to the programme (Table 4.4 below).

Table 4.4: Results of the benefit-cost sensitivity analysis

Scenario	Social discount rates					
	8%		5%		2%	
	NPV	BCR	NPV	BCR	NPV	BCR
1. Capital at no cost & wages are expenses	14.5	1.6	18.0	1.6	22.9	1.6
2. Capital at cost & wages are expenses	1.0	1.03	1.6	1.04	2.7	1.05
3. Capital at cost & wages are social benefits	8.8	1.29	11.0	1.30	14.2	1.32

NPV refers to the net present value in 2008 in R million, and BCR is the benefit-cost ratio.

It is clear from table 4.3 and 4.4 above that investment in the eradication of IAPS in the study area pays back its full cost within the 20-year cycle, considering that the lowest BCR for the period was more than 1. This also suggests that this investment generates a rate of return (i.e. IRR) higher than the 8% rate at which the lowest BCR of 1 is achieved (Table 4.4 above). In conclusion, the results of our BCA suggest that the eradication of IAPS produces high social returns that justify the continued investment of public, and even private, funds in these programmes.

One should also note that the above results highly under-estimate the social net worth of the WFW IAPS eradication efforts. First, it is clear that, in the long run, significant net benefits will be realised from the water savings that will be experienced for many years beyond the analysed cycle of 20 years. Moreover, the values of a number of other benefits derivable from IPAS eradication were not accounted for in the analysis. For instance, the above analysis assumes that the land from which IAPS are cleared does not generate any benefits from potential alternative uses, such as livestock grazing and crop farming, or even harvesting of natural products such as wild food and thatching materials. Other potential benefits excluded include biodiversity conservation benefits.

CHAPTER FIVE: SUMMARY, CONCLUSIONS AND IMPLICATIONS FOR RESEARCH AND POLICY

5.1 SUMMARY OF THE PURPOSE, APPROACH AND METHODS OF THE STUDY

The spread of IAPS has accelerated in South Africa over the past few decades as a result of rising human interventions and consequent rapid changes in land use, thereby inflicting high costs on the country. It is estimated that IAPS now cover about 10% of the country, which is almost equivalent to the size of Gauteng Province (DWA, 2016). Negative impacts of IAPS range from lost agricultural productivity to damages to sensitive ecosystems, human health and biodiversity (Chapman et al., 2002). Of particular importance to South Africa is the impact of IAPS on streamflow and hence on the country's scarce water resources. In addition to the reduced availability of water for downstream uses, the reduction in runoff caused by IAPS has important negative impacts on the water reserve for ecosystems' health. The fynbos (shrub land) and grassland biomes, which supply most of the country's surface water, are the most affected (Van Wilgen et al., 2011). A recent study by van Wilgen (2012) estimated the current loss of usable water to IAPS to be 695 million m3, which is equivalent to 4% of registered water use. The value of lost volumes of water translates into higher water prices for agricultural and urban users, reduced recreational services (Hosking and du Preez, 2004), and increased costs required for additional water treatment and purification (Van Wilgen et al., 2008).

To address the problem of IAPS, a national programme for their eradication (WFW) was established in 1995 to restore important ecosystem services such as water and biodiversity (DWA, 2014). About 750 000 hectares of IAPS have been cleared each year in SA over the past 20 years (Versfeld, 1993), at a very high cost of an estimated R600 million per annum (DWS, 2008). A great deal of financial investment is clearly needed to achieve the objectives of the IAPS eradication programme.

Research on the costs and benefits of the programme is, therefore, needed to help policymakers make informed decisions for the efficient allocation of public funds among competing uses. A number of studies have been carried out in South Africa to evaluate the economic impact of the WFW programme. The common finding of all studies carried out so far is that the IAPS clearing programme has resulted in a significant increase in streamflows and has generated positive economic returns on investment, i.e. benefits of the programme exceeded its costs (Van Wilgen et al., 1997; Marais, 2007; Gillham and Haynes, 2001; Prinsloo and Scott, 2009).

The bulk of previous studies, however, did not account for impacts on many other important ecosystem services (e.g. non-water and non-timber benefits such as biodiversity preservation) and costs (e.g. carbon storage services of trees lost). Moreover, none of the studies attempted to separate and explicitly include in the analysis the expenditure on labour wages as a potential social benefit of these programmes. None of the reviewed studies has accounted for the opportunity cost of funds invested (i.e. the capital component), which is a standard benefit–cost analysis (BCA) practice. Secondly, these studies have significantly diverged in the approaches employed to value and measure impacts on water and other ecosystem services. Thirdly, there has been a clear bias in the focus on the Western Cape region, and particularly the fynbos biome.

The present study endeavoured to contribute to bridging some of the above gaps in the literature by accounting for the opportunity cost of invested funds, the social benefit derived from employment opportunities created, and the timber and carbon sequestration values. The study was carried in Mpumalanga Province, which is another region covered by the WFW programme operations, but where no such BCA has been undertaken yet. Being one of the catchments most severely affected by alien vegetation infestation in Mpumalanga Province, the Inkomati River catchment was chosen as the case study area for conducting the intended analysis. A total area of *6 947 ha* was found to be infested by alien vegetation in the study area. Of this total area, *3 821 ha* were cleared between 2008 and 2017, while *2 432 ha* were cleared prior to 2008 (from 2001 to 2007), with *694* ha still remaining. The benefits and costs emanating from the eradication of IAPS in the study area were measured and compared over the 2008–2017 period.

The study employed several models and quantitative methods to assess the costs and benefits associated with eradicating IAPS, as well as to evaluate the social and economic net worth of the IAPS eradication (WFW) programme in the Inkomati River catchment case study area.

The Le Maitre et al. (1996) hydrological model was employed to estimate water benefits (savings) derivable from IAPS removal. Timber benefits from the volumes of removed IAPS were estimated, and based on these, the carbon sink values were computed using a forest ecology approach. The study employed direct and indirect market and non-market valuation methods to assign values to the biophysical impacts of IAPS and their removal on the considered ecosystem services. IAPS clearing cost structures have been adjusted to separate capital investment costs and expenditure on labour wages from other components. The estimated values of costs and benefits of IAPS removal were then used to evaluate the net social and economic worth of the WFW programme investments. A number of well-known project evaluation techniques were applied, namely Benefit–Cost Ratio (BCR), Internal Rate of Return (IRR), Net Present Value (NPV), and Payback Period (PBP). Data was collected from the Department of Environmental Affairs' project management database and was also solicited through in-depth interviews with the WFW project manager and experts.

5.2 RESULTS AND FINDINGS OF THE STUDY

Results of the study indicate that investing in the eradication of alien vegetation in the study area is economically and socially viable, with benefits attributable to water savings steadily growing over time to constitute 100% of total project benefits after completion of eradication activities. Water benefits will continue to be realised, theoretically forever, at zero cost to the society, as all direct (financial) and indirect (e.g. carbon sink benefits foregone) project costs cease upon completion of the IAPS eradication operations.

Overall, the IAPS eradication project in the study area generates positive NPV and greater than one BCR under all tested project funding scenarios. These results suggest that the WFW programme represents a socially worthwhile investment of the country's resources. Higher NPVs and BCRs were obtained under lower rates of discounting future values. This confirms the importance of the water saving benefits, which continue for a long time beyond the life cycle of the IAPS eradication programme. It is also worth noting that the project's social net worth became even bigger when the expenditure on labour wages was considered to be a social (employment) benefit rather than a direct financial cost. This proves the economic and social worthiness of investment in IAPS eradication, even under strict project funding scenarios that require the sourcing of funding from private capital markets, i.e. borrowing at commercial rates of interest.

The IAPS eradication programme in the Inkomati study area generated a social NPV of R14.5 million over the 20-year period considered (at 8% discount rate), giving a BCR of 1.6. These results suggest that investing in the eradication of IAPS in the study area pays back its costs in full, with a large surplus amounting to 60% of the total investment, within the 20-year project cycle considered, and has an IRR much higher than the ruling commercial lending rate of 8%.

Although the foregoing constitutes strong evidence of the economic worthiness of IAPS eradication, the public sector (government) remains the major stakeholder engaged in eradication of IAPS in the study area through the WFW programme, despite the significant share of land (68%) under private ownership. One of the reasons identified for this situation was the fact that private benefits derived from such expensive eradication efforts (mainly value of harvested timber) cease after the first year of clearing. The value of the significant water savings represents the main benefit, which continues for a long time post-clearing, and is viewed as a public good, i.e. enjoyed by the society at large, but does not accrue directly to private agents. This weakens the incentive for private owners to commit to the eradication programme.

5.3 IMPLICATIONS AND RECOMMENDATIONS FOR POLICY AND FUTURE RESEARCH

5.3.1 Raising public resources for funding IAPS eradication activities

The results of this study confirm that IAPS eradication brings large net benefits to society at large, which justifies investing public funds in these programmes. The benefits accruing from the removal of IAPS, however, are not earmarked to fund investment in the WFW programmes. For example, at least part of the revenue collected from tariffs on the extra water saved through the IAPS removal efforts should be earmarked for reinvestment in funding WFW activities.

The fact that the costs and benefits of IAPS clearing are not evenly distributed among different users calls for designing policy measures to ensure a fair redistribution of these costs and benefits. Downstream users, for instance, enjoy the largest share of the water saved and made available for other potential uses as a result of removing IAPS, but without contributing to the cost of IAPS eradicating upstream. The use of an appropriate system of payments for ecosystem services (PES), designed to collect fees from downstream beneficiaries, including farmers, municipal water users (e.g. industrial, services, and domestic), and rural communities, has a potential to raise substantial funds for investments in IAPS removal activities (Turpie et al., 2016).

5.3.2 Improving the incentives for private landowners to participate in IAPS removal

As noted above, despite the fact that about two-thirds of the land is privately owned, the government is the major player in IAPS eradication in the study area. This is simply due to the fact that private landowners upstream have little incentive to bear all the costs of clearing IAPS, while not sharing in the benefits from their activities that are enjoyed by downstream users. It is therefore necessary to design a scheme of economic incentives to promote the participation of upstream private landowners in IAPS eradication. This can be financed through the provision of direct and/or indirect subsidies to these agents, through reduced water tariffs, tax relief, or other appropriate systems or rewards that are directly linked to their IAPS eradication efforts.

5.3.3 Increased awareness and effective stakeholders' cooperation

Good public–private partnerships (PPPs) between government and private agencies are necessary and crucial for projects of such a public nature to succeed. This will require efforts to be made to increase the awareness of all stakeholders of the serious social, economic and environmental negative impacts associated with invasion by alien vegetation, as well as of the benefits derivable from their eradication. A higher awareness of the costs and benefits of IAPS to society at large should lead to more effective co-operation taking place among different stakeholders to collectively manage and control IAPS.

One recommendation for improving the collective management of IAPS is to require all owners of large land areas that are invaded by IAPS to develop a management plan for clearing IAPS. Such plans should ideally involve the establishment of benchmarks that are crucial for monitoring trends and progress made towards achieving lower levels of invasions, and would be of great assistance to and complement the government's public WFW programme efforts. Such management plans have already been formulated by some companies, like Sappi, which plans delineate the areas in which eradication has been carried out, together with the costs incurred. This would also improve the availability of better management data, which has proven to be a challenge in the study area.

5.3.4 Promote alternative IAPS control methods

Appropriate policy incentives and technological interventions are needed to promote the use of alternative measures to control IAPS, particularly biocontrol agents. While such reforms have the potential to increase the efficiency of, and reduce the costs associated with, the mechanical control measures currently being used, their implications for employment must be carefully evaluated. This is particularly important in contexts where unemployment levels are high, such as the Inkomati Catchment case study area, where unemployment is currently sitting at the rate of *forty-five percent*. It is important to note here that one main social objective, and a motivation of the WFW programme, is to create rural jobs.

5.3.5 Invest in further scientific research on measuring the value of non-timber and non-water ecosystem benefits of IAPS eradication

This study endeavoured to account for the value of non-timber and non-water ecosystem services impacted upon by IAPS and their removal. Impacts of IAPS on a number of other ecosystem services, however, remain unaccounted for and future research into these missing values will be necessary to better inform policy makers of the true value of eradicating IAPS.

5.4 CONCLUSIONS

The results of the benefit–cost analyses carried in this study have provided reasonable empirical evidence in support of the continuation of alien vegetation eradication activities in the study area, and in South Africa at large. The IAPS eradication operations in the study area have generated a very high net economic and social worth, even when calculated at high rates of discounting future values. One should note, however, that high discount rates tend to under-value long-term environmental benefits, such as the water saving impacts of IAPS eradication. The major conclusion of this research study is that, given that all benefits of the programme are incorporated and that costs are measured accurately, the eradication of IAPS is socially and economically worth investing public resources in.

Enhancing the strategic planning for the control of IAPS is critically important, given the high cost of these efforts. Currently, the challenges facing the sustainability of IAPS eradication programmes in the study area and South Africa include raising sufficient funding from private and public sources, and introducing incentive systems to encourage higher collaboration and participation of private landowners in the IAPS eradication efforts which are currently driven primarily by the public sector. The study also suggests a number of policy and technological reforms for addressing the said challenges. Gaps in existing scientific knowledge and certain areas have been identified for further research in the future to further secure the effective management and control of IAPS in the country.

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APPENDIX I

Table X1: Area occupied by selected individual species in the study area

Genus	Area invaded (ha)	Condensed area (ha)[1]	Initial density of Invasion
Acacia mearnsii	3612	957.18	0.265
Solanum mauritianum (bugweed)	2917	802.18	0.275
Eucalyptus	180	26.28	0.146
Pinus spp	238	37.13	0.156

1. *The condensed area is the total area adjusted to bring the cover to the equivalent of 100%. For example, 100 ha with 5% cover of alien plants would be condensed to 5 ha with 100% cover.*
2. *The literature shows that the species reported on the above table are considered priority species in the study area (CSIR, 2011). Priority species are selected in terms of their impact on streamflow, biodiversity and ecosystems.*

APPENDIX II

The Four Dominant species in the study area

Figure A.1: Four dominant species selected in the study area (Prio clearing)

Notes: clockwise from top left: Accacia Mearnsii, Solanum mauritianum, Eucalyptus and Pinus spp.

Source: DWA, 2016

APPENDIX III

Estimation of the carbon sequestration services of IAPS

As shown in Table 4.2, different weights are used to convert timber weight to volume for different species. This was necessary since the mass of timber extracted varied among different species. The following task is to convert the timber volumes to carbon storage densities.

Table X2. Parameters for estimation of carbon-densities of IAPS

Species	**Density of wood (D_W in Mg/m^3)**	**Moisture content at harvest (%)**	**Oven –dried carbon mass fraction (F_C)**	**Stem wood fraction (F_S)**
Pine	0.88	85	0.5	0.67
Eucalyptus	0.86	66	0.5	0.70
Average	0.87	75.5	0.5	0.69

Source: Christie and Scholes (1995)

Appendix IV

Average areas invaded by IAPS and age class of alien vegetation within and outside of riparian zones in the Inkomati catchment.

The total area invaded by IAPS **(i.e. 6 947ha)** in the study area was divided into riparian zones **(5210ha or 75%)** and non-riparian zones **(1737ha or 25%).**

Table X3: Average age class of IAPS and area invaded in riparian zones (Area = 5210ha)

Area/Age	**X21C**	**X31F**	**X31E**	**X31B**	**Average(X2,31C,F,E,B)**
Average age class 1	3 years	3 years	3 years		3 years
Average age class 2	8 years	8 years	8 years	8years	8 years
Average age class 3	15 years	16 years		15 years	16 years
Area under class 1	9%	7%	36%		13%
Area under class 2	88%	79%	64%	62%	73%
Area under class 3	3%	14%		38%	14%

Class 1: Tall alien shrubs

Class 2: Medium alien trees

Class 3: Tall alien trees

Table X4: Average age class of IAPS and area invaded outside riparian zones (Area = 955ha)

Area/Age	**X21C**	**X31F**	**X31E**	**X31B**	**Average(X21C,F,E,B)**
Average age class 1	3 years	3 years	3 years		3 years
Average age class 2	8 years	8 years	8 years	8years	8 years
Average age class 3	15 years	16 years		15 years	16 years
Area under class 1	5%	25%	4%	30%	16%
Area under class 2	85%	75%	80%	70%	77%
Area under class 3	10%		16%		7%

**Tall alien trees are: Pinus species, Acacia spp. and eucalyptus spp.*

**Medium alien trees are: Acacia Mearnsii, medium sized eucalyptus, and acacias mixed spp.*

** Tall alien shrubs are: Solanum maurittianus*

(*Source: Project management data*)

Appendix V

Calculating streamflow reduction due to IAPS located in the study area

The following regression was used to calculate streamflow reduction for each vegetation type:

Streamflow reduction (mm) = 0.0238 * biomass (g/m^3)

Table X5: Equations for streamflow reduction

Equations	**Vegetation class**	**Biomass equation (g/m^3)**
1	Tall alien shrubs	$b = 5240 \log_{10}(a) - 415$
2	Medium alien trees	$b = 9610 \log_{10}(a) - 636$
3	Tall alien trees	$b = 20\,000 \log_{10}(a) - 7060$

**a = age*

[*] *b = biomass*

Streamflow reduction in riparian zones

- **Tall alien shrubs occupy13%** of the invaded area on riparian zones, equivalent to **677.3 ha**. The average age of this vegetation class is **3 years**.
  Biomass equation: $b = 5240 \log_{10} (a) – 415$
  Therefore, **b = 2085.1**
  Thus streamflow reduction (mm): 0.0238 (2085.1g/m^2)
  = 49.63 mm
  Converting streamflow reduction (mm) into m^3
  m^3 = mm * area (ha) * 10

m^3 = 49.63 mm * 677.3ha*10

=336 143 .99m^3

- **Medium alien trees occupy73%** of invaded area in riparian zones, equivalent to **3803.3ha.** The average age of this vegetation class is 8 years.

  Biomass equation: $b = 9610 \log_{10} (a) - 636$

  Therefore, b = **8042.69**

Thus streamflow reduction (mm) = 0.0238 (8042.69g/m^2)

= 191.42 mm

Converting streamflow reduction (mm) into m^3

m^3 = mm * area (ha) * 10

m^3 = 191.42mm * 3803.40ha * 10

= 7 280 468.28m^3

- **Tall alien trees** occupy **14%** of invaded area in riparian zones, equivalent to **729.4ha**. The average age of this vegetation class is 16 years.
  Biomass equation: b = 20 000 $\log_{10}$ (a) – 7060
  Therefore b = **17 022.40**
  Thus streamflow reduction (mm) = 0.0238 (17 022.40g/m^2)
  = **405.13mm**

Converting streamflow reduction (mm) into m^3

m^3 = mm * area (ha) * 10

m^3 = 405.13mm * 729.4ha * 10

= 2 955 018.22 m^3

<u>TOTAL STREAMFLOW REDUCTION IN RIPARIAN ZONES</u>

336 143 .99m^3 + = 7 280 468.28m^3 + 2 955 018.22 m^3 = 10 571 630.49m^3

Streamflow reduction outside riparian zones

- **Tall alien shrubs occupy16%** of invaded area outside riparian zones, equivalent to **277.92 ha**. The average age of this vegetation class is **3 years**.
  Biomass equation: b = 5240 $\log_{10}$ (a) – 415
  Therefore, **b = 2085.1**
  Thus streamflow reduction (mm): 0.0238 (2085.1g/m^2)
  = 49.63 mm
  Converting streamflow reduction (mm) into m^3
  m^3 = mm * area (ha) * 10

m^3 = 49.63 mm * 277.92ha*10

= 137 931.70m^3

- **Medium alien trees** occupy **77%** of invaded area outside riparian zones, equivalent to **1 337.49ha.** The average age of this vegetation class is 8 years.

  Biomass equation: b = 9610 $\log_{10}$ (a) - 636

  Therefore, b = **8042.69**

Thus streamflow reduction (mm) = 0.0238 (8042.69g/m^2)

= 191.42 mm

Converting streamflow reduction (mm) into m^3

m^3 = mm * area (ha) * 10

m^3 = 191.42mm * 1 337.49ha * 10

= 2 560 223.36m^3

- **Tall alien trees** occupy 7% of invaded area outside riparian zones, equivalent to 121.59ha. The average age of this vegetation class is 16 years.

  Biomass equation: b = 20 000 $\log_{10}$ (a) – 7060

  Therefore b = 17 022.40

  Thus streamflow reduction (mm) = 0.0238 (17 022.40g/m^2)

  = 405.13mm

Converting streamflow reduction (mm) into m^3

m^3 = mm * area (ha) * 10

m^3 = 405.13mm * 121.59ha * 10

= 492 597.57 m^3

<u>TOTAL STREAMFLOW REDUCTION OUTSIDE RIPARIAN ZONES</u>

= 137 931.70m^3+ 2 560 223.36m^3 + 492 597.57m^3

= 3 190 752. 63m^3

<u>STREAMFLOW REDUCTION IN THE TOTAL (BOTH RIPARIAN AND NON-RIPARIAN) INVADED AREA</u>

10 571 630.49m^3 +3 190 752. 63$m^3$$m^3$ = 13 762 383.12m^3

(Source: Authors' calculations)

APPENDIX VI

Table X6: Comprehensive Benefit-Cost Analysis Results

	Net present value (NPV) calculations - No capital costs																																
	Discount rate										0.08			Total area	3821		Interest rate on equity capital												1.04				
				PROJECT FINANCIAL ANALYSIS																									Net social benefits				
			STREAM OF COSTS				PROJECT FINANCIAL COSTS						STREAM OF SOCIAL COSTS & BENEFITS										Total costs excluding wages				No employment				Including employment		
Year	Year index		Labor cost	Other cost	Total direc	Cummulat	Capital co	Total Proj	PV 2008	PV 2027		Carbon lo	Total socia	PV 2008	PV 2027		Timber be	Water ber	Total bene	PV 2008	PV 2027		Costs	PV 2008	PV 2027		Net benef	PV 2008	PV 2027		Net benef	PV 2008	PV 2027
2008	0.0		269	179	448	448	466	915	915	3948	31.4%	418	1333	1333	5753	6%	1145	73	1218	1218	5254		1064	1064	4592		-116	-116	-499		154	154	663
2009	1.0		353	177	531	979	552	1082	1002	4325	33.7%	549	1632	1511	6520	8%	1504	138	1641	1520	6558		1278	1184	5108		9	9	38		363	336	1450
2010	2.0		586	279	865	1844	900	1765	1513	6529	34.0%	911	2676	2294	9900	9%	2493	258	2751	2358	10178		2090	1791	7731		75	64	278		661	567	2446
2011	3.0		875	321	1196	3040	1244	2439	1937	8358	35.8%	1360	3800	3016	13018	9%	3722	370	4093	3249	14022		2925	2322	10021		293	233	1004		1168	927	4000
2012	4.0		1216	600	1816	4856	1889	3705	2723	11752	33.8%	1891	5596	4113	17752	10%	5176	572	5748	4225	18235		4380	3219	13893		152	112	483		1369	1006	4342
2013	5.0		1202	854	2056	6912	2138	4195	2855	12321	30.8%	1869	6064	4127	17810	12%	5115	717	5832	3969	17130		4862	3309	14280		-231	-158	-680		970	660	2850
2014	6.0		1043	852	1896	8808	1972	3867	2437	10518	29.6%	1624	5491	3460	14934	15%	4444	796	5240	3302	14250		4448	2803	12097		-251	-158	-684		792	499	2153
2015	7.0		1437	731	2167	10975	2254	4422	2580	11135	33.6%	2236	6658	3885	16765	14%	6119	976	7095	4140	17867		5221	3046	13147		438	255	1102		1874	1094	4720
2016	8.0		1423	1026	2448	13424	2546	4995	2699	11646	30.7%	2214	7208	3894	16807	16%	6058	1130	7188	3884	16761		5786	3126	13490		-20	-11	-47		1403	758	3270
2017	9.0		1076	1001	2077	15501	2160	4238	2120	9149	28.8%	1718	5955	2979	12857	20%	4701	1165	5866	2934	12664		4879	2441	10534		-90	-45	-193		987	494	2130
2018	10.0		686	736	1422	16923	1479	2901	1344	5799	27.8%	1115	4015	1860	8027	26%	3050	1092	4142	1919	8280		3329	1542	6655		127	59	253		813	377	1625
2019	11.0		520	471	991	17914	1031	2022	867	3742	30.1%	870	2892	1240	5353	30%	2381	1041	3422	1468	6334		2372	1017	4390		530	227	982		1050	450	1944
2020	12.0		1342	958	2300	20214	2392	4692	1863	8041	13.0%	702	5394	2142	9245	35%	1922	1014	2936	1166	5032		4053	1609	6946		-2458	-976	-4213		-1116	-443	-1913
2021	13.0		259	256	515	20729	535	1050	386	1666	34.6%	555	1604	590	2546	40%	1518	1001	2519	926	3997		1346	495	2136		915	336	1451		1173	431	1862
2022	14.0		192	176	368	21097	383	751	256	1103	35.4%	411	1162	396	1707	47%	1125	995	2120	722	3115		970	330	1426		958	326	1408		1150	391	1690
2023	15.0		154	131	285	21382	296	581	183	791	34.7%	309	891	281	1212	54%	847	1002	1849	583	2515		736	232	1002		958	302	1303		1112	351	1513
2024	16.0		652	486	1138	22519	1183	2321	677	2924	10.1%	262	2582	754	3253	59%	716	1021	1737	507	2188		1931	564	2432		-846	-247	-1065		-194	-57	-245
2025	17.0		23	55	78	22597	81	159	43	186	47.1%	142	301	81	351	73%	388	1044	1433	387	1671		278	75	324		1132	306	1320		1155	312	1347
2026	18.0		0	0	0	22597	0	0	0	0	100.0%	5	5	1	5	100%	0	1068	1068	267	1154		5	1	5		1063	266	1148		1063	266	1148
2027	19.0		0	0	0	22597	0	0	0	0	100.0%	5	5	1	5	100%	0	1093	1093	253	1093		5	1	5		1088	252	1088		1088	252	1088
TOTAL in R million			**13.3**	**9.3**	**22.6**							**19.2**	**65.3**	**38.0**	**163.8**		**52.4**	**16.6**	**69.0**	**39.0**	**168.3**		**52.0**	**30.2**	**130.2**		**3.7**	**1.0**	**4.5**		**17.0**	**8.8**	**38.1**
Percent of total cost/benefit			**58.9%**	**41.1%**	**100.0%**							**29.4%**	**100.0%**				**76.0%**	**24.0%**	**100.0%**														
Benefit-cost ratio (BCR)																												**1.03**	**1.03**			**1.29**	**1.29**
DISCOUNT RATE of 5%																																	
TOTAL in R million			13.3	9.3	22.6							19.2	65.3	45.8	115.8		52.4	16.6	69.0	47.5	120.0		52.0	36.5	92.1		3.7	1.6	4.1		17.0	11.0	27.8
Percent of total cost/benefit			58.9%	**41.1%**	100.0%							29.4%	100.0%				76.0%	24.0%	100.0%														
Benefit-cost ratio (BCR)																												**1.04**	**1.04**			**1.30**	**1.30**
DISCOUNT RATE of 2%																																	
TOTAL in R million			13.3	9.3	22.6							19.2	65.3	56.3	82.0		52.4	16.6	69.0	59.0	85.9		52.0	44.8	65.3		3.7	2.7	3.9		17.0	14.2	20.6
Percent of total cost/benefit			58.9%	41.1%	100.0%							29.4%	100.0%				76.0%	24.0%	100.0%														
Benefit-cost ratio (BCR)																												**1.05**	**1.05**			**1.32**	**1.32**

Source: Author’s calculations

APPENDIX VII

Table X7: Consumer prices and long-term interest rates (SARB, 2017)

Year	Nominal SAGB10 SA	cpi ECPI SA	Real SA
2006-01-31	7.34	3.57	3.77
2006-02-28	7.30	3.88	3.42
2006-03-31	7.48	3.87	3.61
2006-04-30	7.37	3.35	4.02
2006-05-31	7.75	3.34	4.41
2006-06-30	8.64	3.97	4.67
2006-07-31	8.63	4.94	3.69
2006-08-31	8.74	4.89	3.85
2006-09-30	8.58	5.50	3.08
2006-10-31	8.00	5.16	2.84
2006-11-30	7.95	5.48	2.47
2006-12-31	7.76	5.32	2.44

2007-01-31	7.72	5.79	1.93
2007-02-28	7.54	6.07	1.47
2007-03-31	7.77	5.75	2.02
2007-04-30	7.60	6.18	1.42
2007-05-31	7.92	7.08	0.84
2007-06-30	8.40	6.88	1.52
2007-07-31	8.48	6.98	1.50
2007-08-31	8.47	7.07	1.40
2007-09-30	8.16	6.71	1.45
2007-10-31	7.97	7.29	0.68
2007-11-30	8.38	7.86	0.52
2007-12-31	8.35	8.47	(0.12)
2008-01-31	8.62	8.88	(0.26)
2008-02-29	8.94	10.41	(1.47)
2008-03-31	9.19	11.31	(2.12)

2008-04-30	9.44	11.94	(2.50)
2008-05-31	10.06	11.06	(1.00)
2008-06-30	10.69	11.44	(0.75)
2008-07-31	9.17	12.06	(2.89)
2008-08-31	9.13	12.36	(3.23)
2008-09-30	8.83	12.43	(3.60)
2008-10-31	9.08	12.34	(3.26)
2008-11-30	8.34	11.55	(3.21)
2008-12-31	7.33	11.23	(3.91)
2009-01-31	7.89	10.19	(2.30)
2009-02-28	8.54	8.10	0.44
2009-03-31	8.60	8.58	0.02
2009-04-30	8.58	8.45	0.13
2009-05-31	8.81	8.41	0.41
2009-06-30	8.96	7.96	1.00

2009-07-31	8.90	6.96	1.94
2009-08-31	8.75	6.75	2.00
2009-09-30	8.86	6.34	2.52
2009-10-31	9.03	6.17	2.85
2009-11-30	9.13	6.04	3.09
2009-12-31	9.08	5.91	3.17
2010-01-31	9.11	6.29	2.82
2010-02-28	8.88	6.14	2.74
2010-03-31	8.62	5.71	2.91
2010-04-30	8.56	5.16	3.40
2010-05-31	8.75	4.77	3.97
2010-06-30	8.86	4.64	4.23
2010-07-31	8.29	4.14	4.15
2010-08-31	7.94	3.75	4.19
2010-09-30	7.90	3.50	4.40

2010-10-31	7.84	3.14	4.70
2010-11-30	8.31	3.37	4.94
2010-12-31	8.15	3.49	4.66
2011-01-31	8.62	3.48	5.14
2011-02-28	8.71	3.70	5.01
2011-03-31	8.76	3.68	5.08
2011-04-30	8.47	4.10	4.36
2011-05-31	8.33	4.33	4.00
2011-06-30	8.39	4.55	3.85
2011-07-31	8.25	5.00	3.25
2011-08-31	7.89	5.19	2.70
2011-09-30	8.35	5.42	2.93
2011-10-31	7.97	5.75	2.22
2011-11-30	8.08	5.96	2.12
2011-12-31	8.08	6.18	1.90

2012-01-31	7.86	6.05	1.80
2012-02-29	7.92	6.25	1.67
2012-03-31	8.01	6.10	1.91
2012-04-30	7.80	6.02	1.77
2012-05-31	7.94	6.11	1.83
2012-06-30	7.46	5.65	1.80
2012-07-31	6.89	5.52	1.37
2012-08-31	6.97	4.94	2.03
2012-09-30	6.86	4.93	1.93
2012-10-31	7.14	5.44	1.70
2012-11-30	7.04	5.63	1.41
2012-12-31	6.76	5.61	1.15
2013-01-31	6.87	5.71	1.16
2013-02-28	6.81	5.36	1.46
2013-03-31	6.91	5.85	1.06

2013-04-30	6.32	5.89	0.43
2013-05-31	7.19	5.86	1.32
2013-06-30	7.69	5.56	2.13
2013-07-31	7.83	5.54	2.29
2013-08-31	8.17	6.34	1.83
2013-09-30	7.62	6.43	1.19
2013-10-31	7.67	5.97	1.70
2013-11-30	8.03	5.53	2.50
2013-12-31	7.95	5.31	2.64
2014-01-31	8.79	5.40	3.39
2014-02-28	8.47	5.78	2.69
2014-03-31	8.32	5.92	2.39
2014-04-30	8.34	6.05	2.29
2014-05-31	8.20	6.12	2.08
2014-06-30	8.21	6.63	1.58

2014-07-31	8.17	6.61	1.56
2014-08-31	7.84	6.35	1.49
2014-09-30	8.22	6.42	1.80
2014-10-31	7.75	5.92	1.84
2014-11-30	7.46	5.90	1.56
2014-12-31	7.87	5.80	2.07
2015-01-31	7.00	5.31	1.69
2015-02-28	7.53	4.43	3.10
2015-03-31	7.71	3.91	3.80
2015-04-30	7.85	4.05	3.81
2015-05-31	8.06	4.49	3.57
2015-06-30	8.20	4.57	3.63
2015-07-31	8.18	4.74	3.44
2015-08-31	8.27	4.97	3.30
2015-09-30	8.37	4.59	3.77

2015-10-31	8.25	4.59	3.65
2015-11-30	8.51	4.68	3.83
2015-12-31	9.69	5.28	4.41
2016-01-31	9.14	6.19	2.95
2016-02-29	9.33	7.05	2.28
2016-03-31	9.03	6.28	2.74
2016-04-30	8.90	6.23	2.67
2016-05-31	9.32	6.22	3.10
2016-06-30	8.78	6.30	2.48
2016-07-31	8.61	6.02	2.60
2016-08-31	9.00	5.91	3.09
2016-09-30	8.66	6.12	2.54
2016-10-31	8.70	6.43	2.27
2016-11-30	9.02	6.64	2.38
2016-12-31	8.92	6.72	2.20

Source: South African Reserve Bank (2017)