Sustainable land use planning in the aftermath of the clearing of alien invasive plant species: A system dynamics modelling approach

by

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With regard to [*Chapter 2: An assessment of the costs and benefits of using Acacia Saligna (Port Jackson) and recycled thermoplastics for the production of wood polymer composites in the Western Cape province, South Africa]*, the nature and scope of my contribution were as follows:

Nature of contribution	Extent of contribution (%)
Preparation of manuscript, data collection, data analysis and model building	55%

The following co-authors have contributed to [*Chapter 2: An assessment of the costs and benefits of using Acacia Saligna (Port Jackson) and recycled thermoplastics for the production of wood polymer composites in the Western Cape province, South Africa*]:

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J.N. Blignaut	jnblignaut@gmail.com	Scenario formulation, model inspection, assumption formulations and supervision of study	15%
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		results and discussions	
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"Declaration with signature in possession of candidate and supervisor." **Signature of candidate**	03 October 2018 **Date**

DECLARATION BY CO-AUTHORS

The undersigned hereby confirm that:

1. The declaration above accurately reflects the nature and extent of the contributions of the candidate and the co-authors to *[Chapter 2: An assessment of the costs and benefits of using Acacia Saligna (Port*

Jackson) and recycled thermoplastics for the production of wood polymer composites in the Western Cape province, South Africa],

2. No other authors contributed to *[Chapter 2: An assessment of the costs and benefits of using Acacia Saligna (Port Jackson) and recycled thermoplastics for the production of wood polymer composites in the Western Cape province, South Africa]* besides those specified above, and

3. Potential conflicts of interest have been revealed to all interested parties and that the necessary arrangements have been made to use the material in *[Chapter 2: An assessment of the costs and benefits of using Acacia Saligna (Port Jackson) and recycled thermoplastics for the production of wood polymer composites in the Western Cape province, South Africa]* of this dissertation.

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"Declaration with signature in possession of candidate and supervisor." **N. Nkambule**	Department of Ag. Econ. & Management, University of Swaziland	03 October 2018

PUBLICATIONS IN DISSERTATIONS AND AUTHOR DECLARATION (MSc and PhD)

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DECLARATION BY THE CANDIDATE

With regard to [*Chapter 3: An economic analysis of different land-use options to assist in the control of the invasive Prosopis (Mesquite) tree]*, the nature and scope of my contribution were as follows:

Nature of contribution	Extent of contribution (%)
Preparation of manuscript, data collection, data analysis and model building	65%

The following co-authors have contributed to [*Chapter 3: An economic analysis of different land-use options to assist in the control of the invasive Prosopis (Mesquite) tree*]:

Name	e-mail address	Nature of contribution	Extent of contribution (%)
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		assumption formulations and supervision of study	
N. Vink	nv@sun.ac.za	Supervision of study, manuscript review, inspection of study results and discussions	10%
D. Crookes	d_crookes@hotmail.com	Calibration of system dynamics model and review of modelling results	5%
N. Nkambule	nonoprome@gmail.com	Calibration of system dynamics model and review of modelling results	5%

"Declaration with signature in possession of candidate and supervisor." **Signature of candidate**	03 October 2018 **Date**

DECLARATION BY CO-AUTHORS

The undersigned hereby confirm that:

1. The declaration above accurately reflects the nature and extent of the contributions of the candidate and the co-authors to *[Chapter 3: An economic analysis of different land-use options to assist in the control of the invasive Prosopis (Mesquite) tree]*,

2. No other authors contributed to *Chapter 3: An economic analysis of different land-use options to assist in the control of the invasive Prosopis (Mesquite) tree]* besides those specified above, and

3. Potential conflicts of interest have been revealed to all interested parties and that the necessary arrangements have been made to use the material in *Chapter 3: An economic analysis of different land-use options to assist in the control of the invasive Prosopis (Mesquite) tree]* of this dissertation.

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Abstract

Biological invasions caused by invasive alien plant species (IAPs) pose diverse direct and indirect impacts on economic, social and environmental systems globally. The net impacts can be beneficial or harmful, although in most cases the negative impacts outweigh the beneficial effects. IAPs pose a significant threat to various systems through for example loss of biodiversity, excessive consumption of water, reduction in stream flow, health hazards to both animals and humans, increased fire risks and encroachment into agricultural lands and native ecosystems. Despite these negative impacts, IAPs to a limited extent also offer benefits to society, amongst them carbon sequestration, raw materials for manufacturing of value added products as well as habitat services for fauna. Given the predominant negative effects, however, the government of South Africa, through the Working for Water Programme (WfW), funded the clearing of IAPs mainly through labour intensive manual, mechanical and chemical means, as well as biological control using pathogens and insects as the control agents. Despite the aforementioned clearing efforts, IAPs have continued to spread exponentially, warranting more funding to finance the clearing operations targeting both new invasions and follow up clearing. In addition, the failure to contain invasions by IAPs has also led to sub-optimisation of agricultural land, which is attributed to a deficiency of land use planning frameworks and the ineffectiveness of laws governing agricultural land use in South Africa. As disclosed in this study, most of the research conducted to date has focussed mainly on control, distribution mapping, impact assessments and evaluation and to a lesser extent, partial cost benefit analyses of controlling IAPs. Given the complexities involved in the science of IAPs and land use planning decisions, the linear approach used in most studies has not been successful in fully capturing all the system elements, dynamics, causal and effect relationships thereof in order to understand the impacts of IAPs on the whole system. These complexities are further exacerbated by differences in land tenure systems.

In order to understand the implications of the various land use options on land restored through clearing IAPs, within different contexts and tenure systems, it is imperative to undertake a non-linear analysis that captures the aforementioned complexities. This study identified the key decision-rules that should guide decision making in selecting the best land use and management options under diverse contexts, within the aforementioned complex and dynamic system. This was done using a system dynamics modelling approach and a multiple criteria decision analysis. The, focus was put on four study sites in the Western Cape and Northern Cape provinces of South Africa.

Three system dynamics models and one multiple criteria decision analysis (MCDA) model were developed for: (i) understanding the integrated (i.e. both private and externality) benefits and costs associated with restoration of natural capital[1] through the clearing of IAPs; (ii) exploring and identifying the land use capability of the land restored through clearing of IAPs and the alternative best use land types based on multiple criteria decision analysis; (iii) investigating the potential economic, social and environmental sustainability of the returns emanating from the land use types and value added industries implemented inter alia the valuation of ecosystem goods and services; (iv) assessing the economic feasibility of prospective land use types and value added products (VAPs) that can be pursued in the areas were clearing of IAPs has taken place in South Africa (with a specific focus on four sites in SA) (v) determining the opportunity cost of unrestored land cleared from invasive alien plant species in South Africa (vi) formulating scenarios under which the land use types, VAPs and management options considered will be tested using the system dynamics modelling approach in order to see the respective impacts thereof; and for (vii)understanding the policy shortcomings, options, and implications with respect to restoration of natural capital and land use types in South Africa.

Validation tests of system dynamics models were also done. These included structure verification, parameter verification, dimensional consistency and extreme conditions tests which were undertaken to check for the structural validity. In addition, a behavioural validity test was conducted using multivariate sensitivity analysis to test the sensitivity of the Net Present value to the discount rate. As for the MCDA model, a parametric sensitivity analysis was conducted to test the sensitivity of the results to a change in the model parameters in order to build confidence in the analysis.Lastly, while efforts were made to capture all the economic, social and environmental aspects of IAPs management and land use planning decisions, not all core aspects were

[1] Natural capital is one of the five forms of capital which refers to the global inventory of ecosystem goods and services and natural resources from which mankind derive their livelihoods (see Blignaut and De Wit, 2004).

considered due to unavailability of data, methodological limitations and other unanticipated modelling complications. The limitations of the study were made explicit while concluding remarks and recommendations were made.

Opsomming

Die biologiese indring veroorsaak deur uitheemse indringer plante (UIP) skep ’n verskeidenheid van direkte en indirekte ekonomiese, sosiale, en omgewingsimpakte op verskeie stelsels regoor die wêreld. Die netto uitwerking van hierdie indringing kan óf positief óf negatief wees, maar oor die algemeen oorheers die negatiewe die positiewe gevolge. UIP is ’n noemenswaardige bedreiging vir verskeie sisteme deur byvoorbeeld ’n verlies aan biodiversiteit, die oormatige verbruik van water, die verlies aan water vloei in ’n rivier, gesondheidsrisiko’s vir beide mens en dier, toenemende brandgevare en die indringing van landbougrond en inheemse ekosisteme. Ten spyte van hierdie negatiewe gevolge, het UIP ook beperkte positiewe gevolge, soos, onder andere, die absorpsie van koolsuurgasse, die verskaffing van ru-materiaal vir die vervaardigingsindustrie, sowel as habitat vir fauna. Gegewe die oorweldigende negatiewe gevolge van UIP, befonds die Suid-Afrikaanse regering, deur die Werk-vir-Water (WvW) program die skoonmaak en beheer van UIP, meestal by wyse van arbeidsintensiewe, meganiese en chemiese metodes, maar ook by wyse van biologiese beheer deur van patogene en insekte gebruik te maak. Ten spyte van hierdie beheermaatreëls, versprei UIP eksponensieel en dit regverdig meer befondsing om die beheermaatreëls te finansier ten einde beide huidige en nuwe indringing die hoof te kan bied sowel as opvolg aksies te kan uitvoer. Die onvermoë om UIP te beheer het ook gelei tot die sub-optimale gebruik van landbougrond. Dit is toe te skryf aan die gebrek aan grondgebruik beplanningsraamwerke en die oneffektiwiteit van die grondgebruik wetgewing in die landbou sektor in Suid-Afrika. Soos onthul word in hierdie studie, die meeste van die navorsing tot op hede het gefokus op die beheer van, die kartering van verspreiding, impak analise en die evaluasie daarvan, en tot ’n mindere mate die koste-voordeel analise van die beheer van UIP. Gegewe die kompleksiteit betrokke in die wetenskap van UIP en grondgebruiksbeplanning besluitneming, was die liniêre benadering wat gebruik is in die meeste studies onvoldoende om al die elemente van die dinamiese sisteem, sowel as die oorsaaklikheid en die oorsaak en gevolg verhoudings van UIP, na wese weer te gee of te verstaan. Hierdie kompleksiteit word verder verdiep deur die verskille in grondeienaarskapstelsels wat bestaan.

Ten einde beter begrip te hê vir die impak van die verskeidenheid grondgebruik opsies van gerestoureerde grond nadat UIP verwyder is, binne ’n verskeidenheid van kontekste en grondeienaarskapstelsels, is dit belangrik om ʼn nie-lineêre analise te onderneem wat poog om die voorafgenoemde kompleksiteite weer te gee. Hierdie studie identifiseer die kern veranderlikes wat besluitneming behoort te rig ten einde die beste grondbestuursopsies te kies – en dit binne die genoemde komplekse agtergrond. Dit was gedoen deur van ʼn sisteem dinamiese model en ʼn veelvoudige kriteria analities-besluitnemings model gebruik te maak. Vier studie areas in die Wes en Noord Kaap provinsies van Suid-Afrika was gekies vir hierdie studie.

Drie sisteem dinamiese modelle en een veelvoudige kriteria analities-besluitnemings model is ontwikkel ten einde: i) ʼn begrip te ontwikkel vir die geïntegreerde voordele en kostes verbonde aan die restourasie van natuurlike kapitaal[2] deur die beheer van UIP; ii) die ondersoek na en identifisering van die grondgebruik vermoë na restourasie by wyse van die beheer van UIP en die soeke na die beste grondgebruik gebaseer op ʼn veelvoudige kriteria analities-besluitnemings model; iii) die ondersoek van die potensiële volhoubaarheid op grond van ekonomiese, sosiale en omgewingsoorwegings voortvloeiend die voordele van die verskillende grondgebruiksmoontlikhede en addisionele waardetoevoeding en die toename in die waarde van die ekosisteem; iv) die evaluering van die ekonomiese lewensvatbaarheid van die voornemende grondgebruik opsie en die waardetoevoeging by wyse van produkte wat ondersoek kan word in areas waar UIP verwyder is in Suid-Afrika (met spesifieke verwysing na die vier studie areas); v) die beraming van die geleentheidskoste van ongerestoureerde grond; vi) die formulering van scenario’s waaronder die grondbestuur tipes, die waardetoegevoegde produkte, en die bestuuropsies getoets word by wyse van ʼn sisteem dinamiese model ten einde vas te stel wat die onderskeie gevolge daarvan is, en vii) om insig te verkry in die beleidstekortkominge, en die opsies en implikasies daarvan met betrekking op die restourasie van natuurlike kapitaal en die verskillende grondgebruik tipes in Suid-Afrika.

Die sisteem dinamiese model is ook onderwerp aan stawingstoetse. Hierdie sluit onder andere strukturele stawing, parameter stawing, toetse insake dimensionele konsekwentheid en ekstreme voorwaardes ten einde die strukturele stawing. Gedragstoetse is ook onderneem deur meervoudige veranderlike sensitiwiteitsanalise ten einde die sensitiwiteit van die netto huidige waarde vir die diskontokoers te bepaal. Wat die veelvoudige

[2] Natuurlike kapitaal is een van die vyf vorme van kapitaal wat verwys na die globale voorraad van ekosisteem goedere en dienste en die natuurlike hulpbronne waarvan die mensdom sy bestaan put (sien Blignaut en De Wit, 2004).

kriteria analities-besluitnemings model betref, ʼn sensitiwiteitstoets insake verskeie parameters is onderneem ten einde die sensitiwiteit van die resultate ten opsigte van ʼn verandering in die model parameters vas te stel om sodoende vertroue in die model en die analise te bou. Laastens, terwyl ʼn verskeidenheid van pogings aangewend is om al die ekonomiese, sosiale en omgewings impakte van die bestuur en grondgebruiksbesluitneming van UIP vas te vang, kon nie alle impakte geïnkorporeer word nie as gevolg van ʼn gebrek aan data, metodologiese beperkings, en onverwagte modellerings aspekte. Die beperkings van die studie word pertinent uitgewys binne die konteks van die slot opmerkings en aanbevelings.

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Dedication

I dedicate the dissertation to my creator, provider and protector, the Almighty King Jesus Christ who dwells in the heavenly throne at the right hand of God the Father in heaven, and to whom be the glory forever. *"[17]And whatever you do, whether in word or deed, do it all in the name of the Lord Jesus, giving thanks to God the Father through Him"*. (Colossians 3:17).

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List of Abbreviations

ARC- Agricultural Research Council

CARA- Conservation of Agricultural Resources Act

CBA- Cost Benefit Analysis

CIB- Centre for Invasion Biology

CLD- Causal Loop Diagram

CSIR- Centre for Scientific and Industrial Research

DAFF- Department of Agriculture Forestry and Fisheries

DEA- Department of Environmental Affairs

DEA: NRM- Department of Environmental Affairs: Natural Resources Management

DRDLR -Department of Rural Development and Land Reform

DWA- Department of Water Affairs

EGS- Ecosystem Goods and Services

GDP- Gross Domestic Product

IAP- Invasive alien plants

IAPs- Invasive alien plant species

MCDA- Multiple Criteria Decision Analysis

NEMBA- National Environment Management: Biodiversity Act

NPV- Net Present Value

PDAL-Preservation and Development of Agricultural Land Act

SA- South Africa

SD- System Dynamics

SPLUMA- Spatial Planning and Land Use Management Act

STATSSA- Statistics South Africa

US$- United States Dollar

VAPs- Value Added Products

WC-DEA&DP- Western Cape Department of Environmental Affairs and Development Planning

WC-DEADP - Western Cape Department of Environmental Affairs and Development Planning

WfW- Working for Water Programme

WPCs- Wood Polymer Composites

ZAR - South African Ran

Chapter 1

Introduction

1.1 Background

1.1.1 What are invasive alien plants?

Invasive alien plants (IAPs) are non-indigenous, human introduced plant species which have established and spread within a non-native geographical environment (Richardson et al., 2000). They have overcome the biotic and abiotic barricades that limit reproduction and sustain populations over generations, therefore, they are able to reproduce rapidly and spread over large areas (Richardson et al., 2000; Ortega & Pearson, 2005). IAPs threaten ecosystems and displace other species in invaded habitats (Humpfries et al., 1991; Randall, 1997; Vitousek et al., 1997; Pimentel, 2001; Levine et al., 2003; Mooney, 2005, Didham et al., 2007; Pejchar & Mooney, 2009; Vilà et al., 2010), and may result in economic or environmental harm, or even human health harm (Republic of South Africa, 2014).

According to Richardson et al. (2000), five stages of invasion exist even though not all plant species conform to these stages, namely:

(i) **Introduction** – whereby plants/propagules that are not indigenous to a location/area/region are introduced into an area and they establish adult populations;
(ii) **Colonisation** – whereby the adult population begin reproducing, creating a colony;
(iii) **Naturalisation** – a stage whereby the colony produces new populations and continues to spread;
(iv) **Invasion** – whereby the species reproduces rapidly, spreading over a large area; and
(v) **Transformation** – a stage in which the species starts to alter the character, nature, form, or condition of the ecosystem.

1.1.2 Why IAPs need to be controlled

A plant species in its native habitat may not be problematic or negatively domineering but, when introduced into a different set of climatic and ecological settings, its character traits and survival strategies may give it a competitive advantage over native biota (Elton, 1958). Having no local predators, resistance to local diseases and superior life strategies (e.g. quick germination, high fecundity, high growth rates, shorter generation times and superior colonising strategies), IAPs out-grow and out-compete indigenous plants (Sakai et al., 2001; Higgins et al., 1996; Richardson et al., 1996). For this reason an uncontrolled increase of IAPs has the potential to considerably alter the composition, structure and functionality of native ecosystems (Vitousek et al., 1997; Pimentel, 2001; Levine et al., 2003; Mooney, 2005; Didham et al., 2007; Truscott et al., 2008; Gooden et al., 2009; Pejchar & Mooney, 2009; Vilà et al., 2010). IAPs negatively impact various facets of affected ecosystems (Richardson et al., 1989; Wilcove et al., 1998; Davis, 2003). These include above-ground native vegetation (Holmes, 1990; D'Antonio & Mahall, 1991; Galatowitsch & Richardson, 2005; Blanchard & Holmes, 2008; Buckley, 2008), physical environment (geomorphology) (Birken & Cooper, 2006; Cadol et al., 2011) and soil chemical and physical properties (D'Antonio & Meyerson, 2002; Ehrenfeld, 2003; Marchante et al., 2009).

Invasive alien plants promote soil erosion (Tabacchi et al., 2000), increase water use and reduce water availability (Bosch & Hewlett, 1982; Le Maitre et al., 1996, 2000; Van Wilgen et al., 1996; Scott et al., 2000; Dye & Jarmaine, 2004; Le Maitre, 2004; Görgens & Van Wilgen, 2004; McDonald et al., 2009). They also shade-out forest understorey due to dense canopy cover (Brooks et al., 2004; Gaertner et al., 2009), influence channel morphology through large wood debris in riparian ecosystems (Naiman & Décamps, 1997), alter decay rates and hence carbon cycling (Yelenik et al., 2004; Lindsay & French, 2005) and modify fire regimes (Billings, 1990; D' Antonio & Vitousek, 1992; Scott et al., 1998; Van Wilgen & Scott, 2001; Holmes, 2001; Forsyth et al., 2004; Ritter & Yost, 2009), cause declines in native species diversity (D'Antonio & Mahall, 1991; Sans et al., 2004; Garcia-Serrano et al., 2007; French et al., 2008; Vilà et al., 2011). In addition, they lower the capacity of natural habitats to produce ecosystem services, as well as decrease the recreational, aesthetic and cultural value of natural environments (Chapin, 2003; Pejchar & Mooney, 2009; Vilà et al., 2010). The dominance of IAPs can ultimately result in environmental and economic losses. For these reasons, the presence of IAPs is a major threat to plant and animal biodiversity, ecosystems, economies, and human health (Drake et al., 1989; Mooney & Hobbs, 2000; Secretariat on the Convention on Biological Diversity, 2001; Solarz, 2007; Wal et al., 2008; Reid et al., 2009).

1.1.3 The IAPs problem in South Africa

According to Macdonald et al. (2003) and Richardson et al. (2011), there are approximately 8750 terrestrial alien plant species present in South Africa's terrestrial ecosystems, of which 199 are considered to be invasive. Furthermore, 177 of these alien plant species are thought to have been intentionally introduced to South Africa in the last three centuries (Von Bretenbach, 1990) for various purposes, amongst them to support the forestry and agriculture sectors and for ornamental purposes (Van Wilgen et al., 2008; Grotkopp et al., 2010; Reichard, 2011; Essl et al., 2011; Wise et al., 2012) as well as dune stabilization in coastal areas. Moreover, South Africa has approximately 23 freshwater alien plant species at present, of which 13 are considered to be invasive, and 10 marine alien plant species (of which 4 are algae species); however none of the latter are currently considered invasive (Hill, 2003; Macdonald et al., 2003; Mead et al., 2011).

IAPs have a long establishment history in South Africa (Richardson et al., 2003). Since 1652, exotics ranging from Australian acacias and English oaks were imported to Cape Town to set up a garden for the Dutch East India Company (Keet, 1936, 1974; King 1943). In 1839, the timber industry introduced black wattle and blue gums to KwaZulu-Natal (Poynton 1979a, 1979b; Shaughnessy, 1986; Wells et al., 1986; Cameron, 1991). Some of the problems caused by the introduction and establishment of IAPs in South Africa include:

(i) IAPs invade land

Approximately 10 million uncondensed hectares (i.e. 8% of the country's land surface area) is estimated to be covered with IAPs and they are still spreading (Versfeld et al., 1998, Le Maitre et al., 2000, 2011). In terms of condensed hectares, this is equivalent to approximately 1.813 million hectares, calculated as a percentage invasion (density) as a proportion multiplied by the polygon area (Marais & Wannenburgh, 2008; Van Wilgen et al., 2012), showing an increase from 1996 when it was reported that 1.736 million hectares had been invaded (Le Maitre et al.,2011).

(ii) IAPs waste water

IAPs pose a significant threat to water resources and can result in catastrophic effects if they reach greater rooting depths than the indigenous plant species, or if they achieve greater biomass (Mooney, 2005). Because South Africa is a water scarce country, IAPs aggravate the situation through the loss of ground, surface or runoff water to evapotranspiration and reduction of surface area for water storage in dams and water courses infested by invasive plant species (Binns et al., 2001; Department of Water Affairs (DWA), 2010). Quantities of water used by IAPs are quite substantial (Dye & Jarmain, 2004; Hope et al., 2009), for example one study done in Cape Town estimates that as much as 30% of water supply in riparian zones, dams and catchments could be experienced if nothing is done to control invasive alien plants in Cape Town (Van Wilgen et al., 1996).

(iii) IAPs threaten biodiversity

IAPs cause major damage to ecosystems through crowding and displacing native plants thereby reducing biodiversity (Richardson et al., 1989; Wilcove et al., 1998; Davis, 2003, Van Wilgen et al., 2008). The Cape Floristic Region as a centre of endemism and a biodiversity hotspot that generates substantial revenue through tourism yearly. Several studies have documented the negative impacts of IAPs in many many ecosystems including those with endemic vegetation for example the Mediterranean type ecosystems (MTE) (Cowling et al., 1996; Rejmánek & Randall, 1994; Rouget et al., 2003; Seabloom et al., 2006; Underwood et al., 2009).

(iv) IAPs cause run-away fires and erosion

Invasive alien plants have the ability to modify the natural processes of a natural ecosystem because of their influence on fire regimes (Billings, 1990; D'Antonio & Vitousek, 1992; Mooney 2005). IAPs have large amounts of biomass that provide excessive amounts of fuel in ecosystems that are shaped by natural fire events. The presence of IAP therefore alters frequency and intensity or fires resulting in substantial loss of seeds for regeneration of plants that exhibit serotinous ecological adaption. Additionally, high intensity fires fuelled by IAPs produce significant changes to soil physical properties, while the removal of plant cover promotes soil erosion resulting in siltation, reduction of water quality and nutrient enrichment of water bodies connected to infested habitats (Richardson & Van Wilgen, 1986; Van Wilgen & Scott, 2001; Richardson & Van Wilgen, 2004).

(v) IAPs take over rivers, dams and lakes

Aquatic weeds have spread over large areas in the country with the water hyacinth (*Eichhornia crassipes*), red water fern (*Azolla filiculoides*), Kariba weed (*Salvinia adnata*), water lettuce (*Pistia stratiotes*) and parrot's feather (*Myriophyllum aquaticum*) being the five major aquatic weeds (Van Wilgen et al., 2001). The most significant and damaging weed species among these is *Eichhornia crassipes* (Van Wilgen et al., 2001) It is prevalent in every province of South Africa and the Vaal River (Gauteng, Free State provinces) is one of the worst affected, in addition to other rivers in the Eastern and Western Cape provinces, Mpumalanga and KwaZulu-Natal (Richardson & Van Wilgen, 2004).

(vi) Many IAPs are toxic to livestock and humans

Plants such as morning glories (*Ipomoea purpurea*), oleanders (*Nerium oleander*), privets (*Ligustrum lucidum*) and syringas (*Melia azedarach*) are toxic to humans while tickberry (*Lantana camara*) is a well-known noxious weed affecting livestock thereby causing huge financial losses for farmers in South Africa). Several other studies done in other parts of the world document the impacts of poisonous IAPs on human and livestock health (Lonkar et al., 1974; Narasimhan et al., 1980, 1985; Rao et al., 1985; Khadhane et al., 1992; Evans, 1997).

(vii) IAPs are difficult and expensive to eradicate.

It has been shown that South Africa spends approximately R400 million each year to control IAPs and it is estimated that about R600 million will be needed each year to continue controlling IAPs over the next 20 years (Department of Environmental Affairs (DEA), 2018). Several studies have tried to quantify the cost of clearing invasive alien plants in South Africa (Van Wilgen et al., 1996, 1997; Higgins et al., 1997a, b; Heydrenrych, 1999; Hosking & Du Preez, 1999; Turpie & Heydenrych, 2000; Le Maitre et al., 2002; Van Wilgen et al., 2000, 2004; De Wit et al., 2001; McConachie et al., 2003; De Lange & Van Wilgen, 2010; Mugido et al., 2014). However, more work is still needed to understand the full economic costs of clearing and the benefits derived thereof. The aforementioned authors in their findings corroborate that IAPs have significant economic, ecological and social implications for South Africa, making the IAP problem in South Africa a crucial one that warrants urgent and increased attention (Blignaut & De Wit, 2004).

1.1.4 Legislation to control IAPs in South Africa

There exists two Acts of law pertaining to invasive species in South Africa namely the CARA[3] (2001) and the NEMBA (2004, amended in 2014). The CARA was replaced by the NEMBA[4], but is still described in this review. The CARA classifies the control of IAPs into 3 categories:

- **Category 1:** Plants that fall into this category are prohibited plants and it is required that they be removed and destroyed. Examples include lantana, water hyacinth, bugweed, yellow oleander, pom pom weed, cat's claw creeper, pampas grass and red sesbania (Republic of South Africa, 2014).
- **Category 2:** In this category are invader plants of commercial value that can be planted in public spaces (e.g. schools, parks and hospitals) after the solicitation of a permit from the regional offices of the National Agriculture Department.; Examples of these are watercress, black wattle, Port Jackson willow, cluster pine, red eye, guava and grey poplar (Republic of South Africa, 2014).
- **Category 3:** In this category are invader plants used as ornamentals that are not grown any more or for sale in nurseries, but if kept under control one can have such plants in one's garden. Examples in this category include jacaranda, Bailey's wattle, pepper tree wattle, morning glory, New Zealand Christmas tree, Australian silky oak and Formosa lily (Republic of South Africa, 2014).

The NEMBA also classifies the control of IAPs into three categories:

- **Category 1a:** Plants in this category require compulsory control and must be eradicated; for example, cascade wattle, hop wattle, lollipop-climber, rough horsetail, common scouring-rush, water poppy and yellow water-lily. (Republic of South Africa, 2014).
- **Category 1b:** Plants that fall into this category require control in terms of an approved management programme. For these plants to be kept on a property a permit must be issued. Examples of these plants include lantana, golden wattle, mistflower, cherry pie, three-horned bedstraw, corn-cleavers, arsenic bush, smooth senna, wild strawberry and prickly malvastrum (Terbalnche et al., 2015; Republic of South Africa, 2014).
- **Category 2:** Plants in this category are plants that are regulated by area. To grow, breed, import, possess, sell, buy or accept as a gift, one requires a demarcation permit. Examples of plants that fall into this category are nodding thistle and old man saltbush. (Republic of South Africa, 2014).
- **Category 3:** Invasive species in this category are regulated by activity. One requires a permit to grow, breed, import, possess, sell, buy or accept as a gift category 3 invasive plants. However, permits for category 3 plants are not issued for riparian zones. Examples of plants in this category are shell ginger, pink porcelain lily, Chinese sagewood and marram grass (Republic of South Africa, 2014; South African National Biodiversity Institute, 2015).

1.1.5 Overview of IAP studies and the Working for Water Programme

Long back before European colonialisation, human beings stayed in South Africa and there were no invasive alien plants (Deacon & Deacon, 1999). It is thought that alien plants were introduced into the country via human and livestock migration pathways from North Africa (Richardson et al., 2003). Richardson et al. (2003) state that this was then followed by the introduction of more alien plants by colonial settlers in about the 17th century. Three phases of introductions have been differentiated spanning approximately three and a half centuries (dating back from the year 1652) and these have been driven by needs and activities of humans (Richardson et al., 2003). As a result some of the exotic plants introduced became invasive in South Africa (McDonald et al., 1986).

[3] CARA-Conservation of Agricultural Resources Act
[4] NEMBA- National Environment Management: Biodiversity Act

Most of the alien plants were introduced for the purposes of fodder, ornamentals, horticulture, silviculture and agriculture (Wells et al., 1986). It is important to note that in many cases it is those species that were introduced for horticulture and forestry (e.g. *Acacia spp, Pinus spp, Euculyptus spp* and *Echium plantagineum* (i.e. Patterson's Curse) purposes which have become the worst invaders (Richardson et al., 2000, 2003).

In as early as the early-1900s, the deleterious impacts of IAPs on South Africa's natural fynbos vegetation were already being felt, but it was only in 1945 that the repercussions of these IAPs became a major cause of concern (Van Wilgen et al., 1997). Wicht (1949) embarked on an experiment to determine the hydrological implications of afforestation while Malherbe in 1968 quantified the direct reduction in streamflow due to afforestation (Dye & Versfeld, 2007). In 1977, Kruger estimated the water loss from IAPs and concluded that regional water supplies are very likely to be seriously impacted by extensive invasion in the Cape Mountains (Van Wilgen et al., 1997). Following these early studies, clearing of IAPs commenced in the early 1970s and interest on IAPs research intensified (Nowell, 2011). Eventually political constraints and lack of funds resulted in the disbandment of IAPs control programmes. Cowling (1992) reiterated the issue of addressing water loss in the fynbos biome due to IAPs. Cowling (1992) stressed the devastating impacts on the country's industry, cities and agriculture should IAPs not be controlled. Cowling's predictions resulted in a project that looked at the implications of not managing IAPs, funded by the DEA. The findings of this project were convincing and resulted in the Minister of Water Affairs (Kader Asmal at the time) supported by a team of scientists commissioning of the Working for Water (WfW) Programme under the Department of Water Affairs in 1995 (Van Wilgen et al., 1997).

The WfW programme undertaken and facilitated by the Department of Environmental Affairs' Natural Resource Management directorate was initiated in 1995 with the aim of controlling IAPs in the country. The WfW programme is a nation-wide programme to control IAPs (Van Wilgen et al., 2012). In addition, the programme's objectives are to enhance water security for rural and urban areas (Dye & Versfeld, 2007; Binns et al., 2001), reinstate the productive potential of the land, invest in marginalised sectors in the country, improve the quality of life through job creation, improve the ecological integrity of natural systems, and generate economic benefits from land, water, wood and trained people (WfW Programme, 2000). The programme's comprehensive approach to IAP control is characterised by a number of unique features, namely combining chemical and mechanical control of IAPs in targeted areas and employing underprivileged people as the task force. This is complemented by the expansion of biological control options that target priority IAP species (Moran et al., 2005), the encouragement of payment for ecosystem services in order to raise funds to support control programmes (Turpie et al., 2008), and the promulgation of legislation that compel landlords to address the IAPs problem (Van Wilgen et al., 2011).

The WfW programme is a national-level initiative, operating in all nine provinces (Van Wilgen et al., 2012). It is said to be the most efficient and effective instrument used by the government to alleviate poverty (WfW Programme, 2000) and considered to be amongst some of the world's most successful integrated land management programme (Hobbs, 2004). A significant amount of money has been spent by WfW on the control of alien plants. According to DEA:NRM (2017), Working for Water spends (i) R572 million (US$[5] 41,3 million) per annum for the mechanical and chemical control of terrestrial IAPs, (ii) R60 million (US$ 4,3 million) per annum for high altitude mechanical and chemical control of IAPs, (iii) R18 million (US$ 1,3 million) per annum for the manual and chemical control of aquatic IAPs, (iv) R37 million (US$ 2,7 million) per annum for biological control of terrestrial and aquatic IAPs, (v) ZAR 22 million (US$ 1,6 million) for the control of emerging IAPs and (iv) ZAR 157 million (US$ 11,3 million) to support value-added industries. There is, however, need to motivate the continued funding to keep the programme functional in view of national budgetary constraints and a growing number of other competing social development goals.

[5] ZAR:US$ exchange rate: 2017=ZAR 13,86 (NB. All US$ figures are rounded off to 1 decimal place and the 2017 exchange rate is only used in this instance for monetary values adapted from DEA:NRM (2017)).

Most of the research done to date has focused mainly on the negative impacts emanating from invasions by IAPs (e.g. Richardson et al., 1989; Wilcove et al., 1998, Binns et al., 2001; Dye & Jarmain, 2004; Hope et al., 2009; DWA, 2010) and the methods that can be used to control these alien plants. Furthermore, the studies that have focused on the cost benefit analysis of clearing specific invasive alien plants (Van Wilgen et al., 1996, 1997; Higgins et al., 1997a, 1997b; Heydrenrych, 1999; Hosking & Du Preez, 1999; Turpie & Heydenrych, 2000; Van Wilgen et al., 2000, 2004; De Wit et al., 2001; Le Maitre et al., 2002; McConnachie et al., 2003; Mwebaze et al., 2010; De Lange & Van Wilgen, 2010; Van Wilgen & De Lange, 2011) underestimate the costs and benefits of clearing IAPs (Van Wilgen & De Lange, 2011) especially in the South African context. Most of the studies have mainly focused on passive restoration (i.e. the clearing of invasive alien plants and then leaving the land fallow so that it can naturally recover to a state similar to what it was prior to invasion).

One of the common observations in areas that have undergone clearing is the rapid re-emergence of IAPs which then reestablish at the same or greater density than the previous infestation where follow up operations are not implemented owing to massive seedling recruitment from the abundant soil seed bank. Thus transforming these areas into some productive land use systems can potentially reduce the re-invasion risks of the areas that have been cleared. There is currently a knowledge gap pertaining to appropriate, cost effective and sustainable measures that should be implemented post clearing of IAPs under the WfW programme. In light of the aforementioned theoretical knowledge gap and complexity with respect to land use optimisation with a view to maximise the sustainable exploitation of public goods (under various land tenure systems), the development of a conceptual framework is important for guiding decision making post the clearing of IAPs. As a result the overall aim of this research was to develop a road map of the potential land uses types, value added industries and management options that can be implemented post the clearing operations.

1.2 Problem statement

Environmental degradation and initiatives to restore degraded natural capital presents complex and dynamic challenges that have practical, conceptual, spatial and temporal implications. Because of these dynamics, which increases both risk and uncertainty, a haphazard approach towards restoration is unlikely to succeed. This is due to the fact that embedded within such a complex system are cause and effect relationships as well as feedback linkages that control the performance of the ecological system and its response to restoration. The impacts of such are not always foreseeable intuitively. These complexities are exacerbated by differences in land tenure systems. Understanding the impact of the future, desirable and sustainable land use on restored land within different contexts and tenure systems, is imperative to guide policymakers and land owners/users on the best land use trajectory that is inclusive of externalities and which embraces a process of restoration over time. This study sought to identify the key decision-rules that should guide decision-making in selecting the best land use options under various contexts, within the aforementioned complex and dynamic system.

1.3 Objectives of the study

The major objective of this research was to develop a road map of the potential land uses types and explore management options that can be implemented post the clearing of IAPs using a system dynamics modelling and a multi-criteria decision analysis approach

In order to achieve the major objective, the specific research objectives for this study were formulated as follows:

- Understand the integrated (i.e. both private and externality) benefits and costs associated with restoration of natural capital through the clearing of IAPs
- Explore and identify the land use capability of the land restored through clearing of IAPs and the alternative best use land types based on multiple criteria decision analysis

- Investigate the potential economic, social and environmental sustainability of the returns emanating from the land use types and value added industries implemented *inter alia* the valuation of ecosystem goods and services
- Assess the economic feasibility of prospective land use types and value added products (VAPs) that can be pursued in the areas were clearing of IAPs has taken place in South Africa (with a specific focus on four sites in SA).
- Assess the opportunity cost of unrestored land cleared from invasive alien plant species in South Africa
- Formulate scenarios under which the land use types, VAPs and management options considered will be tested using the system dynamics modelling approach in order to see the respective impacts thereof.
- Identify the policy shortcomings, options, implications and recommendations with respect to restoration of natural capital and land use types in South Africa (with a specific focus on four sites in SA).

1.4 Significance of the study

While the system dynamics modelling approach is well-known in various interdisciplinary fields of study (such as engineering, economics, epidemiology, urban and regional planning and so forth), it has not been used much in the economics of restoration studies in South Africa, with a few exceptions (see Crookes, 2012; Crookes et al., 2013). Moreover no comprehensive research has been undertaken to ascertain the integrated costs and benefits of clearing IAPs, the opportunity cost of unrestored land and the land use types that can be implemented after the restoration of natural capital. As such, this study is one of the first of its kind (from an agricultural economics discipline within the South African context), and it is anticipated to pave the way for many future studies. The information generated in this study will assist relevant stakeholders (e.g. the state, policy makers, civil society stakeholders and private stakeholders) in dealing with change, foreseeing opportunities and coping with uncertainties emanating from the land use types and management options implemented post IAPs clearing programmes in South Africa.

1.5 Research methodology

1.5.1 Analytical framework

The system dynamics modelling approach in conjunction with a multi-criteria decision making analysis framework (see section 5.3) were utilised to assess the sustainable land use types that can be implemented after restoration of natural capital to alleviate sub-optimisation of land use, and to capture the essence from various stakeholder meetings. This methodological approach is appropriate for modelling the complex interactions between environmental degradation and the restoration of natural capital (Ford, 2009; Crookes, 2012). Furthermore the dynamic consequences resulting from the land use types implemented post the clearing of IAPs are difficult to understand as a result of the complexity of the hidden relationships between the environmental systems components and the time lags between the implementation of the land use types, management options and the future impacts emanating therefrom. System dynamics modelling is a tool that enables the assessment of these dynamic consequences in order to adapt to change, anticipate opportunities and prepare for future unintended consequences (Sterman, 2000; Ford, 2009).

1.5.2 System dynamics modelling defined

System dynamics modelling is a tool that is used to study and manage complex systems that change over time (Ford, 2009). Coyle (1996) further defines system dynamics modelling as a methodology that deals with time dependent behaviour of managed systems. The methodology aims to describe the system and help understand, through qualitative and quantitative models, how information feedbacks govern its behaviour (Sterman, 2000; Ford, 2009). Through system dynamics modelling it is possible to design robust information feedback structures and control policies through simulation and optimisation (Sterman, 2000; Ford, 2009). Thus system dynamics modelling enables researchers to quantify systems thinking based on stock and flows, cause and effects, feedback linkages, time lags and non-linearity(Sterman, 2000; Ford, 2009). This enables us to improve our understanding of the relations between the structure of a system and its behaviour and the extent to which various policies influence its functioning mechanisms.

1.5.3 Brief history of system dynamics modelling

System dynamics modelling originated in the 1960's from the works of Jay Forrester and his counterparts at the Massachusetts Institute of Technology (Forrester, 1961). It was initially applied to the study of industrial systems which led to the publication of Urban Dynamics in 1969 (Forrester, 1969; Schroeder and Strongman, 1974). Furthermore it was applied to solve macroeconomic and social issues (Forrester, 1969) and environmental concerns in the early 1970's (Forrester, 1971). Moreover, the publication of Urban Dynamics inspired one of the most widely known applications of system dynamics modelling which led to the publication of the controversial Limits to Growth by Meadows et al. (1972). This led to the adoption of the method for use in assessing the impacts of the increase in human population and industrial production in global systems over the next century, with a specific focus on resource production and food requirements (Ford, 2009). The approach has since expanded rapidly, fuelled by the invention of powerful computers and software packages enabling the development of complex models that do not require mainframe access (Crookes, 2012).

1.5.4 Applications of system dynamics modelling in economics

The system dynamics modelling approach is consistent with traditional economic approaches to modelling dynamic phenomena as reported by Smith and Van Ackere (2002). From a global perspective, the first applications of system dynamics modelling were in the field of economics, with specific focus on industrial dynamics and urban planning as explained earlier. Furthermore this approach has also been applied to assess the complex interactions between mineral policy and the respective investment flows emanating as a result of this policy (O' Reagan and Moles, 2006). Moreover it has also been applied to evaluate the impacts of economic and political factors affecting agricultural practices, and the relationship between income, population and nutrition as reported by Fisher et al. (2003). Additionally, Nobre et al. (2009) also presented the system dynamics modelling approach as a tool to resource economists for sustainable aquaculture management in China.

In the South African context, system dynamics modelling was first used in the field of resource and environmental economics by Crookes (2012) who pioneered the application of this approach whilst looking at the ecological-economic impacts of restoring natural capital. Furthermore, Crookes et al. (2013) applied system dynamics modelling to investigate the economic feasibility and risk assessment of ecological restoration in South Africa. Nkambule (2015) also used system dynamics modelling to measure the social costs of coal based electricity generation in South Africa.

1.5.5 System dynamics modelling software

There are many software packages that support the formulation, construction and testing of system dynamics modelling namely:

- Dynamo
- Stella
- iThink
- Extend
- Model Maker
- Powersim
- Vensim
- Simile
- Simulink

- & GoldSim, only to mention a few

Of these software packages Dynamo was the first to be used for system dynamics modelling, with the others being more recently introduced. Each software package has its advantages and disadvantages however these are not going to be discussed as they are beyond the scope of this study (for more info see Costanza and Voinon, 2001). For the purpose of this study, the Vensim PLP software package was used mainly due to its user friendliness, compatibility with Microsoft windows, relatively low cost and high learning curve rating.

1.5.6 Data Collection

The data used for the purposes of this study was obtained from the Departments of Environmental Affairs (DEA) and of Agriculture, Forestry and Fisheries (DAFF), Council for Scientific and Industrial Research (CSIR), Centre for Invasion Biology (CIB). In addition personal site visits, research workshops, focus group discussions, telephonic interviews, consultation with experts, the Working for Water catchment management plans, internet searches and extensive literature surveys were used to supplement the data collected from the aforementioned organisations.

1.5.7 Study sites

This study focussed on four study sites from two South African provinces namely the Northern Cape and Western Cape. In the Northern Cape the study focussed on Onseepkans and Phela sites falling under the Orange River quaternary catchment water management area. In the Western Cape the study sites considered were Citrusdal that falls in the Olifants River quaternary catchment water management area and the Berg river quaternary catchment water management area. The major reason why these sites have been chosen is because the restoration of natural capital through the clearing of invasive alien plants is currently underway and post restoration activities are slowly taking place, with the land being transformed into some form of agricultural land use types. The system dynamics models constructed for these sites can serve as a national benchmark for informing and guiding the way forward with land post clearing of invasive alien plants. In most quaternary catchment areas country wide, most of the land that has been passively restored has been left fallow thereby availing the opportunity to assess risk of re-invasion in previously cleared landscapes as afore mentioned.

1.6 Chapter overview and layout

This dissertation is made up of six chapters consisting of an introduction, four research chapters and, the conclusions and recommendations. Each chapter, excluding chapters 1 and 6, is structured as a journal manuscript for publication, each consisting of a complete abstract and reference list.

Chapter 1 gives the introduction of the study. It gives a brief but comprehensive description of the study background, problem statement and the objectives of the study. In addition it also presents the methodological approach, scientific contribution of the study and, the chapter layout of the dissertation.

Chapter 2 is a research study assessing the costs and benefits of using *Acacia saligna* (Port Jackson willow) and recycled thermoplastics from the production of wood polymer composites in the Western Cape Province, South Africa. This manuscript has been published in the *African Journal of Agricultural and Resource Economics*, 12(4):322-365.

Chapter 3 focusses on the economic analysis of different productive agricultural land use options as a strategy to assist in the control of *Prosopis* (Mesquite) in the Orange River water management areas in the Northern

Cape Province. This manuscript has been published in the *African Journal of Agricultural and Resource Economics*, 12 (4):366-411.

Chapter 4 assesses the opportunity cost of unrestored land cleared from invasive alien plant species in the Western Cape Province, South Africa using a system dynamics modelling approach. This manuscript has been submitted to the *Land Use Policy Journal* (https://www.journals.elsevier.com/land-use-policy).

Chapter 5 focuses on a multi-criteria decision analysis for assisting land owners and other relevant stakeholders in making land use planning decisions in the aftermath of clearing invasive alien plant species in Berg River quaternary catchment water management area in the Western Cape Province, South Africa. This manuscript has been submitted to the *Restoration Ecology Journal* (https://onlinelibrary.wiley.com/journal/1526100x).

Chapter 6 concludes the dissertation and presents the study limitations and recommendations. In addition, a conceptual framework to assist decision makers in making land use planning and management decision in the aftermath of clearing IAPs is developed, explained and recommended subject to the research findings of this dissertation.

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Chapter 2

An assessment of the costs and benefits of using *Acacia saligna* (Port Jackson willow) and recycled thermoplastics for the production of wood polymer composites in the Western Cape province, South Africa

Abstract

Acacia saligna (Port Jackson willow) is one of the most pervasive IAPs in South Africa. By and large, the government's control efforts have not been co-financed by the private sector due to a lack of incentives. Here we develop a system dynamics model to assess the costs and benefits of using the invasive *Acacia saligna* for the production of wood polymer composites (WPCs). The cumulative net present value for clearing *Acacia saligna* and making WPCs amounts to approximately –ZAR122.1 million for the baseline scenario (no WPC production), and is estimated to be ZAR144.4 million for Scenario 2 (WPC production with a 20% co-finance), ZAR172.7 million for Scenario 3 (50% co-finance) and ZAR211.2 million for Scenario 4 (100% co-finance). In addition to these direct financial benefits, the control of *Acacia saligna* also offers benefits with respect to employment, an increase in the state' tax revenue base, and the contribution to GDP.

2.1 Introduction

2.1.1 Background

Invasive alien plants (IAPs) and municipal solid waste pose environmental concerns both for South Africa and internationally (Williamson 1996; Richardson & Van Wilgen 2004; Reinhart et al. 2010; Couth & Trois 2012; DEA 2012; Republic of South Africa 2014; Friedrich & Trois 2016). The government of South Africa, through its Department of Environmental Affairs: Natural Resource Management programme (DEA:NRM), has allocated substantial resources towards the control of IAPs. Approximately ZAR3 billion (US$457 million) is spent annually by the DEA:NRM on the control of IAPs within the country. More than 50% of this amount has been spent on the control of *Acacia species*, *Pinus species*, *Eucalyptus species* and *Prosopis species*, which are the major invaders in most of the country's biomes (Van Wilgen et al. 2012). Various IAPs are invasive within the Western Cape Province, among others *Pinus species*, *Acacia Cyclops* (Rooikrans), *Acacia saligna* (Port Jackson), *Eucalyptus species*, *Prosopis species* and *Acacia Mearnsii* (Versfeld et al. 1998; Kotzé et al. 2010). This study investigates the feasibility of using *Acacia saligna*, which does not offer much commercial opportunity in the form of timber, as an input material in the production of wood polymer composites (WPCs).

The production of WPCs can be augmented by thermoplastics sourced from municipal waste. Municipal solid waste is defined as any kind of waste material and includes durable goods (such as car tyres and office desks), non-durable goods (such as newspapers, disposable cups and plates, plastic cutlery), containers and packaging (such as plastic bottles and wrapping materials) and other waste material (such as food and yard waste) (EPA 2015; Centre for Sustainable Systems 2016). Najafi (2013) states that waste thermoplastics comprises a major part of municipal solid waste from a global perspective – this presents a potential raw material source for the manufacture of WPCs. It is estimated that approximately 108 million tonnes of municipal solid waste was generated in South Africa in 2011 (DEA 2012; Godfrey et al. 2015) with 98 million tonnes being disposed at landfill sites. Approximately 6% of the waste generated was reported to be plastic waste (DEA 2012; Godfrey et al. 2015). In the Western Cape Province, approximately 3.8 million tonnes of municipal solid waste is generated per annum with 70% of this being generated by the City of Cape Town (WC-DEADP 2012). As a result, the City of Cape Town spends approximately ZAR2.1 billion (US$150 million) on operations and between ZAR200 million (US$14.285 million) and ZAR250 million (US$17.857 million) on capital expenditure in managing solid waste (Western Cape Provincial Treasury 2013).

Both IAPs and municipal solid waste are characterised by undesirable environmental concerns and resulting costs. Both, however, can also be used to make WPC. In producing WPCs, value is created from IAPs and thermoplastic waste that can contribute toward its management cost. The recycling rate of municipal solid waste is very low, with the national rate for South Africa at 9.8% and the Western Cape, specifically, at 14% (WC-DEA&DP 2013). Therefore, there is much scope to improve the use of thermoplastics. Likewise, *Acacia saligna* that have been cleared are largely abandoned at the clearing sites.

Nafaji (2013) states that the literature on the use of recycled thermoplastics to make WPCs is limited, mostly focussed on a single type of thermoplastic waste (Yam et al. 1990; Youngquist et al. 1994; Selke & Wichman 2004; Lei et al. 2007) and a combination of recycled thermoplastics waste and virgin thermoplastics (Ha et al. 1999; Tzankova Dintcheva & La Mantia 1999; Sellers et al. 2000; Kamdem et al. 2004; Kazemi-Najafi et al. 2006; Ashori & Nourbakhsh 2009; Kiaeifar et al. 2011) and a few on recycled thermoplastic waste blends (Ha et al. 1999; Jayaraman & Halliwell 2009; Kiaeifar et al. 2011). Moreover, little has been reported on the use of wood flour obtained from IAPs as a raw material for WPCs with only cases of *Pinus* species having been mentioned (Sellers et al. 2000; Jayaraman & Bhattacharyya 2004). Furthermore, all these studies have been greatly limited to the effect of recycled thermoplastics on the tensile strength, hygroscopic properties and the impact strength of WPCs. No studies to date have been conducted to determine the costs and benefits of using biomass from IAPs and recycled thermoplastic waste regarding the feasibility of such value-adding activities.

2.1.2 Wood polymer composites

A composite material is made by combining two or more materials to give a unique combination of properties (Kim & Pal 2011). WPCs can be defined as a group of materials that are manufactured from mainly wood and thermoplastic polymers, and occasionally, a marginal amount of additives (Teuber et al. 2016). In most cases renewable resources, such as wood and/or waste, are used to manufacture WPCs (Teuber et al. 2016). The most widespread uses of WPCs are outdoor decks, park benches, indoor furniture, and window and door frames (Kim & Pal 2011). According to Klyosov (2007), the amount of wood used in the manufacture of WPC varies, with up to more than 80% of both soft and hard wood being used, subject to the region of manufacture and availability of a particular type of wood. In terms of the thermoplastic polymers, polyolefin polymers such as polyethylene (PE) and polypropylene (PP) are the most used polymers in the production of WPCs products (Ashori 2008; Carus et al. 2014). Using waste resources such as IAPs and recycled thermoplastic waste can potentially lead to a more responsible and efficient method of resource use. Moreover, such an innovative approach is in line with the principle of cascading use and resource efficiency. Cascading use promotes the use of resources and by-products from production processes multiple times before considering their conversion to thermal energy (Eshun et al. 2012).

2.1.3 Objectives of the study

This study aims to determine the costs and benefits of using IAPs (specifically *Acacia saligna*) and recycled thermoplastic waste for the production of WPCs in the Western Cape Province of South Africa. Externality costs (i.e. carbon sequestration potential loss) and benefits (i.e. water savings) as well as the private costs and benefits incurred in the production of WPCs are also included. It is important for integrated reporting purposes to show both private and social costs (and benefits) emanating from the production of WPCs from the aforementioned raw materials (i.e. *Acacia saligna* biomass and recycled thermoplastic waste). *Acacia saligna* was considered because it is a low-value species which has been mostly abandoned at cleared sites. It is therefore important to assess the economic feasibility of this value-adding opportunity. Also, the study seeks to assess the dynamic behaviour of environmental, social and economic systems over time for several scenarios. This is imperative as it helps decision-makers and other relevant stakeholders to foresee opportunities and threats, adapt to change and be well prepared for any possible adverse consequence.

2.2 Materials and methods

2.2.1 Scope of assessment and study sites

We investigate the clearing of *Acacia saligna* within three study sites in the Western Cape Province of South Africa, namely, the Citrusdal quaternary catchment plot(s) (E10F), the Berg River quaternary catchment plot(s)

(G10A-J) and the De Hoop quaternary catchment plot(s) (G50J & G50K (see Figure 2.1). The *Acacia saligna* biomass cleared within these sites is used as a feedstock for wood flour production, and combined with recycled thermoplastic waste to produce WPCs. We augment the wood flour with recycled thermoplastics sourced from various industries in the country.

For the purposes of this study, it was assumed that the WPC factory would be set up within the City of Cape Town. The Citrusdal quaternary catchment lies 175 km north-west of the City of Cape Town, and the Berg River quaternary catchment about 70 km north of it. The De Hoop quaternary catchment lies 230 km south-east of the City of Cape Town. All the study sites are within the Fynbos biome with a Mediterranean climate, receiving rain in the winter and experiencing dry and hot summers (Mucina & Rutherford 2006).

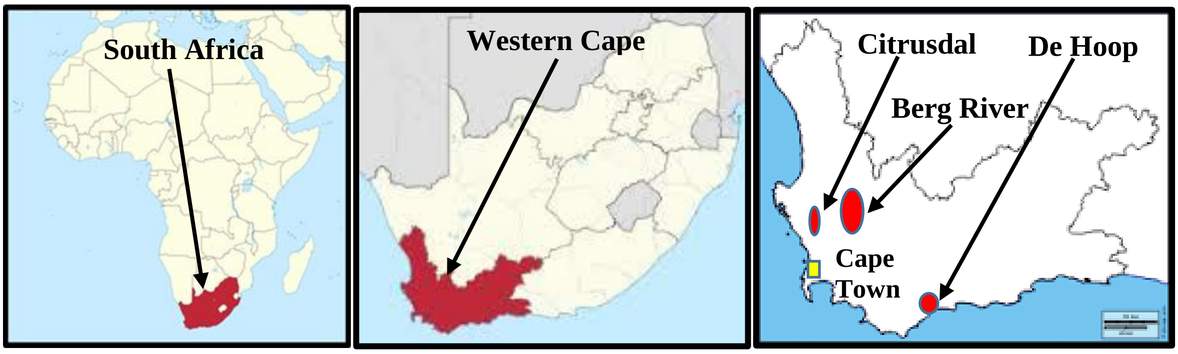

FIGURE 2. 1 LOCATION MAP FOR THE STUDY SITES

Source: Own Analysis

2.2.2 Data collection

The data on IAPs was collected from the DEA:NRM’s central database. This includes data on the clearing costs, person days worked, and the hectares cleared over time. Additionally, extensive literature surveys were conducted to obtain other published data relevant to the purposes of this study. Experts were consulted to validate the data and also to help define the assumptions. The area invaded by *Acacia saligna* was extracted from Kotzé et al. (2010). Focus group discussions were held with experts, the Department of Environmental Affairs personnel and the clearing operations implementing agents. This was done to aid the qualitative system dynamics model building process (i.e. the causal loop diagram). Site visits and investigations were conducted as a form of ground-truthing in order to verify whether the species mapped by Kotzé et al. (2010) and DEA:NRM (2016) correspond to what is on the ground.

The data on recycled thermoplastic waste was sourced from the Western Cape Department of Environmental Affairs and Development Planning, as well as literature surveys. Data on the tensile strength of using wood flour from *Acacia saligna* for the production of WPCs was obtained from an experimental study and analysis conducted by Effah, Van Reenen and Meincken (2017, in press) (see Section B in the supplementary materials segment).

2.2.3 Data analysis

2.2.3.1 Method

A system dynamics model was constructed using the Vensim® PLP software to conduct the analysis for the purposes of this study. System dynamics modelling is normally used when the subject under study involves complex systems that change over time (Ford 2009). Coyle (1977:2) defines system dynamics as *that branch of control theory which deals with socio-economic systems and that branch of management science which deals with problems of controllability*. Biological invasions emanating from IAPs like *Acacia saligna* and the environmental impacts caused by thermoplastic waste are characterised by various hidden dynamics and complexities. Moreover, the use of these two environmentally non-benign sources as raw materials for the production of WPCs, and the corresponding environmental, economic and social impacts, are difficult to assess as a result of the numerous complexities and dynamics of the subject matter. Thus, the system dynamics modelling approach was selected due to its versatility with regards to research problems that are non-linear in nature and characterised by complexities. The PORTJACKSON THERMOPLASTIC-WOOD POLYMER COMPOSITES PORTTHERM-WPC model (PORTTHERM-WPC) was constructed for the purpose of this study and is described in greater detail in Section A in the supplementary materials segment. The qualitative system dynamics model is also illustrated in Section D of the supplementary materials.

2.2.3.2 Scenarios

Four scenarios were developed to assess the benefits and cost of using *Acacia saligna* and thermoplastic waste for the production of WPCs over a 23-year simulation period (2008–2030), namely:

1. **Baseline scenario:**
   The DEA:NRM continues its control of *Acacia saligna* based on historic figures for 2008 until 2015, with the budget for controlling *Acacia saligna* kept constant based on the 2015 figures from 2016 onwards till 2030, with no value addition.

2. **Scenario 2: Low co-finance:**
   The control of *Acacia saligna* is done by the DEA:NRM based on historic figures from 2008 until 2015, with control efforts kept constant based on the 2015 figures from 2016 onwards till 2030, but allowing for a 20% co-finance component from the private sector augmenting the DEA:NRM budget. Additionally, a WPCs factory is established in 2016 and production commences in 2017.

3. **Scenario 3: Moderate co-finance:**
   The control of *Acacia saligna* is done by the DEA:NRM based on historic figures from 2008 until 2015, with control efforts kept constant based on the 2015 figures from 2016 onwards till 2030, but allowing for a 50% co-finance component from the private sector augmenting the DEA:NRM budget. Additionally, a WPCs factory is established in 2016 and production commences in 2017.

4. **Scenario 4: High co-finance:**
   The control of *Acacia saligna* is done by the DEA:NRM based on historic figures from 2008 until 2015, with control efforts kept constant based on the 2015 figures from 2016 onwards till 2030, but allowing for a 100% co-finance component from the private sector augmenting the DEA:NRM budget. Additionally, a WPCs factory is established in 2016 and production commences in 2017.

2.2.3.3 Model validation

The PORTTHERM-WPC model was tested through a three-stage validation processes namely, model debugging, model verification and model validation. In the model debugging stage, all errors were traced and corrected to allow the PORTTHERM WPC-model to simulate the various scenarios properly. During the model verification stage, the model was checked for any obvious errors present within it, for example, unit consistency and numerical accuracy. Lastly, the model validation process was two-pronged consisting of the direct structural test to assess the validity of the model structure compared the reference mode based on prior knowledge of the real world system, and the extreme condition test to gauge how sensitive it was to alteration in some of the variables, as recommended by Sterman (2000).

2.3 Results

2.3.1 Total area invaded by *Acacia saligna*

The PORTTHERM-WPC model results show a decreasing trend in the area invaded by *Acacia saligna* from 2008 to 2014 for all the scenarios (Figure 2.2 in the bottom right graph). During the initial simulation period, the total invaded area for all the sites was approximately 1 614 ha for all the scenarios. In 2014, it had reduced to 1 186 ha (baseline scenario), 850 ha (Scenario 2), 845 ha (Scenario 3) and 911 ha (Scenario 4). As from the year 2015, the total area under invasion began to increase, with the most increase noted in the baseline scenario, followed by Scenario 2 (with 20% co-finance), Scenario 3 (with 50% co-finance) and, lastly, Scenario 4 (with

100% co-finance). At the end of the simulation period the total area under invasion from *Acacia saligna* was reported to be 5 840 ha, 3 617 ha, 2 768 ha and 2 257 ha for the baseline scenario, 2, 3 and 4, respectively. As illustrated in Figure 2, most of the invasion emanates from the Citrusdal site, which shows an exponential dynamic behaviour pattern over time (Figure 2.2 left bottom graph) for all scenarios, in contrast to the Berg River (except for the baseline scenario) and De Hoop sites, which show a decline in invasion under all scenarios with invasion being almost zero from 2010 till the end of the model simulation (as shown in the two top graphs in Figure 2.2). According to the CapeNature (2016), *Acacia saligna* is the second IAP that is causing problems in the De Hoop Nature Reserve. In contrast to the area invaded by *Acacia saligna* in De Hoop (Figure 2.2 top left graph), showing almost zero invasion as from 2012 onwards given our model assumptions and the historical clearing budget incurred by Working for Water, this can possibly be attributed to a re-bound effect. The current norm is that Working for Water clears an area of IAPs in anticipation that the area will restore itself to its natural pre-invasion state. Since in our case, we only focussed on the quaternary catchment plots G50J and G50K, the DEA:NRM needs to check whether or not the areas cleared have been re-invaded given the recent report published by CapeNature (2016). The De Hoop Nature Reserve is a big site with quaternary catchment plots ranging from G50A-K. In this study, only quaternary catchment plots G50J and G50K were considered since these are the sites that the DEA:NRM has been working on and which have available data on clearing costs and invasion densities mapped (Kotzé et al. 2010; Van Staden pers. comm. 2015; Pitseng pers. comm. 2015; Moerat pers. comm. 2015). The two quaternary catchment plots are invaded mainly by *Acacia cyclops* followed by *Pinus spp*, *Acacia saligna* and *Eucalyptus spp* to a lesser extend (Kotzé et al. 2010).

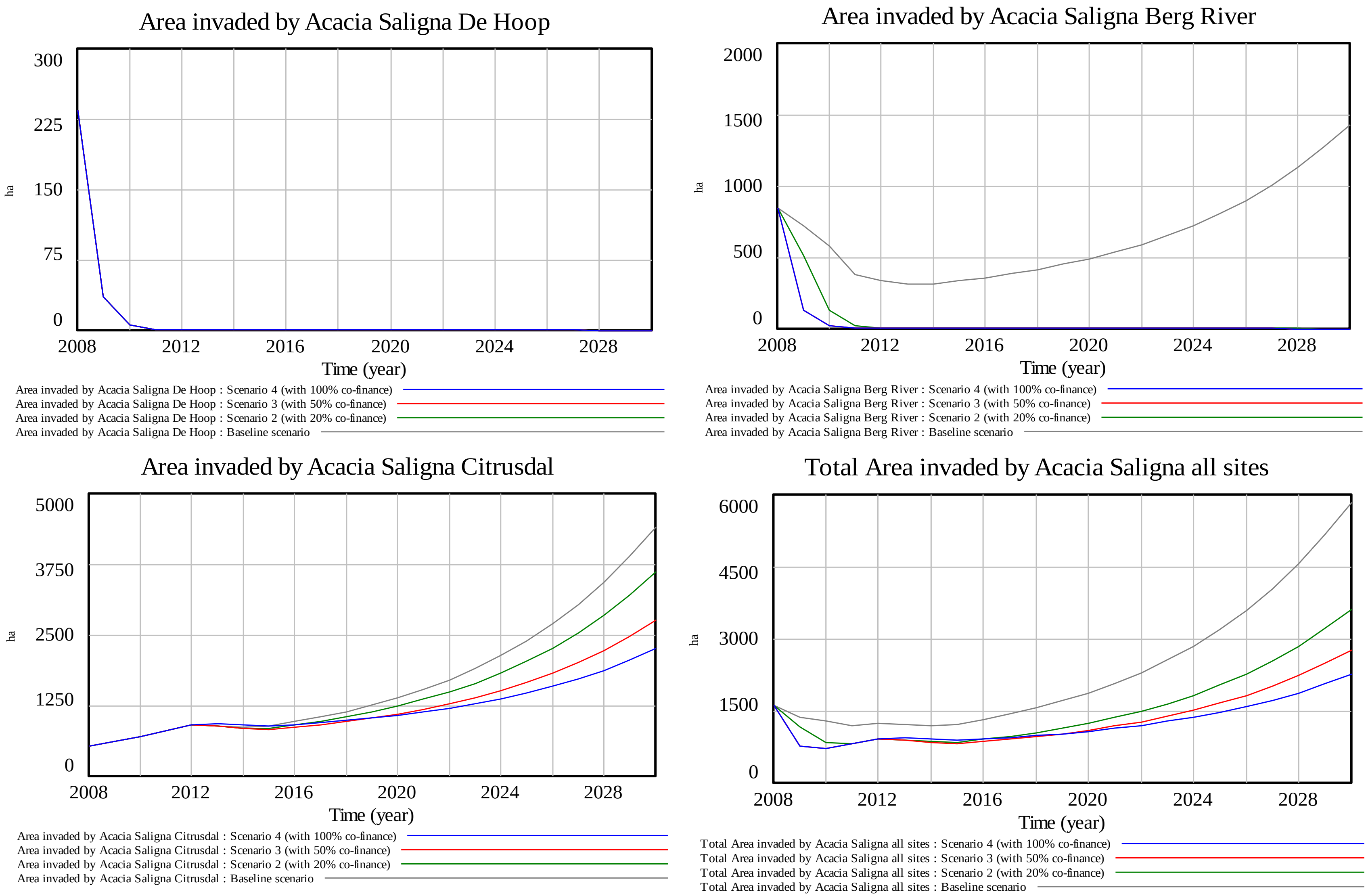

FIGURE 2. 2 DYNAMIC PATTERN OVER TIME OF THE TOTAL AREA INVADED BY ACACIA SALIGNA FOR ALL SITES

Source: Own Analysis

2.3.2 Private benefits and costs of WPC production

2.3.2.1 Total WPC Production output per annum

The PORTTHERM-WPC model results show that the total production output from converting *Acacia saligna* wood flour and recycled thermoplastics (at a 50:50 ratio) amounts to 1 354 tons (Scenario 2), 1 628 tons (Scenario 3) and 2 041 tons (Scenario 4) per annum from the year 2017 till the end of the model simulation, respectively. During the period 2008–2016, the total production output is zero for Scenarios 2, 3 and 4 respectively, because of the assumption that the WPC extrusion moulding production line is set up in 2016, and production commences in 2017 allowing for a one-year lag time. However, for the baseline scenario, the production output amounts to zero for the entire simulation period due to the "do nothing" assumption. As a result, there is an opportunity cost of not transforming the harvested biomass into value-added products such as WPCs considered in this study. The annual WPCs total production output is presented in Table 2.1. This annual production output is then apportioned on a pro-rata basis to the production of solid WPC decking planks (150x18x580 mm) and solid WPC wall cladding decking planks (145x12x580 mm) at 50% proportion for each WPC product typology.

2.3.2.2 Total solid WPC decking planks output and value per annum

The PORTTHERM-WPC model shows that no production of solid WPC decking planks occurs for the period 2008–2016 for Scenarios 2, 3 and 4, due to the assumption that the production line is set up in 2016 and the production commences in 2017. As for the baseline scenario, no production occurs due to the "do nothing" assumption made for this particular scenario. As from 2017 till the end of the simulation (i.e. 2030), the amount of solid WPC decking planks produced sums up to 43 674 planks, 52 518 planks and 65 834 planks per annum for Scenarios 2, 3 and 4, respectively. In addition, each solid decking plank weighs 0.0155 tons (or 15.5 kg) valued at ZAR675 per plank (or ZAR43.55 per kg). This equates to an approximate annual gross value of ZAR29.5 million, ZAR35.5 million and ZAR44.4 million per year for Scenarios 2, 3 and 4, respectively. The total annual solid WPC decking planks produced are presented in Table 2.1.

2.3.2.3 Total solid wall cladding planks output and value per annum

The results emanating from the PORTTHERM-WPC model show that the quantity of solid WPC wall cladding planks produced sum up to approximately 67 770 planks, 81 494 planks and 102 156 planks per annum for Scenarios 2, 3 and 4, respectively, from 2017 till the end of the simulation period (i.e. 2030). Each solid wall cladding plank weighs 0.010 tons (or 10 kg) valued at ZAR505 per plank (or ZAR50.5 per kg). As for the baseline scenario, no production takes place for the entire simulation due to the "do nothing" assumption. Furthermore, zero production output is recorded during the period 2008–2016 for Scenarios 2, 3 and 4 due to the assumption that production only commences in 2017, after the production line has been installed in 2016. The gross value of the solid wall cladding planks amounts to approximately ZAR34.2 million (Scenario 2), ZAR41.2 million (Scenario 3) and ZAR51.6 million (Scenario 4) per annum respectively. The total solid WPC wall cladding planks produced per annum are also presented in Table 2.1.

2.3.2.4 Total WPC material and production costs

The total material and production costs incurred in the production of WPC products (i.e. solid WPC decking and wall cladding planks) are reported to be zero for all the scenarios for 2008–2016. This is because of the assumption (Scenarios 2, 3 and 4) that the production only commences in 2017 after the WPC extrusion production line is set up in 2016. As for the baseline scenario, the manufacturing and production costs are zero due to the "do nothing" assumption. From 2017 until the end of the simulation period, the total manufacturing and production cost for the WPC products were constant at approximately ZAR4.8 million, ZAR5.8 million and ZAR7.3 million for Scenarios 2, 3 and 4, respectively. The total material and production cost for manufacturing WPCs products are also presented in Table 2.1.

TABLE 2. 1: SUMMARY OF ANNUAL PRODUCTION COSTS AND POTENTIAL REVENUES REALISED DUE TO WPC PRODUCTION FOR THE PERIOD 2017-2030

Variable (Unit)	Baseline Scenario	Scenario 2 (20% co-finance)	Scenario 3 (50% co-finance)	Scenario 4 (100% co-finance)
Total annual production output of WPC products (tons)	0	1 354	1 628	2 041
Total solid WPC decking planks produced (planks)	0	43 674	52 518	65 834
Total solid WPC wall cladding planks produced (planks)	0	67 770	81 493	102 156
Total Sundry costs (ZAR)	0	230 661	277 369	347 698
Total WPC material and production costs (ZAR)	0	4 843 880	5 824 756	7 301 667
Total clearing and wood processing costs (ZAR)	0	4 947 034	6 150 275	8 132 663
Net Value of WPC products (ZAR)	0	53 913 276	64 629 008	80 593 240

Source: Own Analysis

2.3.2.5 Total establishment costs for the WPC factory plant

The once-off establishment cost incurred to set-up the WPC production plant amounted to approximately ZAR31.2 million for all the scenarios (except for the baseline scenario which is zero throughout the entire simulation period) within 2016. It is zero for all the other years in the simulation since the machines in the factory would not have reached their lifespan (assumed to be 15 years in this case) to warrant a replacement cost of the WPC production line components. With regards to the baseline scenario, there was no WPC production plant establishment cost due to the absence of the manufacturing process as a result of the "do nothing" assumption.

2.3.3 Externality benefits and costs due to clearance of *Acacia saligna*

2.3.3.1 Water savings benefit and monetary value

The water savings emanating from the clearance of *Acacia saligna* from the study sites (combined) decrease over time from 2008–2011, followed by a rise until 2014 and another decline in 2015. From 2016 onwards, the water savings due to the clearing of *Acacia saligna* in the Berg River and Citrusdal sites become constant at 54 431 m^3, 43 339 m^3, 52 114 m^3 and 54 327 m^3 for the baseline scenario, 2, 3 and 4, respectively. Using a unit price of water of ZAR2 per m^3, this translates to a value of ZAR108 864, ZAR86 676, ZAR104 228 and ZAR130 655 for the baseline scenario, 2, 3 and 4, respectively. The De Hoop site is excluded since all the water saved flows to the sea (Mudavanhu et al. 2016). The water savings per annum emanating from the clearance of *Acacia Saligna* are shown in Section F of the supplementary material in much greater detail.

2.3.3.2 Carbon sequestration potential loss and cost value

The carbon stock sequestered, stored and removed as a result of clearing *Acacia saligna* amounted to approximately, 13 437 tons (baseline scenario), 19 405 tons (Scenario 2) and 30 495 tons (Scenarios 3 & 4) in the beginning of the model simulation. This translates to ZAR1.6 million (baseline scenario), ZAR2.3 million (Scenario 2) and ZAR3.6 million (Scenario 3 & 4) in monetary terms. In 2011 for Scenarios 3 and 4, and 2030 for the baseline scenario, the negative value shows that there is a carbon sequestration benefit due to the re-invasion by *Acacia saligna* outweighing the clearance. The annual carbon sequestered, stored and removed is presented in in Section F of the supplementary material in much greater detail

2.3.4 Cumulative net present value (NPV) for clearing *Acacia Saligna* and making WPCs

The PORTTHERM-WPC model shows a positive NPV value for all the scenarios considered in this study with the exception of the baseline scenario. The cumulative NPV for the simulation period was –ZAR122.1 million, ZAR144.4 million, ZAR172.7 million and ZAR211.2 million for the baseline scenario, 2, 3 and 4, respectively. The dynamic pattern of the results output produced from the PORTTHERM-WPC model is presented in Figure 2.3.

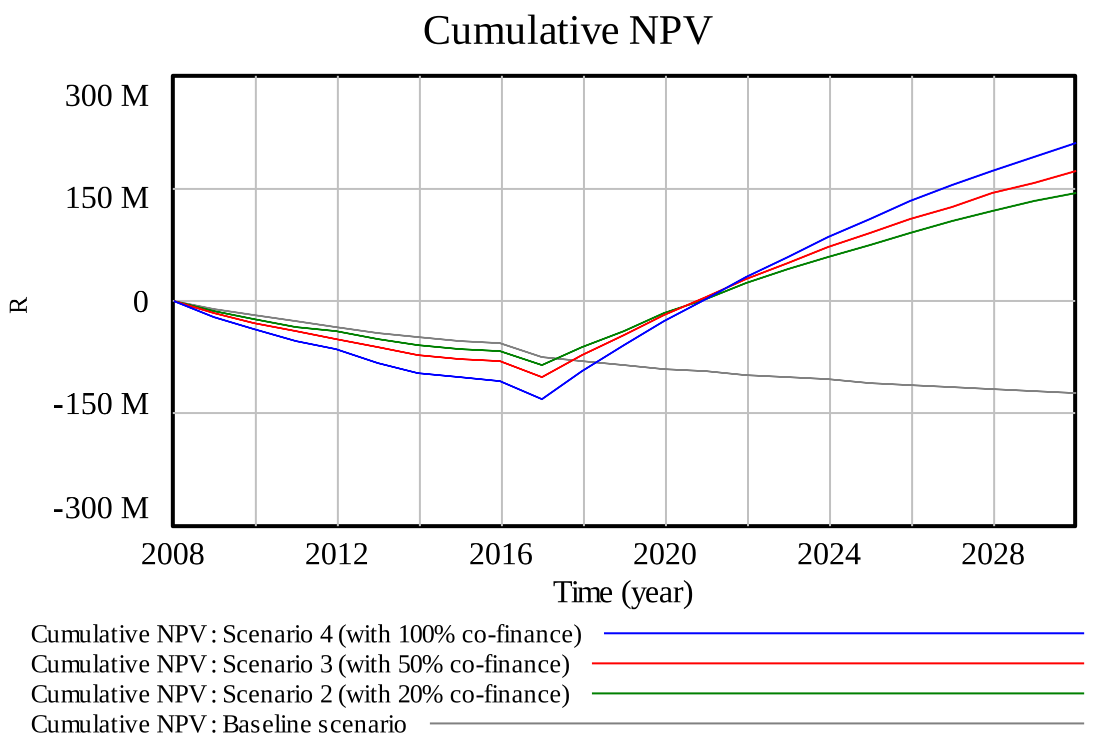

FIGURE 2. 3: CUMULATIVE NPV FOR CLEARING *ACACIA SALIGNA* AND MAKING WPC PRODUCTS

Source: Own Analysis

2.4 Discussion and concluding remarks

Given the empirical findings produced by the PORTTHERM-WPC model, the results give an indication that the clearing of *Acacia saligna* and using the cleared biomass to make WPC value-added products, is economically viable. However, clearing *Acacia saligna* without using the biomass to make WPCs, yields a negative cumulative NPV for the baseline scenario. The rule of thumb in cost-benefit analysis using the NPV method, is that all projects yielding a positive NPV are desirable and preferable, with the highest priority being assigned to the alternative yielding the highest NPV value. In this case, Scenario 4 is more favourable, followed by Scenario 3 and, lastly, Scenario 2. The baseline scenario should be avoided at all costs. The annual net economic value from clearing *Acacia saligna* and making WPC value-added products (i.e. solid WPC decking and wall cladding planks) were discounted at a 6% discount rate yielding the aforementioned total cumulative values for the respective scenarios. It is important to note that the negative cumulative NPV yielded in the baseline scenario presents an opportunity cost associated with not using the biomass for value-adding purposes. As a result, income and opportunities that would have risen due to value-adding activities through the manufacture and sale of WPCs product, are forgone in this case, and thus this scenario should be avoided by decision-makers.

The results also show that augmenting the state budget through private sector co-finance, can help reduce the area under invasion with the most impact being realised with 100% co-finance, followed by the 50% co-finance and lastly the 20% co-finance options (see Figure 2). The strategic importance of these dynamics as shown in Figure 2, is that they justify the importance of increasing the clearing budget in order to battle the problems of invasion by IAPs such as *Acacia saligna*. However, despite the increased funding due to co-finance from the private sector, the area under invasion gradually starts to increase again over time, but a slower rate. This emphasises the strategic importance of follow-up clearing operations.

As shown in Figure 2, the effects of clearing IAPs differ from one site to another. It can be clearly observed that for the Citrusdal site, the area under invasion maintains an almost constant (and stable) growth pattern from 2008–2015 and then eventually starts to increase for all the scenarios. As for the Berg River site, the area under invasion by *Acacia saligna* initially declines from the beginning of the simulation period and stabilises at almost zero from 2012 till the end of the simulation. Lastly, for the De Hoop site, the area under invasion by *Acacia saligna* gradually declines from the initial time of the model simulation to almost zero in the year 2012, and thereafter, the same trend is maintained until the end of the model simulation with invasion being almost zero. The general upward increase in the total area invaded by *Acacia saligna* for all sites combined, can be attributed to the Citrusdal site (with the exception of the baseline scenario of the Berg river site). As a result more control efforts should be focused on the Citrusdal site. This shows that site-specific case studies should not be treated with a "one size fits all" approach. The factors influencing invasion by IAPs vary on both a spatial and temporal scale, presenting a challenge as to how we understand the behaviour of a system. For this reason, the system dynamics modelling approach is ideal in enabling us to supplement and augment our models with more insights, which we would otherwise have ignored.

The results produced by the PORTTHERM-WPC Model also show that clearing *Acacia saligna* is a contentious issue. Despite it being an IAP that causes several harmful impacts on the environment, economy and society at large, *Acacia saligna* also sequesters carbon dioxide from the atmosphere, thereby reducing the amount of greenhouse gasses. Furthermore, it can be used to create value-added industries which can create employment, add to the government's tax revenue and also increase the country's GDP and GNP, having multiplier effects on the downstream and mainstream economy.

Despite the presence of NEMBA regulations, there has generally been a lack of policy alignment and enforcement across various sectors affected by IAPs. As a result, a more robust legal framework that prohibits illegal planting of the IAPs must be set up and enforced, through the help of environmental law enforcement agencies and respective courts of law. As there is the potential of value-adding and generating profit, there is also a risk of the incentive to grow these IAPs.

The results emanating from this study show that there is great potential for using *Acacia saligna* biomass as a raw material in the manufacture of WPC products. Despite the negative impacts posed by *Acacia saligna*, benefits actually accrue as a result of its use in the production of WPC products. Thus, policy-makers should view the use of *Acacia saligna* as an alternative way in which the private sector can be incentivised to help augment the current state budget, which is by far not enough to tackle the problem of IAPs.

It is recommended that this study be replicated at other sites, to test and gauge if the same research findings can be obtained. Furthermore, a market research analysis (for both local and export markets) should be conducted before considering setting up a WPC plant in the City of Cape Town to produce the products assessed in this study. In conclusion, more research should be conducted to assess the feasibility of using *Acacia saligna* in comparison to other IAPs invading the sites under investigation and also to test other value-added products such as timber, bioelectricity production, charcoal and firewood.

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2.6 Supplementary materials

Section A: The PORTTHERM-WPC sub-models

Model description

The PORTTHERM-WPC model consists of 7 sub-models, namely i) the *Acacia saligna* clearance sub-model, ii) the WPCs production sub-model, iii) the material and production cost sub-model, iv) the clearing cost sub-model, v) the carbon sequestration sub-model, vi) the water consumption sub-model and vii) the net present value sub-model. The parameters used in this study, as well as the respective equations used to derive the endogenous variables, are shown in Section C in the supplementary materials segment with its supporting causal loop diagram (i.e. qualitative system dynamics model) presented in Section D (in the supplementary materials segment). Section E offers the model boundary chart which illustrates the endogenous, exogenous and excluded variables used in the model. The exogenous variables are those variables that are derived from factors external to system modelled, while endogenous variables are those that are derived within the model through equations. Excluded variables refer to those variables that are included within the qualitative system dynamics model (i.e. the causal loop diagram), but are excluded from the model simulations either because of a lack of data or because they are beyond the scope of the study.

The *Acacia saligna* clearance sub-model

This sub-model establishes the area invaded by *Acacia saligna* that is cleared within the three study sites. It consists of three stock variables representing the three study areas under invasion by *Acacia saligna*. Stock variables refer to the accumulations within the system that are increased by inflows and drained by outflows. The areas invaded by *Acacia saligna* are increased by its re-growth, which is influenced by the growth rate of *Acacia saligna* and the area invaded. The areas invaded by *Acacia saligna* are drained by the clearing operations, which are influenced by the effect of person days on hectares cleared and the proportion invaded by *Acacia saligna* relative to other IAPs invading the sites under investigation. Figure A2.1 below illustrates this sub-model in greater detail.

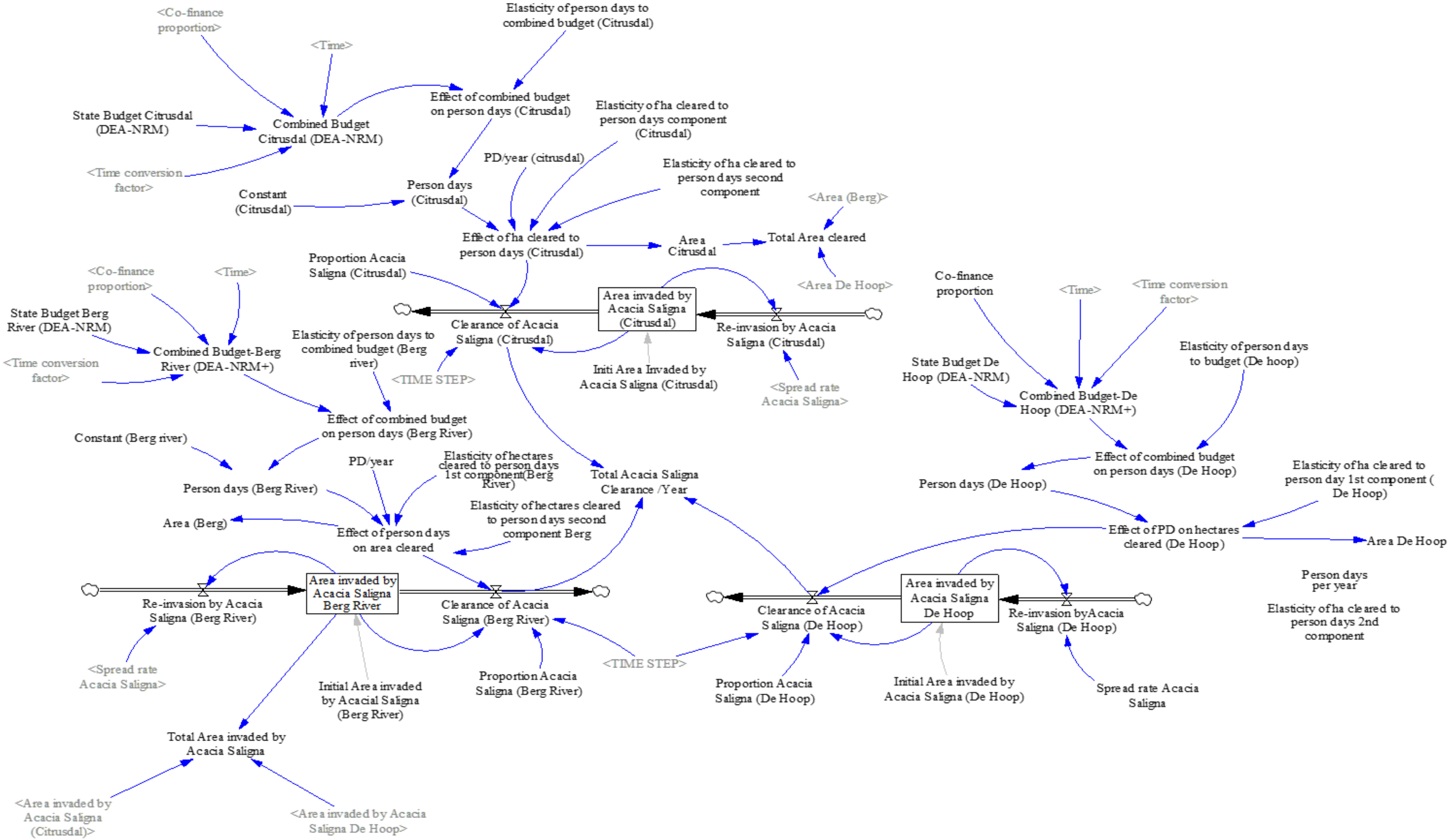

FIGURE A2. 1 THE *ACACIA SALIGNA* CLEARANCE SUB-MODEL

Source: Own analysis

The WPC production sub-model

This sub-model models the amount of WPCs produced from *Acacia saligna* wood flour and recycled thermoplastic waste at a 50:50 ratio. In this sub-model, low-density polyethylene (LDPE) recycled thermoplastics are considered for the production of WPCs. The *Acacia saligna* wood flour is a function of the dry useable biomass. The recycled thermoplastic granules are apportioned at the same quantity as the total amount of *Acacia saligna* wood flour generated per annum. The raw WPC material is then moulded into solid wall cladding and decking planks. The production of WPC solid decking planks (150x18x5800 mm) and WPC wall cladding planks (145x12x5800 mm) is assumed to be at a pro-rata basis with 50% of the raw WPC being moulded into each of the two value-added products considered here. The weight of the WPC products is then derived as the density multiplied by the volume of the products. Thereafter, the gross value of the manufactured WPC products is derived as a function of the price per unit (ZAR/plank) and the number of WPC products (planks) produced per annum. Furthermore, the total gross value of all combined products (WPC wall cladding planks and decking planks) is derived by adding their respective gross values. Lastly, the net value of all WPC products combined is calculated by subtracting the total material and production cost for WPC products produced and the total clearing and wood processing costs from the gross production value. The WPC production sub-model is shown in detail in Figure A2.2.

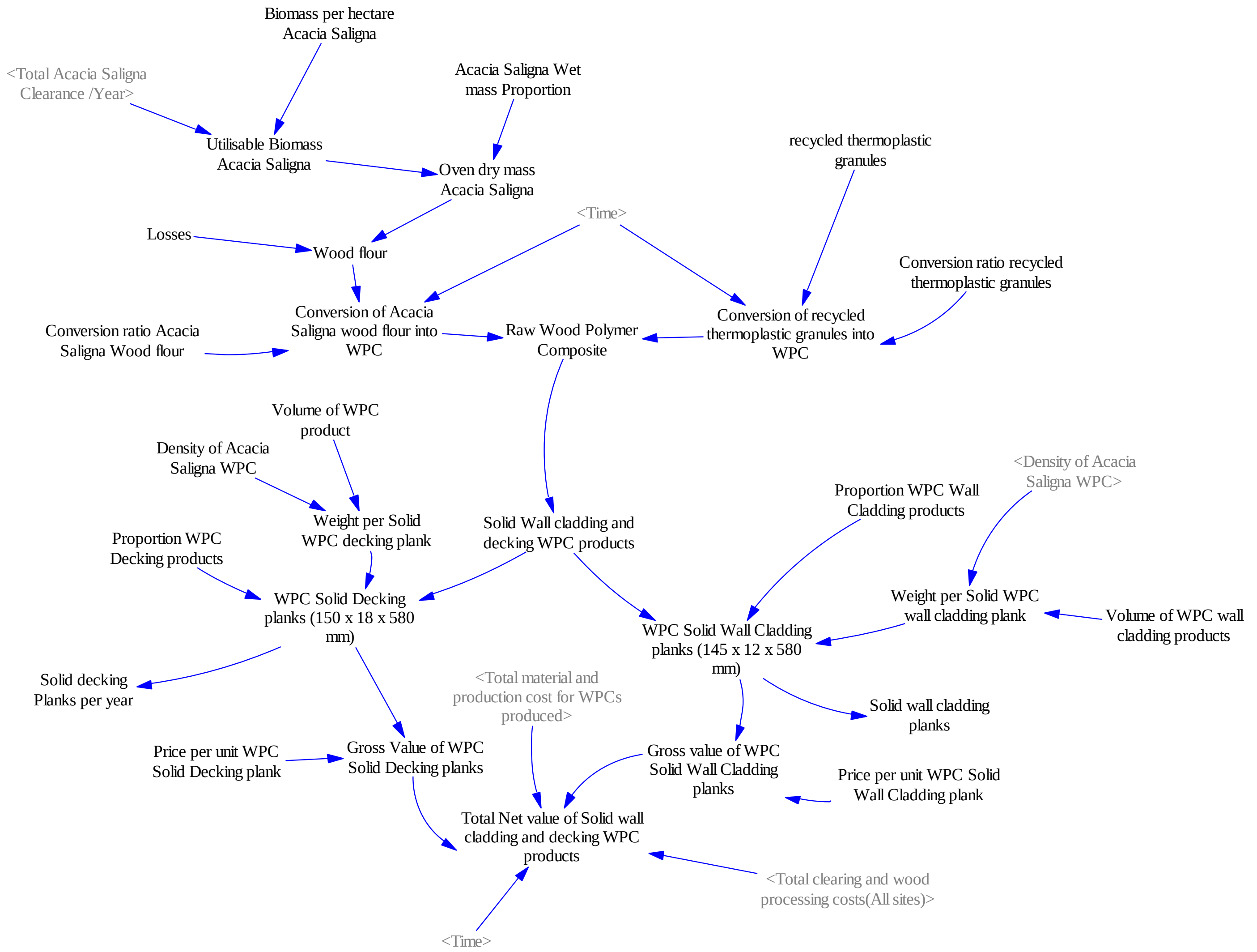

FIGURE A2. 2 THE WPC PRODUCTION SUB-MODEL

Source: Own analysis

The materials and production cost sub-model

The material and production cost sub-model establishes the production and manufacturing costs incurred when undertaking the production of WPCs (see Figure A2.3). According to Rowell (1998, modified), the materials costs of WPCs are derived as follows:

$$ZAR/ton = \frac{[P(X)+F(Y)+C]}{E} \quad (1)$$

Where

ZAR/ton is the production costs in ZAR per ton
P is the percent of plastic in the composite
X is the estimated cost of the plastic in ZAR per ton
F is the percent of *Acacia saligna* wood flour in the WPC
Y is the estimated cost of *Acacia saligna* wood flour per ton
C is the cost of compounding in ZAR per ton
E is the efficiency of operation, assumed here to be equal 1

The material cost, however, is only a proportion of the total manufacturing costs (i.e. 77%). In addition, 15% of the total cost represents machine costs, while 5%, 7% and 3% represent the proportion spent on tools, labour, and packaging and transport, respectively (Ghasem 2013). Lastly, a 5% conservative provision (as a percentage of the total material and productions costs) was allowed to cater for the logistical costs associated with bringing other non-IAPs raw materials used in the WPC production process.

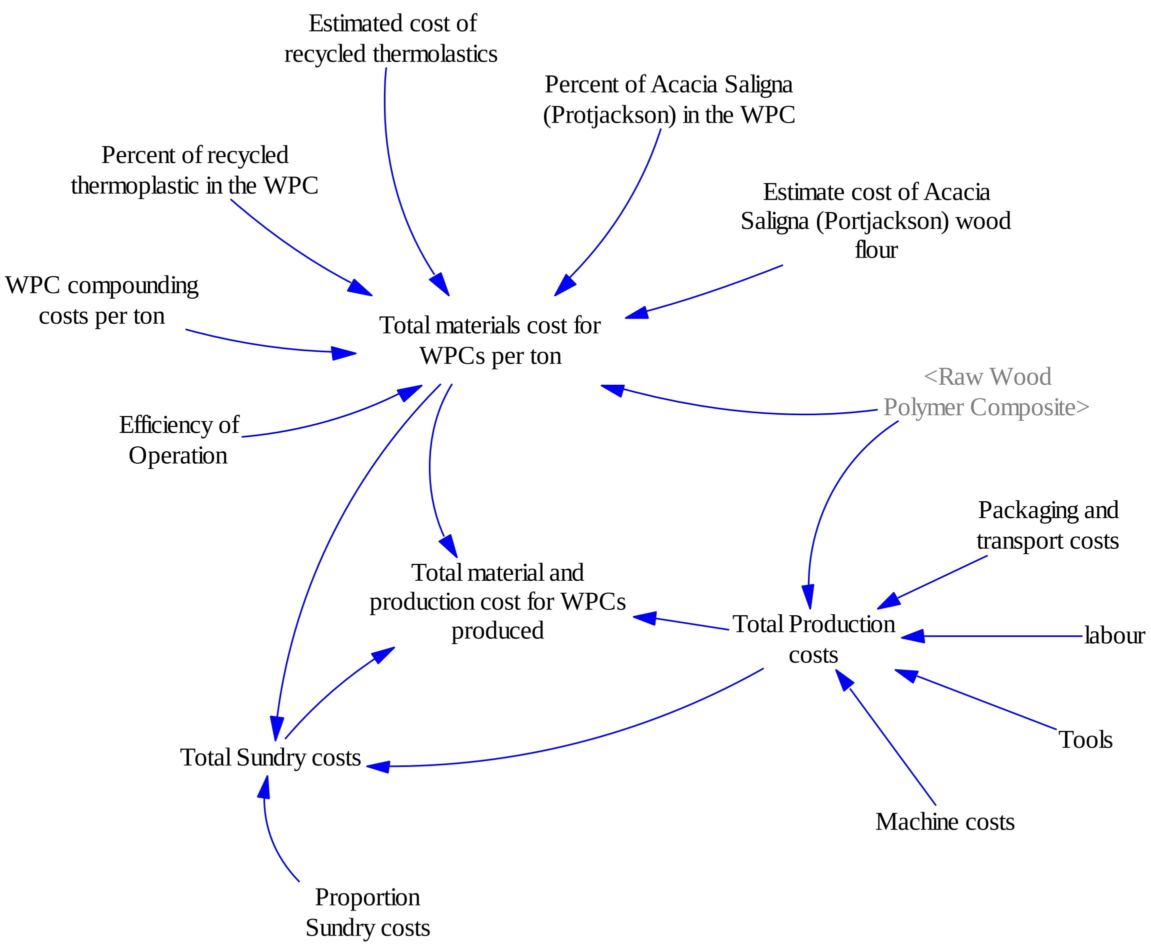

FIGURE A2. 3 MATERIALS AND PRODUCTION COST SUB-MODEL

Source: Own analysis

The establishment cost sub-model

The establishment cost sub-model establishes the once-off cost to setting up the WPC production plant. The complete plant consists of five sub-components (consisting of five units for each component), namely the WPC profile extrusion plant machine, the high-speed mixer machine, the vertical type cooling blender machine, the pelletiser extrusion line machine and the wood powder machine. The total WPC once-off factory establishment cost is derived through the product of the number of units for each component and the respective price (cost) per component of the aforementioned five sub-components. The establishment cost sub-model is illustrated in Figure A2.4.

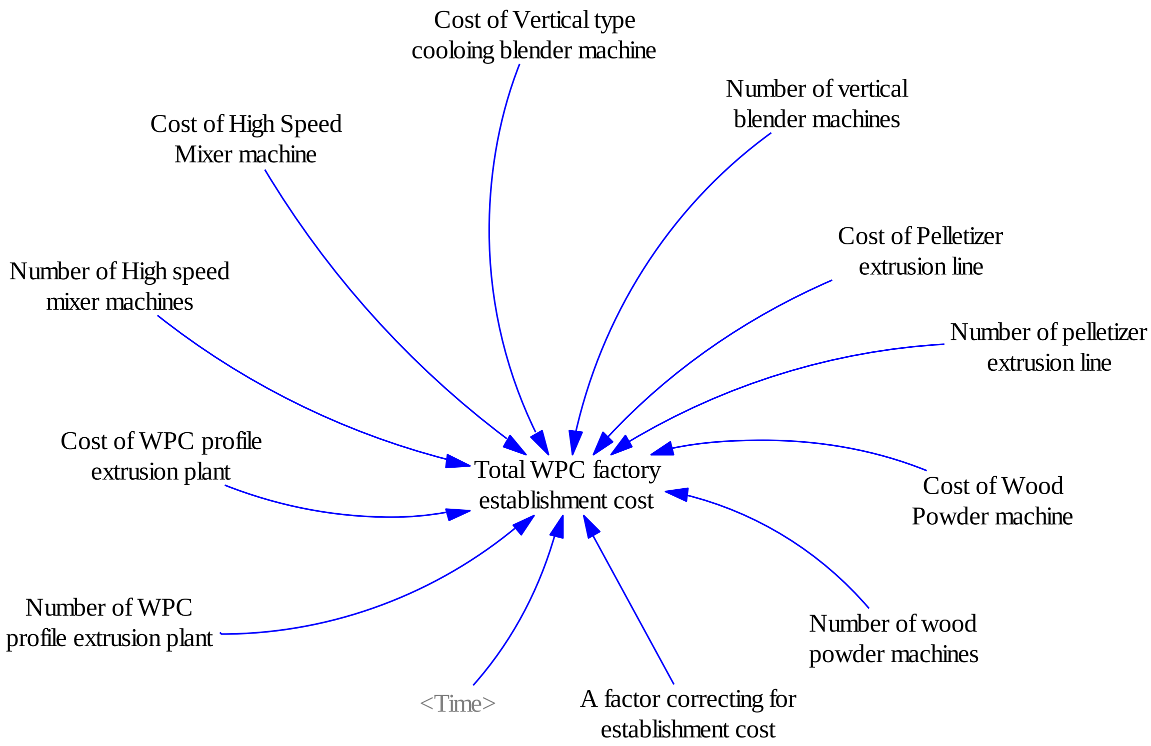

FIGURE A2. 4: THE WPC PRODUCTION PLANT ESTABLISHMENT COST SUB-MODEL

Source: Own Analysis

The clearing and wood process cost sub-model

The clearing cost sub-model models the total clearing and wood processing costs incurred to clear *Acacia saligna* within the study sites. The unit clearing cost is a function of the combined clearing budget within the sites and the annual clearance (ha) of *Acacia saligna*. The combined budget refers to the total amount of money invested by DEA:NRM to clear *Acacia saligna* and a co-finance option from the private sector which augments the funding being provided by the government. Chipping and transport costs per hectare cleared are then added to give the total clearing and wood processing cost. The clearing cost sub-model is shown in Figure A2.5.

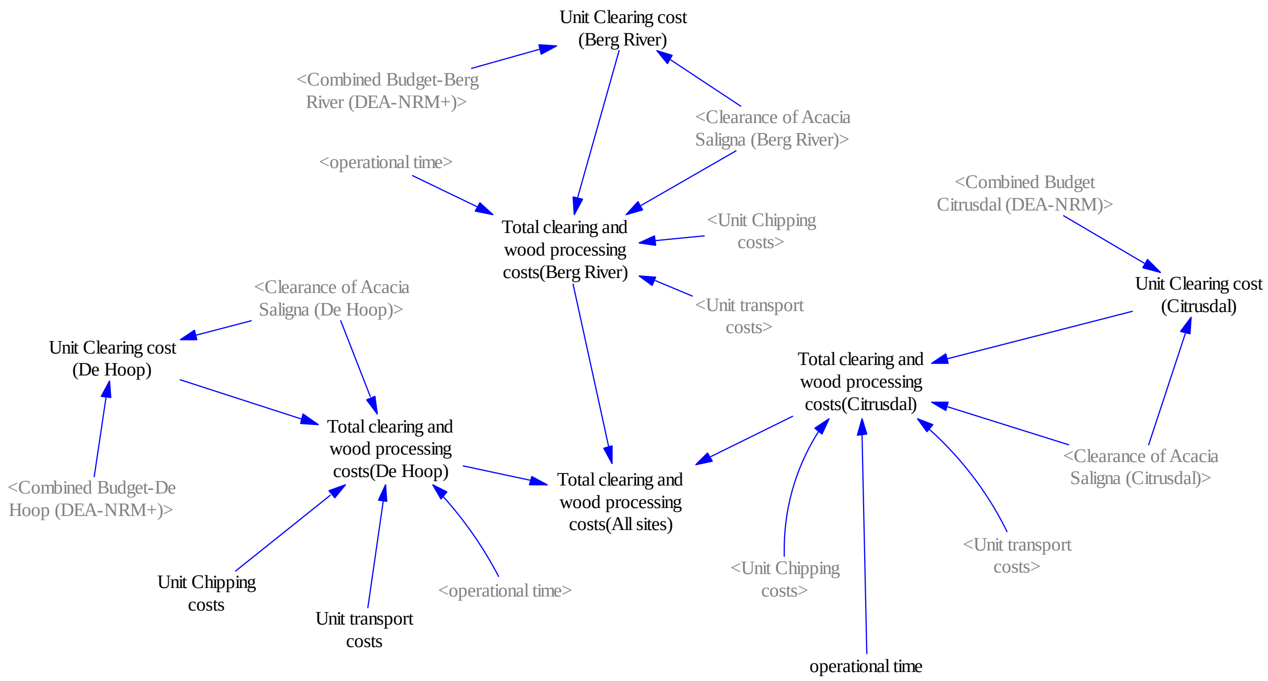

FIGURE A2. 5: THE CLEARING AND WOOD PROCESSING COST SUB-MODEL

Source: Own analysis

The carbon sequestration sub-model

The carbon sequestration sub-model establishes the value of net carbon stock sequestered, stored and removed that is lost as a result of clearing *Acacia saligna* and the carbon sequestered and stored as a result of re-invasion by *Acacia saligna*. *Acacia saligna* sequesters and store carbon from the atmosphere as a result of photosynthesis. Thus, by clearing *Acacia saligna* there is an opportunity cost involved due to the loss of carbon sequestration potential which is, to a certain extend, offset as a result of re-invasion. The carbon sequestration potential is derived by the product of *Acacia saligna* biomass, the net dry mass conversion ratio of *Acacia saligna*, the clearance of *Acacia saligna* (or re-invasion by *Acacia saligna* in the case of carbon sequestered as a result of re-invasion by new *Acacia saligna* plants) and CO_2:Carbon ratio. The net carbon sequestered and stored value that is removed, is then calculated by multiplying the net carbon removed (i.e. net carbon sequestered and removed due to clearance less the carbon addition emanating from re-invasion by *Acacia saligna*) and the unit price of carbon. The carbon sequestration sub-model is shown in Figure A2.6.

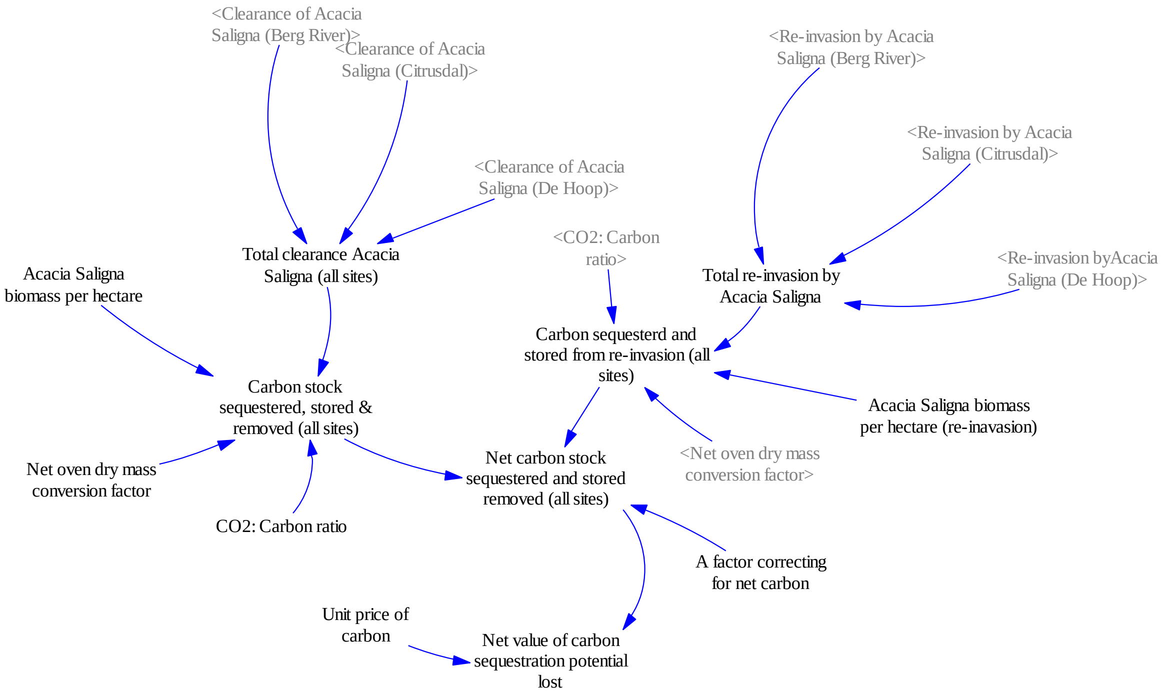

FIGURE A2. 6: THE CARBON SEQUESTRATION SUB-MODEL

Source: Own analysis

The water consumption sub-model

This sub-model estimates the water reduction caused by the invasion by *Acacia saligna* within the study sites. Water that was previously consumed by these IAPs is saved as a result of clearing and augments the water supply from the Berg River and the Olifants River of the Western Cape. This water becomes available for other uses such as agricultural irrigation and supply of potable water to residential and industrial areas supplied by these water bodies. The water savings from De Hoop are not considered in this study since all the water savings due to clearing of IAPs flows to the ocean (Mudavanhu et al. 2016). The water that is used by *Acacia saligna* is derived through the product of water reduction per hectare by *Acacia saligna* and the clearance of *Acacia saligna*. The monetary economic value of water that is saved as a result of clearing is then calculated by multiplying the unit value of water and the water use by *Acacia saligna* which has become freed after the clearing operations. This sub-model is illustrated in Figure A2.7.

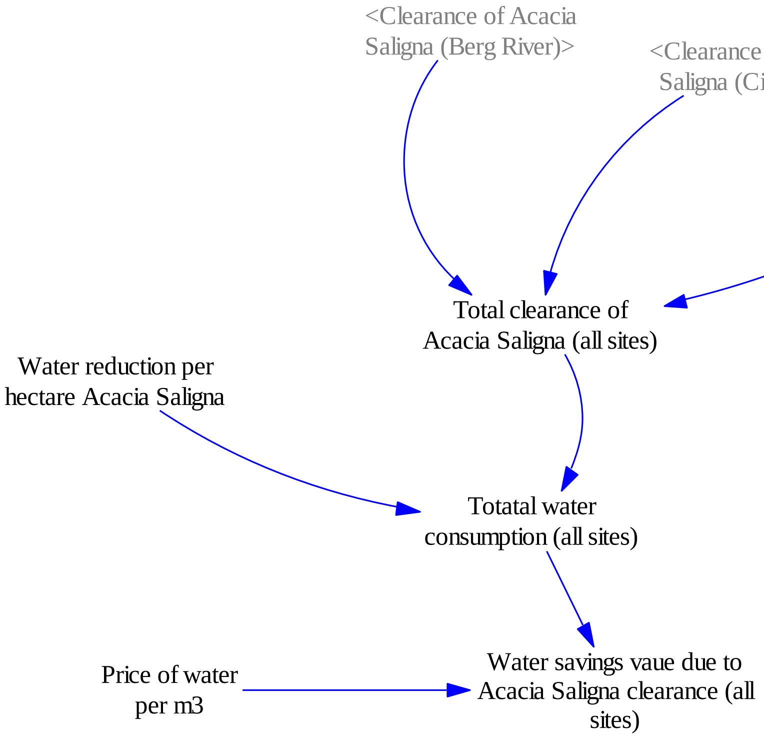

FIGURE A2. 7: WATER CONSUMPTION SUB-MODEL

Source: Own analysis

The NPV sub-model

This sub-model estimates both the costs and the benefits of using wood flour derived from *Acacia saligna* and recycled thermoplastic to make WPCs by estimating the net present value of the operations. This analysis is important in order to determine its economic feasibility. The net benefits from using *Acacia saligna* wood flour and thermoplastic waste to make WPCs is derived through the following equation(s):

- Net benefits = Total benefits – Total costs (2)

Where:

- Total benefits = Water savings value due to *Acacia saligna* clearance + Total net value of solid wall cladding and decking WPC products (3)
- Total costs = Total clearing and wood processing costs + Carbon sequestration potential lost + Total material and production costs + Total WPC factory establishment costs (4)

The net present value is then derived by dividing the net income from the sale of WPCs and water savings value by the discount factor. The net present value is then accumulated for the entire simulation period to give the cumulative NPV (see Figure A2.8)

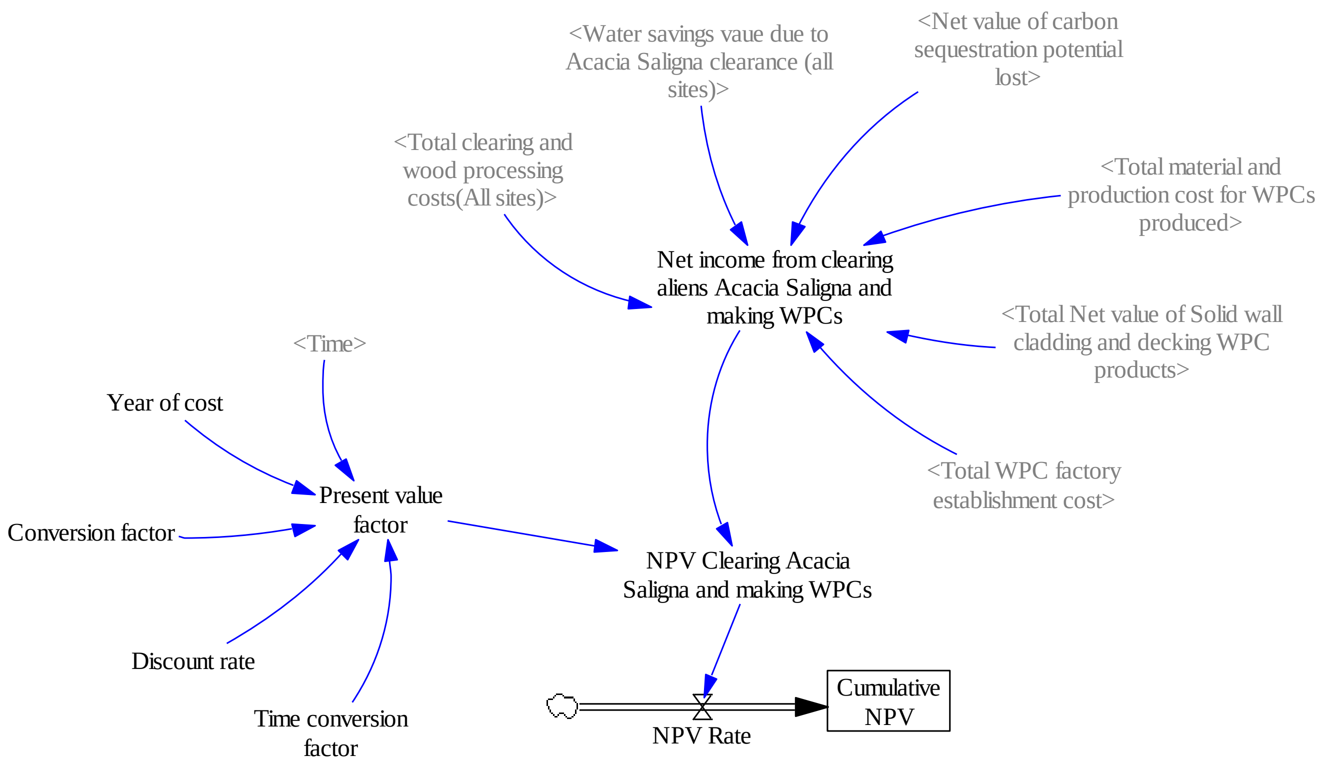

FIGURE A2. 8: THE NET PRESENT VALUE (NPV) SUB-MODEL

Source: Own analysis

Section B: Physical and Mechanical Properties of Port Jackson (*Acacia saligna*) WPC

Composite	**Physical**		**Mechanical**				
	MC (%)	Density (g/cm^3)	Tensile strength (MPa)	Tensile Modulus (MPa)	Elongation (%)	Impact	Hardness
LDPE + 50% wood flour	-	-	11.78 ± 1.04	1309.06 ± 165.73	2.57 ± 0.12	6.9 ± 0.82	61.7 ± 2.02
LDPE + 50% wood flour + 10% PE-g-MA	4.24 ± 0.13	0.99 ± 0.01	16.25 ± 2.34	1354.6 ± 230.15	2.8 ± 0.55	8.4 ± 0.82	60.8 ± 4.83

Source: Adapted with permission from Effah et al. (2017)

Section C: Model parameters and equations used in the PORTTHERM-WPC model

***Acacia saligna* clearance sub-model parameters**				
Variable	**Value/Formula**	**Units**	**Data Source**	**Comments**
"Co-finance proportion"	1	Dmnl	Policy variable	
"State Budget Citrusdal (DEA-NRM)"	Lookup	R/year	DEA-NRM (2016)	
Time conversion factor	1	year	Policy Variable	
Time	Internally defined in model	year		
"Elasticity of person days to combined budget (Citrusdal)"	0.0056	PD/R	Own calculation	
"Constant "	255.86	PD/year	Own calculation	
"PD/year (Citrusdal)"	1	PD/year	Policy variable	
"Elasticity of ha cleared to person days component (Citrusdal)"	-3e-007	ha/PD	Own calculation	
Elasticity of ha cleared to person days second component	0.0233	ha/PD	Own calculation	
"Proportion *Acacia saligna* (Citrusdal)"	0.38	Dmnl	Own calculation	
TIME STEP	1	year	Policy variable	
"Initial Area Invaded by *Acacia saligna* (Citrusdal)"	530.714	ha	DEA-NRM (2016)	
Spread rate *Acacia saligna*	0.15	Dmnl/year	Van Wilgen & Le Maitre (2013)	Conservative estimate for annual spread rate
"State Budget Berg River (DEA-NRM)"	Lookup	R/year	DEA-NRM (2016)	
"Elasticity of person days to combined budget (Berg river)"	0.0035	PD/R	Own calculation	
"Constant (Berg river)"	5114.9	PD/year	Own calculation	
"Elasticity of hectares cleared to person days 1st component (Berg River)"	79.409	ha/PD	Own calculation	
"Elasticity of hectares cleared to person days 2nd component (Berg River)"	0.0001	ha/PD	Own calculation	

"Proportion *Acacia saligna* (Berg River)"	0.0983	Dmnl	Own calculation	
"Initial Area invaded by *Acacia saligna* (Berg River)"	849.69	ha	DEA-NRM (2016)	
"State Budget De Hoop (DEA-NRM)"	Lookup	R/year	DEA-NRM (2016)	
"Elasticity of person days to budget (De hoop)"	0.0049	PD/R	Own calculation	
"Elasticity of ha cleared to person day 1st component (De Hoop)"	1894.9	ha/PD	Own calculation	
"Initial Area invaded by *Acacia saligna* (De Hoop)"	233.75	ha	DEA-NRM (2016)	
"Proportion *Acacia saligna* (De Hoop)"	0.0983	Dmnl	Own calculation	
***Acacia saligna* clearance sub-model equations**				
Variable	**Value/Formula**	**Units**	**Data Source**	**Comments**
"Combined Budget Citrusdal (DEA-NRM)"	"Co-finance proportion"*"State Budget Citrusdal (DEA-NRM)"(Time/Time conversion factor)	R/year	Own calculation	
"Effect of combined budget on person days (Citrusdal)"	"Combined Budget Citrusdal (DEA-NRM)"*"Elasticity of person days to combined budget (Citrusdal)"	PD/year	Own calculation	
"Person days (Citrusdal)"	"Effect of combined budget on person days (Citrusdal)"+"Constant (Citrusdal)"	PD/year	Own calculation	
"Effect of ha cleared to person days (Citrusdal)"	(("Elasticity of ha cleared to person days component (Citrusdal)"*("Person days (Citrusdal)"*"Person days (Citrusdal)"))/"PD/year (Citrusdal)")+(Elasticity of ha	ha/year	Own calculation	

	cleared to person days second component*"Person days (Citrusdal)")			
Area Citrusdal	"Effect of ha cleared to person days (Citrusdal)"+1.9165	ha/year	Own calculation	
Total Area cleared	Area Citrusdal + "Area (Berg)"+Area De Hoop	ha/year	Own calculation	
"Clearance of *Acacia saligna* (Citrusdal)"	MIN(("Effect of ha cleared to person days (Citrusdal)"+1.9165)*"Proportion *Acacia saligna* (Citrusdal)" , "Area invaded by *Acacia saligna* (Citrusdal)"/TIME STEP)	ha/year	Own calculation	
"Re-invasion by *Acacia saligna* (Citrusdal)"	"Area invaded by *Acacia Saligna* (Citrusdal)"*Spread rate *Acacia saligna*	ha/year	Own calculation	
"Area invaded by *Acacia saligna* (Citrusdal)"	INTEG("Re-invasion by *Acacia saligna* (Citrusdal)"-"Clearance of *Acacia saligna* (Citrusdal)")			
"Combined Budget-Berg River (DEA-NRM+)"	"Co-finance proportion"*"State Budget Berg River (DEA-NRM)"(Time/Time conversion factor)	R/year	Own calculation	
"Effect of combined budget on person days (Berg River)"	"Combined Budget-Berg River (DEA-NRM+)"*"Elasticity of person days to combined budget (Berg river)"	PD/year	Own calculation	
"Person days (Berg River)"	"Effect of combined budget on person days (Berg River)"+"Constant (Berg river)"	PD/year	Own calculation	
Effect of person days on area cleared	"Elasticity of hectares cleared to person days (Berg	ha/year	Own calculation	

	River)"*"Person days (Berg River)"			
"Re-invasion by *Acacia saligna* (Berg River)"	Area invaded by *Acacia saligna* Berg River*Spread rate *Acacia saligna*	ha/year	Own calculation	
"Clearance of *Acacia saligna* (Berg River)"	MIN((Effect of person days on area cleared-149293)*"Proportion *Acacia saligna* (Berg River)" , Area invaded by *Acacia saligna* Berg River/TIME STEP)	ha/year	Own calculation	
Area invaded by *Acacia saligna* Berg River	INTEG("Re-invasion by *Acacia saligna* (Berg River)"-"Clearance of *Acacia saligna* (Berg River)")	ha	Own calculation	
Total Area invaded by *Acacia saligna*	"Area invaded by *Acacia saligna* (Citrusdal)"+Area invaded by *Acacia saligna* Berg River + Area invaded by *Acacia saligna* De Hoop	ha	Own calculation	
"Combined Budget-De Hoop (DEA-NRM+)"	"Co-finance proportion"*"State Budget De Hoop (DEA-NRM)"(Time/Time conversion factor)	R/year	Own calculation	
"Effect of combined budget on person days (De Hoop)"	"Combined Budget-De Hoop (DEA-NRM+)"*"Elasticity of person days to budget (De hoop)"	PD/year	Own calculation	
"Person days (De Hoop)"	"Effect of combined budget on person days (De Hoop)"-315.26	PD/year	Own calculation	
"Effect of PD on hectares cleared (De Hoop)"	(("Elasticity of ha cleared to person day 1st component (De Hoop)"*("Person days (De Hoop)"*"Person days (De	ha/year	Own calculation	

	Hoop)"))/"PD/year")+(Elasticity of ha cleared to person days 2nd component*"Person days (De Hoop)")			
"Re-invasion by *Acacia saligna* (De Hoop)"	Area invaded by *Acacia saligna* De Hoop*Spread rate *Acacia saligna*	ha/year	Own calculation	
"Clearance of *Acacia saligna* (De Hoop)"	MIN("Effect of PD on hectares cleared (De Hoop)"*"Proportion *Acacia saligna* (De Hoop)" , Area invaded by *Acacia saligna* De Hoop/TIME STEP)	ha/year	Own calculation	
Area invaded by *Acacia saligna* De Hoop	INTEG("Re-invasion by *Acacia saligna* (De Hoop)"-"Clearance of *Acacia saligna* (De Hoop)")	ha	Own calculation	
WPCs production sub-model parameters				
Variable	**Value/Formula**	**Units**	**Data Source**	**Comments**
Biomass per hectare *Acacia saligna*	23.2	ton/ha	Mugido et al. (2014)	Conservative estimates
Acacia saligna Wet mass Proportion	0.55	Dmnl	Thomas & Martin (2012)	55% moisture is removed from cleared biomass to be left with the 45% oven dry mass.
Conversion ratio *Acacia saligna* Wood flour	1	Dmnl	Effah et al. (2017)	Assuming a 50%: 50% ratio of wood flour and thermoplastics
Losses	0.1	Dmnl	Consultation with experts	Conservative estimate based on consultation with experts
Recycled thermoplastics	583.212	ton/year	Own Calculation	
Conversion ratio recycled thermoplastic granules	1	Dmnl	Effah et al. (2017)	Assuming a 50%: 50% ratio of wood flour and thermoplastics

Volume of WPC product (solid decking plank 150*18*580 mm)	1566	Cm^3	Own calculation	
Density of *Acacia saligna* WPC	9.9e-007	ton/cm3		
Proportion Sundry costs	0.05	Dmnl	Policy variable	Assumption made for modelling purposes
Proportion WPC Decking products	0.5	Dmnl	Policy variable	Assumption made for modelling purposes
Proportion WPC Wall Cladding products	0.5	Dmnl	Policy variable	Assumption made for modelling purposes
Volume of WPC wall cladding products (145*12*580 mm)	1009.2	Cm^3	Own calculation	
Price per unit WPC Solid Wall Cladding plank	505	R/plank	www.nudek.co.za	
Price per unit WPC Solid Decking plank	675	R/plank	www.nudek.co.za	
WPCs production sub-model equations				
Variable	**Value/Formula**	**Units**	**Data Source**	**Comments**
Utilisable Biomass *Acacia saligna*	Biomass per hectare *Acacia saligna**"Total *Acacia saligna* Clearance /Year"	ton/year	Own calculation	
Oven dry mass *Acacia saligna*	Utilisable Biomass *Acacia saligna**(1-*Acacia saligna* Wet mass Proportion)	ton/year	Own calculation	
Utilisable thermoplastic waste	Recoverable Percentage*"Total thermoplastic waste generated/year in the City of Cape Town"	ton/year	Own calculation	
Wood flour	Oven dry mass *Acacia saligna*-(Oven dry mass *Acacia saligna**Losses)	ton/year	Own calculation	
recycled thermoplastic granules	Utilisable thermoplastic waste-(Utilisable thermoplastic waste*Losses)	ton/year	Own calculation	

Conversion of *Acacia saligna* wood flour into WPC	Conversion ratio *Acacia saligna* Wood flour*Wood flour	ton/year	Own calculation	
Conversion of recycled thermoplastic granules into WPC	Conversion ratio recycled thermoplastic granules*recycled thermoplastic granules	ton/year	Own calculation	
Raw Wood Polymer Composite	Conversion of *Acacia saligna* wood flour into WPC + Conversion of recycled thermoplastic granules into WPC	ton/year	Own calculation	
Weight per Solid WPC decking plank	Density of *Acacia saligna* WPC*Volume of WPC product	ton/plank	Own calculation	
Solid Wall cladding and decking WPC products	(Raw Wood Polymer Composite)/(WPC Extruder units*Output per hour*Total production hours per annum)*A factor correcting for WPC	ton/year	Own calculation	
"WPC Solid Wall Cladding planks (145 x 12 x 580 mm)"	(Proportion WPC Wall Cladding products*Solid Wall cladding and decking WPC products)/Weight per Solid WPC wall cladding plank	plank/year	Own calculation	
"WPC Solid Decking planks (150 x 18 x 580 mm)"	(Proportion WPC Decking products*Solid Wall cladding and decking WPC products)/Weight per Solid WPC decking plank	plank/year	Own calculation	
Gross Value of WPC Solid Decking planks	Price per unit WPC Solid Decking plank*"WPC Solid Decking planks (150 x 18 x 580 mm)"	R/year	Own calculation	
Gross value of WPC Solid Wall Cladding planks	Price per unit WPC Solid Wall Cladding plank*"WPC	R/year	Own calculation	

	Solid Wall Cladding planks (145 x 12 x 580 mm)"			
Total Gross value of Solid wall cladding and decking WPC products	Gross Value of WPC Solid Decking planks + Gross value of WPC Solid Wall Cladding planks	R/year	Own calculation	
Material and Production Cost sub model parameters				
Variable	**Value/Formula**	**Units**	**Data Source**	**Comments**
Estimated cost of recycled thermoplastics	3120	R/ton	Green Cape (2016)	Conservative estimate
"Estimate cost of *Acacia saligna* (Port Jackson) wood flour"	0	R/ton		The cost is zero since there will be no cost of buying the wood biomass from *Acacia saligna*. They just clear and use the biomass.
Efficiency of Operation	1	Dmnl	Rowell (1998)	
"Percent of *Acacia saligna* (Port Jackson) in the WPC"	1	Dmnl	Effah et al. (2017)	Assuming a 50%: 50% ratio of wood flour and thermoplastics
Percent of recycled thermoplastic in the WPC	1	Dmnl	Effah et al. (2017)	Assuming a 50%: 50% ratio of wood flour and thermoplastics
WPC compounding costs per ton	837.408	R/ton	Ghasem (2013)	Conservative estimate
Material and Production Cost for WPCs sub-model equations and equation(s)				
Time (year)	"Total WPC factory establishment cost" Runs:	Total WPC factory establishment cost		
Total materials and production cost for WPCs per ton	("Percent of *Acacia saligna* (Port Jackson) in the WPC"*"Estimate cost of *Acacia saligna* (Port Jackson) wood flour "+Percent of recycled thermoplastic in the	R/ton	Rowell (1998)	Conservative estimate

	WPC*Estimated cost of recycled thermoplastics +WPC compounding costs per ton)/Efficiency of Operation			
Total material and production cost for WPCs produced	Raw Wood Polymer Composite*Total materials and production cost for WPCs per ton	R/year	Own calculation	
Total sundry costs	Proportion Sundry costs*(Total materials cost for WPCs per ton +Total Production costs)	R/year	Own calculation	
WPC production plant establishment cost sub-model parameters				
Variable	**Value/Formula**	**Units**	**Data Source**	**Comments**
Cost of WPC profile extrusion plant machine	1 820 000	R	http://www.made-in-china.com/products-search/hot-china-products/Wpc_Board_Plant.html	
Number of WPC profile extrusion machines	5	Dmnl	Model assumption	2 machines with an output of 650kg per hour are enough, however we assumed 5 are needed to cater for possible breakdowns and other unforeseen circumstances
Cost of high speed mixer machines	2 184 000	R	http://www.made-in-china.com/price/high-speed-mixer-price.html	
Number of high speed mixer machines	5	Dmnl	Model assumption	2 machines with an output of 650kg per hour are enough, however we assumed 5 are needed to cater for possible breakdowns

				and other unforeseen circumstances
Cost of Vertical type cooling blender machine	1 400 000	R	http://shica-machinery.en.made-in-china.com/product/lXynrTUWEdcF/China-Stainless-Steel-Vertical-Paddle-PVC-Mixer-Machine.html	
Number of vertical type cooling blender machines	5	Dmnl	Model assumption	2 machines with an output of 650kg per hour are enough, however we assumed 5 are needed to cater for possible breakdowns and other unforeseen circumstances
Cost of pelletizer extrusion line	490 000	R	http://faygounion.en.made-in-china.com/product/kvMQEOiwyNVK/China-PVC-Plastic-Compound-Granules-for-Pelletizer-Extrusion-Line-Price.htm	
Number of pelletizer extrusion line machines	5	Dmnl	Model assumption	2 machines with an output of 650kg per hour are enough, however we assumed 5 are needed to cater for possible breakdowns and other unforeseen circumstances
Cost of wood powder machine	350 000	R	http://ww.alibaba.com/showroom/wood-powder-making-machine-for-sale.html	
Number of wood powder machines	5	Dmnl	Model assumption	2 machines with an output of 650kg per hour are enough, however we assumed 5

				are needed to cater for possible breakdowns and other unforeseen circumstances
Total WPC production plant establishment cost	IF THEN ELSE(Time=2017, ((Cost of High Speed Mixer machine*Number of High speed mixer machines)+(Cost of Pelletizer extrusion line*Number of pelletizer extrusion line)+(Cost of Vertical type cooling blender machine*Number of vertical blender machines)+(Cost of Wood Powder machine*Number of wood powder machines)+(Number of WPC profile extrusion plant*Cost of WPC profile extrusion plant))*A factor correcting for establishment cost , 0)	R/year	Own calculation	

Clearing and wood processing cost sub-model equations

Variable	**Value/Formula**	**Units**	**Data Source**	**Comments**
"Unit Clearing cost (Berg River)"	"Combined Budget-Berg River (DEA-NRM+)"/"Clearance of *Acacia saligna* (Berg River)"	R/ha	Own calculation	
"Unit Clearing cost (De Hoop)"	"Combined Budget-De Hoop (DEA-NRM+)"/"Clearance of *Acacia saligna* (De Hoop)"	R/ha	Own calculation	
"Unit Clearing cost (Citrusdal)"	"Combined Budget Citrusdal (DEA-NRM)"/"Clearance of *Acacia saligna* (Citrusdal)"	R/ha	Own calculation	

Unit chipping cost	6 428	R/ha	Mugido et al. (2014)	2013 Values adjusted to current prices using the 2017 CPI index adapted STATS SA (2017)
Unit transport cost	3 908	R/ha	Mugido et al. (2014)	2013 Values adjusted to current prices using the 2017 CPI index adapted STATS SA (2017)
"Total clearing and wood processing cost (De Hoop)"	("Clearance of *Acacia saligna* (De Hoop)"*"Unit Clearing cost (De Hoop)")+ (Clearance of *Acacia saligna* (De Hoop)* unit chipping cost*operational time)+(Clearance of *Acacia saligna* (De Hoop)* unit transport cost*operational time)	R/year	Own calculation	
"Total clearing cost (Berg River)"	"Clearance of *Acacia saligna* (Berg River)"*"Unit Clearing cost (Berg River)"+ (Clearance of *Acacia saligna* Berg river* unit chipping cost*operational time)+(Clearance of *Acacia saligna* (Berg river)* unit transport cost*operational time)	R/year	Own calculation	
"Total clearing cost (Citrusdal)"	"Clearance of *Acacia saligna* (Citrusdal)"*"Unit Clearing cost (Citrusdal)"+ (Clearance of *Acacia saligna* (Citrusdal* unit chipping cost*operational time)+(Clearance of *Acacia saligna* (Citrusdal)* unit transport cost*operational time)	R/year	Own calculation	
"Total clearing costs (All sites)"	“Total clearing and wood processing costs(Berg	R/year	Own calculation	

	River)"+"Total clearing and wood processing costs(Citrusdal)" +"Total clearing and wood processing costs(De Hoop)"			
Carbon sequestration sub-model parameters				
Variable	**Value/Formula**	**Units**	**Data Source**	**Comments**
Acacia saligna biomass per hectare	23.2	ton/ha	Mugido et al. (2014)	Conservative estimates
"*Acacia saligna* biomass per hectare (re-invasion)"	2.32	Ton/ha	Conservative estimate based on consultation with experts	It takes 10 years for *Acacia saligna* to reach full biomass and hence we divide the full biomass by 10 years to get biomass of re-invasion per annum
A factor correcting for net carbon	0.75	Dmnl	Policy Variable	
Net oven dry mass conversion factor	0.45	Dmnl	Thomas & Martin (2012)	55% moisture is removed from cleared biomass to be left with the 45% oven dry mass.
"CO2: Carbon ratio"	3.6667	Dmnl	Thomas & Martin (2012)	3.6667 is the ratio of CO_2 over carbon
Unit price of carbon	120	R/ton	National Treasury (2013)	
Carbon sequestration sub-model equations				
Variable	**Value/Formula**	**Units**	**Data Source**	**Comments**
"Total clearance *Acacia saligna* (all sites)"	"Clearance of *Acacia saligna* (Berg River)"+"Clearance of *Acacia saligna* (Citrusdal)"+"Clearance of *Acacia saligna* (De Hoop)"	ha/year	Own calculation	
"Carbon stock sequestered and stored (all sites)"	*Acacia saligna* biomass per hectare*"Total clearance *Acacia saligna* (all sites)"*Net	ton/year	Own calculation	

	oven dry mass conversion factor*"CO2: Carbon ratio"			
"Net carbon stock sequestered and stored removed (all sites)"	(("Carbon stock sequestered, stored & removed (all sites)")-"Carbon sequestered and stored from re-invasion (all sites)")*A factor correcting for net carbon	ton/year	Own calculation	
Net value of carbon sequestration potential lost	"Net carbon stock sequestered and stored removed (all sites)"*Unit price of carbon	R/year	Own calculation	
"Carbon sequestered and stored from re-invasion (all sites)"	"*Acacia saligna* biomass per hectare (re-invasion)"*"Total re-invasion by *Acacia saligna*"*"CO2: Carbon ratio"*Net oven dry mass conversion factor	ton/year	Own calculation	
"Total re-invasion by *Acacia saligna*"	"Re-invasion by *Acacia saligna* (Berg River)"+"Re-invasion by *Acacia saligna* (Citrusdal)"+"Re-invasion by *Acacia saligna* (De Hoop)"	ton/year	Own calculation	
Water consumption sub-model parameters				
Variable	**Value/Formula**	**Units**	**Data Source**	**Comments**
Water reduction per hectare *Acacia saligna*	634.81	m^3/ha	Le Maitre et al. (2015)	An estimate for the whole country
Unit value of water	2	R/m^3	Consultation with anonymous farmers and experts	Conservative estimate for the Orange river irrigation water
Water consumption sub-model equations				
Variable	**Value/Formula**	**Units**	**Data Source**	**Comments**

"Total clearance of *Acacia saligna* (all sites)"	"Clearance of *Acacia saligna* (Berg River)"+"Clearance of *Acacia saligna* (Citrusdal)"+"Clearance of *Acacia saligna* (De Hoop)"	ha/year	Own calculation	
"Total water consumption (all sites)"	"Total clearance of *Acacia saligna* (all sites)"*Water reduction per hectare *Acacia saligna*	m3/year	Own calculation	
"Water savings value due to *Acacia saligna* clearance (all sites)"	Price of water per m3*"Total water consumption (all sites)"	R/year	Own calculation	
NPV sub-model parameters				
Variable	**Value/Formula**	**Units**	**Data Source**	**Comments**
Year of cost	[(2008,1)-(2057,50)] Lookup	Dmnl	Policy variable	
Conversion factor	1	Dmnl	Policy variable	
Discount rate	0.06	Dmnl	Policy variable	Based on National Treasury rates
Time conversion factor	1	year	Policy variable	
NPV sub-model equations				
Variable	**Value/Formula**	**Units**	**Data Source**	**Comments**
Present value factor	((Conversion factor + Discount rate)^Year of cost((Time/Time conversion factor)))	Dmnl	Own calculation	
Net income from clearing aliens *Acacia saligna* and making WPCs	Net value of carbon sequestration potential lost +"Total clearing costs (All sites)"+ Total material and production cost for WPCs produced + Total Net value of Solid wall cladding and decking WPC products +"Water savings value due to	R/year	Own calculation	

	Acacia saligna clearance (all sites)"			
NPV Clearing *Acacia saligna* and making WPCs	Net income from clearing aliens *Acacia saligna* and making WPCs/ Present value factor	R/year	Own calculation	
NPV Clearing *Acacia saligna* and making WPCs	NPV Clearing *Acacia saligna* and making WPCs	R/year	Own calculation	
Cumulative NPV	INTEG(NPV Rate)	R	Own calculation	

Section D: Causal loop diagram (i.e. qualitative system dynamics model)

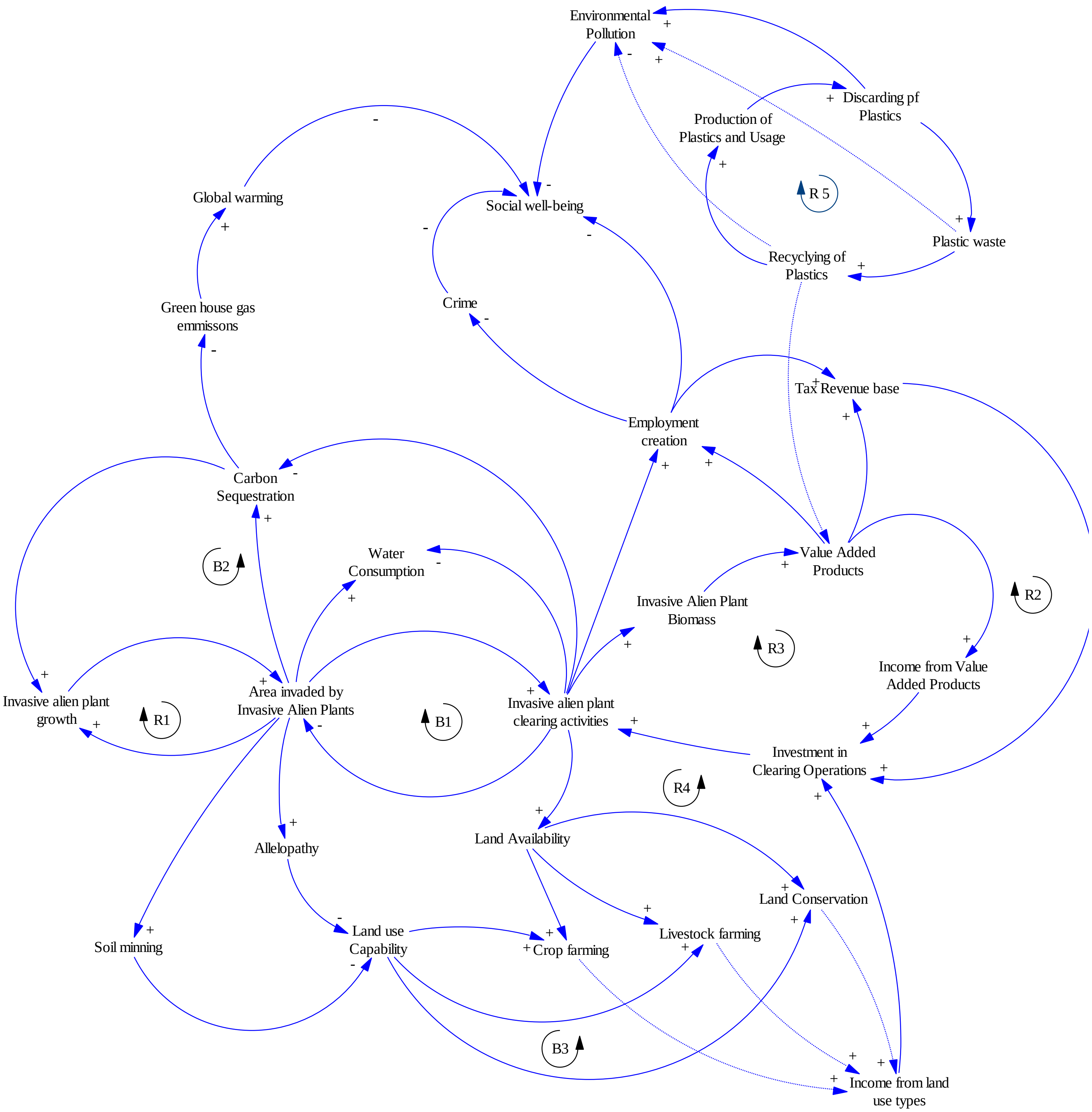

FIGURE D1: CAUSAL LOOP DIAGRAM

Section E. PORTTHERM-WPC model boundary chart

Exogenous Variables	**Endogenous Variables**	**Excluded Variables**
A factor correcting for net carbon	"Area (Berg)"	Employment creation
A factor correcting for WPC	Area Citrusdal	Production of thermoplastic and usage
Acacia saligna biomass per hectare	Area De Hoop	Other types of recycled thermoplastic waste plastics (apart from LDPE)
Acacia saligna Wet mass Proportion	"Area invaded by *Acacia saligna* (All sites)	Other value added products apart from WPCs
Biomass per hectare *Acacia saligna*	"Carbon stock sequestered and stored (all sites)	Other Municipal solid waste factors
"Co-finance proportion"	"Clearance of *Acacia saligna* (All sites)"	WPC factory establishment costs
"CO2: Carbon ratio"	"Combined Budget Citrusdal (DEA-NRM)" All sites	Land use options
"Constant (All sites)"	Conversion of *Acacia saligna* wood flour into WPC	Other Negative impacts from IAPs (e.g. soil mining, allelopathy, decline in biodiversity etc.)
Conversion factor	Conversion ratio recycled thermoplastic granules	Greenhouse gas emissions
Conversion ratio *Acacia saligna* Wood flour	Cumulative NPV	Tax revenue base
Density of *Acacia saligna* WPC	Effect of combined budget on person days	Social wellbeing factors
Discount rate	"Effect of ha cleared to person days (All sites)"	Environmental pollution
Efficiency of Operation	"Effect of PD on hectares cleared (All sites)"	Other costs (e.g. transport of biomass from sites, chipping costs, electrical, water, packaging and other sundry expenses)
Elasticity of person days to combined budget (All sites)	Gross Value of WPC Solid Decking planks	Physical tensile strength of WPCs
Elasticity of ha cleared to person day (All sites	Gross value of WPC Solid Wall Cladding planks	Physical tensile modulus of WPCs
Estimated cost of *Acacia saligna* (Port Jackson) wood flour	"Net carbon stock sequestered and stored removed (all sites)"	Mechanical Elongation of WPCs
Estimated cost of recycled thermoplastics	Net income from clearing aliens *Acacia saligna* and making WPCs	Mechanical impact of WPC
Final Time	Net value of carbon sequestration potential lost	Mechanical hardness of WPCs
Initial Area Invaded by *Acacia saligna* (All sites)	NPV Rate	Monomers
INITIAL TIME	Oven dry mass *Acacia saligna*	
Losses	Person days (All sites)	
Net oven dry mass conversion factor	Present value factor	
Output per hour	Raw Wood Polymer Composite	
"PD/year	"Re-invasion by *Acacia saligna* (All sites)	

"Percent of *Acacia saligna* (Port Jackson) in the WPC"	Recoverable Percentage	
Percent of recycled thermoplastic in the WPC	Solid decking Planks per year	
Price of water per m3	Solid wall cladding planks	
Price per unit WPC Solid Decking plank	Solid Wall cladding and decking WPC products	
Price per unit WPC Solid Wall Cladding plank	recycled thermoplastic granules	
Proportion *Acacia saligna* (All sites)	Total *Acacia saligna* Clearance /Year	
Proportion WPC Decking products	Total Area cleared (All sites)	
Proportion WPC Wall Cladding products	Total Area invaded by *Acacia saligna* (All sites)	
Recoverable Percentage (thermoplastic waste)	Total clearing cost (All sites)	
Spread rate *Acacia saligna*	Total materials and production cost for WPCs per ton	
State Budget Berg River (DEA-NRM) (All sites)	Total Net value of Solid wall cladding and decking WPC products	
Time conversion factor	Total thermoplastic waste generated/year in the City of Cape Town	
Total production hours per annum	Total water consumption (all sites)"	
Unit price of carbon	Unit Clearing cost (All sites)	
Volume of WPC decking products	Utilisable Biomass *Acacia saligna*	
Volume of WPC wall cladding products	Utilisable thermoplastic waste (LDPE thermoplastics)	
Water reduction per hectare *Acacia saligna*	Weight per Solid WPC decking plank	
WPC compounding costs per ton	Weight per Solid WPC wall cladding plank	
WPC Extruder units	Wood flour	
Year of cost	WPC Solid Decking planks (150 x 18 x 580 mm)	
	"WPC Solid Wall Cladding planks (145 x 12 x 580 mm)"	

Section F: Summary table of annual externality costs (carbon sequestered, stored and removed) and benefits (water savings) emanating from the clearance of *Acacia saligna*

	Carbon sequestered, stored and removed [units]*				Water Savings [units]*			
Time [year]	Baseline scenario [tons & (ZAR)]	Scenario 2 [tons & (ZAR)]	Scenario 3 [tons & (ZAR)]	Scenario 4 [tons & (ZAR)]	Baseline scenario [m^3 & ZAR)]	Scenario 2 [m^3 & ZAR)]	Scenario 3 [m^3 & ZAR)]	Scenario 4 [m^3 & ZAR)]
2008	13 473 (1 612 408)	19 405 (2 328 561)	30 495 (3 659 456)	30 495 (3 659 456)	164 082 (328 163)	296 038 (592 077)	541 266 (1 082 532)	541 266 (1 082 532)
2009	7784 (934 046)	13 775 (1 653 001)	4419 (530 290)	4419 (530 290)	162 836 (325 672)	293 329 (586 658)	82 783 (165 566)	82 783 (165 566)
2010	7751 (930 174)	3658 (438 991)	475 (56 954)	475 (56 954)	180 213 (360 427)	85 476 (170 952)	14 010 (28 021)	14 010 (28 021)
2011	2 633 (315 924)	323 (38 704)	-155 (-18 602)	-155 (-18 602)	68 942 (137 884)	14 414 (28 829)	3 695 (7 389)	3 695 (7 389)
2012	6 093 (731 157)	4 555 (546 642)	4 431 (531 734)	3 235 (388 219)	146 521 (293 041)	109 375 (218 751)	106 604 (213 209)	80 161 (160 321)
2013	5 145 (617 365)	4 335 (520 222)	4 522 (542 687)	3 986 (478 369)	125 200 (250 399)	104 239 (208 477)	108 392 (216 784)	96 937 (193 875)
2014	3 659 (439 126)	3 461 (415 358)	3 978 (477 381)	4 438 (532 587)	92 208 (184 415)	84 622 (169 244)	96 003 (192 007)	106 804 (213 607)
2015	1 937 (232 411)	1 597 (191 634)	2004 (240 449)	2 576 (309 120)	54 432 (108 864)	43 345 (86 689)	52 115 (104 230)	65 328 (130 657)
2016	1 895 (227 391)	1 572 (188 591)	1 986 (238 328)	2 563 (307 618)	54 432 (108 864)	43 339 (86 678)	52 114 (104 229)	65 328 (130 655)
2017	1 847 (221 619)	1 543 (185 122)	1 966 (235 894)	2 549 (305 897)	54 432 (108 864)	43 338 (86 677)	52 114 (104 229)	65 327 (130 655)
2018	1 792 (214 981)	1 509 (181 137)	1 942 (233 095)	2 533 (303 918)	52 114 (104 229)	65 327 (130 655)	52 114 (104 229)	65 327 (130 655)
2019	1 728 (207 348)	1 471 (176 555)	1 916 (229 877)	2 514 (301 642)	52 114 (104 229)	65 327 (130 655)	52 114 (104 229)	65 327 (130 655)
2020	1 655 (198 570)	1 427 (171 285)	1 885 (226 176)	2 492 (299 025)	52 114 (104 229)	65 327 (130 655)	52 114 (104 229)	65 327 (130 655)
2021	1 571 (188 475)	1 377 (165 226)	1 849 (221 920)	2 467 (296 015)	52 114 (104 229)	65 327 (130 655)	52 114 (104 229)	65 327 (130 655)

2022	1 474 (176 865)	1 319 (158 257)	1809 (217 026)	2 438 (292 554)	52 114 (104 229)	65 327 (130 655)	52 114 (104 229)	65 327 (130 655)
2023	1 363 (163 514)	1 252 (150 243)	1 762 (211 397)	2 405 (288 574)	52 114 (104 229)	65 327 (130 655)	52 114 (104 229)	65 327 (130 655)
2024	1 235 (148 161)	1 175 (141 027)	1 708 (204 925)	2 367 (283 996)	52 114 (104 229)	65 327 (130 655)	52 114 (104 229)	65 327 (130 655)
2025	1 088 (130 505)	1 087 (130 428)	1 646 (197 481)	2 323 (278 732)	52 114 (104 229)	65 327 (130 655)	52 114 (104 229)	65 327 (130 655)
2026	918 (110 200)	985 (118 240)	1 574 (188 920)	2 272 (272 679)	52 114 (104 229)	65 327 (130 655)	52 114 (104 229)	65 327 (130 655)
2027	724 (86 849)	869 (104 223)	1492 (179 076)	2 214 (265 717)	52 114 (104 229)	65 327 (130 655)	52 114 (104 229)	65 327 (130 655)
2028	500 (59 996)	734 (88 104)	1 398 (167 755)	2 148 (257 711)	52 114 (104 229)	65 327 (130 655)	52 114 (104 229)	65 327 (130 655)
2029	243 (29 115)	580 (69 567)	1 289 (154 736)	2071 (248 505)	52 114 (104 229)	65 327 (130 655)	52 114 (104 229)	65 327 (130 655)
2030	-53 (-6 399)	402 (48 250)	1 165 (139 764)	1 983 (237 917)	52 114 (104 229)	65 327 (130 655)	52 114 (104 229)	65 327 (130 655)

Source: Own Note: All number in brackets represent the values of carbon sequestration potential losses and water savings in South African Rands (ZAR).

Analysis
* Units represented in quantity and (monetary values).
Note: Monetary values are shown in brackets whilst the physical quantities are not in bracket

Chapter 3

An economic analysis of different land-use options to assist in the control of the invasive *Prosopis* (Mesquite) tree

Abstract

Invasive Mesquite (*Prosopis* spp.) trees are one of the major causes of disturbances affecting the Orange River water management areas in the Northern Cape, South Africa. These disturbances impact natural capitalare, such as a reduction in stream flow of the Orange River, a decline in biodiversity of the native Nama Karoo vegetation, excessive water consumption, and invasion of dryland areas. Therefore, we assess the economic value of different land-use options following the control of *Prosopis spp* to prevent re-invasion using a system dynamics model. This study yields positive cumulative NPV values of between ZAR28.3 million and ZAR98.3 billion when co-finance of between 20% and 100% is considered to clear the *Prosopis spp,* combined with the productive land-use of the cleared land by the private sector. This is in stark contrast to a negative NPV of -ZAR11.6 million when no alternative land-use activity on the land cleared, is implemented. This study empirically showed that clearing *Prosopis spp* and restoring the cleared land for agricultural land-use options is a cost-effective strategy for controlling the invasive *Prosopis spp* trees.

3.1 Introduction

The invasiveMequite tree (*Prosopis* spp.)tree is one of the major disturbances affecting the Orange River water management areas in the Northern Cape province, South Africa. These disturbances include, for example, the reduction in stream flow and excessive water consumption (Le Maitre et al. 2000; Dzikiti et al. 2013; Shackleton et al. 2014), reduction in grazing potential, and biodiversity losses (Steenkamp & Chown 1996). However, despite these negative impacts, it also poses beneficial economic and social benefits, for example, fodder for livestock (Felker 1979; Felker et al. 2003; Choge et al. 2007; Wise et al. 2012), shade for humans and livestock (Shackleton et al. 2014), and raw materials for many value-added products (Felker 1979; DeLoach 1985; Felker et al. 2003; Bradshaw et al. 2004; Blignaut & Aronson 2008). Because *Prosopis spp* have both negative and positive impacts, the control thereof has become contentious, especially from a biological control perspective that uses biological agents to kill the tree indiscriminately (Zachariades et al. 2011).

This conflict is exacerbated by the fact that *Prosopis spp* has been intentionally introduced, from the late 19th century through to the mid-20th century (Harding 1987; Harding & Bate 1991; Henderson & Harding 1992), as a livestock fodder crop *inter alia* the provision of shade for livestock (Wise et al. 2012). This introduction was even with the support of government policies through the subsidies and extension service initiatives (Poynton 1988). During the 1970s the negative impacts of *Prosopis spp* became evident as the impacts became more prominent in areas beyond where it was initially introduced. In a study conducted by Vorster (1977) in the Karoo region of South Africa, approximately 186 000 ha were found to be invaded by *Prosopis spp*. The invasion increased to 200 000 ha in the late 1980s (Harding 1987) and by the year 1998, 1.8 million ha of South Africa were invaded with 50% of this area being in the Northern Cape province (Versfeld et al. 1998). This finding is supported by Van den Berg (2010) who reported that by 2007, approximately 1.473 million ha were under *Prosopis spp* invasion within the Northern Cape province, with the extent expected to increase if nothing is done to control its rapid growth (Wise et al. 2012; Shackleton et al. 2014).

Prosopis spp are invasive not only in South Africa, but alsoin Kenya (Muturi et al. 2013), Ethiopia (Wakie et al. 2016b), Namibia (Schachtschneider & February 2013; Simali pers. comm. 2016; Sishuba pers. comm. 2016), India (Kaur et al. 2012), Brazil (De Souza Nascimento et al. 2014) and the United Arab Emirates (El-Keblawy & Al-Rawai 2007). In its native regions in the Americas (i.e. Argentina, Chile, Honduras, Mexico, Peru and USA) it grows in arid and semi-arid environments, but it does not form dense invasive stands such as in its non-native areas (Zimmermann 1991; Pasiecznik et al. 2001).

To date, the control efforts undertaken to deal with *Prosopis spp* have been mainly manual, mechanical, chemical and biological control approaches, but it has had little effect on the growth thereof (Vorster 1977; Harding 1989; Van den Berg 2010). Other control options include the harvesting thereof for productive use (Shackleton et al. 2014; Wakie et al. 2016a) and cultural control (Shackleton et al. 2014). However, the success of these measures to curb its invasiveness have not been tested widely. The detrimental impact of *Prosopis spp* is clearly noted in literature (Poynton 1988; Harding & Bate 1991; Zimmerman 1991; Pasiecznik et al. 2001; Admasu 2008; Van den Berg 2010; Wakie et al. 2012; Dzikiti et al. 2013; Shackleton et al. 2014). Only a few studies, however, have tried to calculate the economic costs and benefits of using it productively as a raw material for various value-added products such as firewood, charcoal, pulp, flour, honey and medicinal properties (Blignaut & Aaronson 2008; Choge et al. 2012; Wise et al. 2012; Van Wilgen et al. 2012; Sato 2013).

This study aims to assess the contribution of alternative productive agricultural land-use options following clearing as a means to control and inhibit the re-growth of *Prosopis spp* in the Northern Cape province with a particular focus on the Orange River water management area. We develop a system dynamics model for this purpose.

3.2 Study sites: A description

This study was conducted in the Orange River water management areas between Onseepkans (quaternary catchment D81E) and Pella (quaternary catchment D81G) in the Northern Cape province of South Africa.

3.2.1 Onseepkans (quaternary catchment D81E)

Prosopis spp invasion in Onseepkans is estimated to cover approximately 601 condensed ha (DEA:NRM 2016). Onseepkans is a small rural settlement located on the banks of the Orange River (Coordinates 28.7990°S 19.31E) (see Figure 3.1). The area acts as the border between South Africa and Namibia. The land was initially occupied by a settler and land prospector by trade named Edwells, and was bought from him by a group of farmers who realised the land’s potential for irrigated agriculture. The irrigated crops include table grapes, citrus, lucerne, beans, pomegranates, dates and essential oils (Clarke & Erasmus 2013).

The Onseepkans area lies within the desert biome and is regarded as one of the driest regions in South Africa. It receives rain in summer with a mean annual precipitation of 116 mm with a precipitation seasonality (i.e. coefficient of variation) of 69% (Gallaher 2014). The mean annual temperature for the area is 20°C (Gallaher 2014). In terms of the geology, the Onseepkans area consists of the Okiep, Bushmanland, Korannaland and Geelvloer group (Clarke & Erasmus 2013) with the predominant soils being unconsolidated sand, calcrete, calcarenite, aeolinite, conglomerate, clay, silcrete and limestone (DWA 2009).

The population of Onseepkans consists of approximately 2 090 people comprising 558 households, with a very low population density of approximately 76 people/km^2 (StatsSA 2011). In terms of gender, females make up 50.24% (i.e. 1 050 people) while males represent 49.76% (i.e. 1 040 people) of the total population. With respect to the population groups, 78.13% (i.e. 1 633 people) of the population is coloured, while 18.95% (i.e. 396 people) is black Africans, whites represent 1.48% (i.e. 31 people), and Asians and Indians represent 1.43 % (30 people) (StatsSA 2011). Afrikaans is the dominant language and is spoken by 78.13% of the population (StatsSA 2011).

3.2.2 Pella (quaternary catchment D81G)

Pella (see Figure 3.1) is a small rural settlement located in the Namaqua (Bushmanland) region of the Northern Cape province. The name originally referred to an oasis found within that area, which was historically used by the Khoisan herders. The area is also close to the river banks of the Orange River bordering South Africa and Namibia. Similar to the Onseepkans area, the land within Pella is suitable for the cultivation of table grapes, dates, essential oil crops, lucerne and pomegranates. Extensive livestock agriculture systems are practiced, with most smallholder farmers rearing sheep, goats and a few cattle. The areas close to the Orange River are densely invaded by *Prosopis spp* with 401 condensed ha having been mapped (DEA:NRM 2016).

Pella also lies in the desert biome, with the same key climatic statistics as Onseepkans (Gallaher 2014). In terms of the geology, Pella consists of the Okiep, Bushmanland, Korannaland and Geelvloer group (Clarke & Erasmus 2013), with the predominant soils being unconsolidated sand, calcrete, calcarenite, aeolinite, conglomerate, clay, silcrete and limestone (DWA 2009).

The population of Pella consists of approximately 2 470 people residing in about 712 households; with a population density of approximately 5people/km^2 (StatsSA 2011). There is an even distribution between the number of males and females, with 96.07% of the population being coloured, and 97.45% of the population speaking Afrikaans (StatsSA 2011).

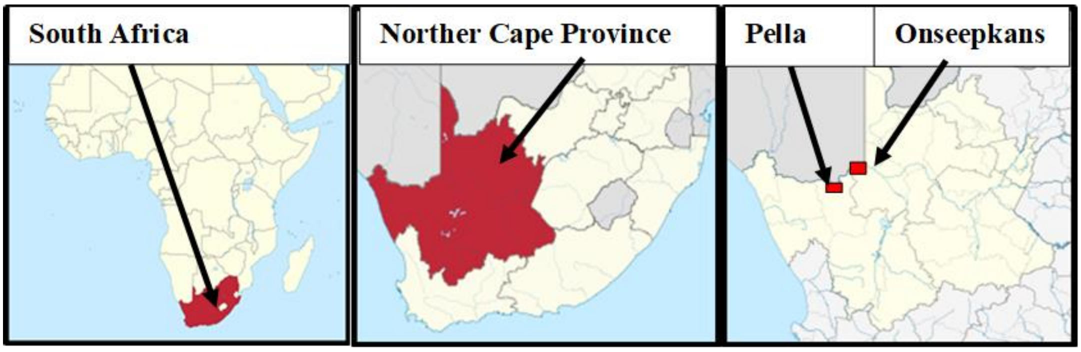

FIGURE 3. 1: LOCATION ONSEEPKANS AND PELLA WATER MANAGEMENT AREAS D81E & D81G

Source: Own analysis

3.3 Materials and methods

3.3.1 Data collection

The data used for this study was collected from the Natural Resource Management directorate of the Department of Environmental Affairs' (DEA:NRM) database. The data extracted from this database include the clearing costs, person days worked, the area invaded by *Prosopis spp* and the hectares cleared. Extensive literature surveys were also conducted to obtain other published data relevant to this study. Field experts and the relevant DEA:NRM project managers were consulted to validate the data and assumptions. Focus group discussions were held with experts, the DEA:NRM personnel, and the clearing operations' implementing agents, to aid the qualitative system dynamics model building process (i.e. the causal loop diagrams). The data pertaining to the alternative land-use options following clearing was obtained from the Bureau for Food and Agricultural Policy (BFAP), Hortgro, VinPro, the South African Table Grapes Industry (SATI) and consultation with farmers and experts. This was then supplemented with data obtained from literature on the respective land-use options. Site visits were also conducted to assist in the ground truthing of the data and the assumptions.

3.3.2 Data analysis

3.3.2.1 Method

A Prosopis spp land-use trade-off model (i.e. the PROLAND-model) was compiled using the Vensim® PLP software. Richardson (1996) defines system dynamics as a computer-aided approach to policy analysis and design related to dynamic problems characterised in complex social, managerial, economic and ecological systems. The interaction between the invasive alien plant control methods, its rate of spread, and the value of alternative land-use options, qualifies as such a complex system and therefore system dynamics modelling is applied here. The PROLAND-model is described in Part A in the Supplementary Materials segment in much greater detail, while the model parameters and equations used are shown in Part B and, lastly, the model validation is described in Part C.

3.3.2.2 Model scenarios

Four scenarios were developed to assess the impact of clearing *Prosopis spp* and converting the cleared land to four land-use options (i.e. table grapes, raisins, citrus and natural vegetation) over a 23 year (2008–2030) simulation period.

Scenario 1 (with 0% co-finance): Business as usual

Here we assume that clearing interventions are conducted by the DEA:NRM from 2008 until 2015 based on historic figures. From 2016 onwards, clearing interventions are continued at 2015-levels with none of the land being used productively.

Scenario 2 (with 20% co-finance): Low co-finance

Here we assume that clearing interventions are conducted by DEA:NRM between 2008 until 2015 based on historic figures, but we allow for a 20% co-finance of the clearing operations by the private sector augmenting DEA:NRM's budget. The co-finance starts from 2016 onward, with clearing interventions continued at 2015-levels. The cleared land is put to productive agricultural use.

Scenario 3 (with 50% co-finance): Moderate co-finance

Similar to scenario 2, except that the co-finance is at 50%.

Scenario 4: (with 100% co-finance): High co-finance

Similar to scenario 2, except that the co-finance is at 100% essentially doubling the clearing effort.

3.4 Results

3.4.1 Clearing *Prosopis spp*

The PROLAND-model results show that invasion by *Prosopis spp* remains pronounced over the whole simulation period for the baseline scenario (i.e. do nothing + 0% co finance). The initial condensed area under *Prosopis spp* invasion was approximately 1 001 ha at the beginning of the model simulation in the year 2008 and remained more or less the same over the entire simulation period with invasions dropping to 900 ha from the year 2026 till the end of the model simulation. As for Scenarios 2, 3 and 4, where the cleared land is converted to productive land use options and there is co-finance from the private land users, the area under invasion immediately starts to decrease with invasion becoming zero by 2025 for Scenario 2 (with 20% co-finance), 2024 for Scenario 3 (with 50% co-finance) and 2023 for Scenario 4 (with 100% co-finance). The dynamic behaviour over time for the area invaded by *Prosopis spp* is illustrated in Figure 3.2.

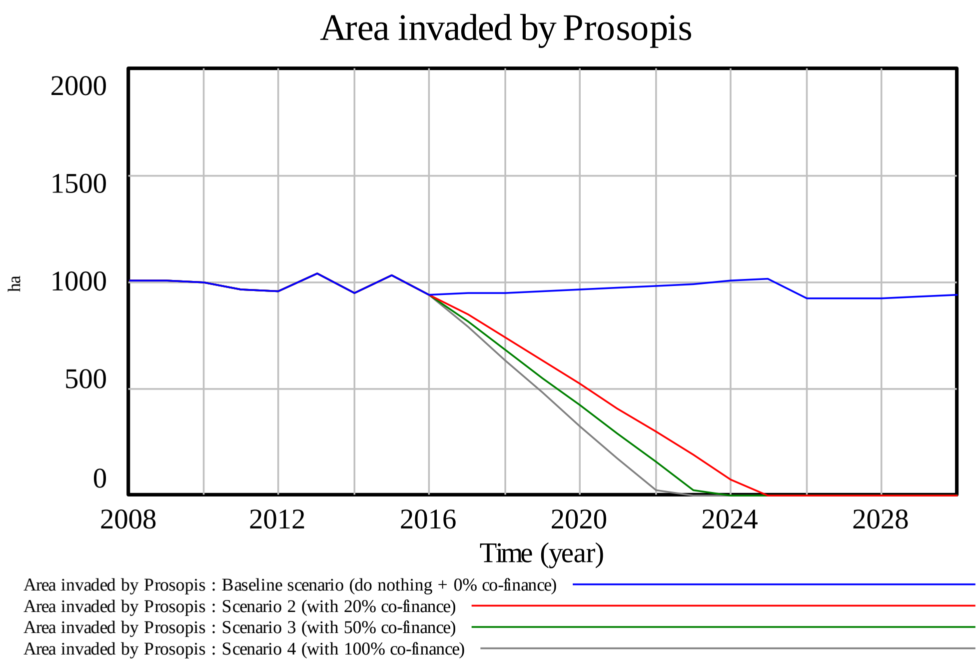

FIGURE 3. 2: THE AREA CLEARED OF *PROSOPIS SPP*

Source: Own analysis

3.4.2 Area restored to active land-use options

The PROLAND-model simulation results show that the area restored to active land-use options grows in a linear fashion until the maximum restoration area threshold is reached with approximately 28 ha, 33 ha and 38 ha being restored for Scenarios 2, 3 and 4, respectively, in year 2016 when restoration commences. Thereafter the maximum area restored to agricultural land-uses is approximately between 234 ha and 241 ha for Scenarios 2, 3 and 4. The maximum area restored to agricultural land-use options is reached in the year 2023 (for Scenario 4 with 100% co-finance), 2024 (for Scenario 3 with 50% co-finance) and 2025 (for Scenario 2 with 20% co-finance.) As for the baseline scenario, no restoration to agricultural land-use occurs as a result of the do nothing assumption. As for the area restored to natural vegetation (i.e. area restored to conversation), the same trend is noticed. However, the maximum area restored to natural vegetation is between approximately 134 ha and 137 ha as result of continued *Prosopis spp* re-growth within the area apportioned to natural vegetation. The maximum area restored to natural vegetation is achieved also in the years 2025, 2024 and 2023 for Scenarios 2, 3 and 4, respectively, and remains constant till the end of the model simulation. The dynamic behaviour over time for the area restored to all active land-use options considered in this study is illustrated in Figure 3.3 below.

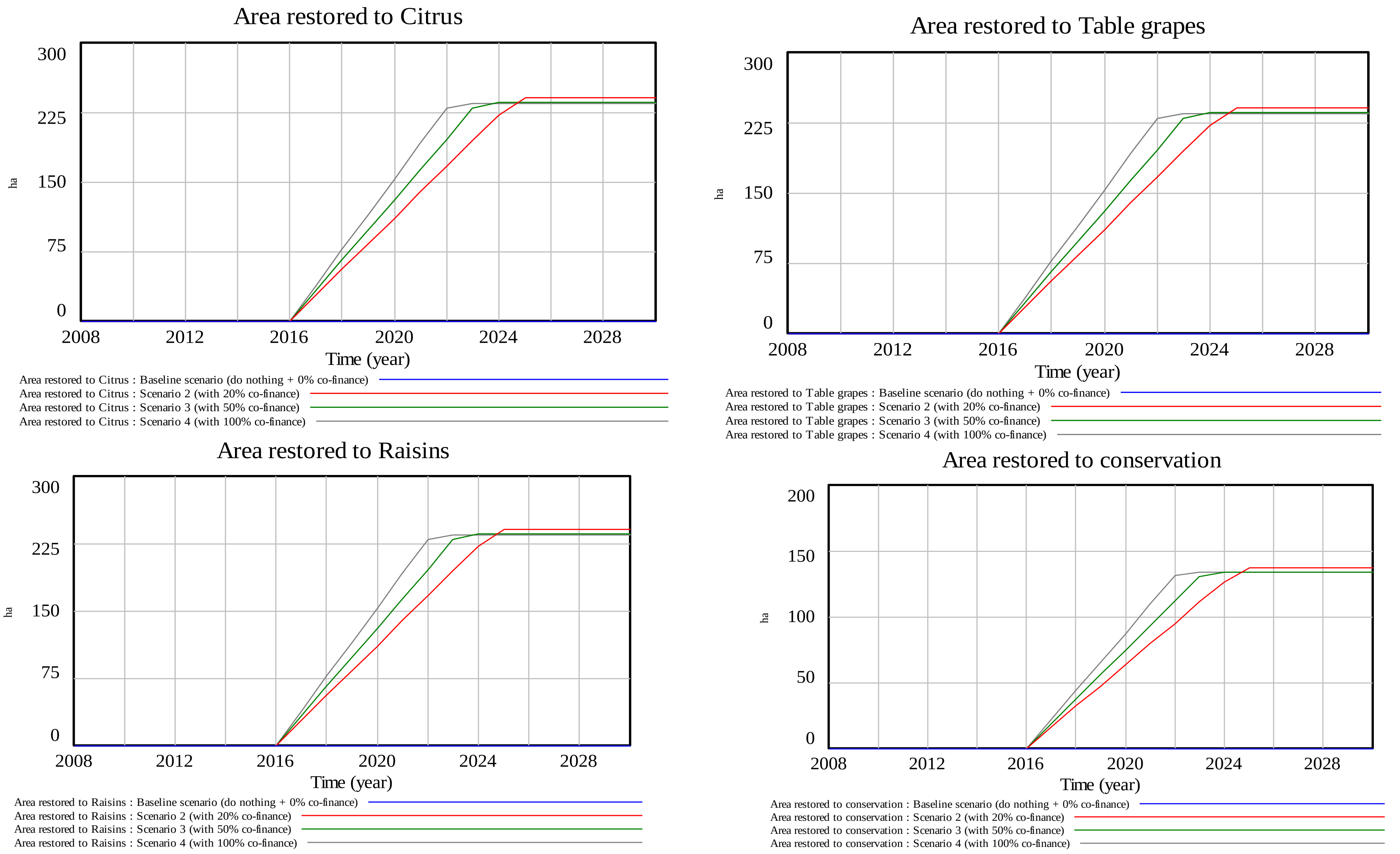

FIGURE 3. 3: DYNAMIC BEHAVIOUR OVER TIME FOR THE AREA RESTORED TO VARIOUS LAND USE OPTIONS

Source: Own Analysis

3.4.3 Private benefits and costs for clearing *Prosopis spp* and restoring to land-use options

3.4.3.1 Private benefits

Net Revenue from table grape land-use option

The PROLAND-model results show negative net revenue values over the period 2017–2022 for the table grape land-use option. In the year 2017 a net revenue loss of approximately -ZAR6.9 million (Scenario 2 with 20% co-finance), -ZAR8.1 million (Scenario 3 with 50% co-finance) and -ZAR9.5 million (Scenario 4 with 100% co-finance) was incurred. The net revenue loss increased overtime as more area was cleared and brought under restoration to table grape farming with approximately -ZAR14.9 million, -ZAR17.6 million and -ZAR20.6 million being incurred in the year 2020 for Scenarios 2, 3 and 4, respectively. Thereafter the net revenue loss started to decline as the maximum restoration area was being reached with approximately -ZAR3.5 million (Scenario 2), -ZAR4 million (Scenario 3) and -ZAR4.8 million (Scenario 4) being incurred in the year 2022. Thereafter, positive net revenue values are realised for the remainder of the simulation period with a maximum net revenue of ZAR48.4 million being realised from 2027 onward (Scenario 4), ZAR48.6 million from 2028 onward (Scenario 3) and ZAR49.7 million from 2029 onward (Scenario 2).

Net revenue from raisins land-use option

The net revenue results for the raisins land-use option are also negative for the period 2017 to 2021 and follow the same trend as that of the table grape farming land-use option. In 2017, a net revenue loss of approximately -ZAR3.3 million, -ZAR3.9 million and -ZAR4.6 million was incurred for Scenarios 2, 3 and 4, respectively. In the year 2021, a net revenue loss of -ZAR2.3 million, -ZAR2.7 million and -ZAR3.2 million was incurred for Scenarios 2, 3 and 4, respectively. Thereafter, positive net revenues values were realised till the end of the model simulation (i.e. 2030) with a maximum net revenue value of ZAR32.3 million being realised in 2027 onward for Scenario 4, ZAR32.5 million from 2028 onward for Scenario 3 and ZAR 33.2 in 2029 onward for Scenario 2.

Net revenue from citrus land-use option

The PROLAND-model results also show negative net revenue values for the citrus land-use option for 2017 to 2021. The growth trend is similar to that experienced in the table grape and raisins land-use options. In 2017 a net revenue loss of -ZAR5.2 million (Scenario 2), -ZAR6.1 million (Scenario 3) and -ZAR7.1 million (Scenario 4) was incurred, while in 2021 it was approximately -ZAR6.5 million (Scenario 2), -ZAR7.7 million (Scenario 3) and -ZAR9 million (Scenario 4), respectively. Thereafter, the net revenue values became positive for the whole simulation period with a maximum value of ZAR112.2 million (Scenario 4) being reached from 2029 onward, ZAR112.5 million (Scenario 3) from 2030 and ZAR113.4 (Scenario 2) from 2030.

3.4.3.2 Social benefits

Economic value of water saved due to clearing *Prosopis spp*

The PROLAND-model results show an increasing and decreasing pattern over time for the economic value of water savings due to *Prosopis spp* clearance from the initial simulation (i.e. 2008) until 2016 based on the historical clearing efforts by DEA:NRM through its Working for Water programme. From 2017 onward (after co-finance starts), the economic value of water saved is constant right through till the end of the simulation period amounting to approximately ZAR229 640 for the baseline scenario. Scenario 2 remains constant at approximately ZAR267 467 till 2023 and then drops to ZAR177 226 in 2024. Thereafter the value becomes zero till the end of the simulation (i.e. 2030). For Scenario 3, the economic value for water saved also becomes constant at ZAR314 871 till 2022 with a corresponding drop in 2023 to ZAR59 506 and thereafter the value becomes zero till the end of the model simulation. Lastly, for Scenario 4, the economic value for water saved due to clearing *Prosopis spp* also becomes constant at ZAR368 979 per annum until the year 2021, dropping to ZAR43 247 in 2022 and then the value becomes zero till the end of the model simulation. The value becomes zero due to all *Prosopis spp* having been cleared off the invaded land.

Economic value of carbon sequestered and stored due to *Prosopis spp* re-growth

The PROLAND-model results show that the economic value of carbon sequestered and stored due to re-invasion by *Prosopis spp* amounts to between approximately ZAR90 887 and ZAR95 914 for all the scenarios between 2008 and 2014. Thereafter, the value stays closely within that range for the baseline scenario until the end of the simulation period, with the exception of 2015 and 2025, when there is very little re-invasion by *Prosopis spp*. For Scenarios 2 and 3, the value drops to ZAR6 590 in 2017 and ZAR2 401 in 2016, respectively. Thereafter, the value becomes zero till the end of the simulation (i.e. 2030) due to very little or no invasion by *Prosopis spp.* As for Scenario 4, the value becomes zero from the year 2015 onward till the end of the model simulation.

3.4.3.3 Private costs

Total production costs for the table grape land-use option

The PROLAND-model simulation results show a positive linear growth pattern for the production costs incurred in the table grape land-use option for the scenarios (with the exception of the baseline scenario which remain zero for the entire simulation period) and this gradually levels off and becomes constant till the end of the simulation once the possible maximum restoration area is reached. These total annual production costs consist of the sum total of all direct and non-direct variable costs and the total fixed and overhead costs. In the year 2017, the initial production costs incurred amounted to approximately ZAR6.9 million, ZAR8.1 million and ZAR9.5 million for Scenarios 2, 3 and 4, respectively. Thereafter the total annual production costs levelled off at approximately ZAR58.1 million in 2023 onward till the simulation end (i.e. 2030) for Scenario 4, ZAR58.6 million in 2024 onward for Scenario 3 and ZAR59.7 million in 2025 onward for Scenario 2 as the maximum possible restoration area is achieved.

Total production costs for the raisins land-use option

The total annual production costs for the raisins land-use option also follow a positive linear growth trend over time until a maximum threshold is reached when all the possible restoration area has been achieved. Thereafter, the annual production costs become constant till the end of the simulation period. The initial production costs for 2017 amounted to approximately ZAR3.3 million (Scenario 2), ZAR3.9 million (Scenario 3) and ZAR4.6 million (Scenario 4) while it was zero for the baseline scenario throughout the whole simulation period due to the do nothing assumption. The annual production costs reached a climax in 2023 amounting to ZAR28.1 million, ZAR28.2 million and ZAR28.9 million approximately for Scenarios 4, 3 and 2. These values then remained constant till the end of the model simulation as all the possible maximum restoration area had been fully restored to raisins.

Total production costs for the citrus land-use option

The PROLAND-model simulation also shows the same growth trend over time for the annual production costs as mentioned for the table grape and raisins land-use options for Scenarios 2, 3 and 4, while the baseline scenario values are also zero as in the aforementioned two land-use options. In 2017, the initial annual production costs incurred amounted to approximately ZAR5.2 million, ZAR6.1 million and ZAR7.2 million for Scenarios 2, 3 and 4, respectively. From 2023, 2024 and 2025, the annual production costs reach a maximum and become constant till the end of the simulation for Scenarios 4, 3 and 2, respectively, and amount to approximately ZAR43.9 million (Scenario 4), ZAR44 million (Scenario 3) and ZAR45.1 million (Scenario 2).

Total establishment costs for all the agricultural land-use options

The PROLAND-model results show that the total annual establishment cost for all agricultural land-use options was constant over time from the year 2016 to 2024 for Scenario 2, 2016 to 2023 for Scenario 3 and 2016 to 2022 for Scenario 4. This amounted to approximately ZAR33.1 million, ZAR39 million and ZAR45.7 million remaining constant until 2021, 2022 and 2023 for Scenarios 2, 3 and 4, respectively. Thereafter, the annual establishment costs dropped to approximately ZAR5.4 million, ZAR7.4 million and ZAR21.9 million in 2022, 2023 and 2024 for Scenarios 4, 3 and 2, respectively. As from the following year onward till the end of the simulation, the annual establishment costs dropped to zero for Scenarios 2, 3 and 4 due to the maximum possible restoration area being achieved. As for the baseline scenario, no annual establishment costs were incurred due to the absence of restoration to active agricultural land uses.

Total *Prosopis spp* clearing costs

The PROLAND-model results show the total clearing costs incurred by DEA:NRM through its Working for Water programme for 2008 (i.e. initial time) to 2015 based on the historical budget for all scenarios with the value being identical since the co-finance option only starts in 2016 onward. In the initial simulation period (i.e. 2008), the total historical clearing cost amounted to ZAR804 135 for all scenarios and ZAR716 054 in the year 2015 for all the scenarios. Thereafter, the total annual clearing costs become constant, amounting to approximately ZAR859 265, ZAR1.1 million and ZAR1.4 million till the year 2024, 2023 and 2022 for Scenarios 2, 3 and 4, respectively. Afterwards, the annual clearing costs become zero as all *Prosopis spp* would have been cleared with the augmentation of the DEA: NRM budget by the private land users. However, for the baseline scenario the total annual clearing costs remain constant at ZAR716 054 from 2016 onward due to the absence of the co-finance option and the continuity of the business-as-usual case.

3.4.3.4 Social costs

Net economic value of carbon sequestered, stored and removed

The annual net economic value of carbon sequestered, stored and removed emanating from the PROLAND-model simulation from 2008 to 2015 are based on the historical clearing efforts by DEA:NRM through its Working for Water programme for all the scenarios. In 2008, the initial total economic value for net carbon sequestered, stored and removed amounted to ZAR613 726 and ZAR637 444 in the year 2015 for all the scenarios. Thereafter, the value reached a climax of approximately ZAR742 447 for Scenario 2, remaining constant until 2023, ZAR874 033 for Scenario 3, remaining constant until 2022, and ZAR1 million for Scenario 4, remaining constant until 2021. Afterwards, the net economic value for the carbon sequestered, stored and removed dropped to approximately ZAR120 046 (Scenario 4), ZAR165 180 (Scenario 3) and ZAR491 952 (Scenario 2) in 2022, 2023 and 2024, respectively, becoming zero thereafter when all *Prosopis spp* has been cleared off and the land put under active land-use (till the end of the model simulation in 2030). As for the baseline scenario, the economic value for the net carbon sequestered declined slightly from the year 2016 onward amounting to approximately ZAR570 000 as result of the absence of the co-finance option assumption that leads to more clearing interventions.

3.4.4 Feasibility analysis of clearing Prosopis spp and the active use of the land

3.4.4.1 Cumulative net present value (NPV)

The PROLAND-model results show a positive cumulative NPV for Scenarios 2, 3 and 4 amounting to approximately ZAR28.3 million, ZAR64.1 million and ZAR91. 8 million, respectively, at the end of the simulation period (i.e. 2030). As for the baseline scenario, the cumulative NPV is negative amounting to approximately -ZAR11.6 million at the end of the simulation period. The dynamic behaviour over time for the cumulative NPV is illustrated in Figure 3.4.

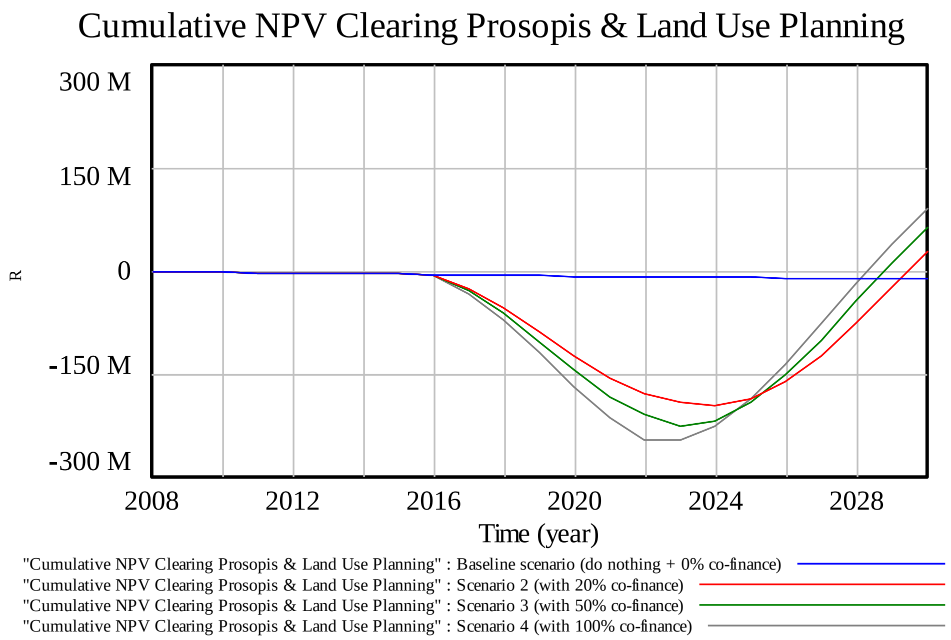

FIGURE 3. 4: THE DYNAMIC BEHAVIOUR OVER TIME FOR THE CUMULATIVE NPV FOR CLEARING *PROSOPIS SPP* AND RESTORING THE CLEARED AREA INTO ACTIVE LAND-USE OPTIONS

Source: Own analysis

3.4.4.2 Sensitivity analysis

In order to see how sensitive the modelled system was to changes in policies, we tested how the cumulative NPV responds in four ways. We assumed that all the land cleared from *Prosopis spp* would be restored i) 100% to the natural vegetation (called conservation in the model) with no land being converted to agricultural land-use options, ii) 100% to the table grape land-use option, iii) 100% to the raisins land-use option and iv) 100% to the citrus land-use option. Having undertaken the aforementioned, only the cumulative NPV for the citrus land-use option was positive, amounting to approximately ZAR314.8 million, ZAR397 million and ZAR468.5 million for Scenarios 2, 3 and 4, respectively, while that for the baseline scenario was negative at approximately -ZAR12 million at the end of the simulation period. As for the all the other land-use options, the cumulative NPV was negative for all the scenarios with approximately -ZAR11.6 million, -ZAR12.9 million, -ZAR14.7 million and -ZAR16.7 million being produced for the baseline scenario, Scenarios 2, 3 and 4, respectively, at the end of the model simulation for the natural vegetation (i.e. conservation) land-use option. Additionally, for the raisins land-use option, the cumulative NPV at the end of the model simulation amounted to approximately -ZAR11. 6 million, -ZAR80.3 million, -ZAR62.3 million and -ZAR47.2 million for the baseline scenario, Scenarios 2, 3 and 4, respectively. Lastly, for the table grape land-use option the cumulative NPV at the end of the model simulation added to approximately -ZAR11.6 million (baseline scenario), -ZAR93 million (Scenario 2), -ZAR65 million (Scenario 3) and -ZAR41.4 million (Scenario 4), respectively.

3.4 Discussion and conclusion

We constructed a system dynamics model (i.e. the PROLAND-model) consisting of 23 simulation periods (running from 2008 till 2030) and 10 sub-models, to assess the role of sustainable land-use planning (through different active land-use options) as a strategy to deal with the invasion by *Prosopis spp* within the study sites under investigation. Cao et al. (2012) mention that land-use optimisation emanating from land-use planning is a challenge marred with high complexity due to the components under investigation being non-linear in nature. As a result, the system dynamics modelling approach was selected due to its wide application in non-linear problems characterised by high complexity (Sterman 2000; Ford 2009; Crookes 2012; Crookes et al. 2013; Nkambule 2015; Crookes & Blignaut 2016; Mudavanhu et al. 2016; Vundla et al. 2016; Morokong et al. 2016).

In light of the above, it is important to take note of the following:

1. We used the current state (i.e. DEA: NRM) budget for clearing *Prosopis spp* in the study sites through the Working for Water programme as our baseline.
2. Only four scenarios were tested in this study with the baseline scenario (i.e. the do-nothing case + 0% co-finance), a co-finance option of 20% (Scenario 2), 50% (Scenario 3) and 100% (Scenario 4) with a conservative assumption that clearing continues at a constant rate according to the state budget for 2015.
3. The *Prosopis spp* clearance activities are based on conservative estimates derived as a function of the effect of person days on hectares cleared and the proportion of *Prosopis spp*, which is much lower as compared to the historical data on hectares cleared.
4. All models are wrong by definition, however some are useful.

Given the aforementioned, it is clear that the amount being invested by the government through its control programmes is not enough to win the battle against *Prosopis spp* as evident by the baseline scenario results (no private co-finance and restoration to active land-use options) (see Figure 3.2). As a result, the efforts by the government are potentially in vain – something that is also called a classic “fixes that fail” archetype within the system dynamics literature (see Maani and Cavana 2007). Given the pressures among various sectors and social spheres for tax payer’s money, the Department of Environmental Affairs should consider options to augment its current clearing budget for clearing *Prosopis spp* and convert the cleared land to active land uses if it is to win the battle with invasion by *Prosopis spp* within the sites under investigation. The results produced by the PROLAND-model show that with increased funding (20% co-finance, 50% co-finance and 100% co-finance), *Prosopis spp* clearing efforts yield promising prospects as evident by the downward trend of the area invaded by *Prosopis spp* over the simulation period which gradually becomes zero by 2023, 2024 and 2025 for Scenarios 4, 3 and 2, respectively (see Figure 2). However, if the government continues with the business-as-usual case (the baseline scenario), the area under *Prosopis spp* invasion will remain significantly high as shown by the growth trend over time in the baseline scenario results (see Figure 3.2).

The cumulative NPV (using a discount rate of 6%) for Scenarios 2, 3 and 4, were negative from the initial simulation period (i.e. 2008) up to 2028 (Scenarios 3 and 4) and up to 2029 (Scenario 2). Thereafter the cumulative NPV became positive, meaning that the integrated payback period (considering both society wide externalities and, private benefits and costs) of clearing *Prosopis spp* and converting the cleared land to active land-use options was 21 years (for Scenarios 3 and 4) and 22 years (for Scenario 2) given the model assumptions and scenarios considered for the purposes of this study. As for the baseline scenario, the cumulative NPV remained negative throughout the whole simulation period owing to the absence of restoration to active land-uses and the co-finance assumption. Overall, at the end of the simulation period (i.e. 2030), the cumulative NPV amounted to -ZAR11.6 million (baseline scenario), ZAR28.3 million (Scenario 2), ZAR64.1 million (Scenario 3) and ZAR91. 8 million (Scenario 4). The conventional approach in cost-benefit analysis assessments is that alternatives yielding a positive NPV are economically sound and preferable, while those with a negative NPV are the opposite and therefore undesirable. Therefore, only Scenarios 2, 3 and 4 are desirable, while the baseline scenario is undesirable. Moreover, Scenario 4 should be given priority as the best possible alternative since it yields the highest cumulative NPV, followed by Scenario 3 and lastly Scenarios 2. The baseline scenario should be avoided at all costs by relevant decision-makers such as the state and private land-users to mention a few.

Having conducted a sensitivity analysis, the PROLAND-model results show that the system that was modelled is highly sensitive to changes in policy assumptions conducted. Having changed the original policy assumption of apportioning the cleared area equally on a pro-rata basis to the active land-use options as explained in Section 3.4.4.2, only the citrus land-use option yields a positive cumulative NPV value while the other land-use options yield negative cumulative NPV values (see Section 3.4.4.2) for all scenarios considered. As a result in line with the highest best use principle, only the two options are favourable namely, i) that of apportioning all the cleared land to active land-use options equally on a pro-rata basis or ii) apportioning 100% of the cleared land to the citrus land-use option. However, between the two, apportioning 100% of all the cleared land to citrus is the most desirable land-use (with a cumulative NPV value amounting to approximately ZAR314.8 million (Scenario 2), ZAR397 million (Scenario 3) and ZAR468.5 million (Scenario 4)) and therefore the highest best use option in this case. The former option (i.e. option (i)) has a cumulative NPV value adding up to approximately ZAR28.3 million (Scenario 2), ZAR64.1 million (Scenario 3) and ZAR91. 8 million (Scenario 4). In the baseline scenario, no restoration to active land-use options occurs due to the do nothing assumption, and hence the cumulative NPV value is negative for both aforementioned highest best use land options.

The results emanating from this study should not be considered as a "one size fits all" approach. The same analysis should be tested at other sites invaded by *Prosopis spp* and other alien invasive species to see whether or not the similar findings can be produced. It is also important to note that the decision on what happens to the land after clearing lies in the hands of the decision-maker (particularly the state and private land users (i.e. farmers) in our case) and, as such, this study serves as guideline to alternatives that can be explored, and an outline of prospective behaviour over time emanating from these alternatives. Despite the two highest best land-use options presented here, other options different from those considered in this study should be explored to see how the modelled system responds and behaves over time. In conclusion, the empirical findings emanating from this study can serve as a guideline to inform land-use policy-makers to come up with optimal land-use allocations from an integrated perspective that does not only look at the private costs and benefits but also the society wide externality costs and benefits. As such, this study serves as one of the pioneering investigations in South Africa to conduct such an analysis.

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3.6 Supplementary materials

PART A: The PROLAND-Model

The *Prosopis spp* land-use trade-off model (the PROLAND-Model) was constructed for the purposes of this study. This system dynamics model consists of 10 sub-models namely, i) the land use sub-model, ii) the yield growth factor sub-model, iii) the raisins farming sub-model, iv) the table grape farming sub-model, v) the citrus farming sub-model, vi) the establishment cost sub-model, vii) the clearing cost sub-model, viii) the carbon sequestration lost sub-model, xi) the water savings sub-model, and x) the net present value sub-model. Part B (in the Supplementary Materials segment) provides the parameters (exogenous variables) used within the model, and the respective equations used to derive the endogenous variables whilst Part C (in the Supplementary Materials segment) presents the model validation process conducted.

A3.1The land-use sub-model

This sub-model models the invaded area that is cleared from *Prosopis spp* and then converted into various land-use options. The land-use sub-model consists of five stock variables, namely i) the area invaded by *Prosopis spp*, ii) the area restored to table grapes (i.e. Prime white seedless cultivar), iii) the area restored to raisins (i.e. Golden sultana cultivar), iv) the area restored to citrus (i.e. Eureka lemon cultivar), and v) the area restored to natural vegetation (called conservation in the model). The area invaded by *Prosopis spp* is increased by the re-growth of *Prosopis spp*, which is influenced by the spread rate thereof, the agricultural land use plantings (i.e. table grape, raisins and citrus plantings) and the area invaded. Furthermore, the area invaded is reduced through clearing operations, which are influenced by clearing budget (and hence person-days employment). With respect to the other stocks (i.e. area restored to table grapes, citrus, raisins and conservation) they only have inflows as shown in Figure A3.1. These inflows are influenced by the proportion assigned to each land-use option, time, the clearance of *Prosopis spp*, the proportion and maximum area assigned to each land use option post-clearing

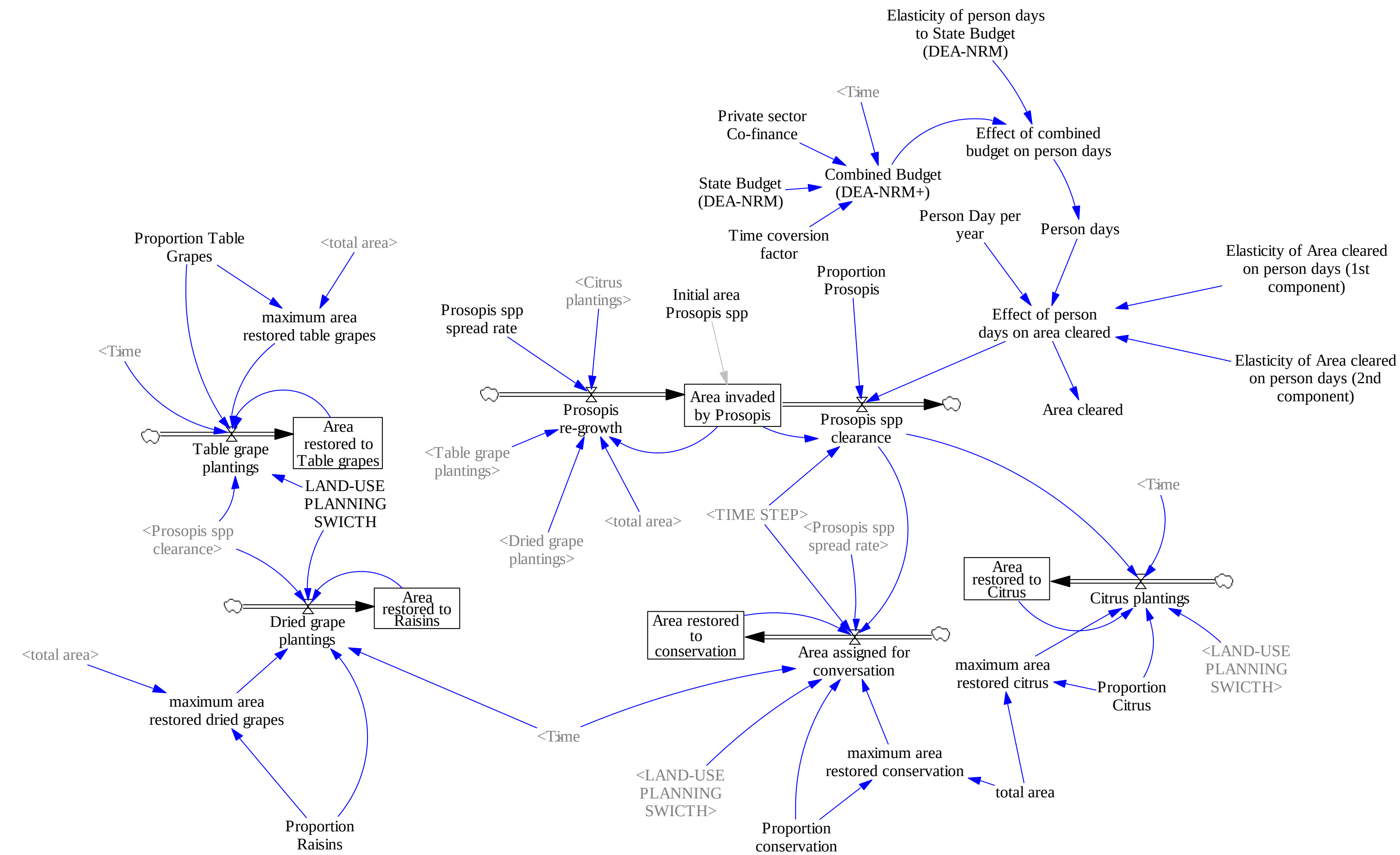

FIGURE A3. 1: LAND-USE SUB-MODEL OF THE PROLAND-MODEL

Source: Own analysis

A3.2 Yield growth factor sub-model

This sub-model establishes the growth in the yield of agricultural land use options considered for the purposes of this study. For the table grapes (i.e. Prime white seedless) and raisins (Golden Sultanas) land use options, the first marketable harvest is realised in the third year after planting, with only 30% of the maximum possible yield being harvested (Moelich pers comm, 2017[6]). In the fourth year the yield harvested increases to 70% and finally to 100% from the fifth year onward when all vines have matured (Moelich per comm, 2017). As a result, for the first two years after planting the yield will be zero. With respect to the citrus (i.e. Eureka lemons) land use option, the first marketable harvest is also realised in the third year after planting with only 15% of maximum possible yield being harvested (Cronje pers comm, 2017[7]). Thereafter, 30%, 60%, 85% and 100% of the maximum possible yield is achieved in the fourth, fifth, sixth and finally the seventh year and onward respectively (Cronje pers comm, 2017). This sub-model is imperative in order to distinguish the yield emanating from the citrus trees which in this case are planted in different points in time. Since the citrus tree plantings are determined by the portion of *Prosopis spp* cleared within a given point in time, the yield growth for the total trees planted differs significantly, with those planted first starting to yield fruit whilst the rest follow suite only later. Thus the yield area for all the agricultural land use options is determined by the plantings per annum and the accumulation of plantings (i.e. the stocks) per given time inter alia the proportion of the growth yield based on the age of the agricultural plants post planting. For illustrative purposes only the table grapes yield growth factor sub-model is shown in Figure A3.2 below. The raisins yield growth factor model looks basically the same, whilst that of citrus runs for seven year since citrus trees take seven years to reach the maximum possible yield.

[6] Mr Dawie Moelich is an experienced horticulturist working as a technical and market access manager for the South African Table Grape Industry (SATI).

[7] Dr Paul Cronje is an experienced horticulturist working as researcher for the Citrus Research International (CRI) in partnership with the horticulture department of the University of Stellenbosch.

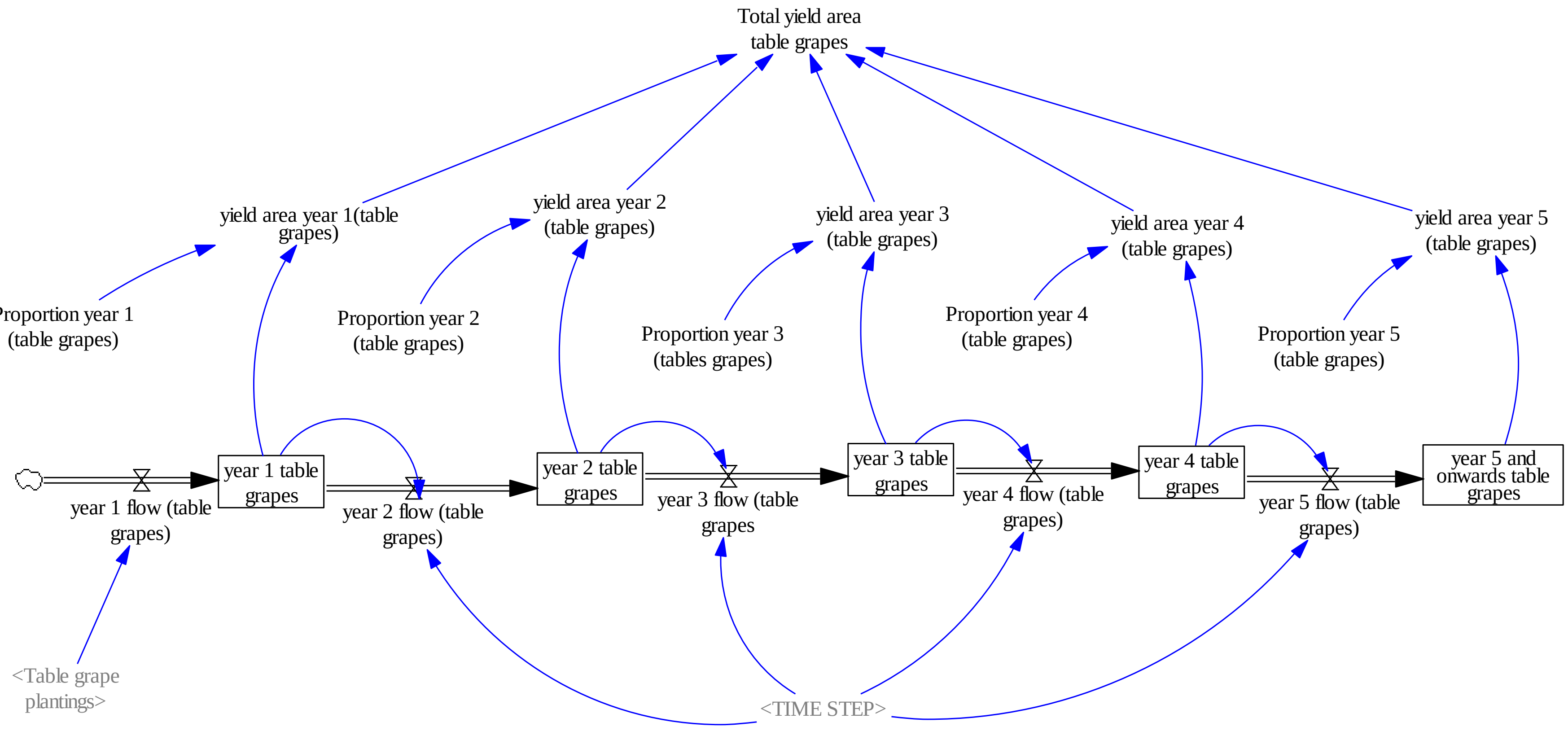

FIGURE A3. 2: TABLE GRAPES YIELD GROWTH FACTOR SUB-MODEL

Source: Own analysis

A3.3 Raisins sub-model

In this study it was assumed that the land restored to all land-use options would be apportioned equally on a pro-rata basis subject to each scenario under investigation. This sub-model models the enterprise budget for the raisins (i.e. Golden sultanas) land-use option. The yield for raisins is determined by the total yield area for raisins (based on the yield growth factor sub-model explained earlier), the dry mass proportion and the respective yield per hectare. The dry mass proportion (i.e. 40%) is imperative to the net weight of the fresh Golden sultanas after drying. The gross revenue for raisins farming is then determined by the product of the total yield from raisins and the respective price per tonne. The gross revenue is apportioned in a two part structure consisting of export market sales and local market sales. The net revenue from the raising farming is then derived by subtracting the fixed costs and overhead costs, and the directly attributable variable costs and indirectly attributable variable costs from the gross revenue. The raisins farming sub-model is shown in greater detail in Figure A3.3.

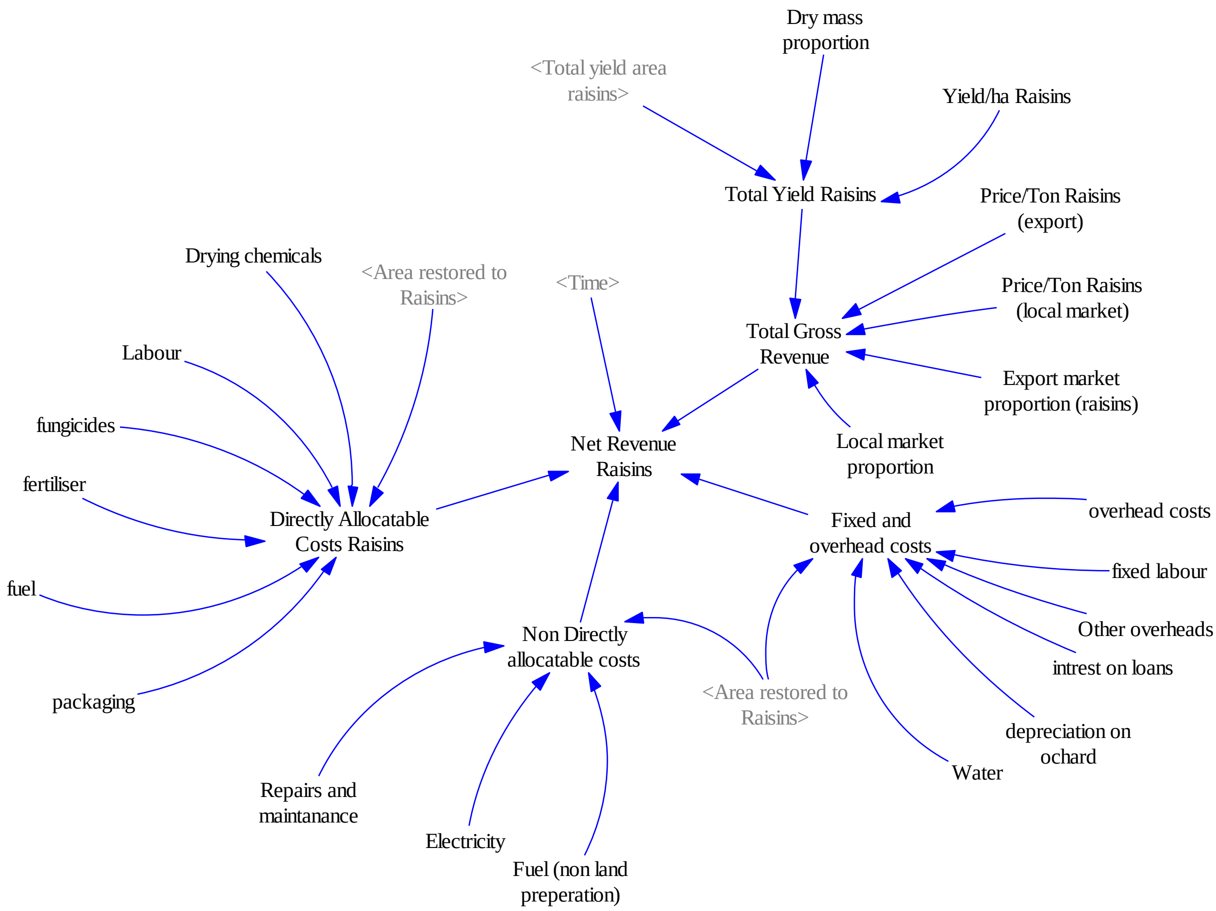

FIGURE A3. 3: THE RAISINS FARMING SUB-MODEL OF THE PROLAND-MODEL

Source: Own analysis

A3.4 Table grape farming sub-model

This sub-models models the table grape (prime white seedless) land-use enterprise budget. Similar to the raisins farming sub-model, the yield of table grapes is influenced by the yield per hectare and the total yield area of table grapes (based on the yield growth factor sub model). The gross revenue from table grape farming is a function of the price per ton and the total yield of table grapes. The gross revenue is also apportioned in a dual part structure consisting of export market sales and local market sales. All total production costs are then subtracted from the gross revenue in order to get the net revenue from table grapes (i.e. profit or loss). The table grape farming land-use model is shown in detail in Figure A3.4.

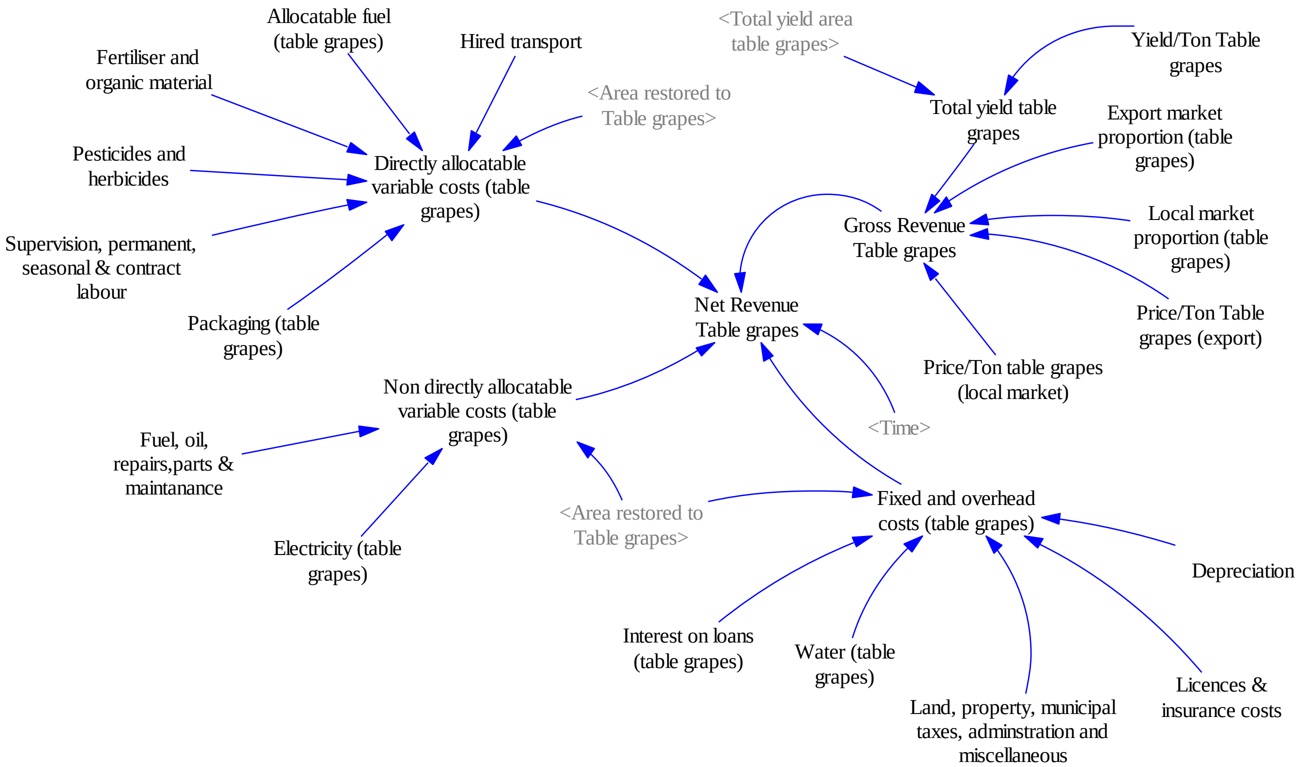

FIGURE A3. 4: TABLE GRAPE FARMING SUB-MODEL OF THE PROLAND-MODEL

Source: Own analysis

A3.5 Citrus sub-model

This sub-model models the citrus (Eureka lemons) land-use option farm budget. The total yield is a function of the total yield area (based on the yield growth factor sub-model) and the yield per hectare. The gross revenue of citrus is then determined by multiplying the price per ton of citrus and the total citrus yield. The net revenue of citrus is then derived by subtracting all the costs (i.e. the directly and indirectly attributable variable costs and the fixed and overhead costs for citrus) from the gross revenue value of citrus. The citrus farming sub-model is shown in Figure A3.5.

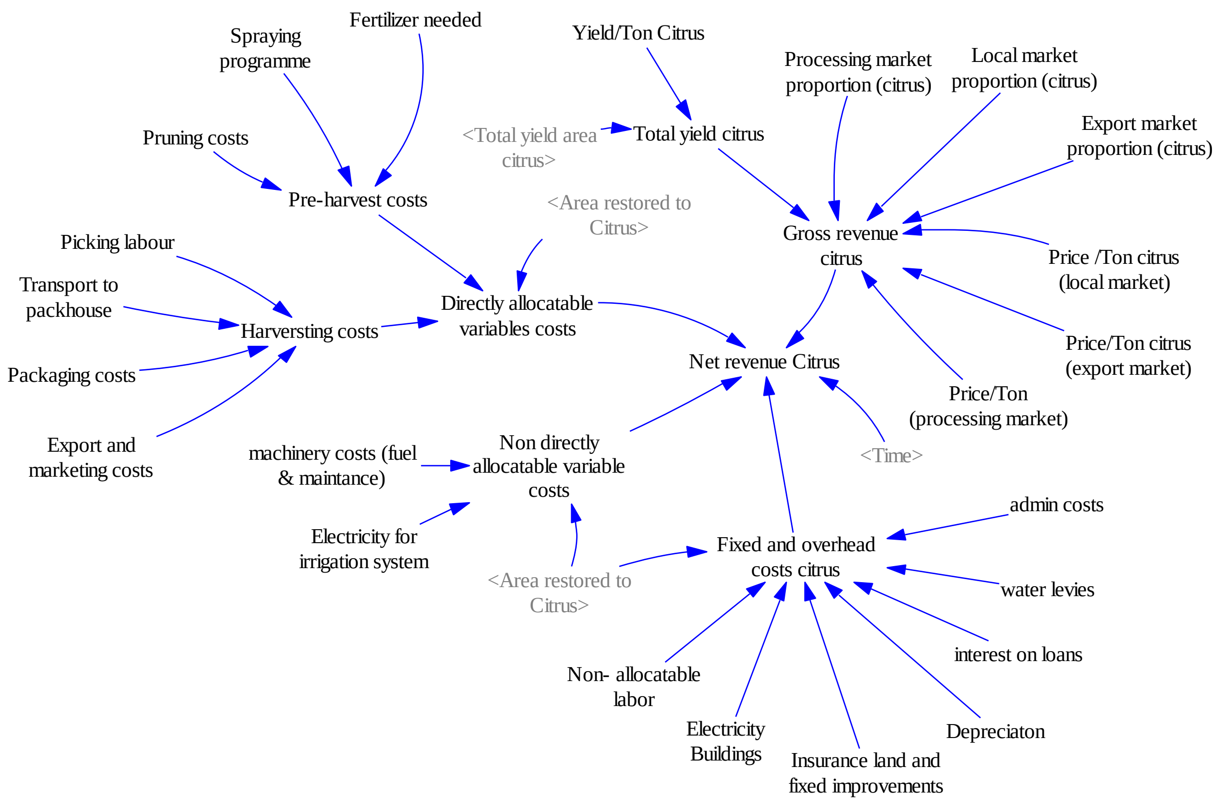

FIGURE A3. 5: THE CITRUS FARMING SUB-MODEL OF THE PROLAND-MODEL

Source: Own analysis

A3.6 Establishment cost sub-model

The establishment cost sub-model models the initial investment required in order to undertake the various land-use options considered for the purposes of this study. The establishment costs for all the land-use options are then aggregated to give the total establishment cost that is incurred as a once-off event. The establishment cost sub-model is illustrated in Figure A3.6.

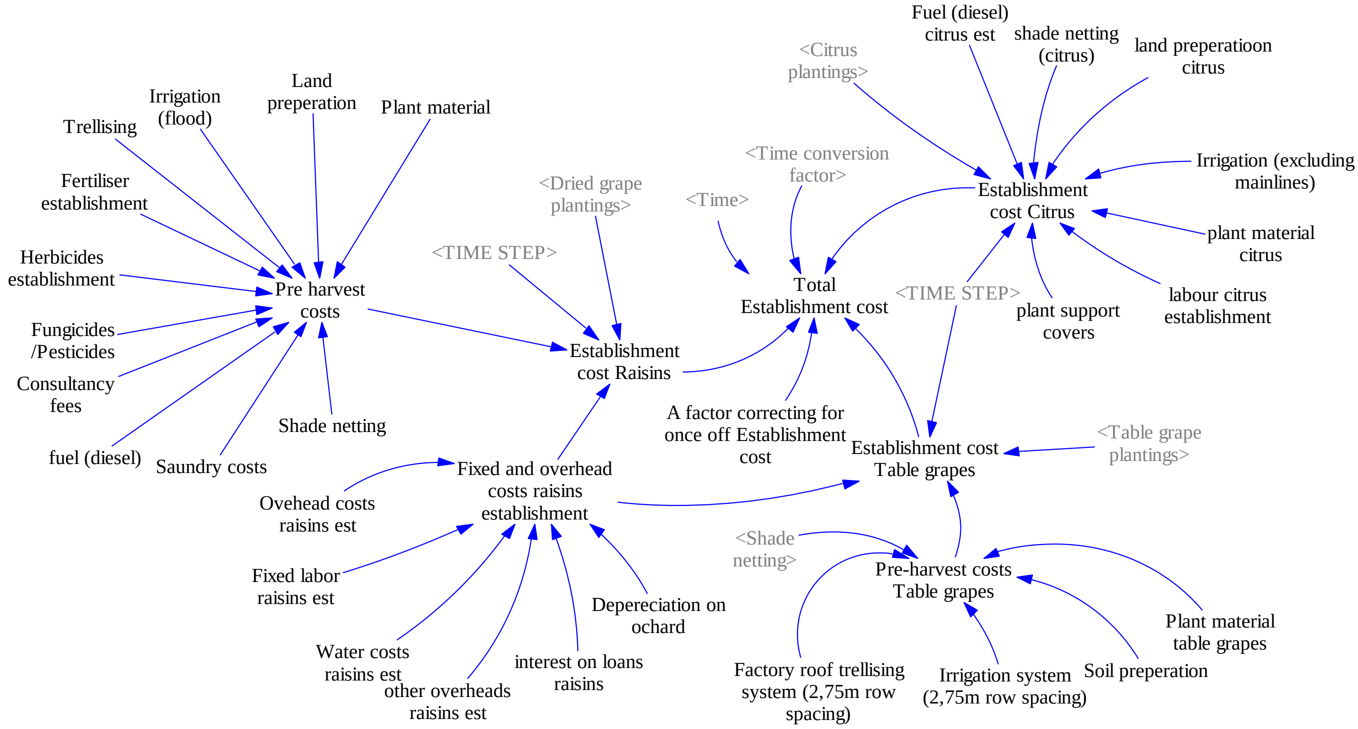

FIGURE A3. 6: ESTABLISHMENT COST SUB-MODEL OF THE PROLAND-MODEL

Source: Own analysis

A3.7 clearing cost sub-model

The clearing cost sub-model involves the modelling of the total clearing costs incurred to clear *Prosopis spp* within the study site. The unit clearing cost is a function of the total budget for clearing *Prosopis* within the sites and the annual clearance of *Prosopis spp*. The budget refers to the total amount of money invested by DEA:NRM to clear *Prosopis spp* within the water management areas of Onseepkans (D81E) and Pella (D81G). The clearing cost sub-model is shown in Figure A3.7.

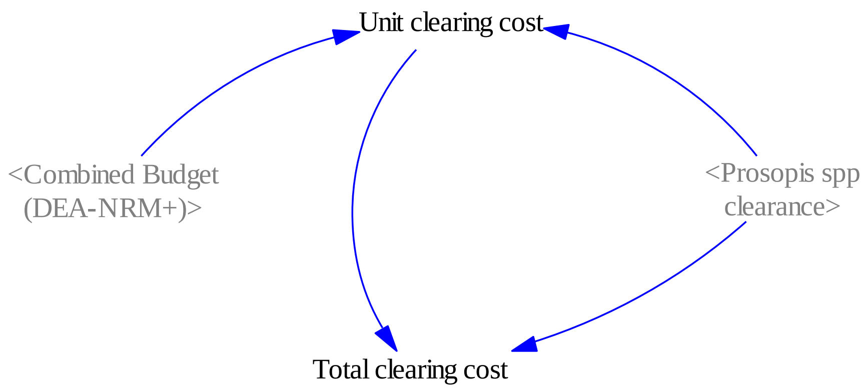

FIGURE A3. 7: CLEARING COST SUB-MODEL OF THE PROLAND-MODEL

Source: Own analysis

A3.8 Carbon sequestration sub-model

The carbon sequestration sub-model establishes the net value of carbon sequestered and stored that is lost as a result of clearing *Prosopis*. *Prosopis spp* sequesters and stores carbon from the atmosphere as a result of photosynthesis. Thus, through clearing there is an opportunity cost involved due to the loss of both historic as well as potential future carbon sequestration capability. The carbon sequestration potential is derived as the product of the *Prosopis spp* biomass, the net dry mass conversion ratio of *Prosopis*, the clearance of *Prosopis*, and CO_2 (carbon dioxide) to carbon ratio. As a result of the re-growth of *Prosopis spp*, there is a marginal corresponding benefit due to carbon sequestered and stored. This is then subtracted from the carbon sequestered, stored and removed to get the net carbon sequestered, stored and removed. The net carbon sequestered and stored value that is removed is then calculated by multiplying the net carbon removed and the unit price of carbon. The carbon sequestration sub-model is shown in Figure A3.8.

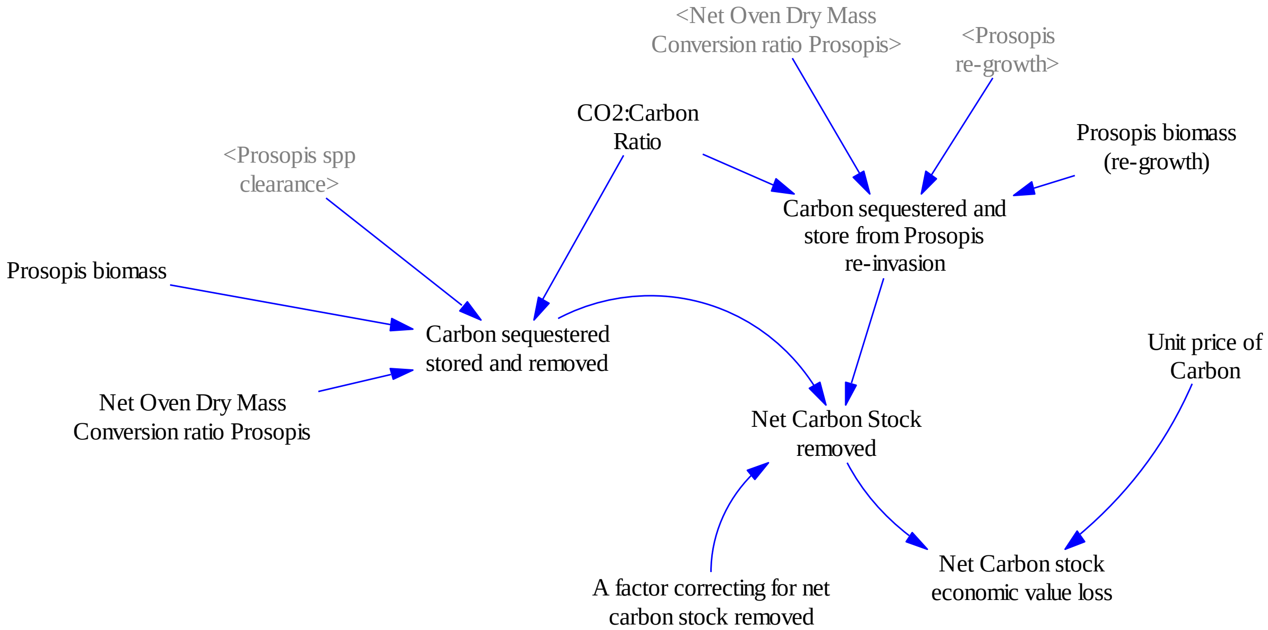

FIGURE A3. 8: CARBON SEQUESTRATION SUB-MODEL OF THE PROLAND-MODEL

Source: Own analysis

A3.9 Water consumption sub-model

This sub-model establishes the water reduction caused through invasion by *Prosopis*. As a result of clearing *Prosopis*, the water that was previously consumed by these invasive alien plants is saved and becomes available, therefore augmenting the water supply of the Orange River. The water that is used by the trees is derived as the product of water reduction per hectare by *Prosopis spp* and the clearance thereof. The monetary economic value of water that is saved as a result of clearing operations is then calculated by multiplying the unit value of water and the water use that has been released. The water consumption sub-model is shown in Figure A3.9.

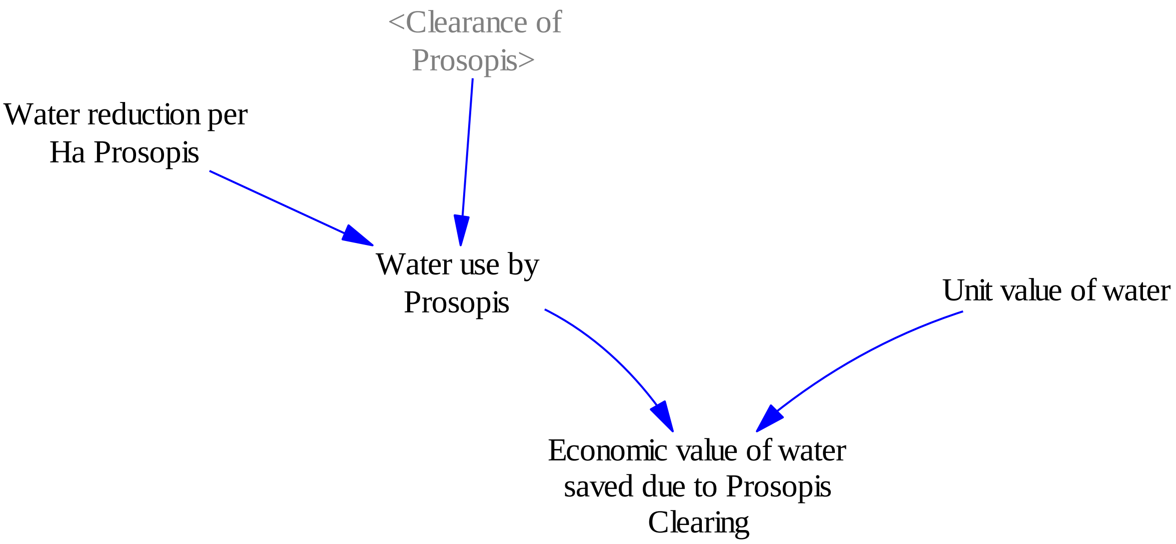

FIGURE A3. 9: WATER CONSUMPTION SUB-MODEL OF THE PROLAND-MODEL

Source: Own analysis

A3.10 NPV sub-model

This sub-model captures the private (and social) benefits and costs of *Prosopis spp* clearing operations by calculating the net present value of the operations. In order to assess the feasibility of clearing *Prosopis spp* and restoring the land cleared to active land use options, the net present value method was utilised for the purposes of this study. The net present value is a method of determining the feasibility of a project (or investment) through discounting the net difference between the annual benefits realised and annual costs incurred by a specific discount rate over a given period of time. The net present value formula used for the purpose of this study is shown in the equations below:

$$NPV = \sum_{T=1}^{T} \frac{B_t}{(1+r)^t} - C_t \quad (1)$$

Where:
B_t = total annul benefits realised during the year t over a given time period (2)
C_0 = total annual costs incurred during year t over a given time period (3)
r = discount rate, and (4)
t= year of cost (5)

The NPV sub-model is illustrated in Figure A3.10.

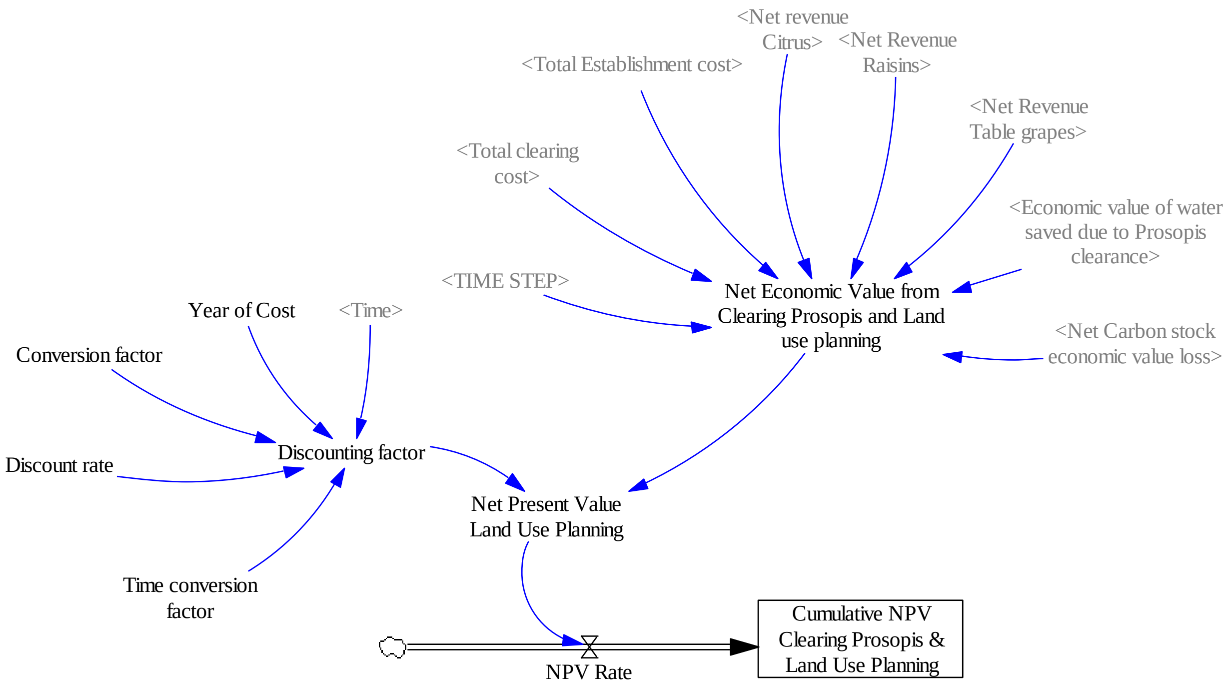

FIGURE A3. 10: NPV SUB-MODEL OF THE PROLAND-MODEL

Source: Own analysis

PART B: PROLAND-model parameters and equations

Land use sub-model parameters				
Description	**Formula/value**	**Unit**	**Reference**	**Comment**
Elasticity of Area cleared on PD (1st component)	-3e-006	ha/PD	Own calculation	
Elasticity of Area cleared on PD (2nd component)	0.0487	ha/PD	Own calculation	
Elasticity of PD to State budget	0.0041	PD/R	Own calculation	
Initial *Prosopis spp*	9 097.64	ha	DEA:NRM (2016)	
Land use planning switch	0	Dmnl	Policy variable	
Person day per year	1	PD/year	DEA:NRM (2016)	
Private sector co-finance	1	Dmnl	Policy variable	
Proportion Citrus	0.25	Dmnl	Model assumption	
Proportion conservation	0.25	Dmnl	Model assumption	
Proportion Prosopis	1	Dmnl	Model assumption	
Proportion Raisins	0.25	Dmnl	Model assumption	
Proportion table grapes	0.25	Dmnl	Model assumption	
Prosopis spp spread rate	0.1075	Dmnl/year	Versfeld (1993) & Vorster (1977) cited in Van Wilgen & Le Maitre (2013)	Based on a number of studies in South Africa
State budget (DEA:NRM)	Lookup	ZAR/year	DEA:NRM (2016)	
Time	Internally defined in model	year		
Time conversion factor	1	year		
Time step	Internally defined in model	year		

Land use sub-model equations				
Description	**Formula/value**	**Unit**	**Reference**	**Comment**
Combined budget (DEA:NRM+)	"Private sector Co-finance"*"State Budget (DEA:NRM)"(Time/Time conversion factor)	ZAR/year	Own calculation	

Effect of combined budget on PD	"Elasticity of person days to State Budget (DEA:NRM)"*"Combined Budget (DEA:NRM+)"	PD/year	Own calculation	
Person days	Effect of combined budget on person days+ 427.12	PD/year	Own calculation	
Effect of person days on area cleared	(("Elasticity of Area cleared on person days (1st component)"*(Person days*Person days))/Person Day per year)+("Elasticity of Area cleared on person days (2nd component)"*Person days)	ha/year	Own calculation	
Area cleared	Effect of person days on area cleared- 34.458	ha/year	Own calculation	
Prosopis spp clearance	MIN((Effect of person days on area cleared*Proportion Prosopis)-34.458 , Area invaded by Prosopis/TIME STEP)	ha/year	Own calculation	
Area invaded by Prosopis	INTEG("*Prosopis spp* re-growth"-*Prosopis spp* clearance)	ha	Own calculation	
"*Prosopis spp* re-growth"	(Area invaded by Prosopis**Prosopis spp* spread rate)+(Area restored to conservation**Prosopis spp* spread rate)	ha/year	Own calculation	
Table grape plantings	IF THEN ELSE(Time<2016, "LAND-USE PLANNING SWICTH"*Proportion Table Grapes**Prosopis spp* clearance , Proportion Table Grapes **Prosopis spp* clearance)	ha/year	Own calculation	

Area restored to table grapes	INTEG(Table grape plantings)	ha	Own calculation	
Dried grape (Raisins) plantings	IF THEN ELSE(Time<2016 , Proportion Raisins**Prosopis spp* clearance*"LAND-USE PLANNING SWICTH" , Proportion Raisins**Prosopis spp* clearance)	ha/year	Own calculation	
Area restored to Raisins	INTEG(Dried grape (Raisins) plantings)	ha	Own calculation	
Area restored to conservation	INTEG(Area assigned for conversation)	ha	Own calculation	
Area restored to Citrus	INTEG(Citrus plantings)	ha	Own calculation	
Citrus plantings	IF THEN ELSE(Time<2016 , Proportion Citrus**Prosopis spp* clearance*"LAND-USE PLANNING SWICTH" , Proportion Citrus**Prosopis spp* clearance)	ha/year	Own calculation	
Area assigned for conversation	(Proportion conservation**Prosopis spp* clearance)-(Area restored to conservation**Prosopis spp* spread rate)	ha/year	Own calculation	
Raisins farming sub-model parameters				
Description	**Formula/value**	**Unit**	**Reference**	**Comment**
Drying chemicals	714.12	R/ha	Hortgro (2015) & VinPro (2016)	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA, 2017) based on the Hortgro and VinPro figures
Labour	13 156.1	R/ha	Hortgro (2015) & VinPro (2016	Conservative estimates adjusted for inflation to current prices using the Jan

				2017 PPI index for agriculture (StatsSA, 2017) based on the Hortgro and VinPro figures
Fungicides	1 941.44	R/ha	Hortgro (2015) & VinPro (2016)	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA, 2017) based on the Hortgro and VinPro figures
Fertiliser	3 719.86	R/ha	Hortgro (2015) & VinPro (2016	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA, 2017) based on the Hortgro and VinPro figures
Fuel	4 960.96	R/ha	Hortgro (2015) & VinPro (2016)	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA, 2017) based on the Hortgro and VinPro figures
Packaging	0	R/ha	Hortgro (2015) & VinPro (2016)	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA, 2017) based on the Hortgro and VinPro figures
Repairs and maintenance	3 056	R/ha	Hortgro (2015) & VinPro (2016)	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA, 2017) based on the Hortgro and VinPro figures
Electricity	0	R/ha	Hortgro (2015) & VinPro (2016	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA, 2017) based on the Hortgro and VinPro figures
"Fuel (non land preparation)"	2 360.5	R/ha	Hortgro (2015) & VinPro (2016	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture

				(StatsSA, 2017) based on the Hortgro and VinPro figures
Water	2344.43	R/ha	Hortgro (2015) & VinPro (2016	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA, 2017) based on the Hortgro and VinPro figures
depreciation on orchard	11055.5	R/ha	Hortgro (2015) & VinPro (2016	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA, 2017) based on the Hortgro and VinPro figures
interest on loans	2579.79	R/ha	Hortgro (2015) & VinPro (2016	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA, 2017) based on the Hortgro and VinPro figures
Other overheads	16163	R/ha	Hortgro (2015) & VinPro (2016	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA, 2017) based on the Hortgro and VinPro figures
fixed labour	14251	R/ha	Hortgro (2015) & VinPro (2016	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA, 2017) based on the Hortgro and VinPro figures
overhead costs	46397	R/ha	Hortgro (2015) & VinPro (2016	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA, 2017) based on the Hortgro and VinPro figures
Export market proportion (raisins)	0.87	Dmnl	Based on Hortgro (2016)	
Local market proportion	0.13	Dmnl	Based on Hortgro (2016)	

"Price/Ton Raisins (export)"	30 765	R/Ton	Hortgro (2015), DAFF (2016), NAMC (2015) & VinPro (2016	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA, 2017) based on the Hortgro, DAFF, NAMC and VinPro figures
"Price/Ton Raisins (local market)"	19 747.4	R/Ton	Hortgro (2015), DAFF (2016), NAMC (2015) & VinPro (2016	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA, 2017) based on the Hortgro DAFF, NAMC and VinPro figures
"Yield/ha Raisins"	22	Ton/ha	Hortgro (2015) & VinPro (2016	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA, 2017) based on the Hortgro and VinPro figures
Raisins farming sub-model equations				
Description	**Formula/value**	**Unit**	**Reference**	**Comment**
Total Yield Raisins	Area restored to Raisins*"Yield/ha Raisins"	Ton	Own calculation	
Area restored to Raisins	INTEG(Dried grape plantings)	ha	Own calculation	
Total Gross Revenue	"Price/Ton Raisins"*Total Yield Raisins	R/year	Own calculation	
Fixed and overhead costs	(depreciation on ochard+fixed labour+intrest on loans+Other overheads+overhead costs+Water)*Area restored to Raisins	R/year	Own calculation	
Net Revenue Raisins	IF THEN ELSE(Time>2017, Total Gross Revenue-Directly Allocatable Costs Raisins-Fixed and overhead costs-Non Directly allocatable costs ,0)	R/year	Own calculation	

Non Directly allocatable costs	(Electricity+"Fuel (non land preperation)"+Repairs and maintanance)*Area restored to Raisins	R/year	Own calculation	
Directly Allocatable Costs Raisins	(Drying chemicals+fertiliser+fuel+fungicides+Labour+packaging)*Area restored to Raisins	R/year	Own calculation	
Table grape farming sub-model parameters				
Description	**Formula/value**	**Unit**	**Reference**	**Comment**
Fuel, oil, repair, parts and maintenance	24 041	R/ha	SATI (2015) & VinPro (2016)	Conservative estimates based on the SATI and VinPro figures adjusted to inflation using the PPI index for January 2017 (StatsSA, 2017)
Electricity (table grapes)	9475	R/ha	SATI (2015) & VinPro (2016)	Conservative estimates based on the SATI and VinPro figures adjusted to inflation using the PPI index for January 2017 (StatsSA, 2017)
"Packaging (table grapes)"	0	R/ha	SATI (2015) & VinPro (2016)	Conservative estimates based on the SATI and VinPro figures adjusted to inflation using the PPI index for January 2017 (StatsSA, 2017)
Supervision, permanent, seasonal & contract labour	135 559	R/ha	SATI (2015) & VinPro (2016)	Conservative estimates based on the SATI and VinPro figures adjusted to inflation using the PPI index for January 2017 (StatsSA, 2017)
Pesticides and herbicides	22 255	R/ha	SATI (2015) & VinPro (2016)	Conservative estimates based on the SATI and VinPro figures adjusted to inflation using the PPI index for January 2017 (StatsSA, 2017)
Fertiliser and organic material	9 808	R/ha	SATI (2015) & VinPro (2016)	Conservative estimates based on the SATI and VinPro figures adjusted to inflation using the PPI index for January 2017 (StatsSA, 2017)
Allocatable fuel (table grapes)	4 961	R/ha	SATI (2015) & VinPro (2016)	Conservative estimates based on the SATI and VinPro figures adjusted to

				inflation using the PPI index for January 2017 (StatsSA, 2017)
Hired transport	1 239	R/ha	SATI (2015) & VinPro (2016)	Conservative estimates based on the SATI and VinPro figures adjusted to inflation using the PPI index for January 2017 (StatsSA, 2017)
licences and insurance	805	R/ha	SATI (2015) & VinPro (2016)	Conservative estimates based on the SATI and VinPro figures adjusted to inflation using the PPI index for January 2017 (StatsSA, 2017)
Interest on loans (table grapes)	2 580	R/ha	SATI (2015) & VinPro (2016)	Conservative estimates based on the SATI and VinPro figures adjusted to inflation using the PPI index for January 2017 (StatsSA, 2017)
Water (table grapes)	1 305	R/ha	SATI (2015) & VinPro (2016)	Conservative estimates based on the SATI and VinPro figures adjusted to inflation using the PPI index for January 2017 (StatsSA, 2017)
Land, property, municipal taxes, administration and miscellaneous	7284	R/ha	SATI (2015) & VinPro (2016)	Conservative estimates based on the SATI and VinPro figures adjusted to inflation using the PPI index for January 2017 (StatsSA, 2017)
Electricity table grapes	1580	R/ha	SATI (2015) & VinPro (2016)	Conservative estimates based on the SATI and VinPro figures adjusted to inflation using the PPI index for January 2017 (StatsSA, 2017)
water cost	1257	R/ha	SATI (2015) & VinPro (2016)	Conservative estimates based on the SATI and VinPro figures adjusted to inflation using the PPI index for January 2017 (StatsSA, 2017)
Depreciation	28956	R/ha	SATI (2015) & VinPro (2016	Conservative estimates based on the SATI and VinPro figures adjusted to inflation using the PPI index for January 2017 (StatsSA, 2017)
Export market proportion (table grapes)	0.93	Dmnl	Based on SATI (2015) and verified by experts	

Local market proportion (table grapes)	0.07	Dmnl	Based on SATI (2015) and verified by experts	
"Price/Ton Table grapes (export)"	21 195.2	R/Ton	SATI (2015) & VinPro (2016	Conservative estimates based on the SATI and VinPro figures adjusted to inflation using the PPI index for January 2017 (StatsSA, 2017)
"Price/Ton Table grapes (local market)"	13 808.3	R/Ton	SATI (2015) & VinPro (2016	Conservative estimates based on the SATI and VinPro figures adjusted to inflation using the PPI index for January 2017 (StatsSA, 2017)
"Yield/Ton Table grapes"	22	Ton/ha	SATI (2015) & VinPro (2016	Conservative estimates based on the SATI and VinPro figures adjusted to inflation using the PPI index for January 2017 (StatsSA, 2017)
Table grape farming sub-model equations				
Description	**Formula/value**	**Unit**	**Reference**	**Comment**
Direct costs	fertiliser Table grapes + Herbicide control + Organic material + Pesticide control + repair and binding material + seed	R/ha	Own calculation	
Total Cash Expenditures	Direct costs + fixed improvements+ General expenditure+ Labour requirements + mechanisation costs	R/ha	Own calculation	
Labour requirements	Permanent labour + Seasonal and contract workers + supervision	R/ha	Own calculation	
General expenditure	admin expenses + Electricity table grapes + taxes + water cost	R/ha	Own calculation	
fixed improvements	Insurance + Repair and maintenance	R/ha	Own calculation	

mechanisation costs	Fuel costs + Hired Transport + licences and insurance + "repair, parts and maintenance"	R/ha	Own calculation	
Provision for renewal	Fixed improvements provisions + Loose assets provisions + Vineyards	R/ha	Own calculation	
Net Revenue Table grapes	IF THEN ELSE(Time>2017, Gross Revenue Table grapes-Total Production Cost , 0)	R/year	Own calculation	
Gross Revenue Table grapes	"Price/Ton Table grapes"*Total yield table grapes	R/year	Own calculation	
Total yield table grapes	Area restored to table grapes*"Yield/Ton Table grapes"	Ton/year	Own calculation	
Total Production Cost	(Provision for renewal +Total Cash Expenditures)*Area restored to table grapes	R/year	Own calculation	
Citrus farming sub-model parameters				
Description	**Formula/value**	**Unit**	**Reference**	**Comment**
Fertilizer needed	4792.95	R/ha	Consultation with anonymous citrus farmers and experts	Conservative estimates based on consultation with anonymous farmers and experts
Spraying programme	17299.3	R/ha	Consultation with anonymous citrus farmers and experts	Conservative estimates based on consultation with anonymous farmers and experts
Pruning costs	71.38	R/ha	Consultation with anonymous citrus farmers and experts	Conservative estimates based on consultation with anonymous farmers and experts
Picking labour	10042.5	R/ha	Consultation with anonymous citrus farmers and experts	Conservative estimates based on consultation with anonymous farmers and experts

Transport to packhouse	3095.24	R/ha	Consultation with anonymous citrus farmers and experts	Conservative estimates based on consultation with anonymous farmers and experts
Export and marketing costs	31980	R/ha	Consultation with anonymous citrus farmers and experts	Conservative estimates based on consultation with anonymous farmers and experts
"machinery costs (fuel & maintenance)"	26145.2	R/ha	Consultation with anonymous citrus farmers and experts	Conservative estimates based on consultation with anonymous farmers and experts
Electricity for irrigation system	2126.17	R/ha	Consultation with anonymous citrus farmers and experts	Conservative estimates based on consultation with anonymous farmers and experts
"Non- allocatable labour"	19184	R/ha	Consultation with anonymous citrus farmers and experts	Conservative estimates based on consultation with anonymous farmers and experts
Electricity Buildings	1856	R/ha	Consultation with anonymous citrus farmers and experts	Conservative estimates based on consultation with anonymous farmers and experts
Insurance land and fixed improvements	1345	R/ha	Consultation with anonymous citrus farmers and experts	Conservative estimates based on consultation with anonymous farmers and experts
Depreciation	6000	R/ha	Consultation with anonymous citrus farmers and experts	Conservative estimates based on consultation with anonymous farmers and experts
interest on loans	1200	R/ha	Consultation with anonymous citrus farmers and experts	Conservative estimates based on consultation with anonymous farmers and experts
water levies	560.75	R/ha	Consultation with anonymous citrus farmers and experts	Conservative estimates based on consultation with anonymous farmers and experts
admin costs	3000	R/ha	Consultation with anonymous citrus farmers and experts	Conservative estimates based on consultation with anonymous farmers and experts
Processing market proportion (citrus)	0.29	Dmnl	Based on CGA (2016) and verified by experts	

Local market proportion (citrus)	0.04	Dmnl	Based on CGA (2016) and verified by experts	
Export market proportion (citrus)	0.67	Dmnl	Based on CGA (2016) and verified by experts	
"Price/Ton citrus (export market)"	14 097.6	R/ton	Based on CGA (2016) and verified by experts	Conservative estimates based on CGA (2016) adjusted for inflation using the PPI index for Agriculture based on StatsSA (2017)
"Price/Ton citrus (local market"	8 568.3	R/ton	Based on CGA (2016) and verified by experts	Conservative estimates based on CGA (2016) adjusted for inflation using the PPI index for Agriculture based on StatsSA (2017)
"Price/Ton citrus (processing market)"	1 582.09	R/ton	Based on CGA (2016) and verified by experts	Conservative estimates based on CGA (2016) adjusted for inflation using the PPI index for Agriculture based on StatsSA (2017)
"Yield/Ton Citrus"	65	Ton/ha	Consultation with anonymous citrus farmers and verified by experts	Conservative estimates based on consultation with anonymous farmers and experts, and CGA (2016)
Citrus farming sub-model equations				
Description	**Formula/value**	**Unit**	**Reference**	**Comment**
"Pre-harvest costs"	Fertilizer needed + Pruning costs + Spraying programme	R/ha	Own calculation	
Harvesting costs	Export and marketing cost s+ Packaging costs + Picking labour + Transport to packhouse	R/ha	Own calculation	
Directly allocatable variables costs	(Harvesting costs + "Pre-harvest costs")*Area restored to Citrus	R/year	Own calculation	
Non directly allocatable variable costs	(Electricity for irrigation system + "machinery costs	R/year	Own calculation	

	(fuel & maintenance)")*Area restored to Citrus			
Fixed and overhead costs citrus	admin costs + Depreciation +Electricity Buildings +Insurance land and fixed improvements + interest on loans +"Non- allocatable labour" +water levies)*Area restored to Citrus	R/year	Own calculation	
Net revenue Citrus	IF THEN ELSE(Time>2018, Gross revenue citrus-Directly allocatable variables costs-Fixed and overhead costs citrus-Non directly allocatable variable costs , 0)	R/year	Own calculation	
Gross revenue citrus	"Price/Ton citrus"*Total yield citrus	R/year	Own calculation	
Total yield citrus	Area restored to Citrus*"Yield/Ton Citrus"	Ton/year	Own calculation	
Establishment cost sub-model parameters				
Description	**Formula/value**	**Unit**	**Reference**	**Comment**
Plant material	36 734.7	R/ha	Hortgro (2015) & VinPro (2016)	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA, 2017) based on the Hortgro and VinPro figures
Land preparation	17 221.6	R/ha	Hortgro (2015) & VinPro (2016)	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA, 2017) based on the Hortgro and VinPro figures
"Irrigation (flood)"	10 119.4	R/ha	Hortgro (2015) & VinPro (2016)	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture

				(StatsSA, 2017) based on the Hortgro and VinPro figures
Trellising	87 937	R/ha	Hortgro (2015) & VinPro (2016)	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA, 2017) based on the Hortgro and VinPro figures
Fertiliser establishment	4 316.87	R/ha	Hortgro (2015) & VinPro (2016)	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA, 2017) based on the Hortgro and VinPro figures
Herbicides establishment	559.13	R/ha	Hortgro (2015) & VinPro (2016)	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA, 2017) based on the Hortgro and VinPro figures
"Fungicides/Pesticides"	516	R/ha	Hortgro (2015) & VinPro (2016)	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA, 2017) based on the Hortgro and VinPro figures
Consultancy fees	1 090.7	R/ha	Hortgro (2015) & VinPro (2016)	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA, 2017) based on the Hortgro and VinPro figures
"fuel (diesel)"	3 598.16	R/ha	Hortgro (2015) & VinPro (2016)	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA, 2017) based on the Hortgro and VinPro figures
Sundry costs	1 226.18	R/ha	Hortgro (2015) & VinPro (2016)	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA, 2017) based on the Hortgro and VinPro figures

Shade netting	160 000	R/ha	Consultation with experts	
Overhead costs raisins (establishment)	59 164	R/ha	Hortgro (2015) & VinPro (2016)	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA, 2017) based on the Hortgro and VinPro figures
Fixed labour raisins (establishment)	20 097.6	R/ha	Hortgro (2015) & VinPro (2016)	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA, 2017) based on the Hortgro and VinPro figures
Water costs raisins (establishment)	2 344.43	R/ha	Hortgro (2015) & VinPro (2016)	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA, 2017) based on the Hortgro and VinPro figures
other overheads raisins (establishment)	16 163	R/ha	Hortgro (2015) & VinPro (2016)	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA, 2017) based on the Hortgro and VinPro figures
interest on loans raisins	9 500.56	R/ha	Hortgro (2015) & VinPro (2016)	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA, 2017) based on the Hortgro and VinPro figures
Depreciation on orchard	11055.5	R/ha	Hortgro (2015) & VinPro (2016)	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA, 2017) based on the Hortgro and VinPro figures
"Factory roof trellising system (2,75m row spacing)"	69926	R/ha	SATI (2015) & VinPro (2016)	Conservative estimates based on the SATI and VinPro figures adjusted to inflation using the PPI index for January 2017 (StatsSA, 2017)

"Irrigation system (2,75m row spacing)"	23281	R/ha	SATI (2015) & VinPro (2016)	Conservative estimates based on the SATI and VinPro figures adjusted to inflation using the PPI index for January 2017 (StatsSA, 2017)
Soil preparation	21000	R/ha	SATI (2015) & VinPro (2016)	Conservative estimates based on the SATI and VinPro figures adjusted to inflation using the PPI index for January 2017 (StatsSA, 2017)
Plant material table grapes	36 734.7	R/ha	SATI (2015) & VinPro (2016)	Conservative estimates based on the SATI and VinPro figures adjusted to inflation using the PPI index for January 2017 (StatsSA, 2017)
Shade netting	160 000	R/ha	Consultation with experts	
plant support covers	1000	R/ha	Consultation with anonymous citrus farmers and experts	Conservative estimates based on consultation with anonymous farmers and experts
labour citrus establishment	10000	R/ha	Consultation with anonymous citrus farmers and experts	Conservative estimates based on consultation with anonymous farmers and experts
plant material citrus	45000	R/ha	Consultation with anonymous citrus farmers and experts	Conservative estimates based on consultation with anonymous farmers and experts
"Irrigation (excluding mainlines)"	30000	R/ha	Consultation with anonymous citrus farmers and experts	Conservative estimates based on consultation with anonymous farmers and experts
Shade netting (citrus)	200 000	R/ha	Consultation with experts	
land preparation citrus	35000	R/ha	Consultation with anonymous citrus farmers and experts	Conservative estimates based on consultation with anonymous farmers and experts
"Fuel (diesel) citrus establishment"	120	R/ha	Consultation with anonymous citrus farmers and experts	Conservative estimates based on consultation with anonymous farmers and experts
Establishment cost sub-model parameters				
Description	**Formula/value**	**Unit**	**Reference**	**Comment**

Pre harvest costs	Consultancy fees + Fertiliser establishment + "fuel (diesel)" + "Fungicides/Pesticides" + Herbicides establishment + "Irrigation (flood)" + Land preparation +Plant material + Sundry costs + Trellising	R/ha	Own calculation	
Fixed and overhead costs raisins establishment	Depreciation on orchard +Fixed labour raisins establishment + interest on loans raisins + other overheads raisins est + Overhead costs raisins establishment + Water costs raisins est	R/ha	Own calculation	
"Pre-harvest costs Table grapes"	"Factory roof trellising system (2,75m row spacing)" + "Irrigation system (2,75m row spacing)"+ Plant material table grape s+ Soil preparation	R/ha	Own calculation	
Establishment cost Table grapes	(Fixed and overhead costs raisins establishment + "Pre-harvest costs Table grapes")*Area restored to table grapes	R/year	Own calculation	
Establishment cost Raisins	(Fixed and overhead costs raisins establishment + Pre harvest costs)*Area restored to Raisins	R/year	Own calculation	
Establishment cost Citrus	Area restored to Citrus*("Fuel (diesel) citrus establishment" + "Irrigation (excluding mainlines)" + labour citrus establishment + land preparation citrus +plant	R/year	Own calculation	

	material citrus + plant support covers)			
Total Establishment cost	(Establishment cost Citrus + Establishment cost Raisins + Establishment cost Table grapes)* A factor correcting for once off Establishment cost (Time/Time conversion factor)	R/year	Own calculation	
Clearing cost sub model equations				
Description	**Formula/value**	**Unit**	**Reference**	**Comment**
Unit clearing cost	"Combined Budget (DEA:NRM+)"/*Prosopis spp* clearance	R/ha	Own calculation	
Total clearing cost	*Prosopis spp* clearance*Unit clearing cost	R/year	Own calculation	
Carbon sequestration sub-model parameters				
Description	**Formula/value**	**Unit**	**Reference**	**Comment**
Prosopis spp biomass	45	Ton/ha	Mugido et al. (2014)	Conservative estimates
Prosopis spp biomass (re-growth)	4.5	Ton/ha	Mugido et al. (2014) and consultation with experts	Conservative estimates, it takes 10 years for *Prosopis spp* trees to reach maximum biomass, as a result this was divided by 10 years to apportion for biomass emanating from re-invasion per annum.
Net Oven Dry Mass Conversion ratio Prosopis	0.45	Dmnl	Thomas & Martin (2012)	55% moisture is removed from cleared biomass to be left with the 45% oven dry mass.
"CO2:Carbon Ration"	3.6667	Dmnl	Thomas & Martin (2012)	3.6667 is the ratio of CO_2 over carbon
A factor correcting for net carbon stock removed	0.5	Dmnl	Policy variable	

Unit price of Carbon	120	R/ton	National Treasury (2013)	
Carbon sequestration sub-model equations				
Description	**Formula/value**	**Unit**	**Reference**	**Comment**
Carbon Sequestration Prosopis	*Prosopis* biomass**Prosopis spp* clearance*Net Oven Dry Mass Conversion ratio Prosopis*"CO2:Carbon Ration"	Ton/year	Own calculation	
Carbon sequestered and stored from *Prosopis* re-invasion	"CO2:Carbon Ratio"*"*Prosopis* biomass (re-growth)"*"*Prosopis* re-growth"*Net Oven Dry Mass Conversion ratio Prosopis Units: Ton/year	Ton/year	Own calculation	
Net Carbon Stock removed	(Carbon sequestered stored and removed-"Carbon sequestered and store from *Prosopis* re-invasion")*A factor correcting for net carbon stock removed	Ton/year	Own calculation	
Net Carbon stock economic value loss	Net Carbon Stock removed*Unit price of Carbon	R/year	Own calculation	
Water consumption sub-model parameters				
Description	**Formula/value**	**Unit**	**Reference**	**Comment**
Water reduction per ha *Prosopis spp*	1203.7	m^3/ha	Le Maitre et al. (2015)	An estimate for the whole country
Unit value of water	2	R/m^3	Consultation with anonymous farmers and experts	Conservative estimate for the Orange river irrigation water
Water consumption sub-model equations				
Description	**Formula/value**	**Unit**	**Reference**	**Comment**

Water use by Prosopis	*Prosopis spp* clearance*Water reduction per ha Prosopis	m^3/year	Own calculation	
Economic value of water saved due to *Prosopis* clearance	Unit value of water*Water use by Prosopis	R/year	Own calculation	
NPV sub-model parameters				
Description	**Formula/value**	**Unit**	**Reference**	**Comment**
Time conversion factor	1	year	Policy variable	
Conversion factor	1	Dmnl	Policy variable	
Discount rate	0.06	Dmnl	Policy variable	Based on National Treasury rates
Year of cost	Lookup	Dmnl	Policy variable	
NPV sub-model equations				
Description	**Formula/value**	**Unit**	**Reference**	**Comment**
Discounting factor	((Conversion factor + Discount rate)^Year of Cost((Time/Time conversion factor)))	Dmnl	Own calculation	
Net Economic Value from Clearing *Prosopis* and Land use planning	(Economic value of water saved due to *Prosopis* clearance + ((Net revenue Citrus + Net Revenue Raisins + Net Revenue Table grapes)/TIME STEP)) - (Total clearing cost + Net Carbon stock economic value loss + Total Establishment cost)	R/year	Own calculation	
NPV Rate	Net Present Value Land Use Planning * 1	R/year	Own calculation	
Net Present Value Land Use Planning	Discounting factor*Net Economic Value from Clearing *Prosopis* and Land use planning	R/year	Own calculation	

"Cumulative NPV Clearing *Prosopis* & Land Use Planning"	INTEG(NPV Rate)	R	Own calculation	

PART C: Model validation

The PROLAND-model was tested through a triple-pronged validation process consisting of i) model debugging, ii) model verification, and iii) model validation. During the model debugging stage, all errors were traced and corrected in order to prevent the PROLAND-model from failing to simulate the various scenarios properly. Among the bugs traced and rectified were unit errors, negative stocks and floating point overflows. During the model verification stage, the model parameters were checked for any noticeable faults based on Forrester and Senge (1980), and these were addressed accordingly after having checked for unit consistency and numerical accuracy based on Sterman (2000). Lastly, the model underwent the model validation process. According to Sterman (2000), the model validation process is imperative in order to increase the confidence in developed model *inter alia* the robustness of the results emanating from simulation of various scenarios. The model validation stage was two-pronged consisting, firstly, of direct structural tests to assess the validity of the model structure in comparison with the reference mode based on prior knowledge of the real world system being modelled. Secondly, the model underwent the extreme condition testing which subjected the model to extreme policies, shocks and parameters as recommended by Sterman (2000). The extreme condition tests conducted for the purposes of this study are shown in Figure A3.11 below, thereby confirming the validity of the PROLAND-model

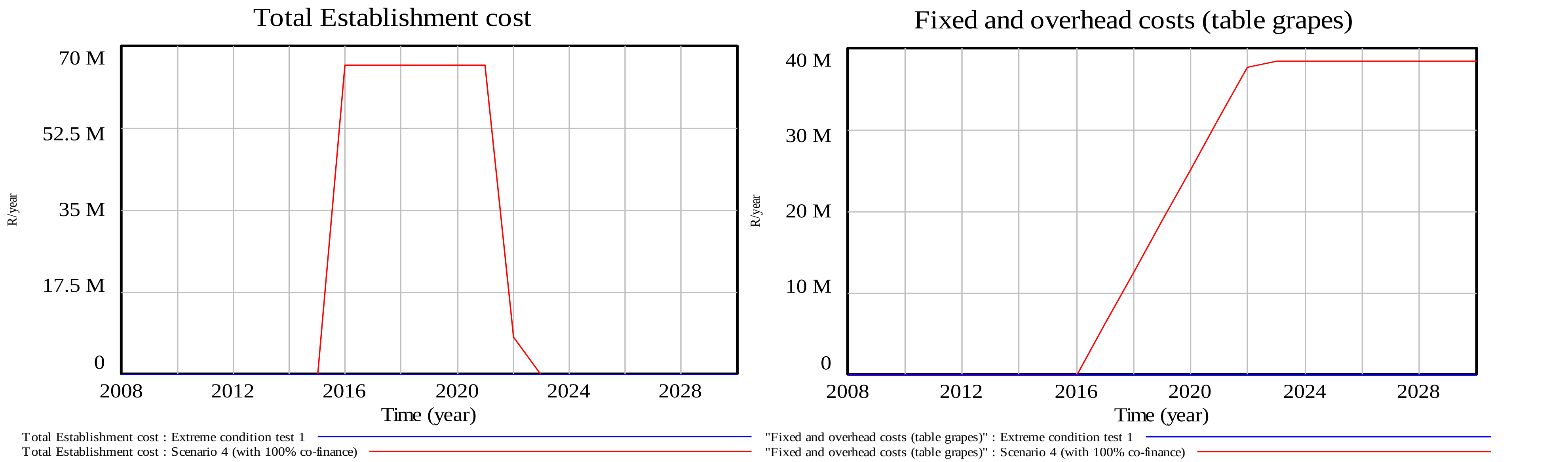

FIGURE A3. 11: EXTREME CONDITION TESTS FOR THE PROLAND-MODEL

Source: Own analysis

Chapter 4

The opportunity cost of unrestored land cleared from invasive alien plant species in the Western Cape province, South Africa: A system dynamics modelling approach

Abstract

Invasive alien plants species (IAPs) are one of the major causes of environmental degradation in the Western Cape, South Africa. IAP clearing activities have been implemented and funded largely by the government through the Working for Water programme under the auspices of the Department of Environmental Affairs' Natural Resource Management directorates (DEA:NRM). Using a system dynamics modelling approach, this study estimates the opportunity cost of not using the cleared biomass to produce value-added products (VAPs) and restoring the cleared land to various productive agricultural land use options under five broad management scenarios. We find that the estimated opportunity cost of unrestored cleared land and the failure to utilise IAPs to produce VAPs is high under certain management scenarios; 2b low co-finance (ZAR 7,9 billion (US$[8] 518,2 million)), 3b medium co-finance (ZAR 8 billion (US$525 million)) and 4b high co-finance (ZAR 8,4 billion (US$ 546,4 million)) in which the private sector co-finance, manufacture of VAPs and restoration of cleared land to productive agricultural land use options begins at the onset of the model simulation. However it was low under management scenarios 1 no co-finance (-ZAR 1,5 billion (-US$ 97.4 million)), 2a low co finance (-ZAR 1,7 billion (-US$ 113,3 million)), 3a high co-finance (-ZAR1,5 billion (-US$ 98,9 million)) in which the private sector co-finance, manufacture of VAPs and restoration of cleared land to productive agricultural land use options was assumed to only begin in the year 2016, whilst that of baseline scenario 5 was zero. A major outcome is that positive estimated NPV values are only realised under scenarios 2b low co-finance (ZAR1,2 billion (US$81,6 million)), 3b medium co-finance (ZAR 923,1 million (US$60,3 million)) and 4b high co-finance (ZAR 19,1 million (US$ 1,2 million)) compared to the negative NPV values under scenarios 1 no co-finance (-ZAR 686,5 million (-US$44,8 million)), 2a low co-finance (-ZAR 780,7 million (-US$ 51 million)), 3a medium co-finance (-ZAR 910,8 million (-US$ 59,5 million)), 4a high co-finance (-ZAR 868,4 million (-US$ 56,7 million)) and the baseline (-ZAR 105,1 million (-US$ 6,9 million)). This study concludes by pointing to the fact that early private sector co-finance, production of VAPs and restoration of cleared land to productive agricultural land use options is a better management option than waiting until the land is severely degraded.

4.1 Introduction

Invasive alien plants (IAPs) are one of the major causes of environmental degradation in the fynbos biome of the Western Cape province, South Africa (Richardson & Van Wilgen, 2004; Gaertner et al., 2011; Mudavanhu et al., 2016; Mudavanhu et al., 2017a, 2017b). IAPs inflict multiple negative effects on natural capital, including a decrease in biodiversity, excessive water consumption (Le Maitre et al., 2013; Shackleton et al., 2014), increase in fire hazards, allelopathic effects and streamflow reduction. These negative impacts do not only affect natural capital, but also pose significant threats to agricultural-societal livelihoods through a reduction in the land use capability induced by decreased

[8] ZAR:US$ exchange rate: 2016= ZAR 15,32 is used for all monetary values in this document except for figures quoted from DEA:NRM (2017) (NB All ZAR and US$ figures are rounded off to 1 decimal place).

grazing potential (Garcia-Llorente et al., 2008), decreased availability of arable land and allelopathic effects (Tererai, 2012; Mudavanhu et al., 2017a) that may potentially inhibit the growth of other plant organisms such as agricultural crops. In addition, IAPs also have an indirect negative effect on the economy due to a potential decrease in the gross domestic product (GDP) as a result of the decline in the land use capacity of agricultural land.

In order to counter these negative impacts, the South African government (herein referred to as the government) initiated the Working for Water programme (WfW) in 1995 supported by the late former Minister of Water Affairs (i.e. Mr Kader Asmal) and a team of scientists (Van Wilgen et al., 1997). The WfW programme has been implemented across all the nine South African provinces under the auspices of the Department of Environmental Affairs' Natural Resource Management (DEA:NRM) directorates to fund the clearing of IAPs (Van Wilgen et al., 2012). In addition, as part of the Expanded Public Works Programme (EPWP), the WfW programme has been used as an instrument to alleviated poverty through employment of unskilled people in previously disadvantaged communities (De Wit et al., 2001; Hobbs, 2004; Turpie, 2008; Nkambule et al., 2017). This has been achieved through the use of labour and capital intensive IAP clearing methods, mainly mechanical and chemical clearing (WfW, 2000). According to DEA:NRM (2017), Working for Water spends (i) R572 million (US$[9] 41,3 million) per annum for the mechanical and chemical control of terrestrial IAPs, (ii) R60 million (US$ 4,3 million) per annum for high altitude mechanical and chemical control of IAPs, (iii) R18 million (US$ 1,3 million) per annum for the manual and chemical control of aquatic IAPs, (iv) R37 million (US$ 2,7 million) per annum for biological control of terrestrial and aquatic IAPs, (v) ZAR 22 million (US$ 1,6 million) for the control of emerging IAPs and (iv) ZAR 157 million (US$ 11,3 million) to support value-added industries. As a result, the WfW programme has been reported as one of the most effective and efficient policy instruments by the government to alleviate poverty (WfW, 2000; Nkambule et al., 2016) and conceivably the world's most successful integrated environmental management program (Hobbs, 2004).

IAPs, however, also offer benefits such as carbon sequestration and a source of raw material for various value-added products (VAPs) such as firewood, charcoal, briquettes, timber, wood chips, bioelectricity and wood polymer composites (Mudavanhu et al., 2016;Vundla et al., 2016; Mudavanhu et al., 2017a, 2017b; Stafford et al., 2017). In addition, in the aftermath of clearing IAPs lies the potential of restoring the cleared land to productive agricultural land use options (Mudavanhu et al., 2017c). Given the fact that the clearing of IAPs is funded mainly by the government, there is the potential to set up value-added industries that use IAPs biomass to make VAPs and restore the cleared land to productive agricultural land use options which will act as an incentive to a private sector co-finance to fight the battle against IAPs in the Western Cape province, South Africa.

This study seeks to assess the opportunity cost of unrestored land cleared from IAPs, focussing on two sites in the Western Cape province, South Africa. In addition, an integrated (i.e. both private and externality) assessment of costs and benefits of clearing IAPs, restoring the cleared land to productive agricultural land use options and transforming the cleared biomass into VAPs is also undertaken. This is imperative to assess whether or not the benefits of the aforementioned outweigh the costs, to assist decision-makers in making informed decisions. The agricultural land use options considered in this study are citrus (i.e. Eureka lemons), table grapes and pome fruit (apples and pears). The value-added products considered are timber, firewood, briquettes, wood chips and charcoal. The analysis in this study is also done to investigate the feasibility of whether or not clearing IAPs, restoring the cleared land to agricultural land use options and setting up value-added industries has the potential to incentivise a private sector co-finance to assist in the clearing of IAPs. Last but not least, the study seeks to show the complexity associated with clearing IAPs, restoring the cleared land to productive agricultural land use options and transforming the cleared biomass into VAPs. This is of paramount importance as it helps relevant stakeholders to take cognisance of issues beyond the comprehension of our mental

[9] ZAR:US$ exchange rate: 2017=ZAR 13,86 (NB. All US$ figures are rounded off to 1 decimal place and the 2017 exchange rate is only used in this instance for monetary values adapted from DEA:NRM (2017)).

models (i.e. perceptions based on human thinking). This will in turn assist decision-makers and all relevant stakeholders to make robust and informed decisions.

4.2 Materials and methods

4.2.1 Study sites and scope of analysis

We focussed our study on two sites in the Western Cape province of South Africa, namely the Berg River quaternary catchment plots ($G10_{A\text{-}J}$) in the Berg River water management area and Citrusdal quaternary catchments plot ($E10_{F}$) in the Olifants River water management area (see Figure 4.1). All the study sites fall within the Fynbos biome and experience a Mediterranean climate, characterised by winter rainfall and hot and dry summers (Mucina & Rutherford, 2006). The major IAPs invading the Berg River quaternary catchment plots are *Pinus* species, *Eucalyptus* species, *Acacia cyclops*, *Acacia Saligna* and Wattle species (mainly *Acacia mearnsii*) (Kotze et al., 2010). According to Kotze et al. (2010), approximately 4 883 condensed hectares are invaded by *Pinus* species, 1 641 condensed hectares by *Eucalyptus* species, 890 condensed hectares by *Acacia cyclops*, 850 condensed hectares by *Acacia saligna* and lastly 376 condensed hectares by Wattle species (mainly *Acacia mearnsii*). As for the Citrusdal quaternary catchment plot, the major IAPs are *Acacia saligna* (500 condensed hectares), *Eucalyptus* species (304 condensed hectares), *Acacia mearnsii* (270 condensed hectares), *Sesbania punicea* (93 condensed hectares) and *Arundo Donax* (86 condensed hectares) (Kotze et al., 2010; DEA:NRM, 2017).

For the purposes of this study, it is assumed that the IAPs biomass cleared from these sites will be used as raw materials in the manufacture of VAPs namely timber, firewood, wood chips, briquettes and charcoal. These VAPs were selected due to the availability of estimated production cost and price data and their production feasibility potential as reported in a consultancy report by Cohen et al. (2015) on the feasibility of using IAPs biomass from the Berg River quaternary catchment to make various VAPs. In addition, the cleared land within the Citrusdal quaternary catchment will be restored to citrus agriculture while that of the Berg River quaternary catchment will be restored to table grapes and pome fruit land use options in equal areas. These agricultural land use options were selected since they are amongst the major agricultural enterprises practiced within the study sites based on agricultural expert consultations. Moreover, the land use capability of the land and local climate in the aforementioned study sites is highly suitable for the aforementioned agricultural land use options.

FIGURE 4. 1: LOCATION MAP FOR THE STUDY SITES

Source: Own adaptation

4.2.2 Data collection

The data used for the purposes of this study was collected from the DEA:NRM's central database and includes clearing cost data, person days worked, the invasion densities and the hectares cleared over time. In addition, the data on the areas invaded by the different IAPs was extracted from the national invasive alien plant survey conducted by Kotze et al. (2010). Supplementary data used for the model building purposes was derived through focus group discussions with invasion biology experts from the University of Stellenbosch's Centre for Invasion Biology (CIB) and experts from the Centre for Scientific and Industrial Research (CSIR), Department of Environmental Affairs (DEA) personnel and the IAPs clearing implementing agents at the respective study sites. Extensive literature surveys were also done to obtain published data considered useful for the purposes of this study (e.g. Thomas and Martin, 2012; Le Maitre et al, 2013; Van Wilgen and Le Maitre;, 2013; Mugido et al., 2014; Cohen et al, 2015). Lastly, personal site visits were conducted in order to verify whether or not the species mapped by Kotze et al. (2010) and DEA:NRM (2017) corresponded to what was on the ground, a process that we call a "ground truthing exercise".

4.2.3 The system dynamics model (i.e. BERGCITRUS land use planning & VAPs-model)

In order to conduct the analysis, a system dynamics model (i.e. BERGCITRUS land use planning & VAPs-model) was built using the Vensim® PLP software. System dynamics is defined as "that branch of control theory which deals with socio-economic systems and that branch of management science which deals with problems of controllability" (Coyle, 1977:2). In addition, Ford (2009) describes system dynamics modelling as a methodological approach that is normally used when the subject under study is characterised by non-static and non-linear complex systems that change over time. The management option of clearing IAPs, using the biomass to make VAPs and restoring the cleared land to productive agricultural land use options is often marred by high complexity due to the hidden causal-effect relationships and feedback loops that are often overlooked (i.e. we do not have mental models). As a result the system dynamics modelling approach was deemed to be the most suitable analytical tool due to its versatility with regards to research problems that are non-linear in nature and marred by complexities.

4.2.3.1 Causal loop diagram (CLD)

The causal loop diagram (i.e. the qualitative system dynamics model) shown below in Figure 2 depicts the complex system being modelled. The detailed causal-effect relationships and the feedback mechanisms involved in the problem under investigation in this study are clearly illustrated in a way that would be otherwise difficult using our mental models. There are six feedback loops emanating from the qualitative system dynamics model in Figure 2. Out of the six feedback loops, four are positive (i.e. reinforcing) feedback loops (i.e. R1, R2, R3 and R4) and two are balancing feedback loops (i.e. B1 and B2). The first reinforcing loop depicted in Figure 2 (i.e. R1) shows that the IAPs spread rate causes the IAPs density to increase, while the IAPs density causes a corresponding increase in the IAPs spread rate. As shown in Figure 2, the polarity of the arrows in the R1 loop are all positive, hence the feedback loop is positive (or reinforcing) in a clockwise direction. The second reinforcing loop (i.e. R2) depicted in Figure 2 shows that the investment in IAPs clearing causes an increase in the area cleared of IAPs, which in turn increases the amount of usable IAPs biomass which leads to more potential for the manufacture of value-added products (i.e. pulp, firewood, wood chips, charcoal, timber and other VAPs). The value-added products made from IAPs biomass will lead to an increase in the income earned from value-added product sales which will in turn lead to an increase in the investment in IAPs clearing. All the polarity signs in this loop are positive and thus it is a positive (i.e. reinforcing) loop in a clockwise direction. The third positive (i.e. reinforcing) loop (i.e. R3) shows that the investment in IAPs clearing causes an increase in the area cleared of IAPs, which in turn increases the land use capability of the cleared land, which then leads to an increase in land available for restoration to various productive agricultural land use options. This then leads to an increase in income earned from productive agricultural land uses which finally leads to an increase in the investment of IAPs clearing. Last but not least, the forth positive (i.e. reinforcing) loop (i.e. R4) follows the same sequence as the R2 loop, except that in R4 the income from IAPs potentially incentivises the illegal planting of IAPs resulting in an increase in the IAPs density which triggers an increase in the required investment in IAPs clearing activities.

As for the negative (i.e. balancing) feedback loops, the first balancing loop (i.e. B1) shows that the IAPs density causes an increase in the investment in clearing of IAPs, while the investment in the clearing of IAPs causes the density of IAPs to decrease. This loop consists of one negative polarity (an odd number of polarities), hence it is a negative feedback (i.e. balancing) loop in clockwise direction. The second balancing loop (i.e. B2) shows that ecosystem disturbances cause a decrease in the functioning of ecosystems, while ecosystem functioning causes an improvement in natural capital stocks and flows. This loop has three negative polarities (i.e. an odd number of polarities) and is balancing loop. In addition the availability of natural capital stocks and flows causes a negative effect on the sustainable use of natural capital while the sustainable use of natural capital leads to less ecosystem disturbances. Given the aforementioned, the causal loop diagram presented in Figure 4.2 shows a more reinforcing system as evidenced by the domination of four positive feedback loops (versus only two balancing loops).

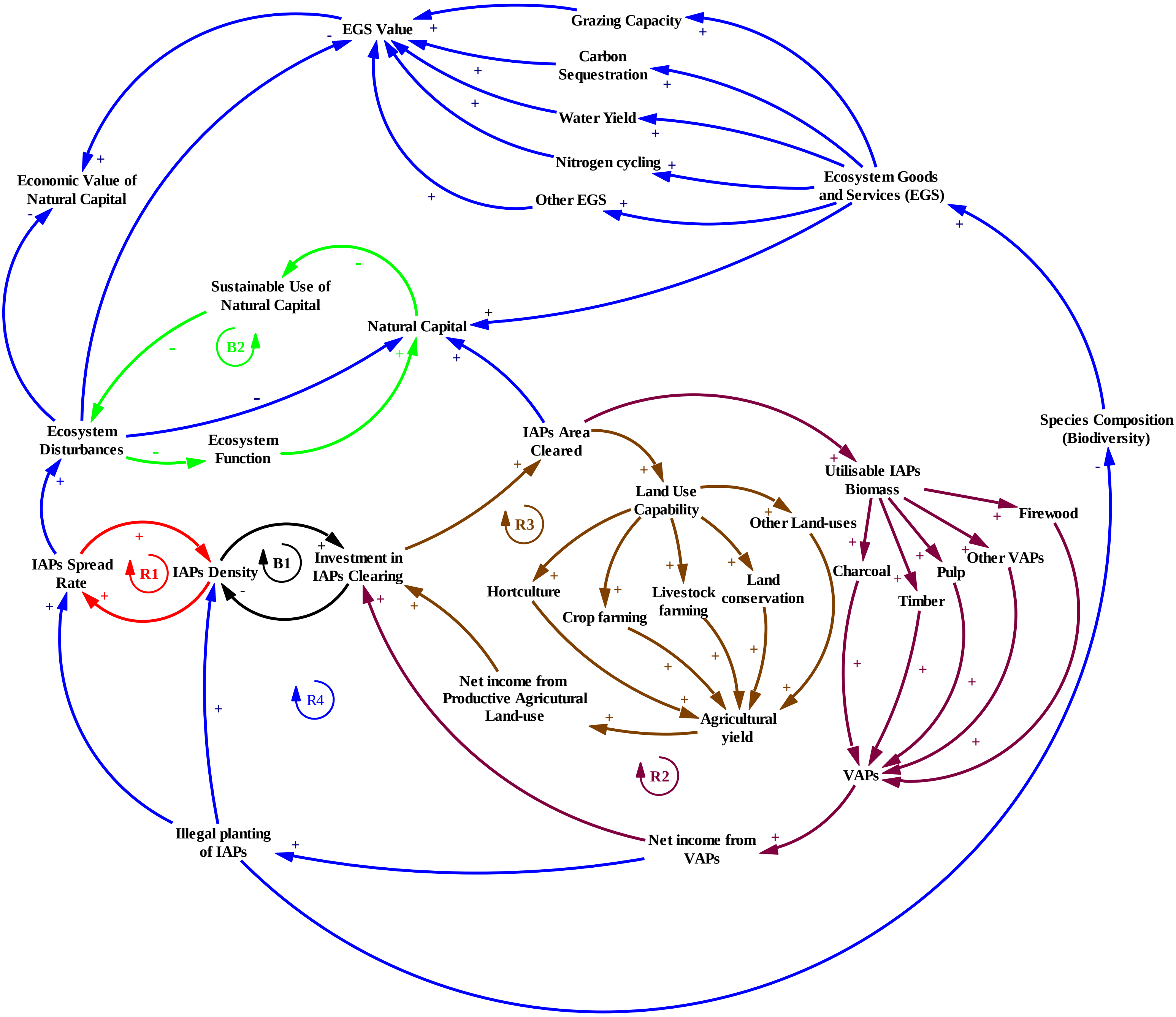

FIGURE 4. 2: THE BERGCITRUS LAND USE PLANNING & VAPS CAUSAL LOOP DIAGRAM

Source: Own adaptation

4.2.3.2 BERGCITRUS land use planning & VAPs sub-models

The BERGCITRUS land use planning & VAPs-model consists of nine sub-models (see Annexure 1), namely:

- IAPs invaded area sub-model (Annexure 4.1A)
- VAPs sub-model (Annexure 4.1B)
- Agricultural land use options sub-model (Annexure 4.1C)
- Agricultural yield growth factor sub-model (Annexure 4.1D)
- Water savings sub-model (Annexure 4.1E)
- Carbon sequestration sub-model (Annexure 4.1F)
- IAPs clearing and agricultural land use establishment cost sub-model (Annexure 4.1G)
- Agricultural land use enterprise sub-model (Annexure 4.1H)
- Net present value sub-model (Annexure 4.1I)

The time period of the simulation runs from 2008 to 2030, with 2008 being the base year due to the fact that the available baseline data for the distribution and spread of IAPs was mapped in 2008 and eventually published in the national invasive alien plant survey report in 2010 (Kotze et al., 2010). The model parameters and equations used in the sub-models are available from the authors on request.

4.2.3.3 Model scenarios

Five main scenarios were developed for the purposes of this study with three having an "a" and a "b" part to investigate the presence of any uncertainties that might arise from the envisaged output from the model simulation and the respective policy implications. In the first scenario (i.e. no co-finance), it is assumed that all clearing is funded through the DEA:NRM's budget with no funding from the private sector. Then in the second scenario (low co-finance), it is assumed that all clearing operations are funded by the DEA:NRM's budget and a 20% co-finance from the private sector. The third (moderate co-finance) and fourth (high co-finance) scenarios are the same as the second scenario, except that the co-finance from the private sector is 50% for the third and 100% for the forth. Lastly, the fifth scenario (baseline) assumes clearing operations are done from the initial time (i.e. 2008) until 2015, after which all clearing activities cease until the end of the model simulation (i.e. 2030). These scenarios are presented in Table 4.1 below.

TABLE 4. 1: MODEL SCENARIOS CONSIDERED

Scenario	Description
1 No co-finance	Clearing activities commence in 2008 and end in 2015. Thereafter the clearing activities are continued at 2015-levels from 2016 until the end of the simulation. The manufacture of VAPs and restoration of cleared land to productive agricultural land uses begins from 2016 onward. In addition, all clearing activities are funded by the government alone through the DEA:NRM's budget.
2a Low co-finance	Same as scenario 1, except that there is a 20% co-finance from the private sector starting from 2016 onwards.
2b Low co-finance+	Same as scenario 1, except that the manufacture of VAPs and restoration to productive agricultural land use options begins from the year 2008 onwards. In addition, the 20% co-finance starts in 2008 onwards.
3a Medium co-finance	Same as scenario 1, except that there is a 50% co-finance from the private sector starting from 2016 onwards.
3b Medium co-finance+	Same as scenario 3(a), except that the manufacture of VAPs and restoration to productive agricultural land use options begins from the year 2008 onwards. In addition, the 50% co-finance starts in 2008 onwards.
4a High co-finance	Same as scenario 1, except that there is a 100% co-finance from the private sector starting from 2016 onwards.
4b High co-finance+	Same as scenario 4(a), except that the manufacture of VAPs and restoration to productive agricultural land use options begins from the year 2008 onwards. In addition, the 100% co-finance starts in 2008 onwards.
5 Baseline scenario (Do nothing)	Clearing activities are done from 2008 to 2015 and thereafter all clearing activities cease. In addition, all the clearing activities are funded by the government alone through the DEA:NRM's budget with no co-finance from the private sector.

Source: Own Adaptation

4.2.3.4 Model verification and validation

According to Forrester and Senge (1980), model verification and validation is a continuous process of activities that seeks to test and establish confidence in a system dynamics model throughout the entire model building process. As a result, the BERGCITRUS land use planning & VAPs-model underwent tests for internal structure validity, behaviour validity and model debugging. The tests are imperative to ensure confidence in the model structure before running the simulation. Based on Pruyt (2013), the model debugging process was done to inspect the model for any errors in order to allow the model simulation process to run adequately without any technical glitches. The BERGCITRUS land use planning & VAPs-model was found to be free of any errors.

The structural and behaviour verification test was also conducted to establish the correctness of the internal structure of the BERGCITRUS land use planning & VAPs-model. This is a four-pronged test consisting of structure verification, dimension consistency, parameter verification and the extreme condition tests (Forrester & Senge, 1980; Sterman, 2000; Zebda, 2002).The structural verification test was done through a comparison between the model structure and the real world system, as reported in the reference literature. The BERGCITRUS land use planning & VAPs-model was found to be consistent with trends observed in the real world system. In order to check for unit uniformity for all the model equations used in the BERGCITRUS land use planning & VAPs-model simulation, the dimensional consistency test was conducted. All units and equations were assessed and confirmed to be dimensionally consistent and correct. In addition, the parameter verification test was conducted to inspect if the BERGCITRUS land use planning & VAPs-model's conceptual and numerical analysis of constants was consistent with that of the real world system. This was achieved by using data parameter values obtained from existing knowledge of the real world system and available quantitative data on IAPs, VAPs and productive agricultural land use options. Finally, the extreme condition test was conducted through assigning extreme values to selected parameters in the model to ascertain the behaviour of the BERGCITRUS land use planning & VAPs-model against the real world system. The model output for this test on the clearance of *Acacia Saligna* is presented in Figure 4.3.

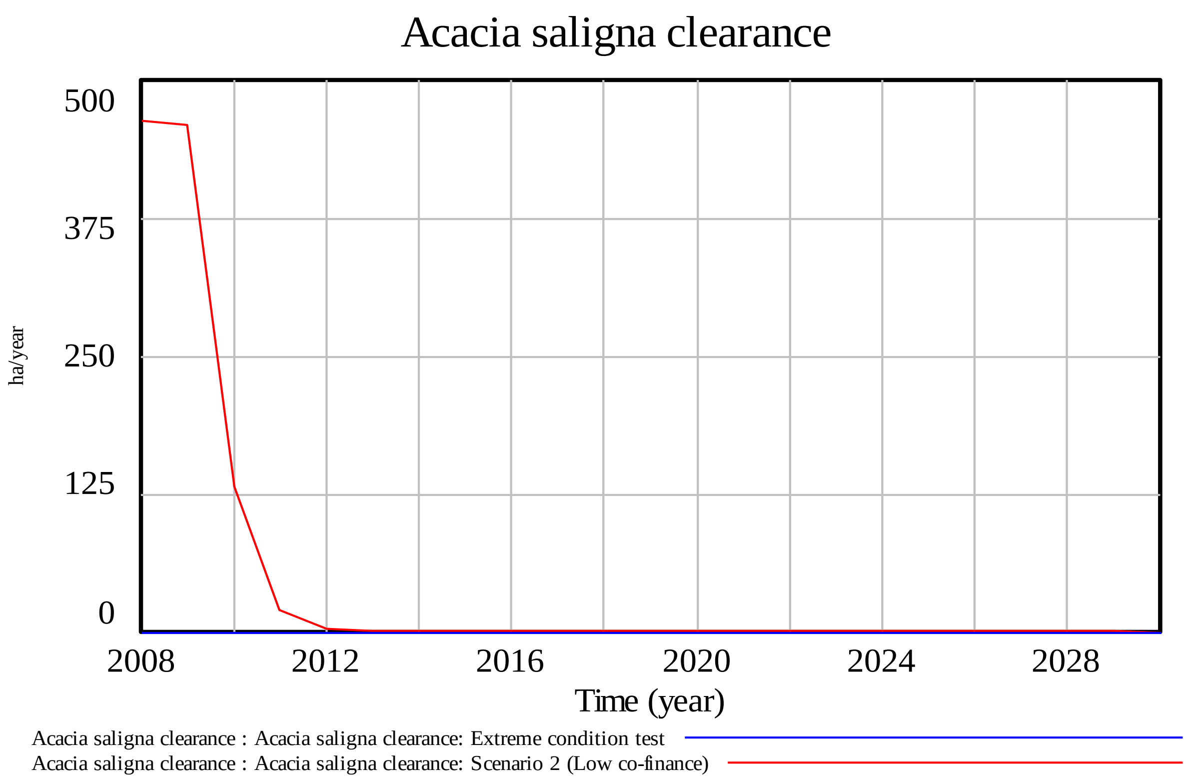

FIGURE 4. 3: MODEL BEHAVIOUR UNDER THE EXTREME CONDITION TEST

4.3 Results and discussion

4.3.1 Total cumulative area cleared

The simulation results from the BERGCITRUS land use planning & VAPs-model show that the cumulative area cleared from IAPs ranged between approximately 6.8 thousand hectares and 10.1 thousand hectares for scenarios considered in this study (see Table 4.2). Under scenario 1, the cumulative area cleared amounted to approximately 8.8 thousand hectares over the whole simulation period (2008–2030). As for scenario 2a and 2b, the total cumulative area cleared was approximately 9 thousand hectares and 6.2 thousand hectares, respectively. In the case of scenarios 3a and 3b, approximately 9.1 thousand hectares and 7.3 thousand hectares were cleared while approximately 8.8 thousand hectares and 10.1 thousand hectares were cleared for scenarios 4a and 4b, respectively. Finally, approximately 6.8 thousand hectares were cleared under scenario 5 (i.e. the baseline) over the whole simulation period. Given the aforementioned simulation results, the largest cumulative area cleared is achieved under the high co-finance scenario where the private sector co-finance is assumed to have commenced at the beginning of the model simulation. The smallest cumulative area cleared is achieved under the baseline scenario (i.e. scenario 5).

4.3.2 Total cumulative public clearing costs

The model simulation conducted shows that the cumulative public clearing costs incurred by the government to clear IAPs ranged between ZAR58,4 million (US$3,8 million) and ZAR91,3 million (US$6 million) approximately for the scenarios considered (see Table 4.2). For all the scenarios the public clearing cost was the same (i.e. ZAR91,3 million (US$6 million)) except for scenario 5 (i.e. the baseline) which incurred approximately R58,4 million (US$3,8 million). The reason for this disparity is because of the assumption considered in scenario 5 that all clearing activities end in the year 2015.

4.3.3 Total cumulative private clearing and agricultural establishment costs

The total cumulative private clearing and agricultural establishment costs ranged between R6 million (US$0,4 million) and R540,1 million (US$35,3 million) approximately for the scenarios considered in this study (see Table 4.2). Under scenario 1 the total private clearing and agricultural establishment costs amounted to approximately R449 million (US$29,3 million). As for scenarios 2a and 2b, these costs were approximately R526,9 million (US$ 34,4 million) and R58,8 million (US$3,8 million), respectively. Under scenario 3a and 3b, the total cumulative private clearing and agricultural establishment costs were approximately R540,1 million (US$35,3 million) and R96,3 million (US$6,3 million), respectively; for scenarios 4a and 4b, the costs amounted to approximately R491,1 million (US$32,1 million) and R6 million (US$0,4 million), respectively. In addition, there were no private clearing and agricultural establishment costs incurred under scenario 5 due to the absence of the co-finance option and restoration of cleared land to productive agricultural land use options. It is clear that the private clearing costs and agricultural establishment costs are much higher when there is a delay in the private sector co-finance and the restoration of the cleared land to productive agricultural land use options. This can potentially be attributed to the fact that in scenarios 1, 2a, 3a and 4a where the co-finance and restoration of cleared land to agricultural land use options happened from 2016 onwards, the clearing budget of the government was not adequate enough to battle the spread of IAPs. As a result the area under invasion remained relatively high in contrast to what potentially happens had the co-finance option, manufacture of VAPs and restoration to productive agricultural land uses (i.e. scenarios 2b, 3b and 4b) commenced at the beginning of the model simulation in 2008. These results clearly show had the co-finance and restoration of cleared land started in 2008, the area invaded by IAPs would have been limited and quickly brought under control due to an adequate budget to control the IAPs. In addition, the reclamation of invaded land through restoration to productive agricultural land use options reduces the risk of re-invasion and further spread of IAPs.

4.3.4 Total cumulative externality costs

Despite the society-wide negative impacts caused by IAPs, they also have a beneficial effect on society. IAPs sequester carbon through the biological process of photosynthesis which in turn reduces the concentration of greenhouse gas emissions within the atmosphere that are responsible for climate change and global warming. Carbon sequestration potential is lost due to the clearing of IAPs. Based on the model simulation results, the cost of carbon sequestered and stored forgone (herein referred to as the externality costs) by IAPs ranged between approximately R85 million (US$5,5 million) and R400,8 million (US$26,2 million) (see Table 4.2). Under scenario 1 the total externality cost of the carbon sequestration potential lost amounted to approximately R114,8 million (US$7,5 million). As for scenarios 2a and 2b, the total cumulative externality costs amounted to approximately R120, 9 million (US$7,9 million) and R118,9 million (US$7,8 million), respectively. Under scenarios 3a and 3b, the cumulative externality costs amounted to approximately R125,5 million (US$8,2 million) and R197,6 million (US$12,9 million), respectively. As for scenarios 4a and 4b, the total cumulative externality cost amounted to approximately R129,9 million (US$8,5 million) and R400,8 million (US$26,2 million). Lastly, the total cumulative externality cost for scenario 5 was approximately R85 million (US$5,5 million). Based on these model simulation results, more externality costs are incurred under scenarios with a co-finance option (i.e. scenarios 2a&b, 3a&b and 4a&b). This can be attributed to fact that more funding becomes available to invest in clearing operations due to private sector co-finance which augments the government clearing budget, and thus more IAPs can be cleared. As a result more carbon sequestration potential is lost due to the more intensified clearing operations under a combined government and private sector IAP clearing budget.

4.3.5 Total cumulative net agricultural financial value

The cumulative net agricultural financial value emanating from restoring the cleared land to productive agricultural land use options ranges between -R1,4 billion (-US$89,3 million) and R8,4 billion (US$548,1 million) over the simulation period considered in this study (see Table 4.2). Under scenario 1 the cumulative net agricultural financial values amounted to approximately -R1 billion (-US$68,2 million) while in scenarios 2a and 2b it amounted to approximately -R1,2 billion (-US$79,2 million) and R7,8 billion (US$514,4 million), respectively. As for scenarios 3a and 3b, the net agricultural financial value amounted to approximately -R1.4 billion (-US$89,3 million) and R8,1 billion (US$526 million) while for scenarios 4a and 4b it was approximated to be -R996,6 million (-US$65 million) and R8,4 billion (US$548,1 million), respectively. However, for scenario 5 (i.e. the baseline), the net agricultural financial value amounted to zero due to the assumption that no cleared land is restored to productive agricultural land use options. Given these results it is clear that in scenarios were restoration to productive land use options occurs only from 2016 onwards, negative net agricultural financial values are recorded (i.e. scenarios 1, 2a, 3a and 4b). This is in stark contrast to the positive net agricultural financial values realised in scenarios 2b, 3b and 4b where it is assumed that the land cleared from IAPs is restored immediately to productive agricultural land use options. In short, what this means is that there is an opportunity cost incurred due to the failure of reclaiming land that was previously invaded and converting it to productive agricultural land use options from the onset of clearing activities. Income that would have been earned from productive agricultural land uses from the onset of the model simulation is forgone resulting in net agricultural financial loses being incurred in scenarios (i.e. 1, 2a, 3a and 4a) where the restoration to productive agricultural land use options only commences in 2016.

4.3.6 Total cumulative net VAPs financial value

The cumulative net VAPs financial value ranges between approximately R59 million (US$3,9 million) and R309 million (US$20,2 million) (see Table 4.2). In scenario 1, the cumulative net VAPs value amounted to R59 million (US$3,9 million) approximately while for scenarios 2a and 2b it amounted to approximately R68,4 million (US$4,5 million) and R184,1 million (US$12 million), respectively. As for scenarios 3a and 3b, the value was approximated to be R68,9 million (US$4,5 million) and R219,5 million (US$14,3 million) while for scenarios 4a and 4b it was approximately R60,8 million (US$4 million) and R309 million (US$20,2 million), respectively. In the case of scenario 5, the value was zero due to the assumption that no VAPs are manufactured. Given these simulation results it is quite clear that in the scenarios (i.e. 2b, 3b and 4b) where it is assumed that VAPs are manufactured from the onset of the model simulation, higher net VAP financial values are observed. However, in scenarios (i.e. 1, 2a, 3a and 4a) where the VAP manufacture begins only in the year 2016, lower net VAP financial values are realised. Similar to the results shown in section 3.5, there is also an opportunity cost incurred as a result of not using the cleared IAP biomass for the manufacture of VAPs.

4.3.7 Total cumulative externality benefits value

As a result of clearing IAPs, water is saved (herein referred to as the externality benefit) due to evapotranspiration losses avoided. Therefore, more water becomes available for other competing downstream water uses such as agriculture, urban water uses and mining within the Berg River and Citrusdal water catchment areas. The total cumulative externality benefit value ranges between approximately R15,7 million (US$1 million) and R35,9 million (US$2,3 million) (see Table 4.2). Under scenario 1 the total cumulative externality benefit value was approximately R20,4 million (US$1,3 million) while for scenarios 2a and 2b it was approximately R21,2 million (US$1,4 million) and R16,2 million (US$1,1 million), respectively. As for scenarios 3a and 3b, the value was approximately R21,4 million (US$1,4 million) and 21,7 million (US$1,4 million), respectively, while it was approximately R21,1million (US$1,4 million) and R35,9 million (US$2,3 million) for scenarios 4a and 4b. In the case of scenario 5, the total cumulative externality benefit amounted to approximately R15,7 million (US$1 million). The results show that the greatest externality benefit is realised under the high co-finance options (i.e. scenarios 4a & 4b) followed by the medium co-finance options (i.e. scenario 3a & 3b). This means that augmenting the government budget with a private sector co-finance of either 100% or 50% will lead to greater externality benefits value as compared to cases where only the government budget is used or in a 20% private sector co-finance option. In addition, abandoning the clearance of IAPs in 2016 onwards (i.e. scenario 5) yields the lowest externality benefits value which also has the potential to offset the externality benefits through more water consumption due to a potential re-invasion risk from 2016 onwards. Starting the private sector co-finance options from the onset of the model simulation yields a much greater externality benefit value as compared to when the co-finance begins only in the year 2016 onwards. These simulation results clearly show that there is an opportunity cost incurred thereof amongst the scenarios considered in this study.

4.3.8 Net cumulative economic value

The net cumulative economic value of clearing IAPs, using the cleared biomass to make VAPs and restoring the cleared land to agricultural land use options was derived by estimating the difference between the total cumulative integrated benefits (i.e. total cumulative private and externality benefits) and the total cumulative integrated costs (i.e. total cumulative private and externality benefits). The net cumulative economic value ranges between approximately -R2 billion (-US$132,8 million) and R8,2 billion (US$538,1 million) (see Table 4.2). The model simulation results show negative net cumulative values for all scenarios where the private sector co-finance starts only in 2016 (i.e. scenarios 2a, 3a and

4a) and where it is absent (i.e. scenarios 1 and 5). However, for scenarios where it assumed that the private sector co-finance commences at the onset of the model simulation, all the net cumulative economic values are positive. Therefore, the simulations results clearly show that there is an opportunity cost involved as a result of the lack of a private sector co-finance to augment the government budget within the first eight years of the 23-year simulation period considered in this study. In short this means that it is highly infeasible to clear IAPs with funding from the government alone. In addition, when the private sector co-finance starts late, net cumulative economic loses are incurred due to potential net benefits forgone in the absence of a private sector co-finance in the first eight years of the model simulation.

4.3.9 Opportunity cost of doing nothing

In order to quantify the opportunity cost of doing nothing (i.e. no manufacture of VAPs and no restoration of cleared land to productive agricultural land use options), we estimated the difference between the net cumulative economic values for all scenarios and that of scenario 5 (i.e. the baseline scenario) (see Table 4.2). As a result the opportunity cost of doing nothing ranged between approximately -R1.9 billion (-US$124,5 million) and R8.4 billion (US$546,4 million). A negative opportunity cost value is realised in all scenarios (except for 2b, 3b and 4b), suggesting a low opportunity cost for all scenarios with the exception of scenarios 2b, 3b and 4b. This means that it is less profitable and economically infeasible to clear IAPs under scenarios 1, 2a, 3a and 4a. However, for scenarios 2b, 3b and 4b the opportunity cost of doing nothing is much higher when the manufacture of VAPs, restoration of cleared land to productive agricultural land uses and the private sector co-finance begin at the onset of the model simulation. This means that it is more profitable and economically feasible to clear IAPs, use the cleared biomass to make VAPs and to restore the area cleared to productive agricultural land use options under scenarios 2b, 3b and 4b.

TABLE 4. 2: SUMMARY OF RESULTS OF THE BERGCITRUS LAND USE PLANNING AND VAPS-MODEL

	Scenario 1	Scenario 2a Scenario 2b#	Scenario 3a Scenario 3b ##	Scenario 4a Scenario 4b ###	Scenario 5
Total cumulative area cleared Ha	8 760	9 076	9 091	8 800	6 767
	-	6 208#	7 304##	10 083###	-
Total cumulative public clearing costs ZAR[US$]	91 296 150 [5 959 279]	91 296 150 [5 959 279]	91 296 150 [5 959 279]	91 296 150 [5 959 279]	58 412 540 [3 812 829]
	-	91 296 150# [5 959 279]#	91 296 150## [5 959 279]##	91 296 150### [5 959 279]###	-
Total cumulative private clearing and agricultural establishment costs ZAR[US$]	449 113 278 [29 315 488]	526 918 158 [34 394 136]	540 100 389 [35 254 595]	491 094 866 [32 055 801]	0
	-	58 843 671# [3 840 971]#	96 275 842## [6 284 324]##	5 957 970### [388 901]###	-
Total cumulative externality costs ZAR[US$]	114 846 507 [7 496 508]	120 897 599 [7 891 488]	125 543 414 [8 194 740]	129 910 963 [8 479 828]	84 953 711 [5 545 281]
	-	118 863 905# [7 758 741]#	197 648 384## [12 901 331]##	400 788 760### [26 161 146]###	-
Total cumulative net agricultural financial value ZAR[US$]	-1 044 259 086 [-68 163 126]	-1 213 540 218 [-79 212 808]	-1 368 365 881 [-89 318 922]	-996 550 907 [-65049015]	0
	-	7 880 141 298# [514 369 536]#	8 058 982 970## [526 043 275]##	8 396 241 874### [548 057 564]###	-
Total cumulative net VAPs financial value ZAR [US$]	58 995 769 [3 850 899]	68 354 850 [4 461 805]	68 937 775 [4 499 855]	60 754 223 [3 965 680]	0
	-	184 104 777# [12 017 283]#	219 451 866## [14 324 534]##	309 034 895### [20 171 991]###	-
Total cumulative externality benefits value ZAR [US$]	20 427 931 [1 333 416]	21 177 456 [1 382 340]	21 364 315 [1 394 538]	21 105 468 [1 377 642]	15 703 973 [1 025 064]
	-	16 156 151# [1 054 579]#	21 746 773## [1 419 502]##	35 897 489### [2 343 178]###	-
Net cumulative economic Value ZAR [US$]	-1 620 091 322 [-105 750 086]	-1 863 119 819 [-121 613 565]	-2 035 003 744 [-132 833 143]	-1 626 993 195 [-106 200 600]	-127 662 278 [-8 333 047]
	-	7 811 398 500# [509 882 409]#	7 914 961 235## [516 642 378]##	8 243 131 379### [538 063 406]###	-
Opportunity cost of doing nothing ZAR [US$]	-1 492 429 044 [-97 417 039]	-1 735 457 541 [-113280518]	-1 907 341 466 [-124 500 096]	-1 499 330 917 [-97 867 553]	0
	-	7 939 060 778# [518 215 455]#	8 042 623 512## [524 975 425]##	8 370 793 656### [546 396 453]###	-

Source: Own calculations

NB: All values are rounded off to the nearest 1 decimal place. #Refers to scenario 2b value, ##Refers to scenario 3b values and ### Refers to scenario 4b values. The brackets should serve as a distinction between the values for scenarios that have an "a" and a "b" part. [ ] Refers to US$ values.

4.3.10 Multivariate sensitivity analysis

In order to test for uncertainty in the economic assessment conducted in this study we undertook a multivariate sensitivity analysis (also known as Monte Carlo simulation). We deemed this important due to the uncertainty of the costs and benefits incurred as a result of clearing IAPs, using the cleared biomass for the manufacture of VAPs and restoring the cleared land to productive agricultural land use options. As a result we used the discount rate and tested the sensitivity of the NPV to a lower and higher range estimate. In order to assess the impact of the discount rate on the NPV outcomes from the model under all scenarios, a minimum (i.e. 4%) and maximum (12%) value was assigned on the discount rate while a baseline value of 6% was used in line with the cost-benefit analysis protocol of the National Treasury of South Africa. The number of simulations was set at 200 in the Vensim® PLP software and the random uniform distribution was used. The output graphs for all scenarios are illustrated in Figure 4.4 below.

The Monte Carlo sensitivity analysis shows a rather slow and gradual declining negative NPV under scenarios 1, 2a, 3a and 4a from 2008–2015 (see Figure 4), which can be attributed to the historical clearing cost budget incurred by the government to clear IAPs. From the year 2016 until the end of the model simulation, the NPV declines faster in a negative trend (with the exception of scenario 4a which shows signs of a positive trend from 2025 onwards). This can be attributed to increased costs due to the manufacture of VAPs and restoration of the cleared land to productive agricultural land use options. Moreover, despite the commencement of productive agricultural land uses and the manufacture of VAPs, not enough income is generated to cover the private and externality costs incurred, hence the negative NPV. The cumulative NPV is estimated at approximately -R686,5 million (-US$44,8 million), -R780,7 million (-US$51 million), -R910,8 million (-US$59,5 million) and -R868,4 million (-56,7 million) for scenarios 1, 2a, 3a and 4a, respectively, at the end of the model simulation. The output graphs (see Figure 4.4) for these scenarios illustrate a wide band of uncertainty on the simulated NPV outcomes, which reinforces the notion that clearing IAPs, using the biomass to make VAPs and restoring the cleared land could be highly unprofitable and infeasible under such management situations.

As for scenarios 2b, 3b and 4b, the Monte Carlo sensitivity analysis shows a rather quick declining NPV from the initial simulation period until 2015 which is mainly as the result of the combined clearing costs (i.e. both the private sector co-finance and the government budget) and the establishment and running costs incurred. This is due to the manufacture of VAPs and the restoration of the area cleared to productive land use options and low net cumulative benefits due to the total integrated cumulative benefits being outweighed by the total integrated cumulative costs. As from 2015 onwards, the NPV becomes incrementally positive ending with positive NPV values for all these scenarios. The cumulative NPV is estimated to be R1,2 billion (US$81,6 million), R923,2 million (US$60,3 million) and R19,1 million (US$1,2 million) for scenarios 2b, 3b and 4b, respectively, at the end of the model simulation. As a result, the output graphs (see Figure 4.4) for these scenarios illustrate a narrow band of uncertainty on the simulated NPV outcomes, which reinforces the notion that clearing IAPs, using the biomass to make VAPs and restoring the cleared land could be highly profitable and feasible under such management scenarios. Scenario 2b yields the best NPV, followed by scenario 3b and, lastly, scenario 4b. Only these management options should be considered (in ascending order) while the rest should be avoided by all means possible. The conventional rule in cost-benefit analysis is that all projects that yield a negative NPV should be shunned while those that yield a positive NPV should be considered starting with the one yielding the highest NPV and ending with the one yielding the lowest NPV.

As for scenario 5, the Monte Carlo sensitivity analysis shows a rather quick declining negative NPV from the initial simulation period (i.e. 2008) until 2015. It then stabilises and becomes constant right through to the end of the model simulation (see Figure 4.4). This is due to the historical clearing costs incurred during the first eight years of the model simulation. Also, this is can be attributed to the assumption that all clearing activities cease in the year 2015 and thereafter the land is abandoned without any restoration of the land cleared to productive agricultural land use options or use of the cleared biomass to manufacture VAPs. As result the NPV remains negative with a cumulative amount of approximately -R105,1 million (-US$6,9 million) being recorded at the end of the model simulation. Last but not least the output graph for this scenario illustrates a very narrow band of uncertainty on the simulated NPV, but despite the low uncertainty, this management scenario is economically infeasible and should thus be avoided by all means possible due to the high opportunity cost due in the absence of continued clearing activities, the manufacture of VAPs and the restoration of the cleared land to productive agricultural land use options

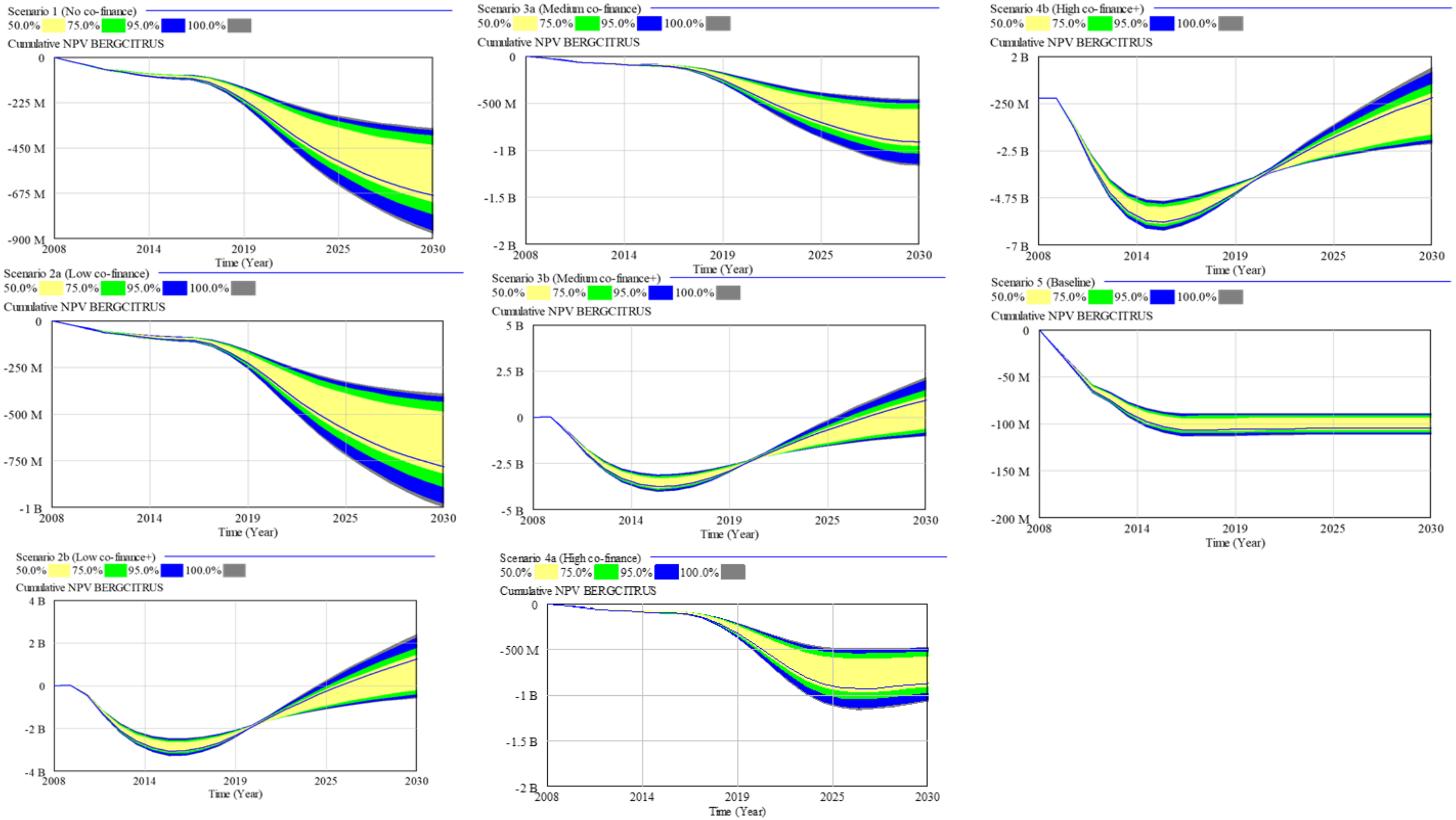

FIGURE 4. 4: MONTE CARLO ANALYSIS FOR DISCOUNT RATE (RANGE: 0.04 TO 0.12) ON THE NPV OUTCOMES UNDER ALL SCENARIOS

Source: Own adaptation

4.4 Conclusion

Our study focussed on the opportunity cost analysis of unrestored land cleared from IAPs in two sites in the Western Cape province of South Africa. In addition, the potential of using the cleared IAPs biomass for the manufacture of VAPs was also included in the analysis. A custom-built system dynamics model (herein referred to as the BERGCITRUS land use planning & VAPs-model) was designed for this study and was simulated under five management scenarios with three having an "a" and a "b" part (see Table 4.1).

Our model simulation results output indicate that the opportunity cost of unrestored cleared land and the failure to use IAPs to make VAPs is high under management scenarios 2b, 3b and 4b. Moreover, positive NPV values are only realised under these same scenarios. In addition, the simulation results clearly point to the fact that early private sector co-financing, manufacture of VAPs and restoration of cleared land to productive agricultural land use options is much better than waiting until the land is severely degraded before the private sector augments the government clearing budget. This is evidenced by positive NPV values realised under scenarios 2b, 3b and 4b where the private sector co-finance begins right at the onset of the model simulation. However, negative NPV values are realised under scenarios 1, 2a, 3a and 4a where the private sector co-finance, manufacture of VAPs and the restoration of cleared land to productive agricultural land use options commences only from 2016 onwards. As result, the clearing of IAPs should not be left to the government alone (as is mostly the current situation in South Africa), but the private sector also has a role to play in assisting the government to clear IAPs. Therefore, these results show that it is financially feasible and profitable to clear IAPs, use the cleared biomass to make VAPs and restore the cleared land to productive agricultural land use options. This should serve as an incentive to unlock private sector co-financing to assist the government in fighting the battle against IAPs.

Our study also has application for other countries that are faced with the problem of invasion by IAPs. Often, in most countries the clearing of IAPs is considered as a public service and as a result the private sector ignores the prospects of co-financing the government clearing budget to bring IAPs under control. However, we clearly show here that if the private sector happens to augment investments by the government in clearing of IAPs coupled with the establishment of value-added industries and restoration of the cleared land to productive agricultural land uses, positive cumulative NPV are possible. These simulation results can potentially be used by policy-makers, government officials, civil society organisations, environmentalists and other relevant stakeholders to make more informed land use policy decisions. In addition, the Monte Carlo sensitivity analysis showed very low uncertainty in the NPV outcomes under scenarios 2b, 3b and 4b meaning that our results are quite robust and thus building more confidence in our model. Last but not least, it is important to note that we are not necessarily advocating for the clearing of IAPs subject to scenarios considered in this study. The simulation results presented in this study should be treated with extra caution and thus decision-makers in study sites other than those mentioned in this study should replicate this study and tailor it according to what is possible in other respective study sites. This will enable decision-makers to first check whether or not the same results are obtained before implementing the recommendations made in this study.

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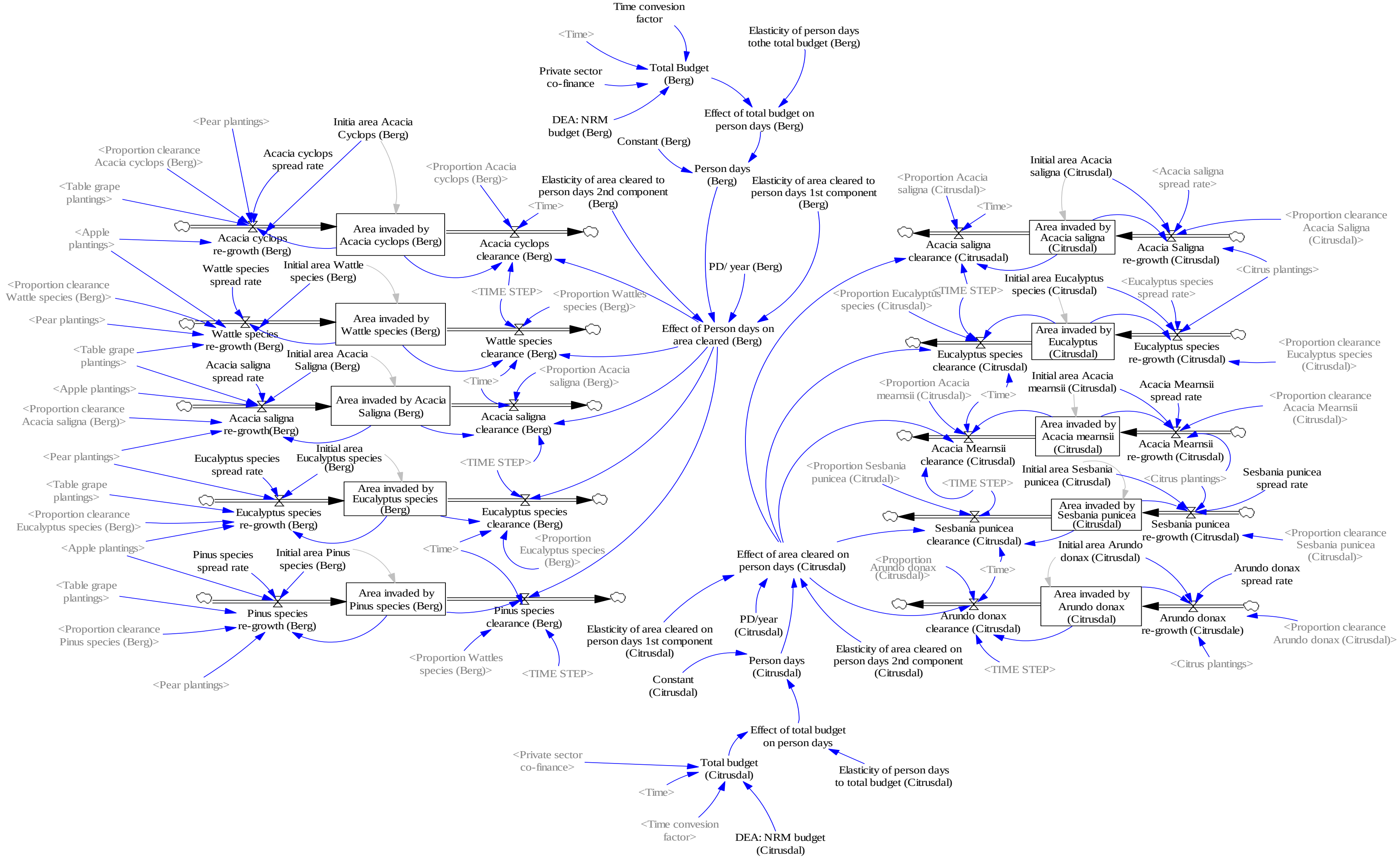
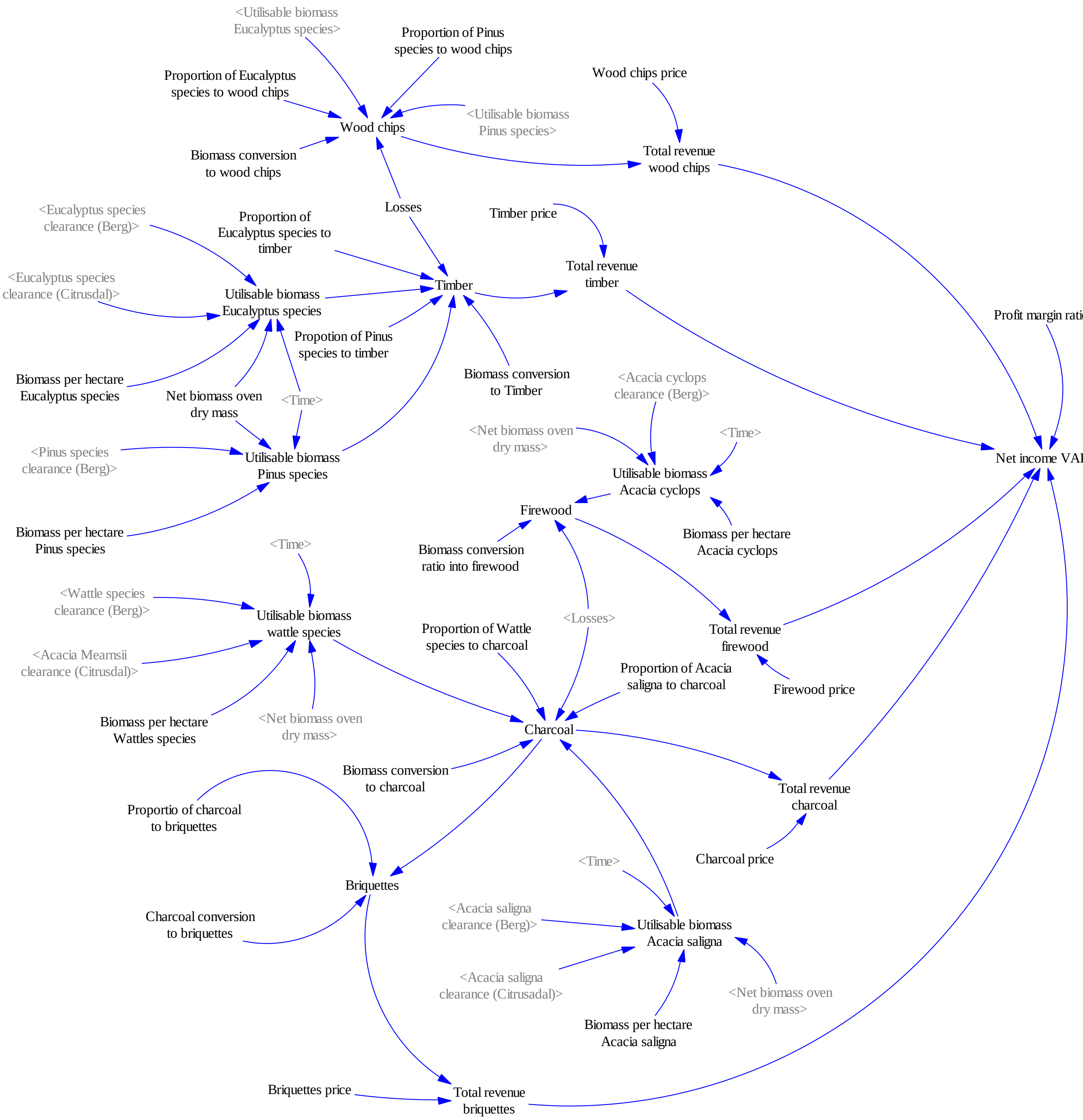
4.6 List of annexures

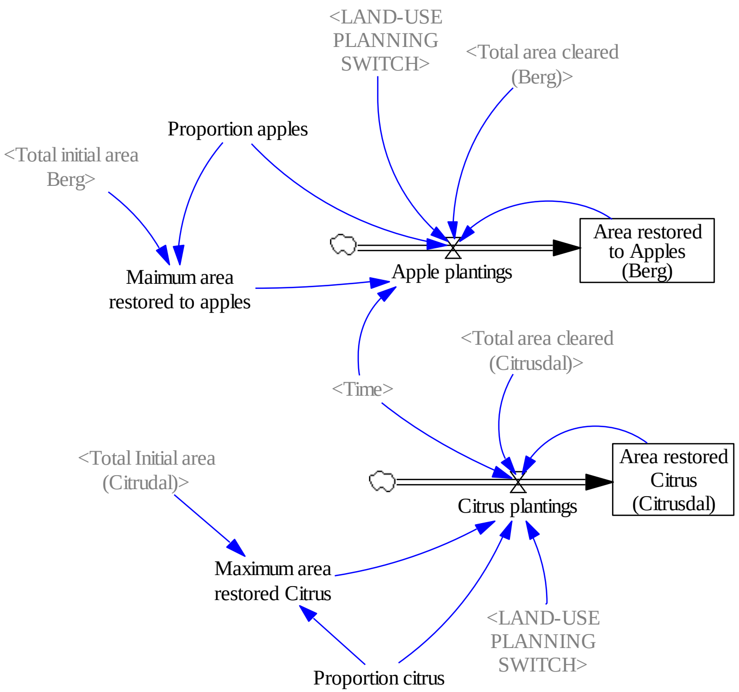
Annexure 4.1A: IAP invaded area sub-model

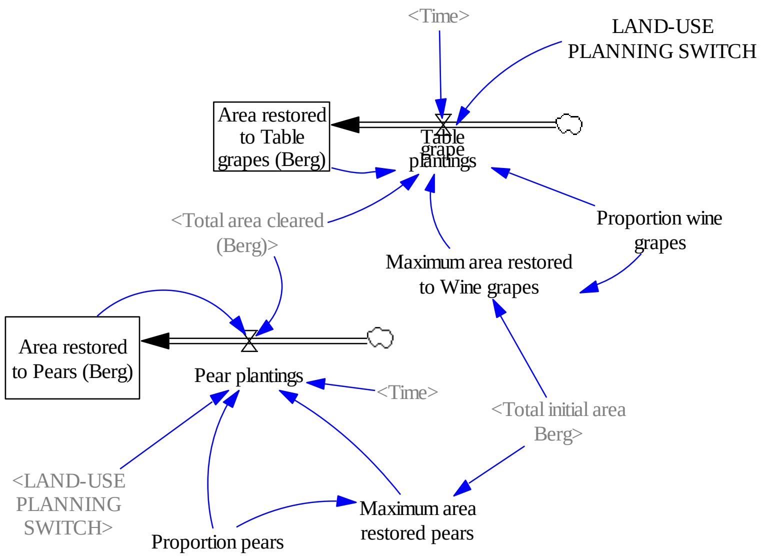


Annexure 4.1B: VAPs sub-model

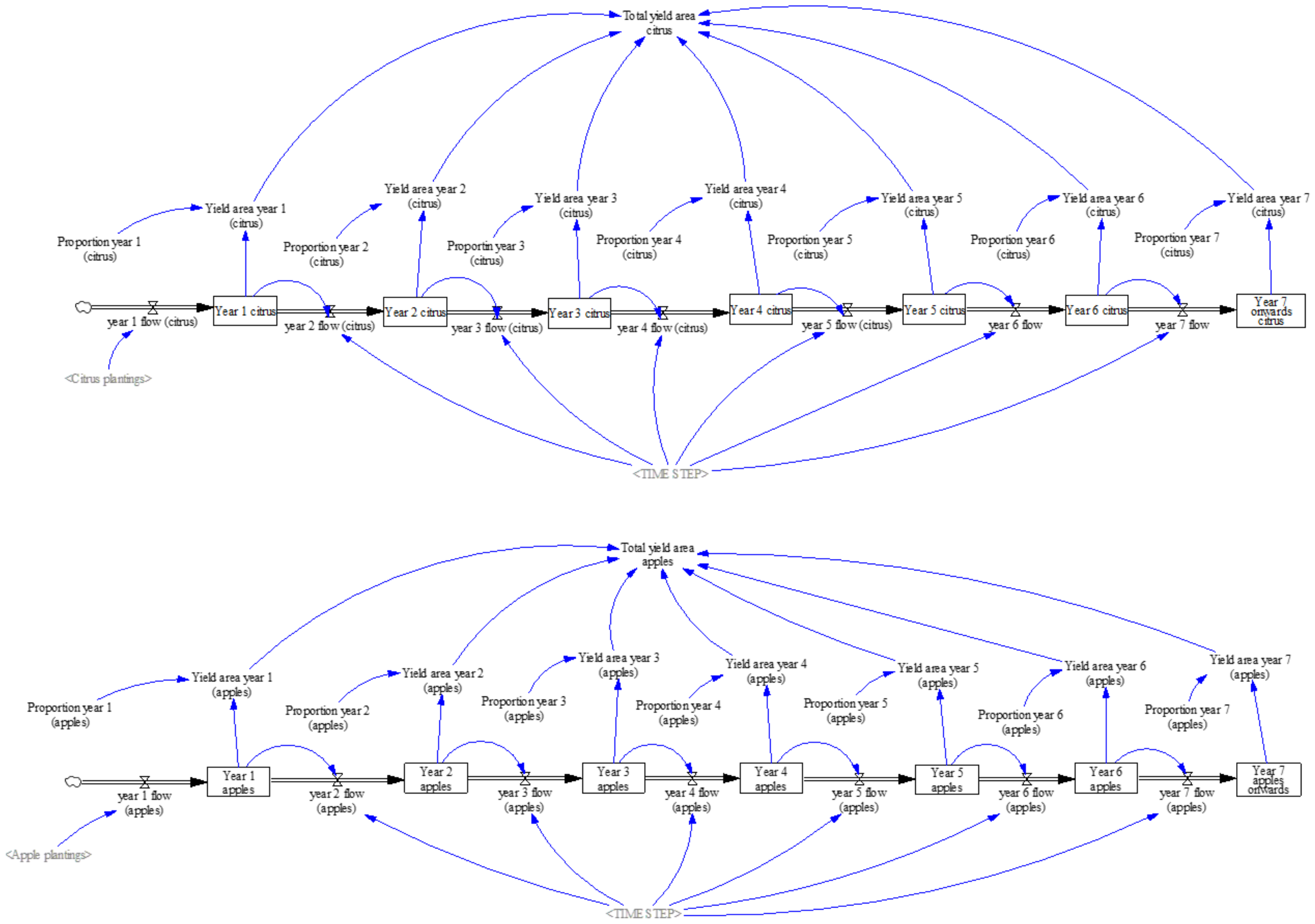


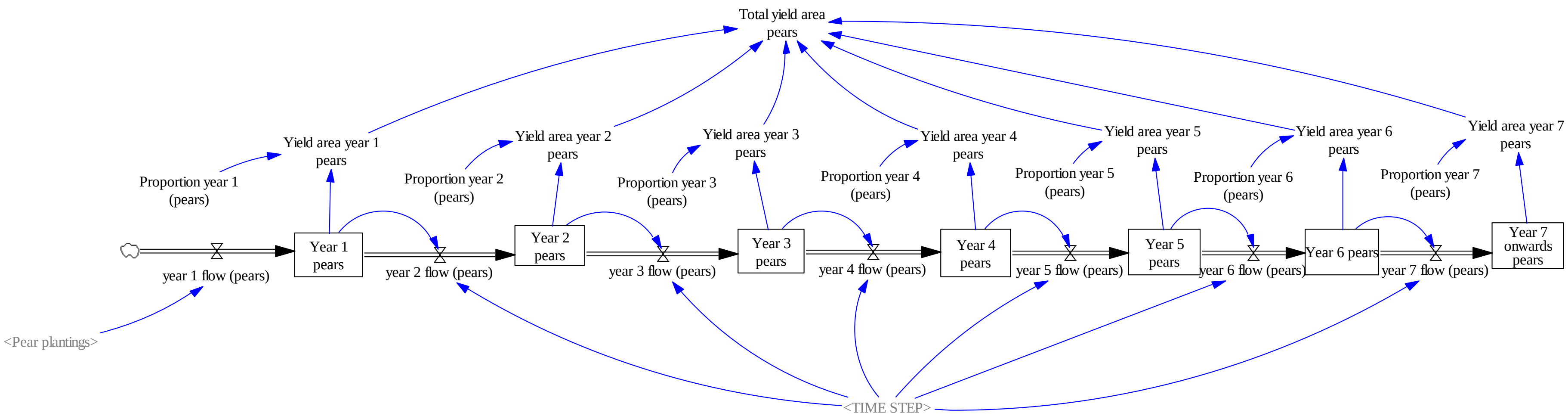
Annexure 4.1C: Agricultural land use sub-model

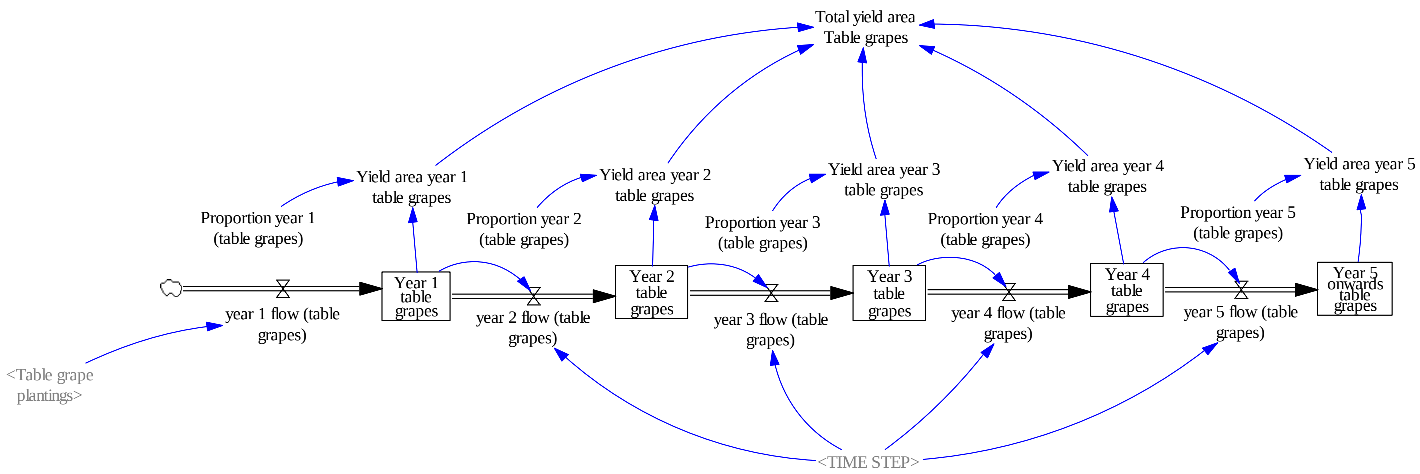




Annexure 4.1D: Agricultural yield growth factor sub-model




Total yield area pears
Yield area year 1 pears
Yield area year 2 pears
Yield area year 3 pears
Yield area year 4 pears
Yield area year 5 pears
Yield area year 6 pears
Yield area year 7 pears
Proportion year 1 (pears)
Proportion year 2 (pears)
Proportion year 3 (pears)
Proportion year 4 (pears)
Proportion year 5 (pears)
Proportion year 6 (pears)
Proportion year 7 (pears)
Year 1 pears
Year 2 pears
Year 3 pears
Year 4 pears
Year 5 pears
Year 6 pears
Year 7 onwards pears
year 1 flow (pears)
year 2 flow (pears)
year 3 flow (pears)
year 4 flow (pears)
year 5 flow (pears)
year 6 flow (pears)
year 7 flow (pears)
<Pear plantings>
<TIME STEP>


Total yield area Table grapes
Yield area year 1 table grapes
Yield area year 2 table grapes
Yield area year 3 table grapes
Yield area year 4 table grapes
Yield area year 5 table grapes
Proportion year 1 (table grapes)
Proportion year 2 (table grapes)
Proportion year 3 (table grapes)
Proportion year 4 (table grapes)
Proportion year 5 (table grapes)
Year 1 table grapes
Year 2 table grapes
Year 3 table grapes
Year 4 table grapes
Year 5 onwards table grapes
year 1 flow (table grapes)
year 2 flow (table grapes)
year 3 flow (table grapes)
year 4 flow (table grapes)
year 5 flow (table grapes)
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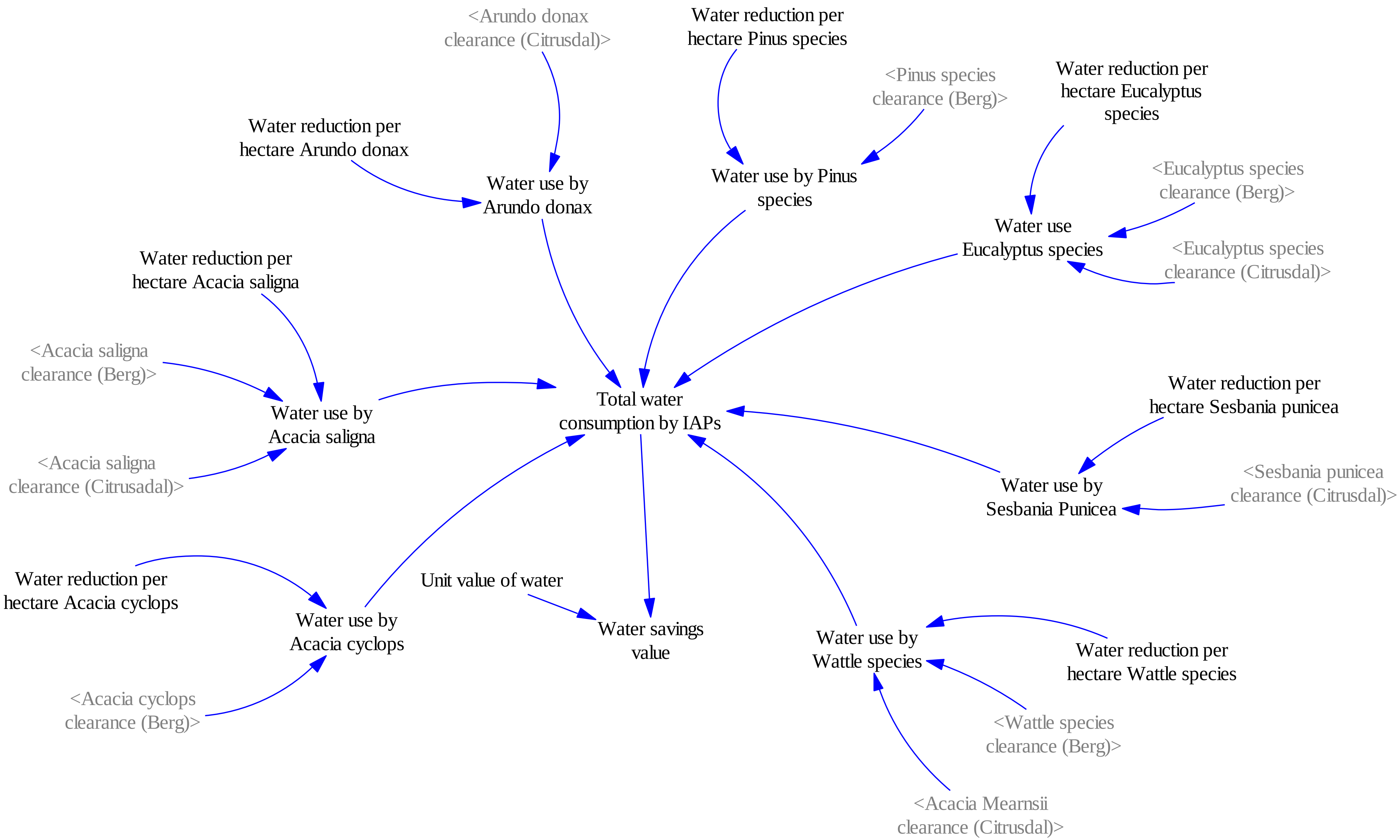
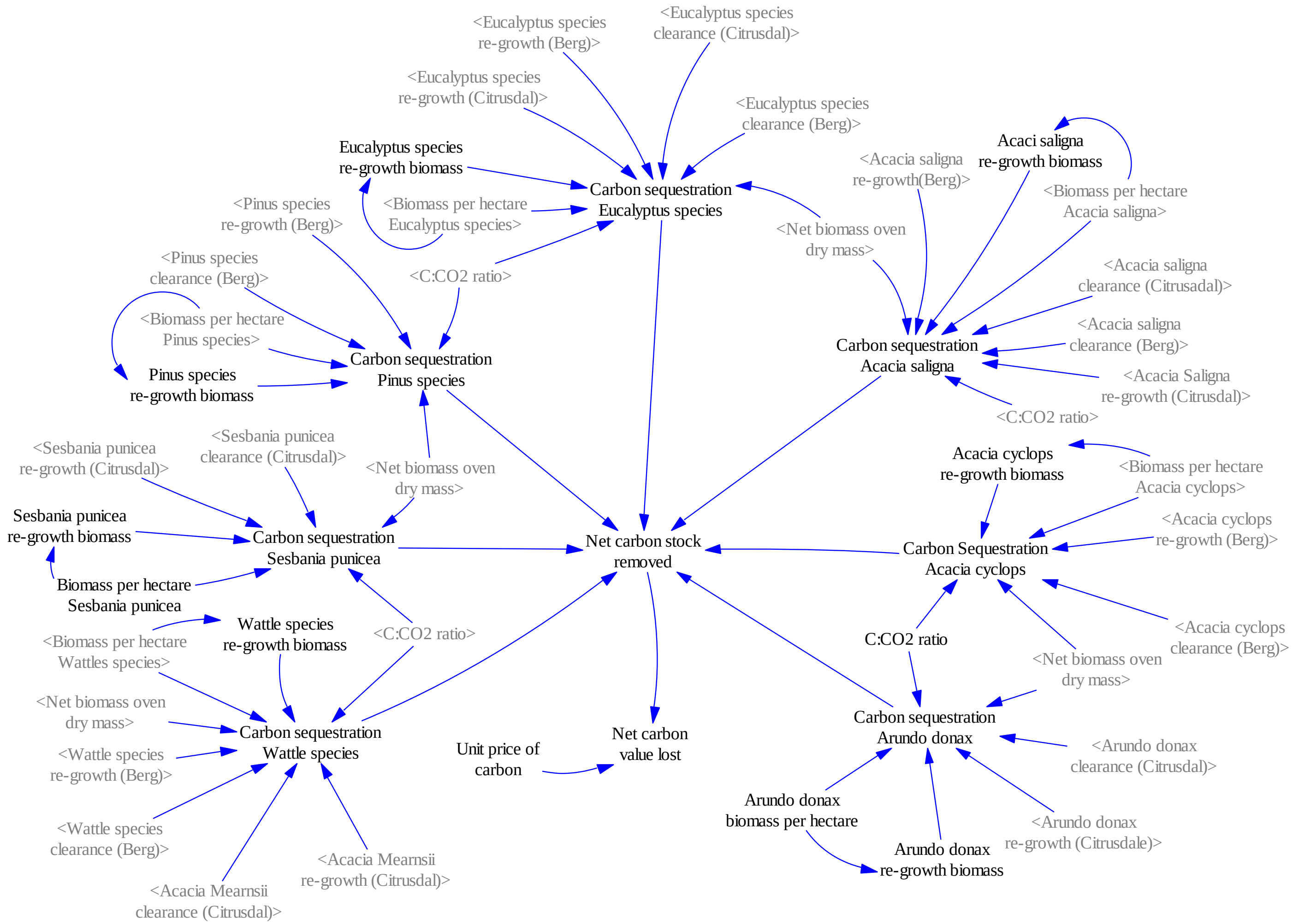
<TIME STEP>

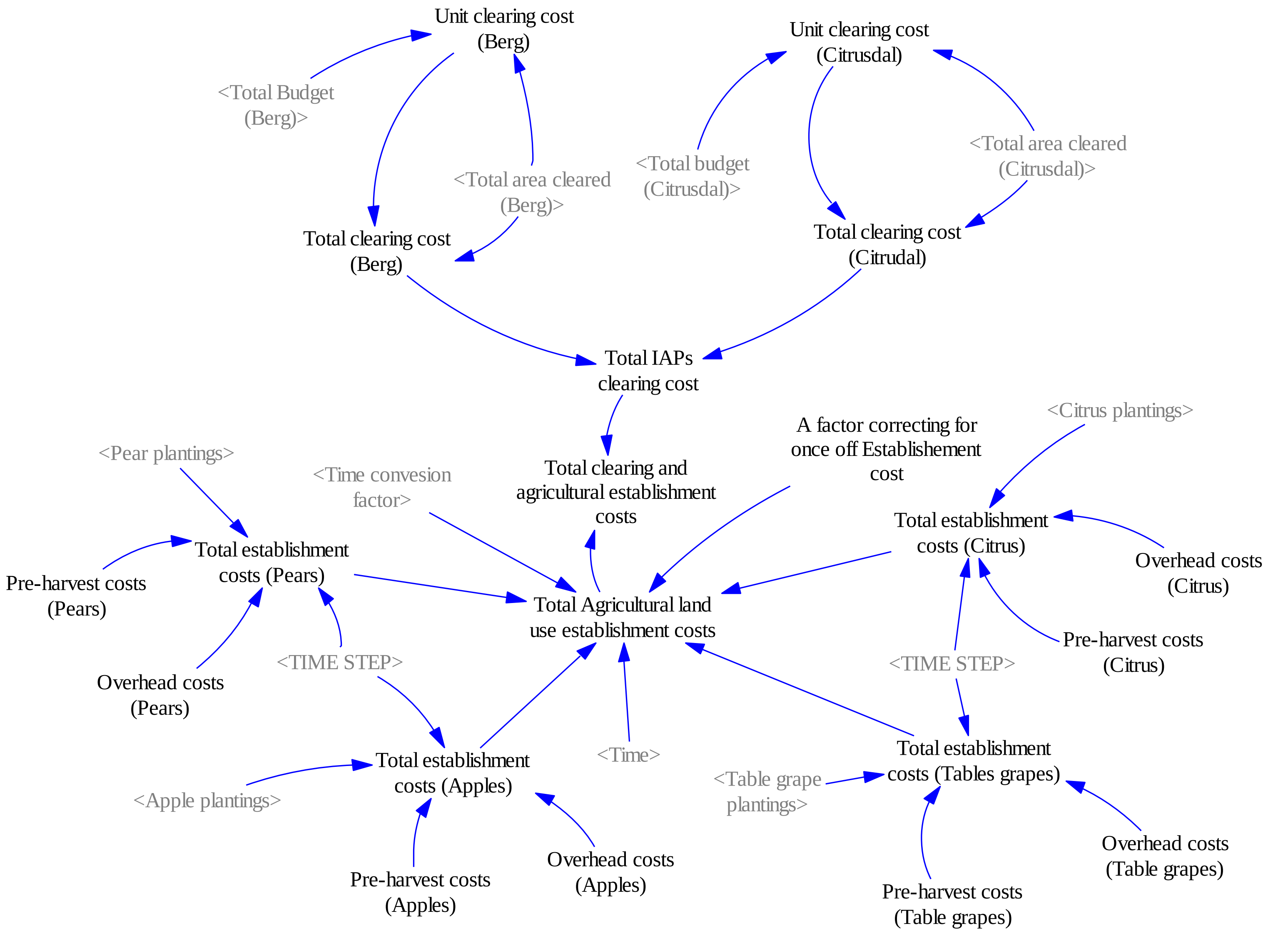
Annexure 4.1E: Water savings sub-model



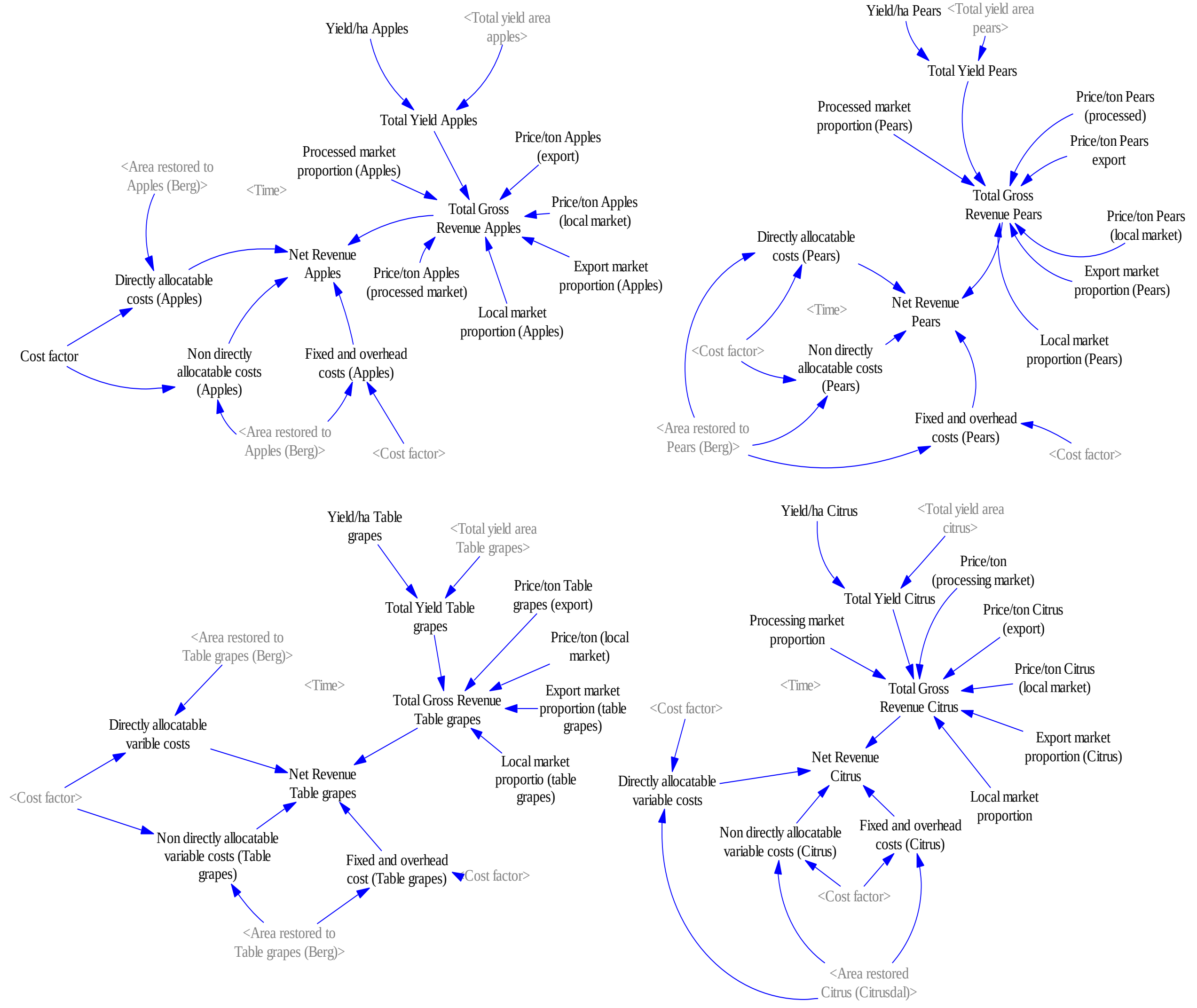
Annexure 4.1F: Carbon sequestration sub-model



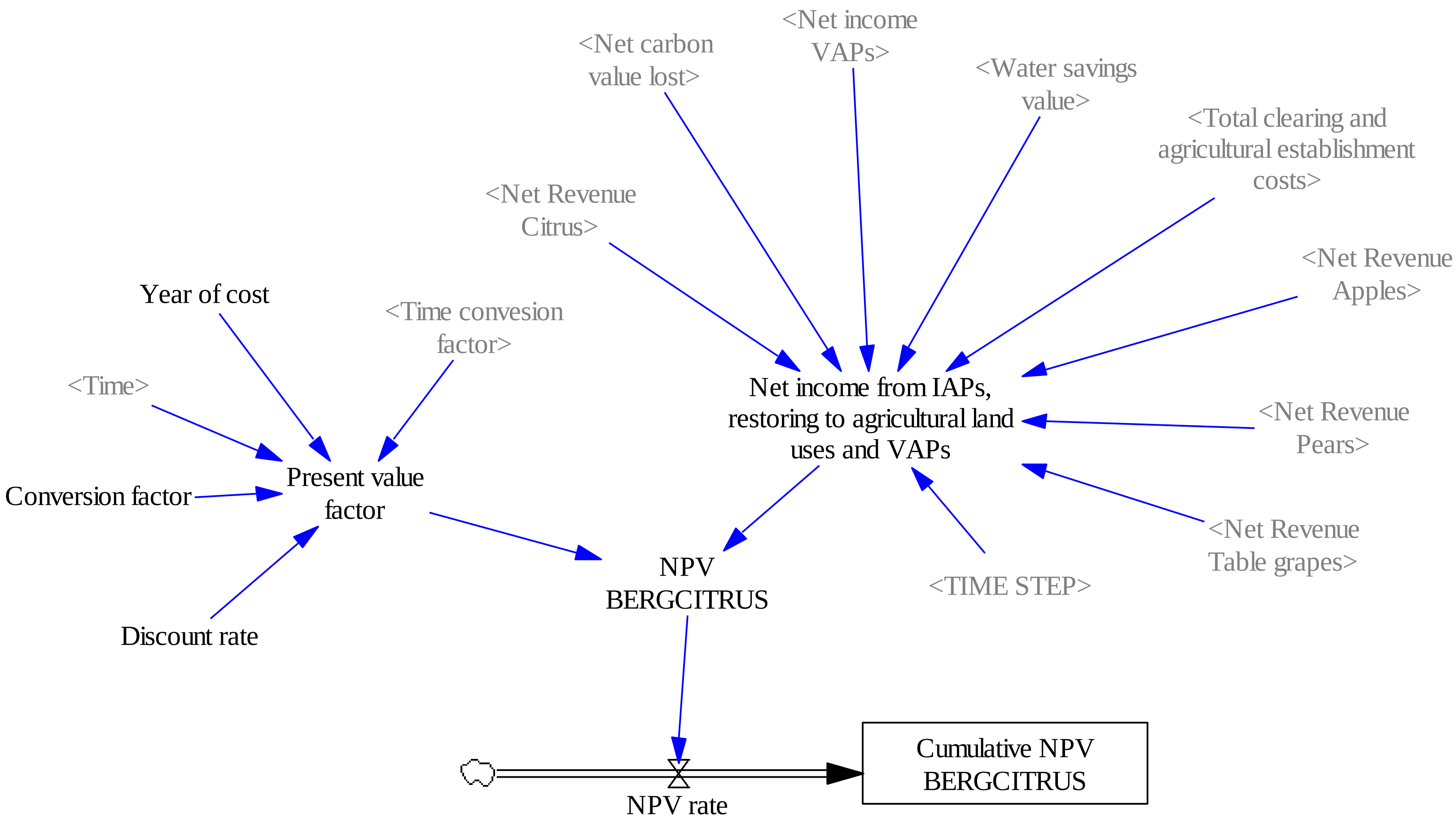
Annexure 4.1G: IAP clearing and agricultural land use establishment cost sub-model



Annexure 4.1H: Agricultural land use establishment cost sub-model



Annexure 4.1I: Cost benefit analysis sub-model



Chapter 5

A multi-criteria assessment of land use planning options in the aftermath of clearing invasive alien plant species: The case of the Berg River quaternary catchment, South Africa

Abstract

Land use planning in the aftermath of clearing invasive alien plants (IAPs) in South Africa is marred by high complexity and much controversy. This can be attributed to heterogeneous land use capabilities, differences in land tenure systems and diverse stakeholder groups with conflicting interests. In most cases, decisions regarding land use planning are made with incomplete information, as our mental models fail to consider the cause and effect relationships of various interrelated factors and dynamics, emanating from particular land use options. Therefore, in this study, we undertook a multi-criteria decision analysis (MCDA) to assess the prospective sustainable agricultural land use options which can be implemented after the clearing of IAPs in Berg River water management catchment, South Africa. A Delphi technique approach was used through independent multi-stakeholder expert interviews and a workshop panel. The five forms of capital (i.e. natural, social, human, manufactured and financial) were used as the main criteria with each having three indicators. The workshop panel identified the following six major prospective land use options that can be implemented at the study site: wine grapes, table grapes, plums, nectarines, wheat and dairy pasture. Table grape farming was the most preferred land use option while dairy pasture was ranked as the least preferred land use option. A parametric sensitivity analysis was undertaken to test for uncertainties and build confidence in the MCDA results. Interestingly, table grape farming remained the highest ranked land use option, while dairy pasture retained the least ranking. This study empirically showed that the MCDA is an effective way of connecting and assisting diverse stakeholder groups in land use planning decision-making. The study concludes by giving recommendations for further study.

5.1 Introduction

Land is one of the most important natural resources needed for the survival of humans, flora and fauna (Verburg et al. 2015). Diverse ecosystem services are derived from land, including regulating services (e.g. water regulation and a buffer against floods), provisioning services (e.g. food production and forage), cultural services (e.g. spiritual and recreational services) and supporting services (e.g. nutrient cycling and habitat services) (Costanza et al. 1997; Hannam & Boer 2004; Blum 2005; MEA 2005). These ecosystem goods and services can be obtained for both direct and indirect use by human beings (Costanza et al. 1997; MEA 2005; Robinson et al. 2009; Dominati et al. 2014). Therefore, sustainable land use is imperative for the survival of both current and future generations and land use planning is critical to prevent sub-optimisation of land use management (Jin et al. 2017).

Careful land use planning is imperative to reduce the negative effects resulting from biological invasions caused by invasive alien plants (IAPs) in the terrestrial biomes of South Africa (Rouget 2015) and other countries at large. These negative effects include a reduction in water flow in riparian zones (Le Maitre et al. 1996; Versfeld et al. 1998; Le Maitre et al. 2000; Görgens & Van Wilgen 2004; Stromberg et al. 2007), an increase in fire risks (Van Wilgen 2009; Van Wilgen et al. 2010), a reduction in biodiversity (Strayer et al. 2006; Ehrenfeld 2010), an invasion of high and medium value agricultural land and allelopathy effects (Tererai 2012), to mention a few. These biological invasions can be attributed largely to a lack of effective legislation and poor land use planning frameworks during the colonial era (i.e. Apartheid era) from a South African perspective (Rouget 2015), when IAPs were introduced for agricultural, forestry and ornamental purposes. The history of the introduction and establishment of IAPs is well documented in literature (King 1943; Keet 1936, 1974; Poynton 1979a, 1979b; Richardson et al. 2003; Van Wilgen et al. 2008; Grotkopp et al. 2010; Essl et al. 2011; Reichard 2011; Wise et al. 2012). Typical examples include *Prosopis* species, which were introduced to provide shelter and fodder for animals, and *Pinus* species, which were introduced for commercial forestry purposes (King 1943; Keet 1936, 1974; Poynton 1979a, 1979b; Richardson et al. 2003). These introductions were never regulated by any land use policy or legislative instrument (Rouget 2015).

Belton and Stewart (2002) mention that land use decision-making in the developing world (of which South Africa is a part) is not an easy task. It is often marred by a high complexity (Young & Crawford 2004) emanating from cause and effect relationships and dynamics among the interrelated system factors (Blum 2005; CEC 2006), differences in the land use capabilities and controversy due to conflicting interests among the diverse stakeholders. Moreover, our knowledge on the functions and ecosystem services provided by land is often incomplete (Daily et al. 1997; Swinton et al. 2006). This complexity and controversy often lead to unintended consequences, from both a local and a global perspective (Belton & Stewart 2002). Therefore, there is no doubt that the lack of effective land use policies, legislative instruments and planning frameworks can lead to the sub-optimisation of land (Rouget 2015; Jin et al. 2017). As a result, it is imperative to recognise the linkages between land use planning and human activities from economic, social, technological, environmental and institutional perspectives. This means that multiple criteria should be considered when land use planning decisions are considered.

To emphasise the consequences of poor decision-making, Rouget (2015) mentions that poor land use planning led to the sub-optimisation of land and unsustainable land developments in South Africa. Rouget (2015) highlights some interesting facts on land use planning blunders made in the past which resulted in the negative legacy of IAPs. Among these blunders were the establishment of forestry plantations in unsuitable land areas and the planting of IAPs (such as *Prosopis* species and *Opuntia* species) for animal fodder (Rouget 2015). The forestry species were never harvested and spread beyond the area of plantation, invading riparian zones. Also, the fodder crops quickly established themselves beyond the areas of introduction, detrimentally affecting the rangelands (Rouget 2015). If there had been land use policies, legislative instruments and decision aid tools that capture the associated complexity, biological invasions caused by IAPs could probably have been avoided (Rouget 2015).

At present, encouraging the optimisation of land use through land use planning policy frameworks and legal instruments in South Africa is still challenging. South Africa still uses outdated legislation namely the Conservation of Agricultural Land Act 43 of 1983 and the Sub-division of Agricultural Land Act 70 of 1970 (Western Cape Provincial Government 2015). These two Acts were formulated to regulate land use by encouraging sustainable use and management of agricultural natural capital (Western Cape Provincial Government 2015). However, the degradation of land through disturbances caused by IAPs has been widely reported (see Le Maitre et al. 2000; Shackleton et al. 2014; Mudavanhu et al. 2016; Nkambule et al. 2017; Stafford et al. 2017) proving the ineffectiveness of these legislative instruments. Moreover, disjointed, incapable and illogical spatial planning and land use planning management schemes were noted almost a decade ago in the NATMAP Land Use perspective (2008). It is clear that the effective transformation of Apartheid-era (i.e. the pre-democracy period before 1994) land use planning blunders like biological invasions by IAPs and non-agricultural developments on high and medium value agricultural land, have been largely hindered. As a result, the South African government promulgated the Spatial Planning and Land Use Management (SPLUMA) Act 16 of 2013 under the auspices of the Department of Rural Development and Land Reform (DRDLR) (DRDLR 2013). In addition, the Department of Agriculture Forestry and Fisheries (DAFF) and the Agricultural Research Council (ARC) are in the process of developing the Preservation and Development of Agricultural Land

(PDAL) Act to provide a legislative framework for the management of agricultural land (PLAAS 2015; [10]Collet 2018, pers. comm.; Modiselle[11] 2018, pers. comm.).

To the best of our knowledge, limited research has been done in South Africa to date, which presents an MCDA to assist land owners and other relevant stakeholders in assessing what land use options to implement in the aftermath of clearing IAPs. Most of the studies mainly focus on the control options of IAPs, effects of IAPs on land use cover and the cost-benefit analysis of clearing IAPs. As a result, there is a knowledge gap regarding how land use optimisation that maximises public goods (under various land tenure systems) can be achieved after clearing IAPs. This study seeks to conduct an MCDA as a decision support mechanism to assist decision makers in identifying prospective agricultural land use options that can be implemented after the clearing of IAPs. The results from this analysis are important to guide policy-makers, land users and other relevant stakeholders in formulating effective land use planning frameworks and policies, and in identifying the best use sustainable land use options that can potentially be implemented after clearing IAPs to avoid the sub-optimisation of agricultural land. We develop a custom-built MCDA tool in the form of a Microsoft Excel spreadsheet for this study. The analysis is focussed on land under the private land tenure system, in the Berg River water management catchment (i.e. $G10_{A-J}$), Western Cape province, South Africa.

5.2 Study site

The Berg River water management catchment is located in the Western Cape province, South Africa (see Figure 5.1). The Berg River flows (from its source in the Drakeinstein mountains in Franschhoek) for approximately 294km (De Villiers 2007) and has a total catchment area of 7 715km^2 (Mudavanhu et al. 2017a). It eventually deposits its water flow at its mouth in the Atlantic Ocean (Mudavanhu et al. 2017a) on the west coast of South Africa. Like other water management areas, the Berg River catchment (i.e. plots $G10_{A-J}$) is invaded by a plethora of IAPs with *Pinus* species, *Eucalyptus* species, *Acacia Cyclops*, *Acacia Saligna* and Wattle species being the major invaders (Kotzé et al. 2010). *Eucalyptus* species are the largest invaders occupying approximately 5 000 condensed hectares while Wattle species (mainly *Acacia mearnsii*) are the least invaders occupying approximately 400 condensed hectares (Kotzé et al. 2010). In terms of climate, the Berg River water management catchment falls under the Mediterranean climate zone characterised by hot and dry summers, and cold and wet winters. The study site receives a mean annual rainfall of 500–2 000mm and the Berg River's flow peaks during June–August as a result of the winter precipitation experienced within the catchment (Mucina & Rutherford 2006). The site is characterised by fynbos vegetation and falls within the fynbos biome (Mucina & Rutherford 2006). The geological characteristics are made up of Cape granites, sandstone, quartzite rocks and Malmesbury shale rocks (De Villiers 2007). As for the soil profile, the Berg River water management catchment is composed mostly of unfertile lithological soils with some limited deep alluvial flood plains and nutrient rich soil deposits (De Villiers 2007).

[10] Mrs Anneliza Collet is an Assistant Director at the DAFF. She is part of the team that is responsible for the formulation of the PDAL Act.
[11] Mrs Salome Modiselle is an Agricultural Economist at the ARC. She is part of the team that is responsible for the formulation of the PDAL Act.

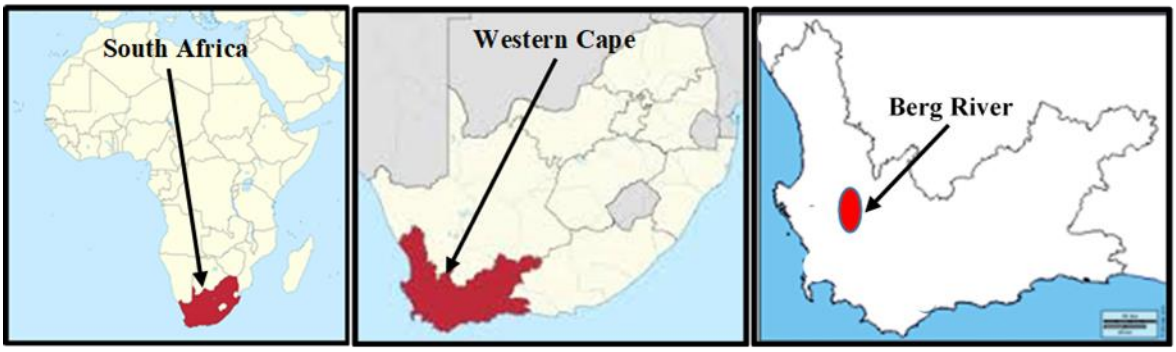


FIGURE 5. 1: LOCATION MAP OF THE BERG RIVER CATCHMENT IN THE WESTERN CAPE, SOUTH AFRICA

Source: Adapted from Mudavanhu et al. (2017a)

5.3 Materials and methods

5.3.1 Multi-criteria decision analysis process

Multi-criteria decision analysis (MCDA) is a decision aid method used to assess and measure benefits, risks and uncertainities in complex decision-making processes often marred by multiple and conflicting charactristics that are valued differently (Saarikoski et al. 2014; Angelis & Kanavos 2017). This analyisis is undertaken through the explicit formulation of criteria and their relative weights under a transparent protocol that incorporates diverse stakeholder views to avoid bias and to express a more balanced viewpoint (Angelis & Kanavos 2017). The multi-criteria decision analysis process can be summarised in five stages (Belton & Stewart 2002) as illustrated in Figure 5.2. The first stage involves the identification of the problem to be solved (Belton & Stewart 2002), whereby the nature of the problem is thoroughly assessed and the difference between the current and desired state of the situation is established. This enables the desion-makers to acquaint themselves with all the necessary information and data requirements for decision analysis (Saaty 2008; Calizaya et al. 2010). The second stage involves the structuring of the MCDA problem into the goal, values, constraints, key issues, uncerternities, alternatives, stakeholders and the external environment (Belton & Stewart 2002). This can be done through cognitive mapping, spray diagrams or causal loop diagrams (CLD) and enables the decision-maker to see how different elements influence the problem through the explicit illustration of the complex cause-effect relationships and dynamics from a systems thinking perspective (Sterman 2000; Maani & Cavana 2007). Stage three would be to build the MCDA model (Belton & Stewart 2002) which involves the specification of alternatives, eliciting values *inter alia* the defination of the criteria to be used to assess the alternatives based on the purposes of what the MCDA seeks to achieve. Next, the fourth stage involves using the MCDA model to inform and challenge our mental models regarding issues which otherwise might have been omitted through the synthesis of available information, critical analysis and sensentivity analyisis (Belton & Stewart 2002). In addition, new alternatives can be created where limitations to the preliminery alternatives considered are found through bulding consensus among all the relevant stakeholders. Last but not least, stage five involves the development of an informed action plan subject to the results of the MCDA process.

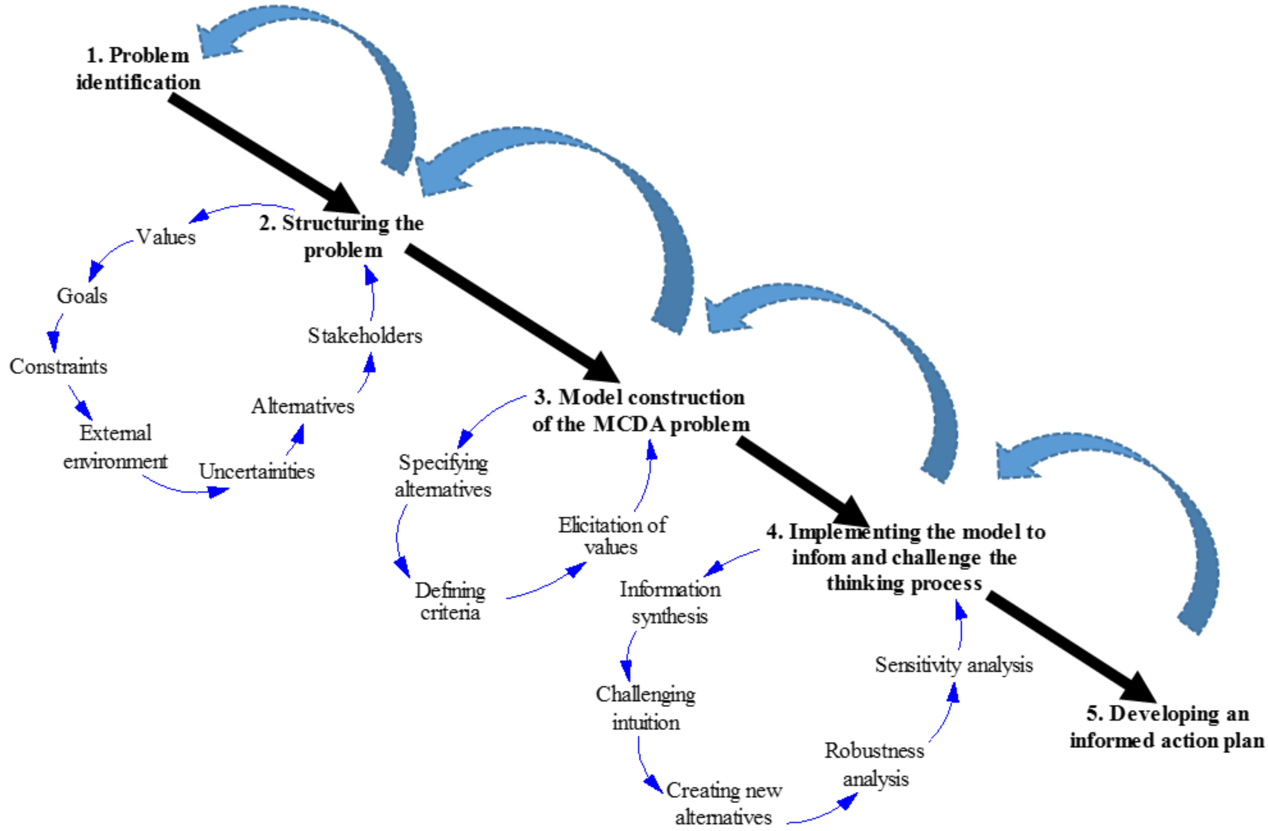


FIGURE 5. 2: A SCHEMATIC DIAGRAM SHOWING THE STEPS INVOLVED IN MULTI-CRITERIA DECISION ANALYSIS PROCESS

Source: Adapted and modified from Belton and Stewart (2002)

5.3.2 MCDA analytical framework design

5.3.2.1 The multi-criteria problem

Adopting the MCDA process by Belton and Stewart (2002), the problem to be solved for this study focussed on land use planning problems after clearing IAPs. IAPs have led to several negative environmental effects, including excessive water consumption, reduction in stream flow, increase in fire hazards, decline in biodiversity and allelopathy effects. As mentioned in Section 1, the invasion by these IAPs is a product of poor land use planning during the Apartheid era which has led to the sub-optimisation of land use within all biomes of the country. For the purposes of this study, it is therefore important to determine which sustainable land use options could be implemented after clearing these IAPs to avoid the sub-optimisation of land. It is also imperative to avoid the negative effects emanating from IAPs. Roy (1996) categorised MCDA problem typologies into four types (i.e. choice, sorting, ranking and description problematiques). Belton and Stewart (2002) add a further two typologies namely the design problematique and the portfolio problematique. According to Belton and Stewart (2002), the land use planning decision problem can be classified under the design problematique. The design problematique is described in Belton and Stewart (2002:15) as follows: “To search for, identify or create new decision alternatives to meet the goals and aspirations revealed through the MCDA process”.

This corresponds to the land use planning problem in this study, where the aim is to identify the prospective land use options which can be implemented after clearing IAPs in order to avoid the sub-optimisation of land and a rebound of the negative effects caused by IAPs.

5.3.2.2 Multi-criteria problem structuring

Belton and Stewart (2002:35) mention that "a problem well-structured is a problem half solved". For the purposes of this study, the land use planning problem is illustrated using a causal loop diagram (CLD) (see Figure 5.3). The CLD (i.e. the qualitative system dynamics model) serves to assist decision-makers to visualise and take cognisance of how diverse elements within a system interact, in order to make informed decisions. In addition, the cause-effect relationship of these elements are systematically presented and captured in a dynamic fashion inter alia the corresponding feedback loops within the system. As shown in the CLD (Figure 5.3), the spread of IAPs is influenced by fire, amount of water reserves, and allelopathy effects, to mention a few. The spread of IAPs then, in turn, influences the area invaded by IAPs, which then reduces the amount of water reserves and stream flow, and increases the fire risks and allelopathy. Other negative effects not shown in the CLD are a decline in biodiversity (Vundla et al. 2016), increased soil erosion (Mudavanhu et al. 2016) and a reduction in grazing capacity (Garcia-Llorente et al. 2008; Stafford et al. 2017). This eventually justifies and triggers the need to clear IAPs which in turn reverses the negative impacts of IAPs and improves the land use capability for agricultural purposes. Converting the cleared land into productive agricultural land leads to the formation of the five forms of capital (see Aaronson et al. 2007) which then influences land use planning decisions that avoid the risk of land use sub-optimisation caused by the spread of IAPs. The stakeholder actions are also imperative as shown in the CLD. The stakeholder actions influence the promulgation of environmental regulations, land use policies and legislation which ensures the maximisation of both private and social benefits (i.e. positive externalities) in a sustainable manner. The CLD shows that the MCDA problem under analysis in this study is more reinforcing than balancing, as shown by the six reinforcing feedback loops (i.e. R1 to R6) versus the two balancing feedback loops (i.e. B1 and B2). A reinforcing loop is one whereby the action leads to causal effects which lead to more of the same action resulting in either a growth or decline. A balancing loop seeks to change the current state of things to a desired state through some form of action that can lead to goal achievements (see www.systems-thinking.org). Having structured the problem, the next step is to build the MCDA model

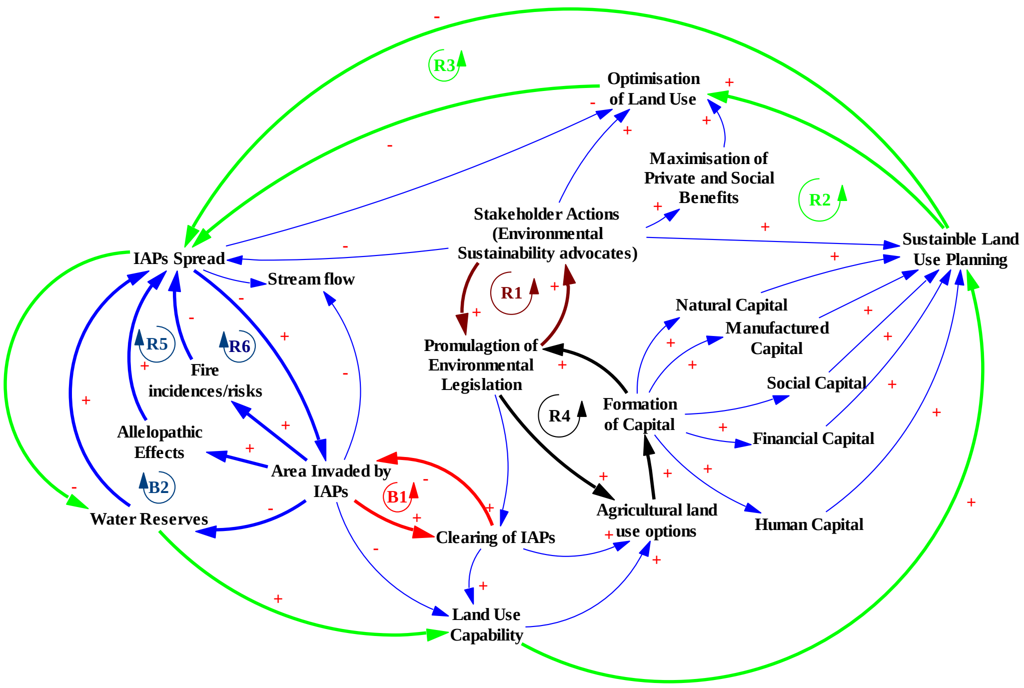


FIGURE 5. 3: CAUSAL LOOP DIAGRAM SHOWING THE STRUCTURE OF THE LAND USE PLANNING PROBLEM AFTER CLEARING IAPS TO ASSIST DECISION-MAKERS IN BUILDING AN MCDA MODEL

Source: Own adaptation

5.3.2.3 Multi-criteria analysis model building

5.3.2.3.1 MCDA model design

The MCDA model building process used in this study consisted of a Delphi technique procedure (through several rounds of expert consultations), literature surveys and an expert workshop panel. Nine experts in the field of invasion biology, environmental science, hydrology and agriculture were consulted over five stages to seek their insights and guidance. A preliminary MCDA framework and a custom-built MCDA tool were presented to the experts through individual consultations to inspect the preliminary criteria, indicators (i.e. the attributes) of the criteria and the proposed alternative land use options that can be implemented after the clearing of IAPs. After receiving insights from the experts, amendments were made to the preliminary framework and analytical tool incorporating all the main suggestions. Thereafter, an upgraded framework was further circulated to the same experts to seek verification and validation. After receiving feedback from the experts once again, the MCDA framework and Microsoft Excel built tool were upgraded respectively. Lastly, the unit of measure for the criteria indicators were incorporated after an extensive literature survey to seek objective and acceptable unit measures for the respective indicators (i.e. attribute components) chosen under each of the five forms of capital. This was then followed by independent expert interviews in which the same nine experts were approached to assign a score to all the criteria attributes (see Section 3.2.3.2). The score was defined using a seven-point Likert scale, with 1 being neutral (or no opinion) and 7 being extremely important. The weights assigned by all the experts were averaged based on the aggregated scores attached and eventually normalised to get a weighted average for each criteria indicator. The normalised weight for each indicator was determined through dividing the average weight of each criteria indicator by the maximum score (i.e. 7) and then multiplying by 100 to convert it to a percentage. The finalised MCDA tool was then taken back again to the experts for final inspection, verification and validation. Thereafter, an MCDA was conducted through a workshop panel consisting of twelve extension officers and agricultural economists from the Western Cape Provincial Government's Department of Agriculture, responsible for the Berg River water management catchment. The detailed parameters and equations (i.e. formulas) used in this MCDA and Microsoft Excel spreadsheet are available from the authors on request.

5.3.2.3.2 The MCDA hierarchical value tree

The MCDA model constructed in this study is illustrated in Figure 5.4 using the value tree approach. The value tree serves to present the MCDA model through the means of a hierarchical structure that explicitly shows the goal of the MCDA, the criteria, sub-components/attributes (i.e. indicators), and the alternatives as explained below.

(i) MCDA goal:

For the purposes of this study, the goal of conducting the MCDA was to determine the best use agricultural land use option(s) that can be implemented after the clearing of IAPs in the Berg River water management catchment. This is important to alleviate re-invasion of the cleared area, to reclaim high and medium value agricultural land taken over by IAPs and to mitigate risks that emanate from IAPs, which in most cases lead to the sub-optimisation of land use.

(ii) Criteria:

The five forms of capital were selected as the main criteria for the MCDA in this study. Aaronson et al. (2007) summarised these forms of capital as natural, social, human, manufactured (i.e. built) and financial. Natural capital refers to the physical stock and flows of physical and biological resources and ecosystem services. Human capital refers to the intellectual and cognitive capacity *inter alia* the man power available. Social capital refers to the values and trust systems, and social networks. Manufactured capital refers to human-built forms of capital such as fixed (i.e. roads and buildings) and moveable infrastructure and assets (i.e. vehicles and machinery). Lastly, financial capital refers to money and its proxies (i.e. substitutes). The five forms of capital enables decision-makers to avoid too many indicators. It is important not to have too many criteria indicators in an MCDA as this will reduce the chances of one criteria indicator to dominate over the others. In addition, when too many criteria indicators are included, it is very easy to double count, which can lead to biased and flawed decision analysis.

(iii) Sub-components or attributes:

After defining five forms of capital as the main criteria, three main indicators for each form of capital were identified. Under natural capital, the impact on ecosystem services (measured using a Likert scale of -3 (i.e. least desirable) to 3 (i.e. most desirable)), environmental contamination risks (measured using the same Likert scale) and water use efficiency (measured in kg/m^3) based on biomass production per unit of water consumed, were identified. In the case of human capital, employment opportunities (measured by the number of jobs), labour productivity and capacity-building (both measured using the Likert scale) were identified. Institutional development, the standard of living (i.e. quality of life), and the social and individual risks (all three measure using the Likert scale) were considered as the main indicators under social capital. In the case of manufactured capital, investment in fixed assets (measured in ZAR[12]), investment in moveable assets (measured in ZAR) and the market value of land (measured in ZAR/ha) were considered the most important indicators. Last but not least, the contribution to economic growth (measured by GDP in ZAR), farm profitability (measured by the Internal Rate of Return (IRR) in %) and the cost to land users (measured in ZAR/ha) were considered as the most important indicators under financial capital.

(iv) Alternative agricultural land use options:

The alternative agricultural land use options were proposed by a workshop panel consisting of 12 extension officers and agricultural economists from the Western Cape Provincial Government's Department of Agriculture. The workshop panel represented diverse skills, and included viticulturists, environmentalists, agronomists, plant pathologists, pomology experts, animal production specialists, horticulturists, silviculturists and agri-business specialists. All the participating experts were knowledgeable of and well acquainted with the Berg River water management catchment. Six prospective productive agricultural land use alternatives suitable within the Berg River areas under clearance from IAPs were identified through an iterative and consensus-building process. The land use options identified were table grape farming, wine grape farming, wheat farming, nectarine orchards, plum orchards and dairy pasture. Thereafter, the panel was asked to rank the identified land use options against each other based on the indicators considered under each form of natural capital (see previous section). This was also done in an iterative and consensus-building manner by the expert panel. The results from the panel discussions were transferred directly to the custom-built Microsoft Excel spreadsheet with linked formulas. The land use options were then ranked in ascending order from the highest weighted score to the lowest weighted score. Finally, having undertaken all these steps, the workshop panel was able to determine the best use agricultural land use option(s) to implement after clearing IAPs subject to the various forms of capital indicators.

[12] ZAR stands for the South African Rand which is the formal monetary currency used in the Republic of South Africa.

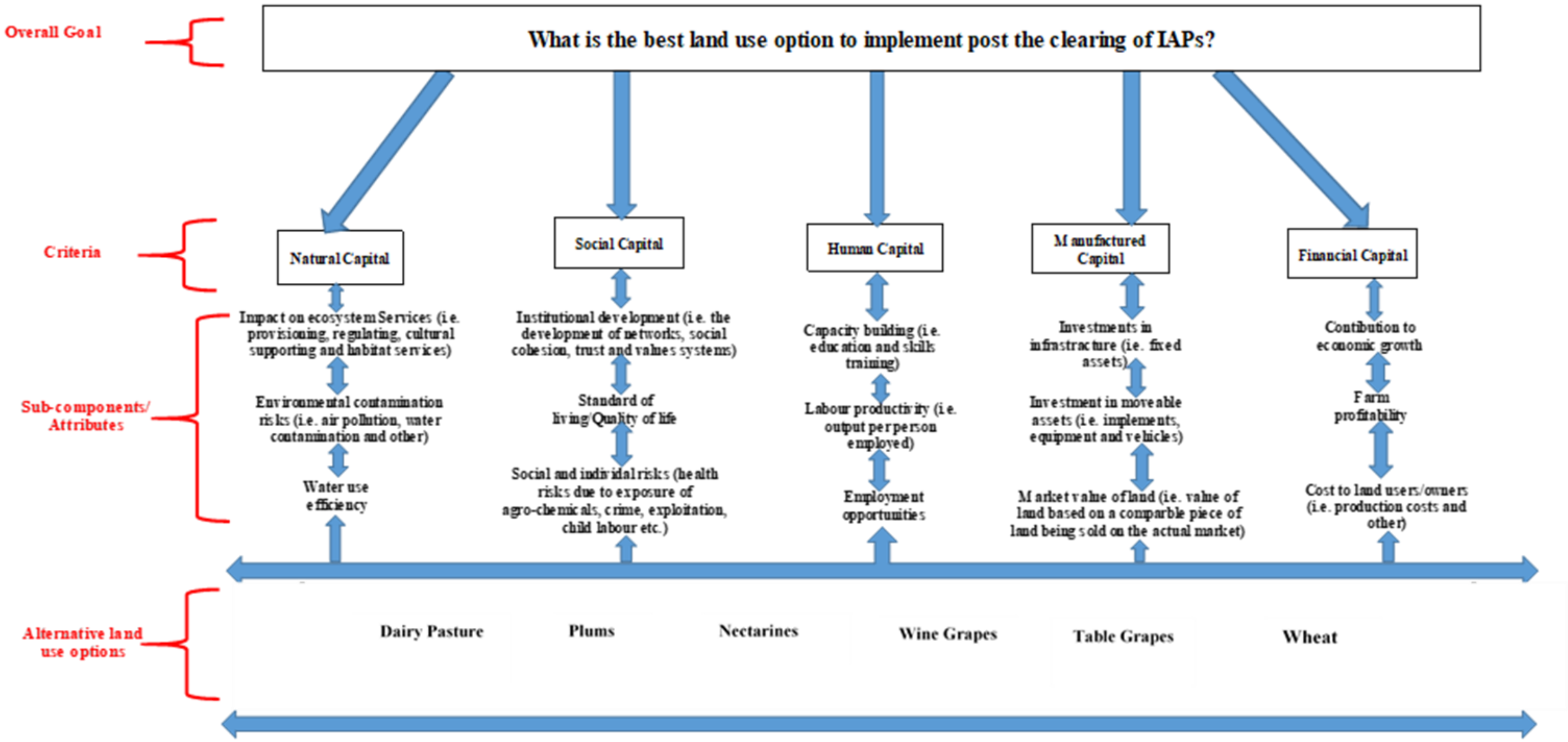


FIGURE 5. 4: SCHEMATIC DIAGRAM SHOWING THE HIERARCHICAL VALUE TREE FOR THE MCDA MODEL TO ASSIST LAND OWNERS/USERS AND OTHER RELEVANT STAKEHOLDERS IN MAKING INFORMED LAND USE PLANNING DECISIONS AFTER CLEARING IAPS

Source: Own adaptation

5.4 Results

5.4.1 Scoring the criteria

A 7-point Likert scale (i.e. -3 to 3) was used to define the score for each indicator. In this study, -3 refers to the least desirable score and 3 refers to most desirable score. All indicators (i.e. sub-components/attributes) were measured objectively through realistic unit measures (see Table A1 in the Appendix section) and explicitly presented in the MCDA Microsoft Excel spreadsheet. The unit measures were identified from the literature, and verified and validated through consultation with experts and individual reflection. See part (ii) and (iii) under section 3.2.3.2 for a detailed description of the criteria and indicators used.

5.4.2 Weighting the criteria

In order to assign weights to the indicators considered under each form of capital, a 7-point Likert scale was set with a maximum value of 7 and minimum value of 1. Based on this, the diverse experts were independently interviewed and asked to give a score of between 1 (no opinion) and 7 (extremely important) in terms of how they viewed the importance of each indicator in land use planning decisions after the clearing of IAPs. After completing all the expert consultations and interviews, an average weight was calculated based on the aggregate scores given by the experts. Finally, the normalised average weight for each indicator was then determined by dividing the average weight of each indicator by the maximum score (i.e. 7) and then multiplying by 100 to convert it to a percentage. The natural capital indicators were deemed to be the most important with a normalised average weight of approximately 8% while the investment in moveable assets and contribution to economic growth were seen as the least important indicators with a normalised average weight of approximately 5%. The results of the criteria weighting exercise to determine the relative importance of each indicator considered in land use planning decisions after clearing IAPs, are shown in Figure 5.5.

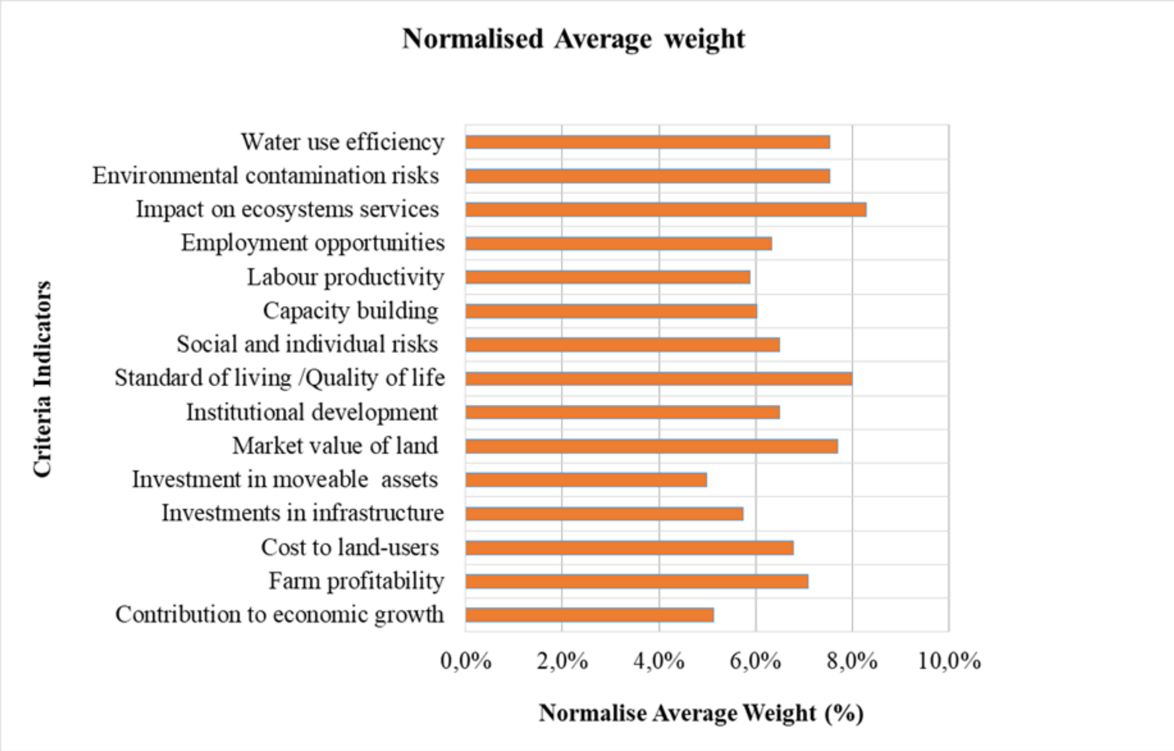


FIGURE 5. 5: NORMALISED AVERAGE WEIGHTS ALLOCATED TO EACH CRITERIA INDICATOR (I.E. ATTRIBUTES)

Source: Own adaptation

5.4.3 Scoring the alternative land use options

The alternative productive agricultural land use options were scored by a panel of experts using the criteria indicators considered in this study (see Likert Scale in Table A1). The detailed scores attached for each land use option are illustrated in Figure 5.6. Wine grape farming was allocated the greatest desirable score (i.e. 3) for the contribution to economic growth, labour productivity and investments in moveable assets, while having the least desirable score (i.e. -3) for farm profitability, environmental contamination risks and the impact on ecosystem services. In the case of table grape farming, the most desirable score (i.e. 3) was for the contribution to economic growth, labour productivity and employment creation while the least desirable score (i.e. -3) was for production costs incurred by land users and the impact on ecosystem services. For plum and nectarine orchards, the most desirable score (i.e. 3) was for the investment in moveable assets, market value of land, standard of living and labour productivity while the least desirable score (i.e. -3) was for the impact on ecosystem services and the production cost to land users. In the case of dairy pasture, the greatest desirable score (i.e. 3) was for the market value of land and institutional development while the least desirable score (i.e. -3) was only for the production costs incurred by the land users. Last but not least, under wheat farming the greatest desirable score (i.e. 3) was for investments in moveable assets, institutional development and the water use efficiency while the least desirable score (i.e. -3) was for investments in fixed infrastructure.

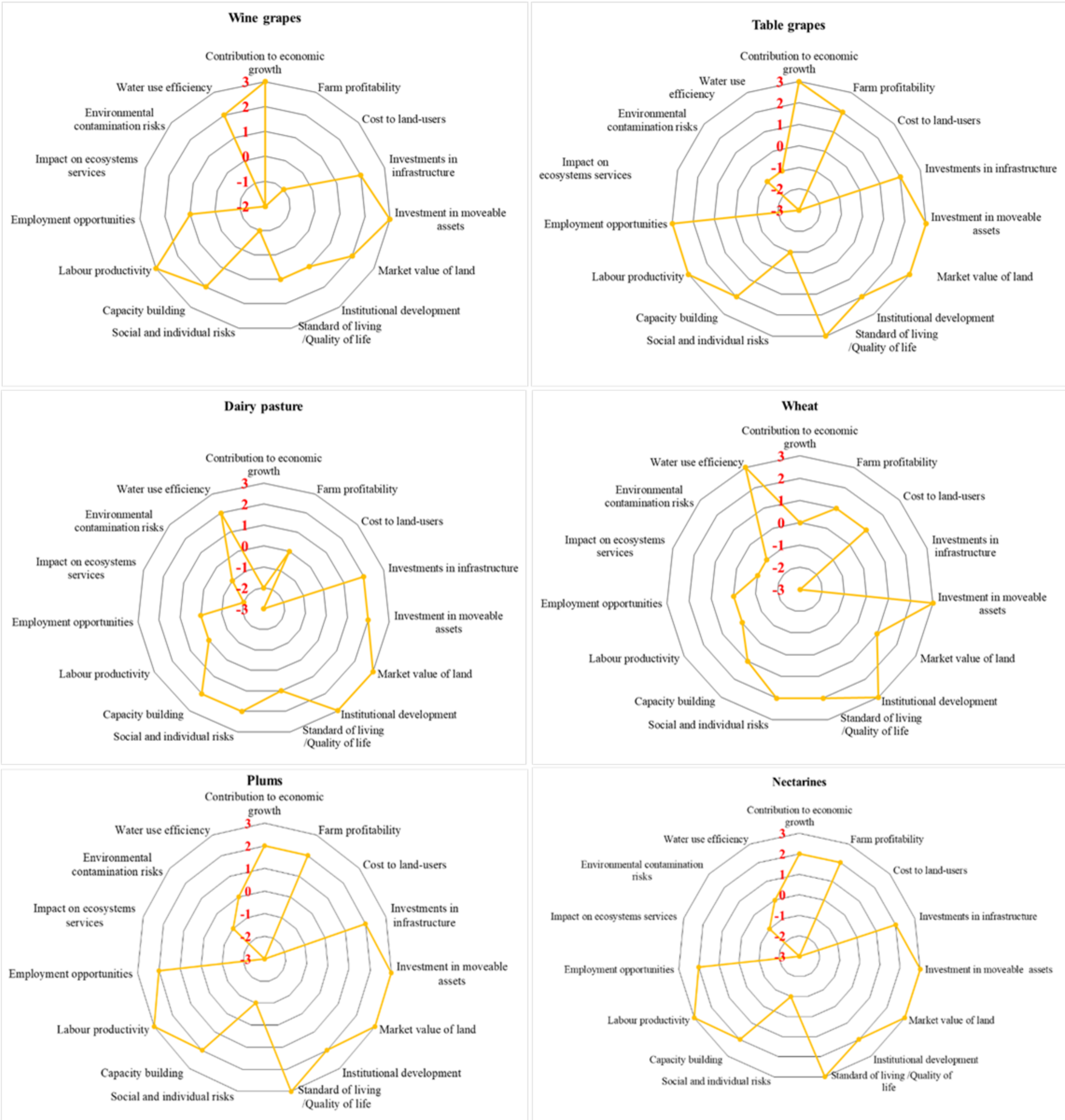


FIGURE 5. 6: INDICATOR SCORES ATTACHED FOR EACH ALTERNATIVE LAND USE OPTION

Source: Own adaptation

5.4.4 Ranking of alternative productive agricultural land use options

After scoring the alternative agricultural land use options, the weighted score for each alternative land use option was determined based on the aggregated scores attached (see Figure 5.6) and the normalised average weights of the criteria indicators (see Figure 5.5). This was calculated using the sum product of the aggregated scores attached to each land use option based on the criteria indicators and the normalised average weights of the criteria indicators. This is important in order to determine the ranking of the alternative agricultural land use options to identify the best use land use option(s) to implement after clearing IAPs. The best use agricultural land use option was found to be table grape farming with a weighted score of 98%, followed by plums and nectarine orchards with an equal weighted score of 94%, wheat farming with 81%, and wine grape farming with 64%, and lastly dairy pasture with 57%. The weighted scores and ranking (shown in red on top of the bars) of the land use options are illustrated in Figure 5.7.

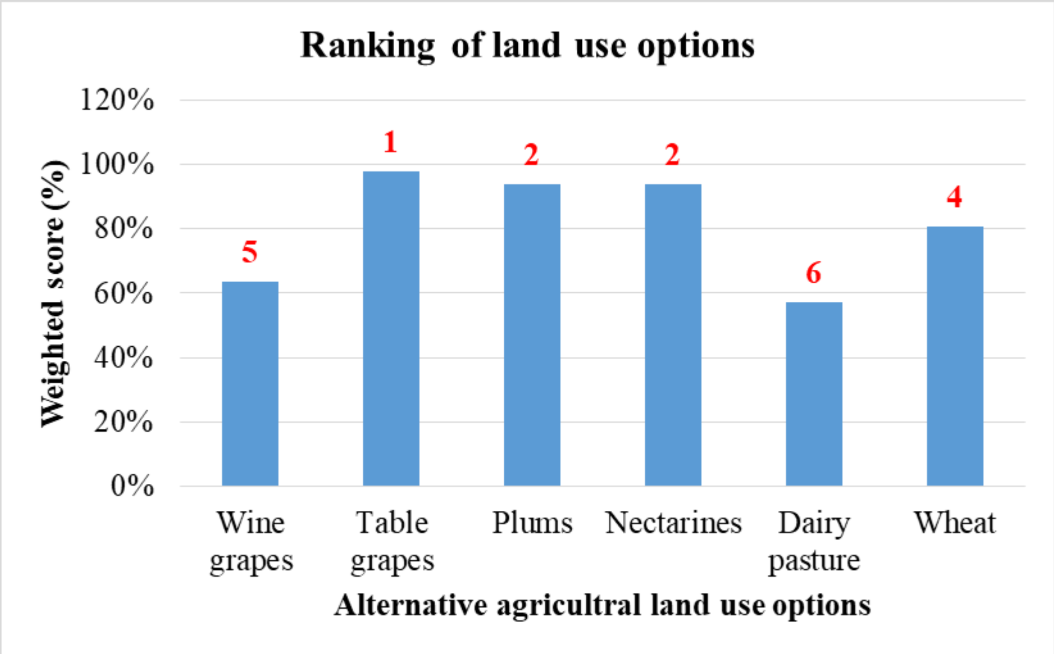


FIGURE 5. 7: FINAL RANKING OF ALTERNATIVE AGRICULTURAL LAND USE OPTIONS CONSIDERED

Source: Own adaptation

5.4.5 Sensitivity analysis

We undertook a sensitivity analysis to test for uncertainties and robustness of the results obtained in this MCDA study in order to build confidence in both the MCDA model used and the results. A sensitivity analysis can be divided into two typologies namely, non-parametric sensitivity analysis and parametric sensitivity analysis (Matos et al. 2012). A non-parametric sensitivity analysis tests for any uncertainties caused by changes in the model structure (e.g. addition or elimination of an indicator in a model) (Matos et al. 2012). In the case of the parametric sensitivity analysis, uncertainties are tested through changing parameter values in the model (e.g. changing score values or normalised average weights) (Matos et al. 2012). In this study, a parametric sensitivity analysis was conducted by modifying the normalised average weights for the criteria indicators through adopting one of the approaches mentioned in Hanan et al. (2013). This was done by assuming that all criteria indicators are of equal importance and as such the 100% cumulative normalised weight was apportioned equally for all 15 indicators (under all the five forms of natural capital) considered in this study. As a result each indicator was allocated a normalised average weight of 6.67%. The sensitivity analysis results of the weighted scores and land use option rankings (shown in red on top of the bars) are illustrated in Figure 5.8.

It is interesting to note that after undertaking the sensitivity analysis, table grape farming still ranked highest (113%), while nectarines and plum orchards still ranked second (107%). The only change noticed was that wine grape and wheat farming became equally ranked (after plum and nectarines orchards) with a weighted score of 80%, whereas in the previous MCDA wheat farming was more preferred to wine grape farming. Last but not least, dairy pasture remained the least ranked alternative agricultural land use option with a weighted score of 60%. Given the aforementioned, we can potentially conclude that the results emanating from the MCDA are robust and that the model might be useful to assist land users and other relevant stakeholders in land use planning decisions after clearing IAPs.

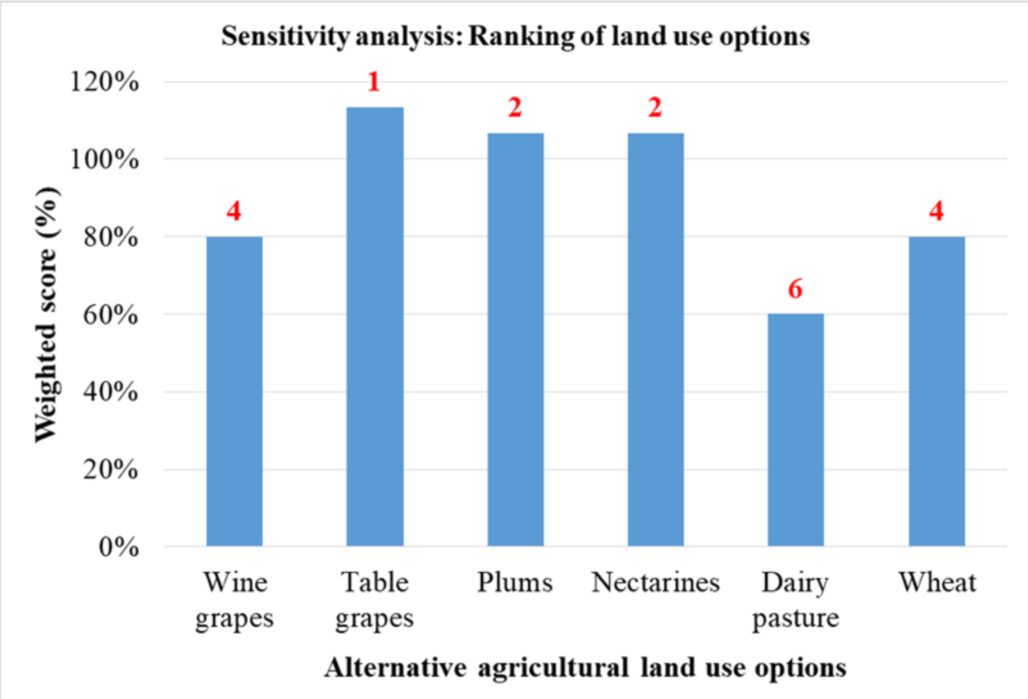


FIGURE 5. 8: SENSITIVITY ANALYSIS

Source: Own adaptation

5.5 Discussion

This study has shown how a MCDA process using a limited number of criteria indicators can be used as a decision aid methodological approach to help land owners, land use policy-makers, environmentalists and other relevant stakeholders to make informed decisions. The MCDA approach followed in this study proved to be a robust and effective way of engaging multiple stakeholders to give their views on important matters that should be considered when faced with land use planning decisions after clearing IAPs. Guided by the literature, it was deemed important to use the five forms of capital (see Aronson et al. 2007) as the main criteria under which indicators were identified, verified and validated (over several rounds of information exchanges) by diverse experts through a Delphi technique process. This added to the confidence in the MCDA model building process conducted in this study. The MCDA approach followed in this study, allowed for both quantitative and qualitative criteria indicators to be amalgamated and objectively assessed. This allowed for the triangulation of data parameters used adding to the confidence of the MCDA process undertaken. Moreover, it is important to note that, for some indicators under social capital, human capital and natural capital, a subjective Likert scale was defined, verified and validated with the help of the expert consultations conducted using the Delphi technique process due to the unavailability of quantitative unit measures to measure the specific indicators. In addition, the use of a subjective Likert scale under such circumstances has been noted in the literature (Wan et al. 2009; Davies et al. 2013). Wan et al. (2009) state that in circumstances under which a criteria cannot be measured quantitatively, the relative importance should be shown using ordinal numbers (here in referred to as the Likert scale) which further added into the confidence of our MCDA model. The MCDA process was made explicit to the workshop panel while at the same time avoiding the use of complicated and ambiguous calculations to process the results. Moreover, the explicit sensitivity analysis conducted (based on Hanan et al. 2013) showed the MCDA results to be robust. As a result, it could be a useful way of cross-checking and reviewing the practicality of the results by experts, the workshop panel, land users and other relevant stakeholders as recommended by Hanan et al. (2013).

The fact that natural capital criteria indicators (each with 8%) were scored highest by the experts under the normalised average weight (see Figure 5) was discussed on completion of consultations with the experts. The experts expressed their concern and displeasure about the negative environmental impacts caused by IAPs. They echoed the sentiment that management options that help to eradicate IAPs are urgently needed since the clearing activities currently funded mainly by the state have failed to bring biological invasions from IAPs under control. The fact that these negative impacts are well reported in literature further justifies the high normalised average weight attached to the aforementioned natural capital indicators. There were mixed feelings about indicators under the other forms of capital (i.e. financial, manufactured, human and social) by experts consulted. Under these criteria some indicators were scored high while others were given a low score (see Figure 5), depending largely on the occupation of the specific expert. The environmentalists and hydrologists gave higher scores for natural capital indicators while giving low scores for the financial and manufactured capital. On the other hand, the economists and agri-business experts gave higher scores for financial and manufactured capital indicators while giving lower scores for the other forms of capital. To dilute this occupational bias, all the scores attached by the diverse experts were aggregated, averaged and normalised to get a weighted average score.

In terms of the ranking of land use options, an expert panel of 12 extension officers (with diverse skills), and agricultural economists from the Western Cape Provincial Government's Department of Agriculture were consulted. All the members considered in the panel were knowledgeable on farming and were well acquainted to the Berg River water management catchment site. Unfortunately, we could not get farmers from the Berg River to participate in the MCDA workshop due to a clash between the workshop date and the busy horticulture harvesting season. Nevertheless, 100% of the panel participants had a strong farming background and understood the principles of agricultural production and farm management well. Upon completion of the MCDA workshop, table grape farming was ranked as the best alternative productive agricultural land use option to implement after clearing IAPs in the Berg River catchment, while dairy pasture was considered to be the least-ranked land use option. In order to test for uncertainties and to build confidence in our MCDA results, we conducted a parametric sensitivity analysis by assuming that all the 15 criteria indicators were of equal importance by apportioning the 100% cumulative normalised average weight equally among all the indicators. Interestingly, we noticed that table grape farming retained the best ranking while dairy pasture retained the least ranking. The only change noted was that wheat farming became equally ranked with wine grapes, were as before, wheat farming was preferred to wine grape farming. Given the aforementioned, our MCDA process proved to be robust.

In general, all the panel members participated well in the workshop and in instances where conflicts were identified, the divergent viewpoints were discussed peacefully and backed with research facts to reach a general consensus. Had there been too many participants (i.e. more than 15), building a consensus would have been difficult especially in instances where the proposed alternative land use options would pose unintended consequences on other panel members' perceptions. Upon completion of the MCDA workshop, the results on the land use ranking were presented and the panel was asked if these were a true reflection of what is possible in the study site. All the panel participants agreed that it was a true reflection of what was possible in the real world scenario.

It is important to note that, despite progress having been made in the control of IAPs in South Africa, the clearing budget funded mostly by the state, is still inadequate. As a result, opportunities that unlock private sector co-financing are urgently needed to help augment the state's IAPs control budget in Berg River and other catchment sites in South Africa. The establishment of value-added industries that use the cleared IAPs biomass (Mudavanhu et al. 2016; Mudavanhu et al. 2017a; Stafford et al. 2017) and the restoration of the cleared land to productive agricultural land use options (Mudavanhu et al. 2017b) offer opportunities that can serve as an incentive to unlock private sector investment in the clearing of IAPs. Given the aforementioned, the MCDA process conducted in this study can potentially serve as a decision aid approach to assist private sector stakeholders in making investment decisions that can potentially augment the state's clearing budget. Moreover, this process also serves to assist land users in making informed land use planning decisions on what best use productive agricultural land use options to implement in the aftermath of clearing IAPs. The interesting fact about the MCDA process, is that the decisions made are not based solely on the financial and manufactured capital indicators which are at most well captured in the market. Instead, externalities classified under natural capital, social capital and human capital (which are in most cases difficult to capture in monetary value due to the absence of markets) are also included in the decision-making process. In most cases, decisions are made without recognising the aforementioned factors (i.e. natural capital, human capital and social capital) which increases the risk of making irrational decisions like the land use planning blunders that led to biological invasions caused by IAPs (see Rouget 2015).

Last but not least, it important to take note of the limitations associated with MCDA processes. In most cases, MCDA methods only allow for eliciting the preferences of small panel groups representing a few relevant stakeholders (Hanley 2001; Saarikoski et al. 2014). As a result, there is a risk of failing to elicit all the preferences by multiple stakeholders across the whole population with diverse and often conflicting interests as highlighted by Hanley (2001). It has also been argued that MCDA is not well suited for dealing with lexicographic preferences[13] (Saarikoski et al. 2014). Given the aforementioned, there is a probability that the results obtained from this MCDA might change if expert panel members with different occupations and opinions (than those in this study) are consulted. Nevertheless, the aim of this MCDA study was not to dictate to decision-makers in the Berg River catchment on what they should do *per se*, but instead to provide them with a decision aid approach that can assist them in making more informed decisions through taking cognisance of the complexity associated with land use planning decisions after clearing IAPs. The aforementioned complexity is made explicit by the causal loop diagram presented earlier in Figure 5.3.

5.6 Conclusions

This study has demonstrated that the MCDA is an effective technique that can help land users, policy-makers and other relevant decision-makers to make more informed land use planning decisions after clearing IAPs. Despite the limitations associated with MCDA methods (see Section 5.5), the results emanating from this study may well be typical of what is possible after clearing IAPs in a real world scenario. All the members included in the workshop panel were knowledgeable on farming and were well acquainted with the Berg River water management catchment site. Moreover, all the workshop panel participants had a strong farming background and understood the principles of agricultural production and farm management well. As an outcome, table grape farming was ranked as the highest best use land use option to implement in the Berg River catchment after clearing IAPs, while dairy pasture was ranked the lowest ranked alternative productive agricultural land use option. These findings were further reinforced by a parametric sensitivity analysis where it was noticed that table grape farming retained the best ranked alternative productive agricultural land use option while dairy pasture retained the rank of being the least preferred land use option, adding to the confidence of our MCDA model results.

We recommend that further research be conducted with MCDA panels and relevant experts on the state land and communal land tenure systems which were not considered in this study. Land use planning decisions are influenced largely by the tenure system. Under communal land tenure systems, where there are no clearly defined property rights, tragedy of the commons risks are likely to occur. In the case of state owned land, the government is likely to favour options that maximise public goods and society wide impacts. In addition, we recommend that this exercise be carried out at other study sites in South

[13] In economics, lexicographic preferences explain comparative preferences in which a particular person prefers any amount of one good (X) to any amount of another (Y).

Africa and in other countries to see if similar findings can be obtained. South Africa is not the only country affected by biological invasions caused by IAPs. Invasions have been reported in Europe, America, Asia and many African countries. Therefore, this study can be used as a benchmark for future similar studies both locally and internationally. Last but not least, we recommend that a similar analysis be conducted for value-added industries that use IAPs biomass to make value-added products, in order to help unlock private sector investment in the clearing of IAPs which is to a greater extent, currently funded mostly by the South African government using tax payers' money.

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5.8 Appendix

TABLE A5. 1: DETAILED DESCRIPTION OF SCORES AND UNIT MEASURES FOR ALL CRITERIA INDICATORS

Criteria 1	**Financial capital**		
Indicators	Contribution to economic growth	Farm profitability	Cost to land users (production costs and other)
Unit Measure	GDP (ZAR)	IRR (%)	ZAR/ha
Score (Likert scale of -3 to 3)	-3: < =ZAR 0 to 0.5 million	-3: < = 0% to 1%	-3: > ZAR 70 000/ha
	-2: >ZAR 0.5 million to 2.5 million	-2: >1% to 2%	-2: >ZAR 55 000/ha to 70 000/ha
	-1: >ZAR 2.5 million to 5 million	-1: >2% to 3.5%	-1: >ZAR 20 000/ha to 55000/ha
	0: >ZAR 5 million to 10 million	0: >3.5% to 4.5%	0: >ZAR 10 000/ha to 20 000/ha
	1: >ZAR10 million to 50 million	1: >5% to 10%	1: >ZAR 5 000/ha to 10 000/ha
	2: >ZAR50 million to 250 million	2: >10% to 20%	2: >ZAR 2 500/ha to 5 000/ha
	3: >ZAR250 million	3: >20%	3: <ZAR 2 500/ha

Criteria 2	**Manufactured Capital (i.e. built capital)**		
Indicators	Investments in infrastructure (fixed assets)	Investment in moveable assets (implements, equipment and vehicles)	Market value of land (i.e. value of land bases on a comparable piece of land being sold on the actual market)
Unit Measure	ZAR	ZAR	ZAR/ha
Score (Likert scale of -3 to 3)	-3: < ZAR 10 000	-3: < ZAR 10 000	-3: <ZAR 2 000/ha
	-2: ZAR 10 000 to ZAR 20 000	-2: ZAR 10 000 to 20 000	-2: >ZAR 2 000/ha to 5 000/ha
	-1: >ZAR 20 000 to ZAR 25 000	-1: >ZAR 20 000 to 25 000	-1: >ZAR 5 000/ha to10 000/ha
	0: >ZAR 25 000 to ZAR 50 000	0: >ZAR 25 000 to 50 000	0: >ZAR 10 000/ha to 20 000/ha
	1: >ZAR 50 000 to ZAR 100 000	1: >ZAR 50 000 to 100 000	1: >ZAR 20 000/ha to 45 000/ha

	2: >ZAR 100 000 to ZAR 500 000	2: >ZAR 100 000 to 500 000	2: >ZAR 45 000/ha to 80 000/ha
	3: >ZAR 500 000	3: >ZAR 500 000	3: >ZAR 80 000/ha
Criteria 3	**Social Capital (i.e. value & trust systems and social networks)**		
Indicators	Institutional development (the development of networks, social cohesion, trust and value systems)	Standard of living (or quality of life)	Social and individual risks (health risks due to exposure of agro-chemicals, crime, exploitation, incidence, etc.)
Unit Measure	Likert scale -3 to 3 (-3 least desirable and 3 most desirable)	Likert scale -3 to 3 (-3 least desirable and 3 most desirable)	Likert scale -3 to 3 (-3 least desirable and 3 most desirable)
Score (Likert scale of -3 to 3)	-3: Will reduce institutional development considerably	-3: Will reduce the standard of living considerably	-3: Will increase the social and individual risks considerably
	-2: Will reduce institutional development moderately	-2: Will reduce the standard of living moderately	-2: Will increase the social and individual risks moderately
	-1:Will reduce institutional development slightly	-1: Will reduce the standard of living slightly	-1: Will increase the social and individual risks slightly
	0: No impact on institutional development	0: No impact on the standard of living	0: No impact on the social and individual risks
	1: Will improve institutional development slightly	1: Will improve the standard of living slightly	1: Will reduce the social and individual risks slightly
	2: Will improve institutional development moderate	2: Will improve the standard of living moderate	2: Will reduce the social and individual risks moderate
	3: Will improve institutional development considerably	3: Will improve the standard of living considerably	3: Will reduce the social and individual risks considerably
Criteria 4	**Human Capital (i.e. man power and cognitive capacity)**		
Indicators	Capacity building (education and skills training)	Labour productivity (i.e. output/per person employed)	Employment opportunities
Unit Measure	Likert scale -3 to 3 (-3 least desirable to 3 most desirable)	Likert scale -3 to 3 (-3 least desirable to 3 most desirable)	Number of jobs
Score (Likert scale of -3 to 3)	-3: Will reduce capacity building considerably	-3: Will reduce labour productivity considerably	-3: <100 jobs
	-2: Will reduce capacity building moderately	-2: Will reduce labour productivity moderately	-2: >100 jobs to 150 jobs
	-1: Will reduce capacity building slightly	-1: Will reduce labour productivity slightly	-1: >150 jobs to 200 jobs
	0: No impact on capacity building	0: No impact on labour productivity	0: >200 jobs to 250 jobs
	1: Will improve capacity building slightly	1: Will improve labour productivity slightly	1: >250 jobs to 500 jobs
	2. Will improve capacity building moderate	2: Will improve labour productivity moderate	2: >500 jobs to 1000 jobs

	3. Will improve capacity building considerably	3: Will improve labour productivity considerably	3: > 1 000 jobs
Criteria 5	**Natural Capital (i.e. natural resources and ecosystem goods and services)**		
Indicators	Impact on ecosystems services (i.e. provisioning, regulating, cultural, supporting and habitat services)	Environmental contamination risks (i.e. air pollution, water contamination and other)	Water use efficiency (i.e. biomass production per unit of water consumed)
Unit Measure	Likert scale -3 to 3 (-3 least desirable to 3 most desirable)	Likert scale -3 to 3 (-3 least desirable to 3 most desirable)	Kg per m^3
Score (Likert scale of -3 to 3)	-3: Will reduce ecosystem services considerably	-3: Will increase environmental contamination considerably	-3: <1 kg/m^3
	-2: Will reduce ecosystem services moderately	-2: Will increase environmental contamination moderately	-2: >1 Kg/m^3 to 2 kg/m^3
	-1: Will reduce ecosystem services slightly	-1: Will increase environmental contamination slightly	-1: >2 kg/m^3 to 5 kg/m^3
	0: No impact on ecosystem services	0: No impact on environmental contamination	0: >5 kg/m^3 to 10 kg/^{m3}
	1: Will increase ecosystem services slightly	1: Will reduce environmental contamination slightly	1: >10 kg/m^3 to 20kg/m^3
	2: Will increase ecosystem services moderate	2: Will reduce environmental contamination moderately	2: >20 kg/m^3 to 30kg/m^3
	3: Will increase ecosystem services considerably	3: Will reduce environmental contamination considerably	3: >30 kg/m^3

Source: Own adaptation

NB. ZAR stands for the South African Rand currency, > means greater than, < means less than, < = means less than or equal to, Kg stands for Kilograms, ZAR/ha means Rands per hectare, IRR stands for Internal Rate of Return and m^3 stands for Cubic metres.

Chapter 6

Summary, conclusions, limitations and recommendations

6.1 Summary and conclusions

The main aim of this research was to lay out a road map of the potential land use types and value added industries that can be implemented post the clearing of IAPs. In addition, the study intended to explore potential and feasible prospective management options. To achieve this seven specific research objectives were formulated and pursued as presented earlier in section 1.3. Models that assess the economic, environmental and social impacts associated with the clearing of IAPs and land use planning decisions were developed using system dynamics modelling and a multi-criteria decision analysis approach. The purpose of developing the aforementioned models was two pronged. Firstly they were developed in order to assist decision makers in understanding the economic, social and environmental impacts of the prospective future, desirable and sustainable, land use on restored land, within different contexts and tenure systems. This is imperative in guiding policymakers, land owners/users, environmentalists and other relevant stakeholders in considering the best land use trajectory, inclusive of externalities, post the clearing of IAPs, whilst embracing a process of restoration over time. Secondly, the models were developed in order to aid stakeholders in identifying the key decision-rules that should guide decision-making when selecting the best land use options under various contexts, within the aforementioned complex and dynamic system.

Chapter 1 of this dissertation presents the background to the study, problem statement, study objectives and the research methodology. A brief but comprehensive review of IAPs literature was conducted, with the ultimate goal of explicitly ascertaining the meaning of IAPs, the reasons why they are a problem in South Africa and the factors warranting the need for IAPs to be controlled. In addition, the aforementioned review was conducted in order to identify the current legislative policies and instruments governing the control of IAPs in South Africa. Lastly, an overview of IAPs studies was undertaken to identify research gaps in the body of knowledge. It has emerged that most of the studies conducted to date on IAPs (in South Africa) have mainly focused on passive restoration which involves the clearing of IAPs and then leaving the cleared land fallow so that it can naturally recover to a state similar to what it was before the invasion by alien plants. However, to the contrary, it has been noted that after a period of time has lapsed, most of the areas previously cleared from IAPs became invaded again posing the risk of a re-bound of the negative impacts caused by these invasive alien plants. Thus transforming these areas into some productive land use systems was seen as a potentially viable option to help eradicate the re-invasion of the areas that have been cleared. Knowledge gaps have been identified with respect to the fate of habitats that have undergone IAPs clearing by the Working for Water programme.

In chapter 2, an assessment of the costs and benefits of using *Acacia saligna* (Port Jackson) and recycled thermoplastics for the production of wood polymer composites (WPCs) in the Western Cape province, South Africa was undertaken. In this chapter the costs and benefits of using IAPs (specifically *Acacia saligna*) and recycled thermoplastic waste for the production of WPCs in the Western Cape Province of South Africa were assessed. This was done by means of a custom built system dynamics model (i.e. the PORTTHERM-WPC model) simulated under different scenarios (see section 2.3.2). The importance for integrated reporting was also emphasised. As a result, both private and social costs (and benefits) emanating from the production of WPCs were considered in the analysis. In addition, the dynamic behaviour of environmental, social and economic systems over time for several scenarios was investigated. This analysis was deemed cruicial as it helps decision-makers and relevant stakeholders in foreseeing opportunities and threats, adapt to change and be well prepared for any possible adverse consequence. The results of the PORTTHERM-WPC simulation indicate that the clearing of *Acacia saligna* and utilising the biomass resulting thereof to make WPCs value-added products, is economically viable. There is therefore an opportunity cost implication should nothing be done to add value to the cleared IAPs biomass.

Chapter 3 focussed on the economic analysis of different productive agricultural land use options as a strategy to assist in the control of *Prosopis* (Mesquite) in the Orange River water management areas in the Northern Cape province. In this chapter, the contribution of alternative productive agricultural land-use options following clearing of IAPs with the objective to control and inhibit the re-growth of *Prosopis spp* in the Northern Cape province was assessed. The Orange River quaternary catchment was the water management area under focus for this assessment. Another custom built system dynamics model (i.e. the PROLAND-model) was developed for this purpose. Four scenarios (see section 3.3.2.2) were developed to assess the impact of clearing *Prosopis spp* and converting the cleared land to four land-use options (i.e. table grapes, raisins, citrus and natural vegetation) over a 23 year (2008–2030) simulation period. It was shown that clearing *Prosopis spp* and restoring the cleared land for agricultural land-use options is a potentially cost-effective strategy for controlling invasive *Prosopis spp*.

Chapter 4 investigates the opportunity cost (i.e. the cost of doing nothing) of not restoring land that has been cleared of IAPs in the Western Cape province, South Africa. In addition, an integrated assessment (i.e. both private and externality) of costs and benefits of clearing IAPs, restoring the cleared land to productive agricultural land use options and transforming the cleared biomass into VAPs was also undertaken. In this chapter, two sites namely the Berg River quaternary catchment water management area and the Citrusdal site under the Olifants River quaternary catchment water management area were the focus of this investigation. The BERGCITRUS land use planning & VAPs-model was used as the analytical framework. Five main scenarios (see section 4.2.3.3) were developed with three having an "a" and "b" part to investigate the presence of any uncertainties that might arise from the envisaged he model simulation and the respective policy implications. It was shown that there potentially is a high opportunity cost incurred as a result of late restoration of land cleared of IAPs (see section 4.3.9). In this chapter it is alluded that early private sector co-finance, production of VAPs and restoration of cleared land to productive agricultural land use options may be a better management option as opposed to just waiting to take action when the land has been severely degraded.

In chapter 5 a multi-criteria decision analysis is presented for assisting land owners and other relevant stakeholders in making land use planning decisions following the clearing IAPs in Berg River quaternary catchment water management area in the Western Cape province, South Africa. An MCDA model was developed following a Delphi technique approach in the form of independent multi-stakeholder expert consultation interviews (in several rounds) and a workshop panel. The MCDA was conducted to serve as a decision support mechanism to assist decision makers in identifying prospective agricultural land use options that can be implemented after the clearing of IAPs. This was deemed imperative for guiding policy-makers, land users and relevant stakeholders in formulating effective land use planning frameworks and policies, as well as identifying the best sustainable land use options applicable post clearing IAPs. It was shown that the information generated by the MCDA model can potentially assist and connect diverse stakeholder groups in their land use planning decision-making processes.

While the system dynamics modelling approach and multiple criteria decision analysis are well-known in various interdisciplinary fields of study (such as engineering, economics, epidemiology, urban and regional planning and so forth), it has not been used much in the economics of natural capital restoration studies in South Africa. There are few exceptions however (e.g. Crookes, 2012; Crookes et al., 2013; Nkambule, 2015). Moreover no comprehensive research has been undertaken to ascertain the land use types that can be implemented after the restoration of natural capital through the clearing of IAPs using a combination of system dynamics modelling and multiple criteria decision analysis. As such this study is one of the first of its kind (from an agricultural economics discipline within the South African context). It is anticipated that this will pave the way for many such future studies. The objectives of this study have been attained and some knowledge gaps in understanding the dynamics of restoration have been filled. This study is novel in various ways which are summarised below:

- It has been shown that there is a significantly high opportunity cost of not restoring land that is cleared from IAPs in South Africa (i.e. the do nothing approach) *inter alia* an integrated economic assessment of benefits and costs that includes externalities. In most cases, economic assessments in agriculture are conducted utilising only the private costs and benefits (whilst ignoring the external costs and benefits). This study has contributed to filling knowledge gaps in this regard.
- Comprehensive studies exploring the joint complexity involved in land use planning decisions and IAPs clearing management options from a South African context could not be found. This study therefore aimed to close that knowledge gap by explicitly outlining these complexities through the use of qualitative system dynamics models (i.e. causal loop diagrams) and simulated custom built system dynamics models. There are significant merits with the modelling approaches used in this study given that the conventional mental models available are often limited and only consider few system elements at any given point in time.
- This study is the first of its kind in South Africa, to undertake an integrated economic feasibility assessment (inclusive of externalities) of utilising IAPs biomass to manufacture wood polymer composites. Most studies (see section 2.1) done to date have focussed mainly on the tensile strength of various combinations inputs in the WPC production process and the science regarding WPCs whilst ignoring the economic feasibility analysis. Unique to this study is that it addresses these deficiencies within the current body of knowledge.
- Studies that identify the best-use agricultural land use options post the clearing of IAPs in South Africa using a multi-criteria decision analysis could not be found. In most cases, land use planning decisions are influenced by factors that are valued in different units. Moreover, some of the factors are often qualitative and difficult to quantify. Consequently, most decisions tend to be counterproductive and flawed due to a failure to incorporate all elements affecting the decision making process. This study has therefore attempted to address these limitations and deficiencies in the South African context.
- To date the clearing of IAPs has been funded mainly by the state through the Working for Water programme. Currently, there are no incentives for the private sector to help co-finance and augment the state's (i.e. Working for Water) clearing budget. The economic feasibility assessments (subject to various scenarios) conducted in this study show that restoration of land cleared of IAPs to productive agricultural land use options as well as the utilisation of the cleared IAPs biomass to make VAPs is viable and profitable. These findings can therefore motivate the incentivisation of the establishment of value added industries and agricultural enterprises by the private sector stakeholders in order to assist the government in clearing IAPs.
- This study is also the first of its kind to layout a road map in the form of a conceptual framework (see section 6.3). The aim here is to assist decision makers in making sustainable land use planning decisions post the of clearing IAPs. Therefore should the proposed conceptual framework, be applied in real world decision making processes, the state, land owners and relevant stakeholders affected by IAPs can be guided in making rigorous and more robust land use planning decisions. This will help avoid further sub-optimisation of land use and financial resources post the clearing of IAPs whilst avoiding the need for follow up clearing operations.

6.2 Limitations of the study

While models are theoretical and sometimes premised on debatable assumptions, they are still very useful. It is therefore important to clarify the limitations of models adopted in this study. While the system dynamics models used here attempt to capture all the major system elements of IAPs clearing operations and their interaction with socio-economic and environmental aspects, not all elements and aspects were incorporated into the computer simulation. In addition, the MCDA model developed in this study captures only a limited number of criteria indicators. The major shortcomings of the models include:

- The omission of other important elements that could potentially influence the model outputs due to a lack of adequate data, such as the allelopathy effects, soil carbon and illegal planting of IAPs all of which are associated with IAPs impacts in the system dynamics simulation models.
- The adjustment for inflation of agricultural enterprise data and VAPs production costs data using the Producer Price Index may potentially underestimate the true cost values of variables in the system dynamics models. This can be attributed to other non-production based impacts such as drought, disease outbreaks, exchange rate fluctuations, supply bottlenecks and other unforeseen events.
- In most cases, MCDA methods only allow for eliciting the preferences of small panel groups representing a few relevant stakeholders (Hanley 2001; Saarikoski et al. 2014). There is therefore a risk of failing to elicit all the preferences by multiple stakeholders across the whole population with diverse and often conflicting interests as highlighted by Hanley (2001). Given the aforementioned, there is a possibility that the results obtained from the MCDA model may differ if the views and inputs of respondents with opinions and assumptions that differ from those used in this study are considered. It is recommended that multiple MCDA exercises be conducted with more workshop panels of diverse expertise and knowledge on the multiple aspects of AIPs and their management in order to gain a better understanding of how diverse groups perceive and rank decision making options based on multiple criteria.
- This research was limited to four study sites in two of the nine provinces of in South Africa. In many cases, factors influencing the restoration of natural capital through the clearing of IAPs differ from place to place at both spatial and temporal scales. Therefore model results presented herewith should not be regarded as a "one size fits all" solution for all scenarios. Thus decision-makers in study sites other than those mentioned in this dissertation should replicate the analysis undertaken here and tailor it according to what is possible and applicable in their respective geographical locations.

6.3 Recommendations

As evidenced previously in Chapter 5, the consequences of poor land use planning decision making were shown. This is in keeping up with what is widely recognised in literature that the absence of land use planning frameworks leads to sub-optimisation of agricultural land and unsustainable development. Therefore, careful land use planning is key in order to reduce the negative effects resulting from biological invasions caused by IAPs in the terrestrial biomes of South Africa (Rouget, 2015) and elsewhere. No study was found, that is relevant to the South African context, which presents a conceptual framework to assist land owners in choosing what land use options to implement post the clearing IAPs. Most studies have mainly focused on the control methods of IAPs, their effects in various biomes as well as ecology and distribution while few have touched on cost benefit analysis of clearing IAPs. In light of the theoretical knowledge gap with respect to land use optimisation with a view to maximise the sustainable exploitation of public goods (under various land tenure systems) findings from this study as well as the conceptual framework developed herein are relevant and highly recommended for guiding decision making post the clearing of IAPs. This framework is highly recommended for use as a guide that can assist land owners in choosing the best-use agricultural land use types and management options post the clearing of IAPs. This is important to prevent future sub-optimal land use post the clearing of IAPs.

The proposed conceptual framework presented herewith is summarised into five main steps. The five different steps are discussed below and illustrated in Figure 6.1.

The first step of the framework involves the tenure of the land. Land tenure can be summarised into a three part structure consisting of privately owned land, communally owned land and state owned land. Land tenure is an important factor in land use planning as it prescribes the rules and constrains pertaining the potential land use options that can be adopted post the clearing of IAPs. In most cases, the land use objectives differ across land tenure systems. Consequently, the aforementioned rules and constraints can potentially pose an impact on the results of a multi-criteria analysis (see step 3).

Having understood the land tenure of a piece of cleared land, step two focuses on the baseline (i.e. existing) ecosystem goods and services available on the land post clearing of IAPs. In order to determine the aforementioned baseline, it is important to conduct a quantitative analysis of the current stocks and flows on both a temporal and spatial scale. In addition, this will make it easier to derive a risk profile emanating from the deleterious impacts caused by IAPs and other human activities on the cleared land. Land use planning decisions in the developing world are complex (Belton and Stewart, 2002). Having derived the risk profile, whatever happens on the land post the clearing of IAPs has the potential to either decrease or increase the aforementioned risks. This is key in land use planning in order to avoid any sub-optimal land use in future.

Step three of the conceptual framework involves risk mitigation strategies post the clearing of IAPs subject to the land use objectives. This is the entry stage for a multi-criteria decision analysis as a decision aid tool for land users, policy makers, NGOs and relevant stakeholders to assist in making informed choices on the most appropriate land use options to adopt. Therefore, it equally important to understand the land use goals post the clearing of IAPs and the criteria to use when ranking the available land use options after clearing IAPs. In terms of the criteria, it is recommended that the five forms of capital (i.e. natural, social, human, manufactured and financial capital) be considered as the point of departure. This will enable classification of the various complex interrelated elements and dynamics, into a more simplified model in order to avoid the risk of double counting.

Step four looks at the financial feasibility making use of an integrated cost benefit analysis (CBA). In this step the intergrated costs and benefits (i.e. both private and external) of the alternative land use options are taken into account. This is important to ensure that externality effects that are quantifiable in monetary terms are incorporated in agricultural enterprise financial analyses. In most cases, various land use options often pose externalities that are usually ignored or even go unnoticed as a result of externalities not being captured in agricultural financial records. Thus an integrated CBA addresses the aforementioned shortcomings, leading to the cognisance of externalities within agricultural financial record keeping systems. Therefore, the environmental footprint of the diverse land use options adopted post clearing can actually be assessed leading to better informed decision making by land users and relevant stakeholders.

The final step proposed in the conceptual framework is that of incentive packages. From a South African perspective, funding for IAP clearing is a major limiting factor, with most of the money sponsored by the government. The other stakeholders need incentives in order to co-finance the clearing of IAPs. Thus ways to incentivise and attract private co-finance for clearing operations should be investigated. Overall, from a land-use planning perspective, the incentives should promote those land use options and management options that maximise the sustainable utilization of public goods (i.e. externality benefits). This is imperative because it is public funds (through the state's Working for Water programme) that is funding most of the clearing operations.

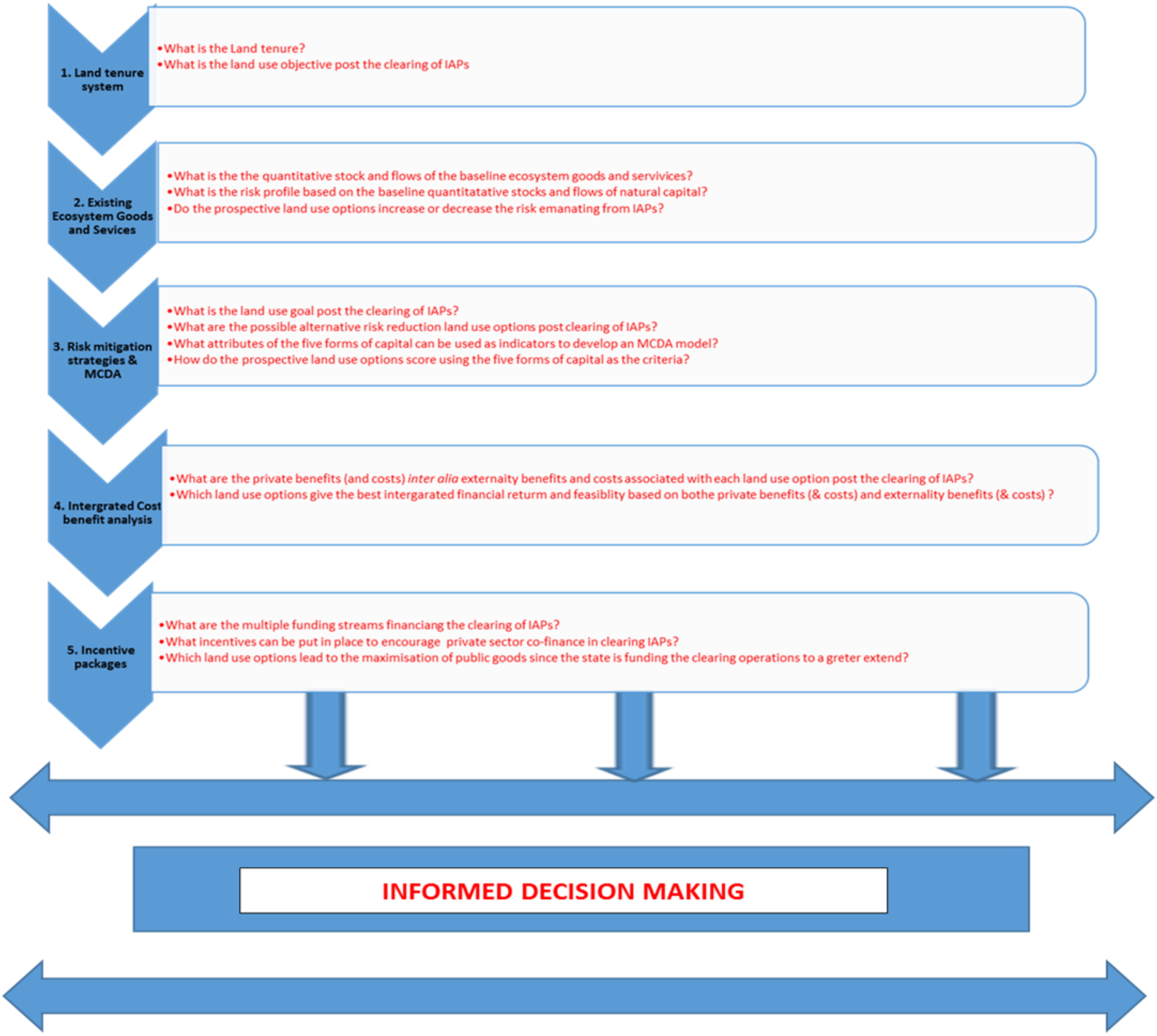

FIGURE 6. 1: PROPOSED CONCEPTUAL FRAMEWORK TO ASSIST LAND OWNERS AND USERS (AND OTHER RELEVANT STAKEHOLDERS) IN MAKING INFORMED LAND USE PLANNING DECISIONS AFTER THE CLEARING OF IAPS IN SOUTH AFRICA.

Source: Own Analysis

Having undertaken and adopted the aforementioned five steps in the above proposed land use planning conceptual framework (post the clearing of IAPs) for South Africa, decision makers should be able to make better informed decisions. As mentioned earlier (in section 5.1), land use planning decisions in the developing world are complex (Belton and Stewart, 2002). This proposed framework can potentially help to assist land owners and users, policy makers, NGOs and other relevant stakeholders to make better informed land use planning decisions in the aftermath of clearing IAPs.

6.4 References

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