MODELLING THE WATER-BIODIVERSITY NEXUS IN FOUR SOUTH AFRICAN PROVINCES

NORTHERN CAPE, EASTERN CAPE, WESTERN CAPE & LIMPOPO

forestry, fisheries & the environment

Department:
Forestry, Fisheries and the Environment
REPUBLIC OF SOUTH AFRICA

PAGE

The report is published as part of the Partnership for Action on Green Economy (PAGE) – an initiative by the United Nations Environment Programme (UNEP), the International Labour Organization (ILO), the United Nations Development Programme (UNDP), the United Nations Industrial Development Organization (UNIDO) and the United Nations Institute for Training and Research (UNITAR).

Citation

PAGE (2022), Modelling the Water-biodiversity Nexus in four South African Provinces: Northern Cape, Eastern Cape, Western Cape and Limpopo – Technical Report

Disclaimer

Acknowledgements

Representatives of the following institutions contributed to the project:

Department of Forestry, Fisheries and the Environment
- Jenitha Badul (Senior Policy Advisor/Director: Sustainability Programmes and Projects, & Chair of the PAGE National Steering Committee)
- Leanne Richards (Deputy Director - Sustainability Programmes and Projects)
- Elizabeth Ntoyi (Assistant Director - Sustainability Programmes and Projects)
- Anam Ngoma (Project Administrator - Sustainability Programmes and Projects)

Department of Science and Innovation
- Henry Roman (Director: Environmental Services and Technologies & member of the PAGE National Steering Committee)

Stellenbosch University
- Josephine Musango (Team Leader, Modelling and report preparation)
- Benjamin Batinge (Modelling and report preparation)

KnowlEdge
- Andrea Bassi (Modelling and report preparation)
- Georg Pallaske (Modelling and report preparation)

United Nations Environment Programme
- Jamal Srouji (Affiliated expert)
- Yaxuan Chen (Affiliated expert)
- Joseph Peissel (Affiliated expert)
- Luciana Fontes de Meira (Programme Management, Officer Economic and Trade Policy Unit)
- Pak Yin Choi (Economic and Trade Policy Unit Intern)
- Gaia Falabella (Economic and Trade Policy Unit Intern)

International Labor Organization
- Siyanda Siko (Secretariat PAGE South Africa)

In addition, the following stakeholders were also consulted:

Department of Forestry, Fisheries and the Environment
- Kent Buchanan
- Lindiwe Chauke
- Noko Mathatho

Department of Planning Monitoring and Evaluation
- Noluthando Qwelani

Western Cape Government
- Ronald Mukanya

Limpopo Economic Development Environment and Tourism
- Tinyiko Petunia Malungani

United Nations Environment Programme
- Isabel Zitha

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ)
- Nondumiso Dumakude

Water Research Commission
- Chantal Kotze

The application of the methodology and the preparation of the Report has been undertaken by Dr. Andrea M. Bassi, Prof. Josephine K. Musango, Georg Pallaske, and Dr. Batinge of the University of Stellenbosch, South Africa.

PAGE gratefully acknowledges the support of all its funding partners: European Union, Finland, Germany, Norway, Republic of Korea, Sweden, Switzerland and the United Arab Emirates.

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

BAU	Business-As-Usual
BAUec	Business-As-Usual excluding Climate Change impacts
CLD	Causal Loop Diagram
DFFE	Department of Forestry, Fisheries and the Environment
EC	Eastern Cape
ECBCP	Eastern Cape Biodiversity Conservation Plan
GE	Green Economy
GRP	Gross Regional Product
IAS	Invasive Alien Species
LP	Limpopo Province
LCPv2	Limpopo Conservation Plan v2
LULUC	Land Use and Land Use Change
Mg/L	Milligram per liter
N	Nitrogen
NC	Northern Cape
NIWIS	National Integrated Water Information System
O&M	Operations and Maintenance
PAGE	Partnership for Action on the Green Economy
SAGEM	South Africa Green Economy Modelling
SANBI	South African National Biodiversity Institute
UN	United Nations
UNEP	United Nations Environment Programme
WC	Western Cape
WWTF	Wastewater Treatment Facility

GLOSSARY OF TERMS

Aquifer	Body of porous rock or sediment saturated with groundwater**.**
Balancing loops	Represented by **circles** of cause and effects in which a change is countered by a push in the opposite direction.
Bioregion	Region whose limits are naturally defined by topographic and biological features (such as mountain ranges and ecosystems)**.**
Calibration	The process of setting model parameter values to reflect an actual case (or specific hypothetical conditions of interest).
Causal link	An arrow in a causal loop diagram or system structure diagram that describes a relationship between two variables with the direction of causality (from cause variable to impacted variable) and the nature of impact (same direction of change or opposite direction of change).
Causal link polarity	A positive (+) or negative (–) sign that indicates the direction of impact of the driving variable on the driven variable. Positive polarity indicates that the impacted variable moves in the same direction (increase or decrease) as the driving variable. Negative polarity indicates that the impacted variable moves in the opposite direction (increase or decrease) to the driving variable.
Causal loop diagram	A tool that represents closed loops of cause–effect linkages (causal links) as a diagram intended to capture how the system variables interrelate and how external variables impact them.
Gross Regional Product	A statistic that measures the size of a region's economy.
Parameters	Constant factors in relationships in a model.
Reinforcing loops	Loops that amplify change in the system.
Reinforcing feedback loop	A feedback loop in which the sum effect of the causal links tends to strengthen (reinforce) the movement of variable values in each direction.
Stranded land	Stranded land is arable land that cannot be cultivated, because of the lack of water. In other words, if water is used in an inefficient way, a small area of land can be cultivated. If water is used efficiently, a larger area of land can be irrigated and cultivated.
Systems dynamics approach	The use of conceptual system models and other tools to improve the understanding of how the feedback, delays and decision-making policies in a system's structure generate the system's behaviour over time.

EXECUTIVE SUMMARY

Water is an essential driver for quality of life and economic growth; however, in terms of international standards[1] South Africa is considered to face medium-high water stress. The country receives 450mm of average annual rainfall, compared to the global average of 860mm. The spatial distribution of water resources has always been skewed due to highly unpredictable rainfall (Mwendera & Atyosi, 2018). According to the 2018 National Biodiversity Assessment, at least 79% of wetland ecosystems in South Africa are in danger. Of these, 48% of wetland ecosystem types are critically endangered, 12% are endangered, and 5% are vulnerable (SANBI, 2019), making it the most threatened of all the ecosystems (SANBI, 2013). This poses challenging issues in relation to access to water and implications for sustenance of life overall.

With the support from the Department of Forestry, Fisheries, and the Environment (DFFE), the Stellenbosch University and KnowlEdge®, this report is published under the Partnership for Action on Green Economy (PAGE) and commissioned by the United Nations Environment Programme (UNEP). The report analyses the interactions between water and biodiversity parameters using a system dynamics model on the Water-Biodiversity nexus in four South African provinces: Eastern Cape, Limpopo, Northern Cape, and Western Cape. Ultimately, this technical report aims to strengthen the knowledge base for high-level policy- and decision- makers in governments for informed, evidence-based decision-making with a set of quantitative policy-relevant findings and a wide range of policy options and solutions in creating the enabling environment of sustainable water management and freshwater biodiversity conservation.

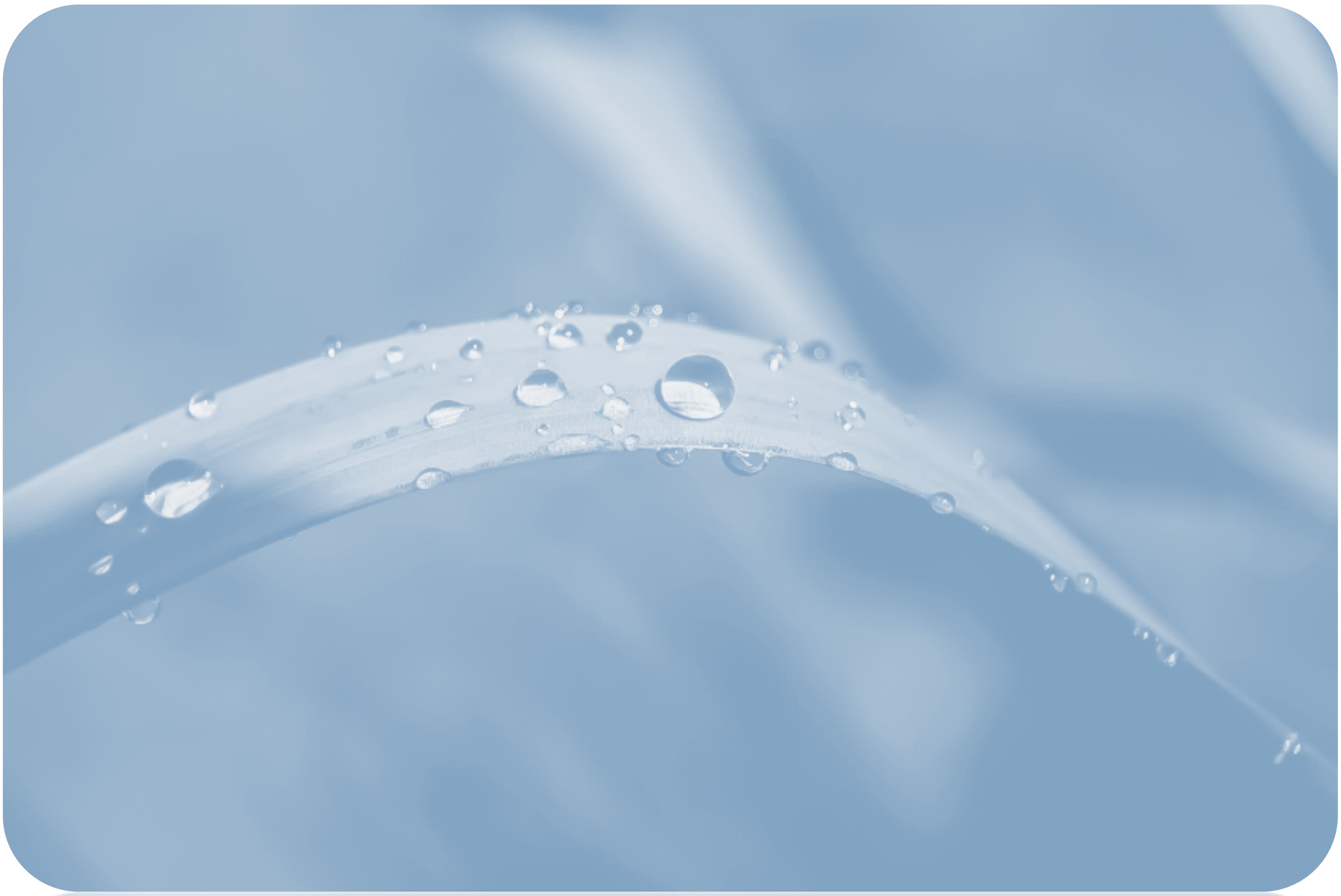
The models demonstrate the effect of green economy policies on the Water-Biodiversity interlinkage, focusing on i) water demand and supply, ii) climate and weather, iii) land use and invasive alien species, and iv) agriculture. It also considers water harvesting, water quality and quantity, water treatment, water effluent quality, water losses, and consumption by invasive alien species. The methodology of this report aims to highlight the role of feedback loops in shaping future development, alongside contributing to analysing trade-offs and potential undesired policy side-effects. In this connection, causal loop diagrams are designed to serve two purposes: (i) illustrate the dynamic interplay between the key indicators that constitute the system, and (ii) represent information about the system on different levels of aggregation and dimensions that allows exploring circular relations or feedback within and between them.

The report also discusses modules/sub-models – macro environment, land use and land use change, water demand and supply, agriculture, and wastewater and nitrogen (N) loadings – at the provincial level. The provincial modules are the key elements for unpacking the issues related to the interconnections between water and biodiversity. The provincial assessments of the water and biodiversity are conducted using scenario analysis. The scenarios simulated are the business-as-usual (BAU) scenario and a Green Economy (GE) scenario. While the former serves as the baseline for assessing the impacts of GE policy interventions on key indicators, the latter assumes the simultaneous implementation of the proposed interventions. As a simplified representation of reality, the model does not intend to predict all future environmental changes in South Africa, and some recent empirical observations may diverge from the modelling assumptions. However, some significant findings can be taken from the analysis of provincial models: (i) Climate impacts in the BAU scenario cause precipitation to decline across all provinces, except for the Western Cape; (ii) Changes in rainfall and evapotranspiration affect the total amount of available renewable freshwater resources on a provincial level, despite the increasing trend in precipitation in the Western Cape, and (iii) the availability of water resources affects provincial value added by assuming that a shortage of water leads to reductions in Gross Regional Product (GRP).

[1] See Global Rank of Water Stress Countries by the World Resources Institute: https://www.wri.org/insights/17-countries-home-one-quarter-worlds-population-face-extremely-high-water-stress

For the provincial Water-Biodiversity analysis, the macroeconomic drivers, water demand and supply, irrigation water losses, water absorbed by invasive alien species, agriculture, wastewater treatment and N loadings, and cost of interventions are covered. In short, the result under the BAU and GE scenarios shows GRP growth will increase in both instances across all provinces by 2040. However, higher growth will be recorded under the GE scenario where the water stress is reduced owing to usage efficiency and proper irrigation practices. Western Cape will record the highest GPR growth, and the highest population increase, by 2040. The reductions in water stress by 2040 range from 0.7% in Western Cape to 18.3% in Eastern Cape. This indicates that the provinces would benefit from implementing water efficiency measures. Under the GE scenario, water efficiency measures reduce total water demand below 2019 levels, in all provinces. Secondly, invasive alien species (IAS) affect surface water runoff. When IAS land is cleared under the GE scenario, the water runoff improves relative to the BAU scenario. The move for more efficient irrigation systems in the GE scenario results in reduced losses from irrigation by 22.3% in all provinces compared to the BAU scenario. Lastly, from the projections, Western Cape will require the highest investment to realize the GE scenario target for irrigation and clearing IAS.

To ensure uptake and relevance of analyses results obtained from this assessment, key areas of action and the corresponding guiding principles by modules presented in this paper are suggested for policy- and decision- makers in government to simulate the GE scenario. Note that the recommendations suggested in Section 3 of this report, are at two levels. At the operational level, policies are stemmed from the current technological solutions that could immediately create impacts; meanwhile, at the strategic level, long-term efforts are needed to push for a paradigm shift.



1. INTRODUCTION

South Africa has a rich diversity of flora and fauna. To preserve nature's capacity to adapt to climate change and, in turn, human adaptability and resilience, it is essential to protect this biodiversity. The Constitution of the Republic of South Africa, in Section 24, recognizes the right of everyone to (a) an environment that is not harmful to their health or well-being; and (b) to have the environment protected, for the benefit of present and future generations, through reasonable legislative and other measures. The Department of Forestry, Fisheries and the Environment (DFFE) has the legal mandate to manage, protect and conserve South Africa's environment and its natural resources. Over time, the Department has developed an extensive environmental management legislative/regulatory framework, which are summarized in the following sections.

1.1 BIODIVERSITY

Policy and regulatory framework related to biodiversity are well developed in South Africa. In fact, the country is one of the few countries with a Biodiversity Act and a Biodiversity Institute. According to the Constitution (Act 108 of 1996), nature conservation is a shared function between the national and provincial governments. As a result, some provinces have their own legislation alongside national legislation.

The national regulatory framework related to biodiversity consist of the white paper on conservation and sustainable use of biodiversity (1997), the National Environmental Management: Biodiversity Act, 2004 (Act No. 10 of 2004), which reforms South Africa's laws regulating biodiversity, and other acts of the Parliament (DFFE, 2022). These include the following:

- The World Heritage Convention Act, 1999 (Act No. 49 of 1999).
- The National Environmental Management: Protected Areas Amendment Act, 2009 (Act 15 of 2009): which regulates National parks.
- National Environmental Management: Protected Areas Act, 2003 (Act No. 57 of 2003): provides for the protection and preservation of ecologically vital areas.
- The National Environmental Management: Protected Areas Amendment Act, 2004 (Act No. 31 of 2004): provides for envisions a national system of protected areas in South Africa as part of a strategy to manage and conserve the country's biodiversity.
- The National Biodiversity Strategy and Action Plan (NBSAP) (2005).
- The National Spatial Biodiversity Assessment (NSBA) (2004, currently being reviewed and updated).
- The National Biodiversity Framework (NBF) (2008).
- The National Protected Area Expansion Strategy (NPAES) (2008).

The enactment of legislation on biodiversity does not, however, automatically eliminate concerns of biodiversity exploitation. A robust implementation effort and strategy is essential for a positive conservation outcome. As such, some provinces in South Africa, in addition to the national legislation, also have provincial legislation that further entrench conservation practices.

1.2 WATER RESOURCES

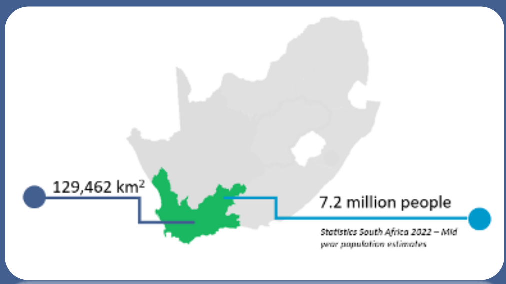
South Africa's Constitution and Bill of Rights address the basic human right to have access to sufficient water and a safe and healthy environment. Government fulfils these rights through the Department of Water and Sanitation, assisted by specific legislation (South Africa Yearbook 2020/21):

- The National Water Act of 1998, which ensures that South Africa's water resources are protected, used, developed, conserved, managed, and controlled in a sustainable and equitable manner, for the benefit of all people.
- The Water Services Act, 1997 (Act 108 of 1997), that prescribes the legislative duty of municipalities as water-service authorities to provide water supply and sanitation according to national standards and norms. The Water Services Act of 1997 places an obligation on the Minister to maintain a National Water Services Information System and to monitor the performance of all water services institutions.
- The Water Research Act, 1971 (Act 34 of 1971), which provides for the promotion of water related research through a Water Research Commission (WRC) and a Water Research Fund.
- The National Environmental Management Act (NEMA), 1998 (Act 107 of 1998), makes provision for cooperative environmental governance by establishing principles for decision-making on matters affecting the environment, institutions that promote cooperative governance and procedures for coordinating environmental functions exercised by organs of state.
- Sanitation provision is governed by the Strategic Framework on Water Services (2003) and the Water Services Act of 1997.

The main legal instrument and mechanism for managing water in all sectors of society is the National Water Resources Strategy (NWRS) issued by the Department of Water and Sanitation of the Republic of South Africa. The third version (NWRS-3) aims to ensure water security and equitable access to water and sanitation. Among other things, the draft calls for protecting and restoring ecological infrastructure, including strategic water source areas, to ensure that water is protected, used, developed, conserved, managed, and controlled in a sustainable and equitable manner (NWRS-3 - Draft 2.6).

1.3 PROVINCIAL LEVEL LEGISLATION

I. WESTERN CAPE

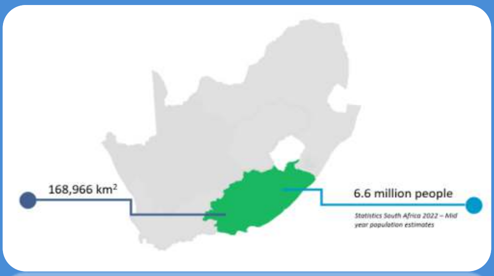


The Western Cape is home to the Cape Floristic Kingdom, which is the only floral kingdom within the confines of a single country. Unfortunately, the Western Cape is also the province with the highest incidence of invasive alien species which ultimately has a negative impact on surface water runoff. This is one of the provinces with major coastal development, which poses a threat to habitats in the surrounding environment. The Western Cape province is also one of the most water-scarce provinces in the country. This partly explains why it records one of the highest irrigated areas annually.

According to the Census of Commercial Agriculture (CoCA) 2017 report, the Western Cape generates the most income from commercial agriculture and it is also the biggest agricultural employer (17% of national commercial farms are in this province). The Western Cape's main commodity is grapes, but it is also the main producer of other fruits such as apples and stone fruit (peaches, pears, and plums). Several of these products are exported to other countries. A large part of the land is used for commercial agriculture (approximately 32% of the total land area of the Western Cape). (CoCA 2017)

In 2017, the Western Cape Government published the Provincial Biodiversity Strategy and Action Plan (2017-2025). The goal of this implementation plan was to promote inclusive and sustainable biodiversity and conservation initiatives. In 2019, the province drafted a bill on biodiversity which was enacted in 2021 (CER, 2019). The bill largely focuses on nature conservation and sustainable use of biodiversity and ecosystems. It covers topical issues including biodiversity planning and monitoring, protected areas, nature reserves, biodiversity stewardship, and protection of ecosystems, ecological infrastructure, and species. It aims to provide for the framework and institutions for nature conservation and the protection, management and sustainable use of biodiversity and ecosystems in the province.

II. EASTERN CAPE



The Eastern Cape Province is the largest by land area and is prominent for varied agricultural activities such as livestock farming and fruit and vegetable production. As such, the province is characterized by large grazing land. A significant amount of surface water runoff in the province is affected by invasive alien species (CoCA 2017).

According to the CoCA of 2017, the Province is the leading producer of pineapples and the second largest producer of apples, lemons, and oranges. (11% of the national total). 5.7 million hectares of land are used by commercial agriculture, this amount represents 34% of the total land area of the Eastern Cape.

Provincial legislation on biodiversity in the Eastern Cape; the first Eastern Cape Biodiversity Conservation Plan (ECBCP, 2007), was fully revised in 2017 (ECBCP, 2017). The revised legislation addressed among other issues the trade-off between socio-economic demand for natural resources and conservation requirements, private reserves, the increased population, resource allocation to biodiversity, community-based natural resource management, and spatial planning, and eco-tourism and commercialization of indigenous species (CER, 2018).

In September 2018, the Member of the Executive Council for Economic Development, Environmental Affairs and Tourism in the Eastern Cape Province, published a Provincial Notice of intention to gazette the Eastern Cape Biodiversity Conservation Strategy and Action Plan 2017: Draft for Public comments.[2] The Notice under which the Draft Eastern Cape Biodiversity Conservation Plan 2018 was published states that the Plan gives notice for Protection of Threatened or Protected Ecosystems in the Province of the Eastern Cape; the Plan will in addition identify Critical Biodiversity Areas, with land use management guidelines, in which certain activities will require environmental authorization.

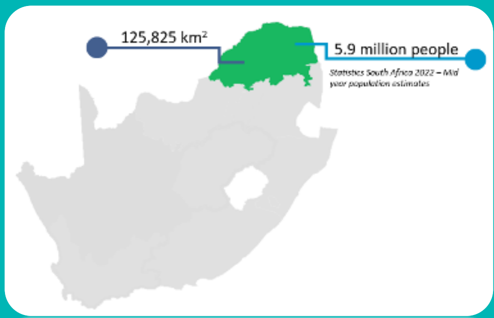
In 2019, the Draft Eastern Cape Environmental Management Bill was published in the Eastern Cape Provincial Gazette for comments. Its professed objectives are to rationalize, consolidate and reform the law regulating environmental management and to provide for the harmonization of provincial legislation with national legislation regulating protected areas, biodiversity, waste management and air quality; and to provide for matters connected therewith.[3]

---

[2] Link to the Draft Eastern Cape Biodiversity Conservation Strategy and Action Plan: https://egis.environment.gov.za/ECBCP-2017

[3] Link to Draft Eastern Cape Environmental Management Bill: https://cer.org.za/virtual-library/legislation/provincial/eastern-cape/draft-eastern-cape-environmental-management-bill

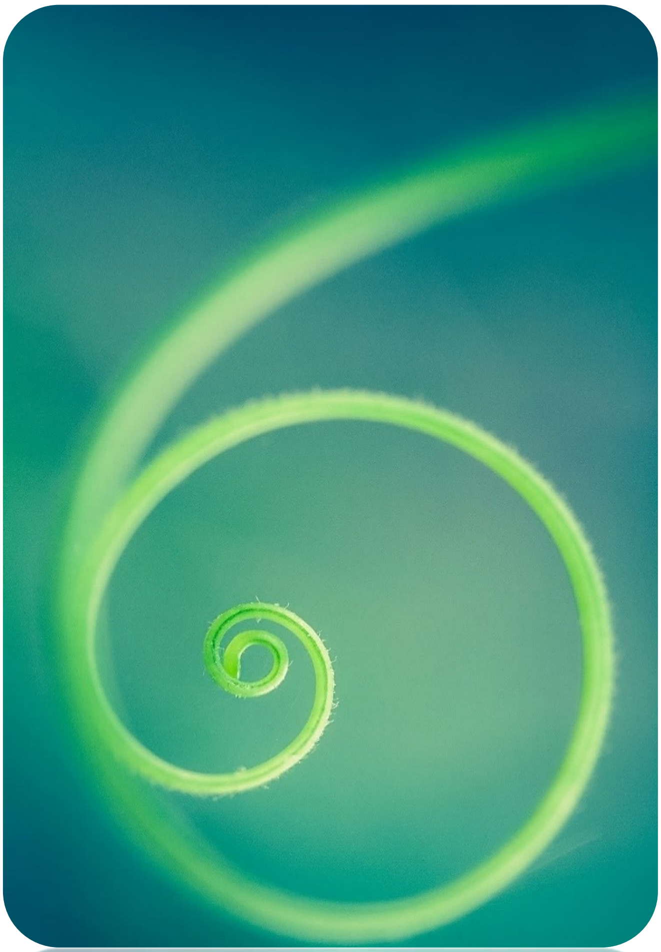
III. LIMPOPO



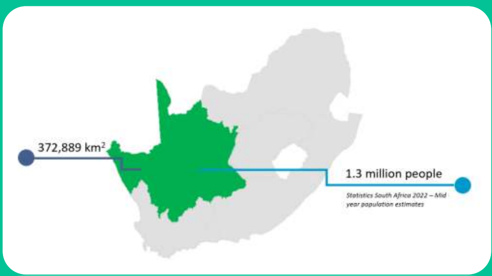
Based on the CoCA 2017 report, in the Limpopo region there are 3,054 commercial farms, and 1,7.million hectares of land are used by commercial agriculture. The province grows the bulk of the country's tomatoes (it drives 72% of national tomato production) and it is also a leading producer of citrus fruits, avocados, and butternut (CoCA, 2017).

Generally, the Limpopo basin comprises a wide range of biodiversity resources in significant quantities. Two key areas, often referred to as the biodiversity hotspots are the coastal forest of Eastern Africa and the Maputoland-Pondoland-Albany. Limpopo Province, together with the Mpumalanga Province, is home to the Kruger National Park which houses a range of species. The Drakensberg mountains, Soutpansberg and the Wolkberg, which are major water sources for the country also span into the province. Most of these areas, however, remain unprotected, risking a major encroachment.

In 2013, the Limpopo Conservation Plan v2 (LCPv2) Technical Report, was published. This project aimed to produce a revised conservation plan for the Limpopo Province that conformed to the Bioregional Planning guidelines published by SANBI, in 2009. This plan has two primary products: the map of Critical Biodiversity Areas (CBA) and associated land-use guidelines. The purpose of the LCPv2 is to develop the spatial component of a bioregional plan (one of a range of tools provided for in the Biodiversity Act), whose purpose is to inform land-use planning, environmental assessment and authorizations and natural resource management by a range of sectors whose policies and decisions impact on biodiversity (Limpopo Conservation Plan v2 Technical Report, 2012).



IV. NORTHERN CAPE



The CoCA 2017 Report states that the Northern Cape Province has 4,829 commercial farms, and 17.2 million hectares of land are used by commercial agriculture (46% of the total land area) (CoCA 2017). The Northern Cape Province, compared to the other Cape provinces, is reliant on nationally promulgated legislation. Although, the provincial level legislation is not recent, it operates within the ambit of national biodiversity laws.

The biological diversity and vast natural resources in the province are facing the threats of biodiversity loss due to transformation and degradation of natural habitat. There are significant changes in land use over time, conversion of natural habitat through cultivation (KHAVHAGALI, 2010). The province also faces other anthropogenically induced biodiversity loss through desertification, urban settlement expansions, extractive activities, and poor environmental management.

The Northern Cape Province is characterized by small dams and has the lowest water storage capacity in the country. The province leads in mixed cropping and is also known for its horticulture output. Numerous invasive alien species are also present in the province. These plants are spread and replace natural trees and plants, thus impacting biodiversity. Moreover, they use much of South Africa's water.

In 2010, the province published the Northern Cape Nature Conservation Act (9/2009). This Act, among other things, provides for the sustainable utilization of wild animals, aquatic biota and plants and the implementation of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (Northern Cape Nature Conservation Act, 2009).

2. METHOD AND MODELLING APPROACH

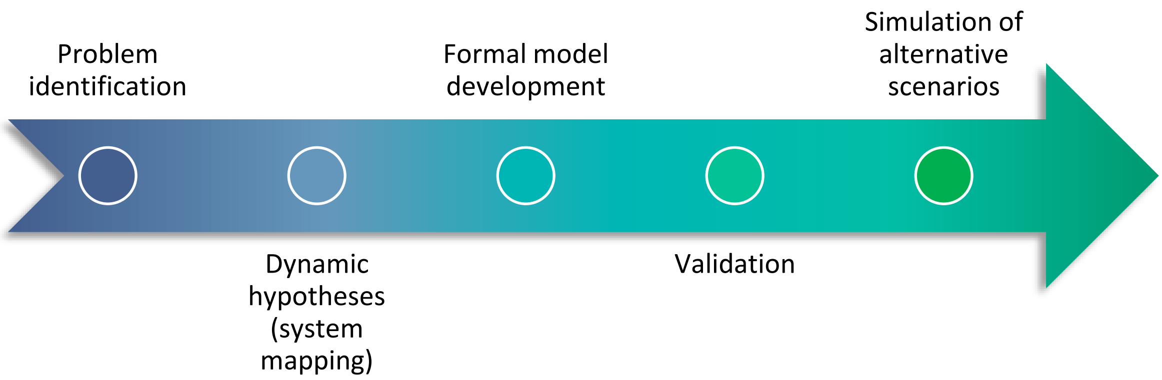
The system dynamics method is used for the analysis of the Water-Biodiversity nexus, in the four South African provinces. A system dynamics model is a modelling technique used to consider the interactions ('dynamics') of various indicators and variables, that together make up a 'system'. Systems are typically 'complex' – when variable X affects variable Y, we might also expect variable Z to change, which then impacts variable X! The interaction between different variables is modelled in a system dynamics model. In this context, the system is the water-biodiversity nexus in the four South African provinces, and this model sets out to consider the dynamics within the system. For example, how economic growth may impact water demand, or population change effect surface water runoff. These dynamics between different variables are modelled as mathematical equations, which are derived from a combination of empirical studies and assumptions.

'System dynamics models' are used to simulate exploratory 'what-if' scenarios to explore potential policy interventions and development trajectories, as opposed to other approaches that focus on optimization. The results of such an analysis inform about potential future impacts of policy interventions (desired and undesired) and the complementarity of policy interventions in achieving specific objectives. Causal relations, feedback loops, delays and non-linearity are at the core of the system dynamics approach, making it particularly well suited for representing and analysing complex real-world systems. Through the explicit representation of stocks and flow, system dynamics models[4] run differential equations to generate future scenarios that policymakers can use to guide their decisions.

The analysis of the Water-Biodiversity nexus aims to capture the interconnections between different socio-economic and environmental sectors. The term 'nexus' refers explicitly to this inter-connectedness, which means that decisions made in a certain policy area frequently have an impact on the others, alongside the ecosystems that ultimately support natural resources and human activity. This type of model was selected as it allows for explicitly capturing sectoral interconnections and facilitates the accounting of benefits that can be accrued by implementing policy interventions (or reaching water efficiency targets) across sectors and economic actors over time (Probst and Bassi, 2014). Therefore, it highlights the role of feedback loops in shaping future development and contributes to analysing trade-offs and potential undesired policy side-effects.

4 Models are simple representation of reality; therefore, they rely on assumptions about background conditions. Despite significant data collection efforts, certain provincial data gaps persist. The gaps in data mainly concern information about the development of water demand and supply over time, agriculture growing seasons, irrigation systems and crop irrigation requirements in the South African context, wastewater treatment and N loadings from various sources. To overcome constraints related to these data gaps, assumptions based on international data are used. The assumptions used are identical across the four provincial models and should be replaced by province level data once this data becomes available. More detailed information about the assumptions used for the parameterization of key indicators are provided in Annexure I through Annexure IV. Information is provided for the following models: Eastern Cape, Limpopo, Northern Cape, and Western Cape. In the tables presented in the Annexures, data sources are documented together with an indication of whether a single data point or time series data was obtained. The replacement of assumptions made with provincial data would contribute to improving the customization of the models to the respective provinces, which leads to reduced uncertainty and in turn higher accuracy of model projections, in general. Data gaps by module and key indicator are summarized in Annexure V.

An iterative five-step process is followed by creating a system dynamics model (Sterman, 2000):



Following each of these steps, requires several processes that contribute to informing the different challenges encountered during the various stages of the UN integrated policymaking cycle.

By modelling the Water-Biodiversity nexus in the four South African Provinces mentioned earlier, this report can demonstrate the effects of green economy policies on Water-Biodiversity interlinkage with a focus on the water demand and supply, climate and weather, land use and invasive alien species, and agriculture.

2.1 CAUSAL LOOP DIAGRAMS

A causal loop diagram is an explicit representation of the causal relationships between different key indicators and can as such be regarded as a map of the system being analysed. This mapping tool is useful for representing and exploring the interconnections between key indicators and variables analysed and for deducting general dynamics exhibited by the system. A causal loop diagram can be described as an integrated map illustrating the dynamic interplay between the key indicators that constitute the system. In doing that, the causal loop diagram presents information about the system on different levels of aggregation and dimensions, which allows for exploring circular relations, or feedbacks, within and between them (Probst & Bassi, 2014).

Causal loop diagrams are created at the beginning of the modelling process and guide the development of the mathematical model. These system maps are typically created together with local stakeholders to ensure that local drivers and key indicators are included and that analysis outcomes fit the needs of the problem owners. Once finalized, causal loop diagrams visualize the complexity of the system analysed and contribute to the identification of main indicators and drivers of change that need to be included in the mathematical simulation model. Furthermore, the explicit mapping of causal relationships between key indicators during the causal loop diagram creation process supports a systemic approach to decision- making, policy design and implementation.

Causal loop diagrams consist of variables and arrows connecting them (also referred to as causal links). Polarities (either + or - signs) are indicated next to the arrow heads and specify whether a positive or negative relationship exists between any two variables. Table 1 illustrates the impact of the indicated polarities using variable A and variable B as examples.

- If a causal link from variable A to variable B indicates a positive relationship, a change in variable A causes a change in a variable B in the **same** direction.
- If a causal link from variable A to variable B indicates a negative relationship, a change in variable A causes a change in variable B in the **opposite** direction.

Table 1.: Causal relations and polarity.

Variable A	Variable B	Sign
Up	*Up*	+
Down	*Down*	+
Up	*Down*	-
Down	*Up*	-

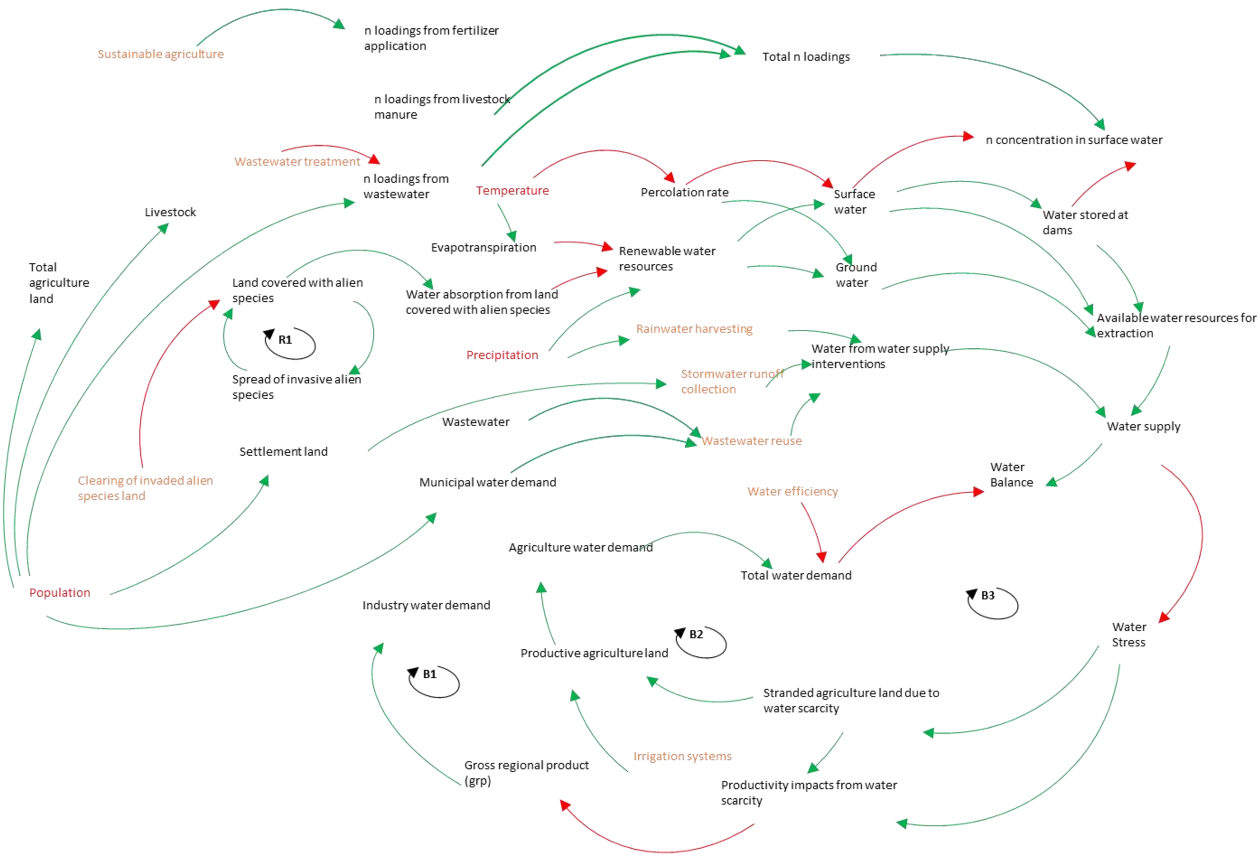
Causal chains in which the initial variable re-affects itself, or circular causal relations, are also referred to as feedback loops: "Feedback is a process whereby an initial cause ripples through a chain of causation ultimately to re-affect itself" (Roberts, Andersen, Deal, Garet, & Shaffer, 1983). Feedback loops can be either reinforcing (R), typically loops that amplify change in the system, or balancing loops (B), that bring stability to the system, represented by circles of cause and effects that counter a change with a push in the opposite direction.

The provincial Water-Biodiversity nexus models consist of 8 different modules:

(i) Macro drivers,
(ii) Land use and land use change (LULUC),
(iii) Climate and weather,
(iv) Water demand,
(v) Water supply,
(vi) Wastewater,
(vii) Agriculture, and
(viii) Nitrogen (N) loadings.

Population and the Gross Regional Product (GRP) are included as macro drivers affecting land use and water demand over time. The dynamics of each module and key indicators included are described in the following sections of this chapter.

The SA Water-Biodiversity models were developed with a focus on water and land covered by invasive alien species. The focus area was confirmed in stakeholder consultations with the Government counterparts. A simplified version of the model structure is illustrated in Figure 1, in the form of a causal loop diagram. The main dynamics of the model are affected by both reinforcing loop, which compound change in one direction, (e.g., R1) and balancing loops (e.g., B1 - B3). In the context of Water-Biodiversity interactions, the three balancing loops indicate natural capital constraints emerging from the current development trajectory.



Reinforcing loops	**R1**
Balancing loops	**B1, B2, B3**

Figure 1.: Causal loop diagram illustrating the core dynamics of the provincial Water-Biodiversity models.

From the diagram, it has been concluded that population growth[5], economic development and the increase in land covered by invasive alien species have led to water scarcity that is reinforced by erratic rainfalls and sinking levels of water supply. The runoff reduction caused by alien species is expected to increase significantly. Runoff reductions could increase from between 1,444 and 2,444 million m^3 per year to around 2,589 - 3,153 million m^3 per year if no immediate remedial actions are taken (van Wilgen & Wilson, 2017).

The extent of land area impacted by alien invasive species is illustrated by the reinforcing loop R1, which causes land covered by invasive alien species, to increase over time. In the baseline, little to no clearing of

[5] Whilst population growth can increase settlement land, resulting in higher stormwater runoff collection, the increase in municipal water demand from a growing population exceeds any increase in stormwater runoff collection, and therefore population growth leads to a net increase in water scarcity.

land under invasive alien species coverage is assumed, and alien species coverage increases, therefore, the runoff reductions from invasive alien species land increase, which reduces overall water supply. The resulting decline in water supply contributes to increasing water scarcity, as total water demand is unaffected by invasive alien species.

The growth of population, Gross Regional Product (GRP) – a monetary measure of economic activity within the province – and the irrigation of agricultural land, all cause total water demand to grow over time. As water demand exceeds local water extraction thresholds, water stress emerges and triggers balancing loops that limit the growth that would be possible if water was available. Balancing loop B1 illustrates how water demand increases water stress and illustrates how water scarcity related productivity impacts balance water demand by reducing total GRP in times of water shortages. A similar dynamic is captured by balancing loop B2, which captures the impact of water scarcity on the cultivation of agricultural land. The more agricultural land under cultivation, the higher the water demand to irrigate the land to maximize production yields. At the same time, as agricultural land increases grows and precipitation declines, the total amount of water required for irrigation increases over time. The greater the amount of water required for irrigation, the higher the amount of land at risk of becoming stranded land. Growth in water demand increases to the point that water stress is exacerbated and causes agricultural land to become stranded during the dry season; a dynamic illustrated by loop B3. The emergence of water stress causes water supply shortages during the dry season and leads to a share of agricultural land that becomes stranded. Once land becomes stranded, it produces at lower yields and consequentially, depending on the extent of the shortage, leads to lower total agriculture production, employment, and GRP.

2.1.1 Macro DRIVERS' modules

Population and GRP are included as macro drivers in the provincial models. As illustrated in Figure 1, population is one of the key drivers in the models. Population affects variables such as agriculture and pastureland, livestock, municipal water demand, and wastewater treatment facilities.

The water demand from the population is estimated based on total population and a per capita water consumption multiplier. For industry water demand, an index of total GRP is applied to the initial industry water demand to project industrial water demand in the simulations.

In case of the GRP, productivity impacts resulting from water stress are assumed. If water demand exceeds water supply, it is assumed that GRP is negatively affected, using the water stress indicator and an elasticity of GRP to water stress. The impact of this feedback is captured by the balancing loop B1, which indicates negative productivity impacts from water scarcity on provincial GRP.

2.1.2 Land use and land use change (LULUC) module

The LULUC module provides information about land use stocks such as cropland, forest land and settlement land, and their development over time. The module contains both natural and anthropogenic land use stocks. Stocks included in the LULUC module are forest land, conservation area, settlement land, cropland, pasture, and land covered by invasive alien species. The causal loop diagram for the LULUC module is presented in Figure 2. The stock of other land is used for estimating forest regeneration and the potential conversion of other land to cropland or pasture.

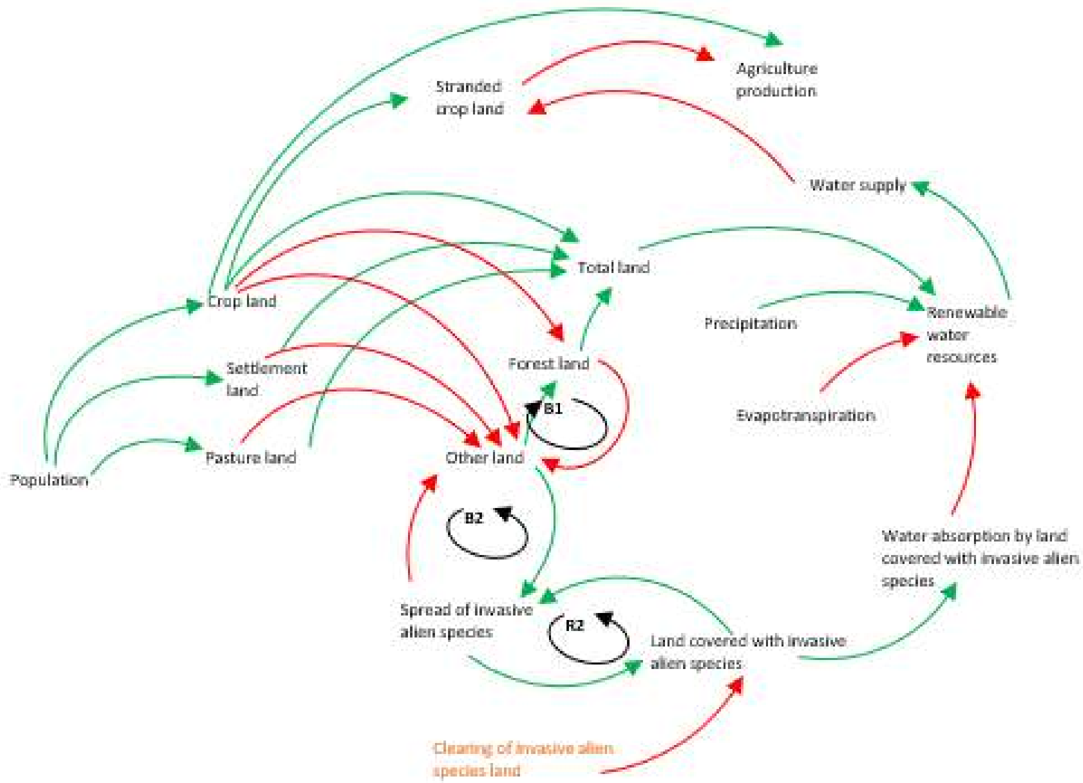


Figure 2.: Causal loop diagram illustrating dynamics of the land use and land use change (LULUC) module.

A specific focus of the analysis was on land covered by invasive alien species and the resultant reduction in surface water runoff. The aggregate land use module and the structure for modelling land covered by invasive alien species are based on the previous South Africa Green Economy Modelling (SAGEM) report. While more detailed information on provincial levels of infestation have become available, the issue of invasive species and their impact on water runoff was already highlighted and analysed during an earlier study entitled the South African Green Economic Modelling (SAGEM) Report released in 2013.[6]

Water runoff reductions from land covered by alien species are projected to grow by almost 50% within the coming years. The reduction in surface water runoff ranges from between 1,444 and 2,444 million m^3 per year to around 2,589 to 3,153 million m^3 per year (van Wilgen & Wilson, 2017). The absorption of water by alien vegetation is calibrated using the total area covered by invasive alien species (by province) and the average water absorption per hectare of alien species land as reported by SANBI (van Wilgen & Wilson, 2017). Water uptake per hectare is assumed to grow by 2% annually after 2017, as data for further years was not available. In addition to reducing water runoff, certain alien vegetation species have detrimental effects on soil cover type and depth as well as reduce species richness locally. Table 2 provides information on the amount of land covered by invasive alien species on the provincial level. This information was obtained from data concerning area covered by invasive species reported for South Africa's primary watersheds. The table further reports on the minimum and maximum amount of water absorbed per hectare for each province, as well as the average value that was used for the calibration of the model.

[6] A relevant element not included in the analysis is the effect of erosion on surface water runoff, which is particularly observed in Eastern Cape province. The impacts to be considered include siltation of dams, reducing the volumes in those impacted dams and topsoil, thus impacting agricultural production.

Table 2.: Summary of land covered by alien species and water uptake per hectare by province.

Province	Area	Water Absorption: Total annual runoff reduction	Water Absorption: By primary watershed	Water Absorption: Provincial average
	Hectare	*million m³ / Year*	*m³/Ha/Year*	m³/Ha/Year
Eastern Cape	**543,569**	**358.48**	-	**688.9**
Sundays	*39,906*	*0.89*	*22.3*	
Swartkops	*23,662*	*11.64*	*491.9*	
Great Fish	*30,385*	*4.83*	*159.0*	
Bushmans	*12,432*	*3.31*	*266.2*	
Great Kei	*59,130*	*46.58*	*787.8*	
Keiskamma-Nahoon	*45,414*	*42.92*	*945.1*	
Mbashe-Umzimvubu	*220,942*	*321.96*	*1,457.2*	
uMzimkulu-uMvoti	*111,698*	*154.35*	*1,381.9*	
Limpopo	**209,838**	**86.23**	-	**410.9**
Crocodile Limpopo	*86,510*	*24.44*	*282.5*	
Olifants Letaba	*123,328*	*61.79*	*501.0*	
Northern Cape	**54,383**	**31.57**	-	**580.5**
Orange	*54.383*	*31.57*	*580.5*	
Western Cape	**168,397**	**252.91**	-	**1,302.1**
Berg-Agulhas	92,970	*111.36*	*1,197.8*	
Olifants Doring	4,825	*3.65*	*756.5*	
Breede-Goukou	45,164	*126.21*	*2,794.5*	
Gouritz	25,438	*11.69*	*459.5*	

Source: van Wilgen & Wilson, 2017

2.1.3 Water demand module

The water demand module captures municipal, industrial and agriculture water demand and provides information about the water balance water stress and the magnitude of potential water shortages. The modelling of water demand is based on provincial water management documents supplemented by various sources (Basson & Rossouw, 2003a; Basson & Rossouw, 2003b; Basson, M.S.; Rossouw, J.D., 2003c; DWAF, 2004a; DWAF, 2004b; DWAF, 2007; DWAF, 2011; DWS, 2019). Modelling water endogenous demand allows to assess policy impacts on sectoral and total water demand. The provincial models allow for simulating various interventions addressing total water demand, such as water efficiency in each of the sectors (e.g., improved irrigation efficiency) or the shift towards the cultivation of drought resistant varieties.

Three balancing loops dominate the water demand module, the loops B1, B2 and B3. Balancing loop B1 captures the effects of water scarcity on provincial productivity and leads to GRP impacts in case of low water supply. The reduction in GRP causes a temporary reduction in industry water demand, introducing a water-based constraint to economic development, a dynamic that is already observed today. Further, the larger the proportion of agricultural land under cultivation, the greater the amount of water, required for the cultivation of crops (assuming that the share of land under irrigation remains constant). Higher irrigation requirements cause water demand to grow, which increases the potential water stress risk and hence the risk of stranded land due to the lack of water for irrigation. This constraint is introduced through the increase in water requirements for irrigation, as represented by balancing loop B2. Finally, B3 illustrates that water scarcity impacts in the agriculture sector cause productivity impacts affecting the province's total factor productivity. This demonstrates that the model captures direct impacts of water shortages, such as reduced productive agricultural land, lower production, and indirect and induced impacts of water shortages economy- wide. This causal relationship provides a strong motivation for the implementation and adoption of climate smart agriculture (CSA) principles. Through CSA, resource input is minimized whilst efficiency is improved leading to increased productivity.

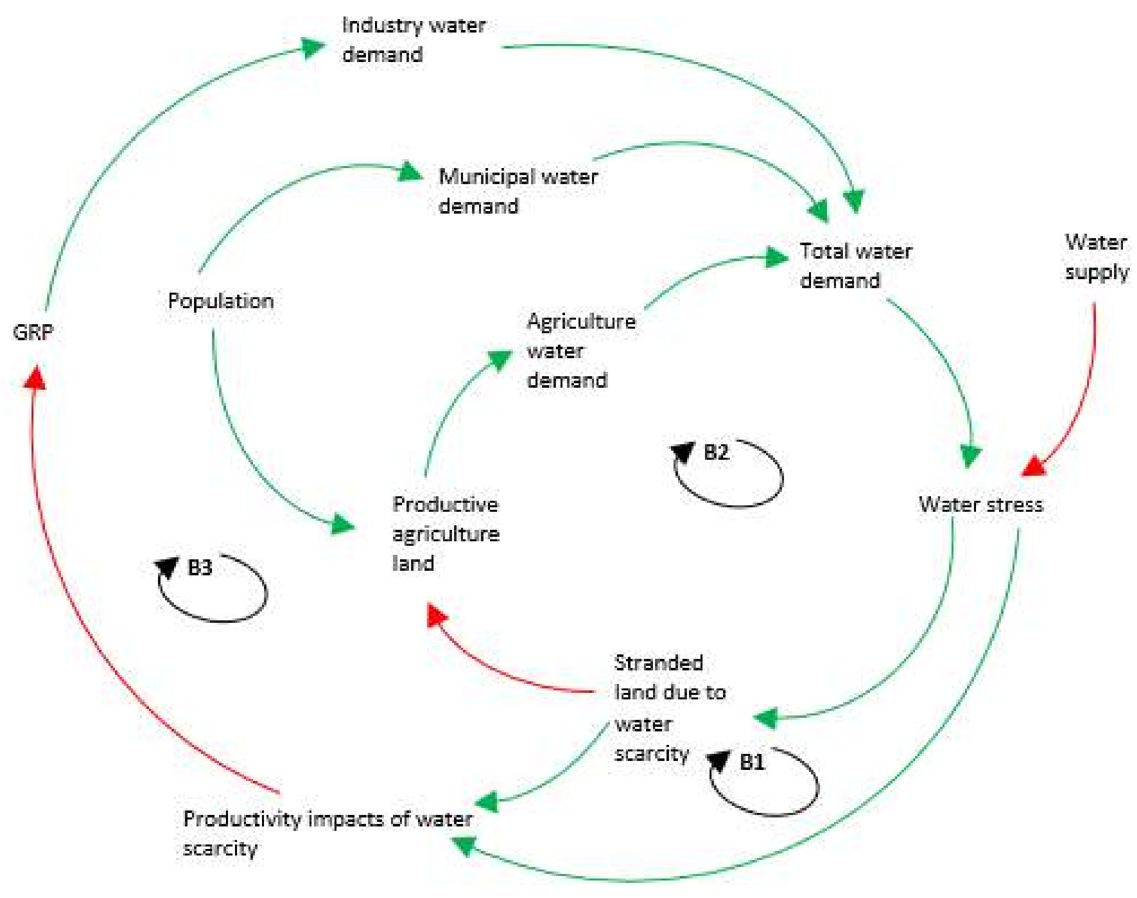


Figure 3.: Causal loop diagram illustrating dynamics of the water demand module.

1.2.4 Water supply module[7]

The water supply module provides information about water supply from different sources. The model considers groundwater, surface water from dams and rivers, and water supply from interventions such as rainwater harvesting, stormwater collection and wastewater recycling.

Total area, precipitation and evapotranspiration are used to estimate total renewable freshwater resources at the provincial level. To ensure consistency between the provincial boundaries and watershed boundaries, data on water demand and supply was collected per province from provincial planning documents (Basson & Rossouw, 2003a; Basson & Rossouw, 2003b; Basson, M.S.; Rossouw, J.D., 2003c; DWAF, 2004a; DWAF, 2004b; DWAF, 2007; DWAF, 2011). The information was compared against water supply data provided by the National Integrated Water Information System (NIWIS), which is hosted on the website of the South African Department of Water and Sanitation (DWS, 2019). Information on dams and average annual reservoir fill levels on provincial level was obtained from the Department of Water and Sanitation (DWS, 2019).

Water supply from dams and mountain aquifers were highlighted as important sources of water supply. Due to a lack of data however, only surface water supply from rivers and dams are calibrated in the provincial models. The structure for simulating water supply from mountain aquifers is developed, however not calibrated. The causal loop diagram for water supply, in the provincial models, is illustrated in Figure 4.

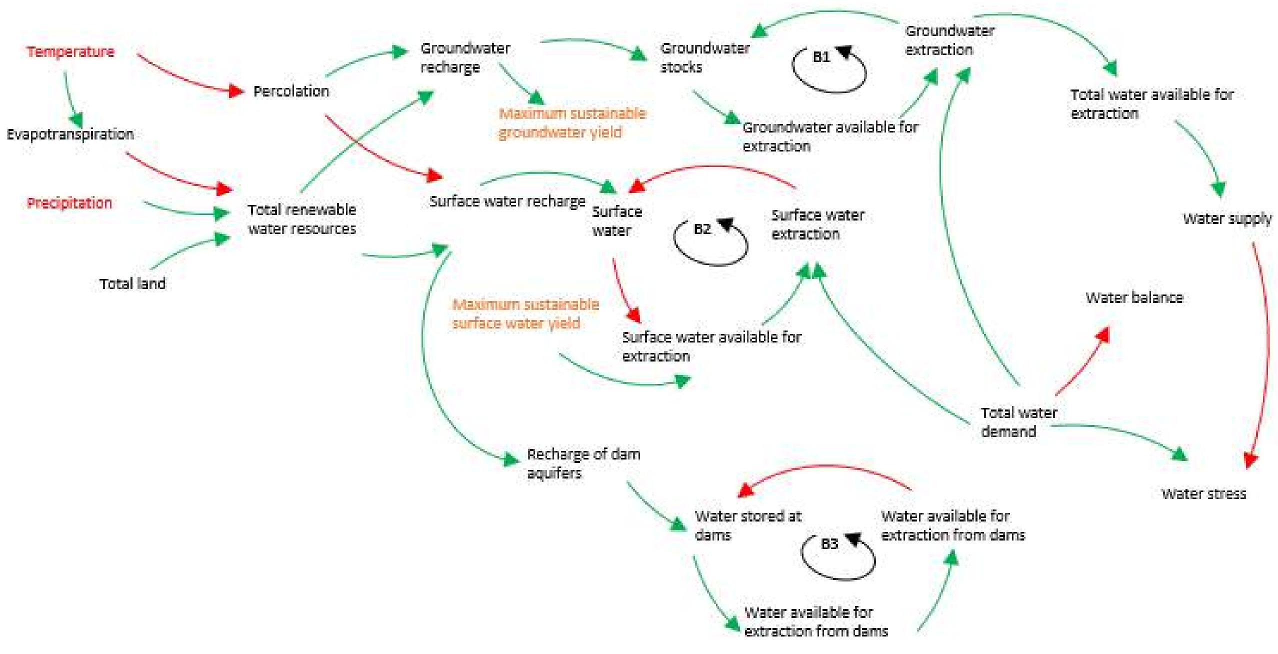


Figure 4.: Causal loop diagram illustrating the dynamics of the water supply module.

[7] Disclaimer: only surface water supply from rivers and dams are calibrated in the provincial models. The water demand from population is estimated based on total population and a per capita water consumption multiplier. For industry water demand, an index of total GRP is applied to the initial industry water demand to project industrial water demand in the simulations.

The water supply module is dominated by three different balancing loops (loops B1 through B3), as highlighted in Figure 4. The loops B1 through B3 fulfil the same function in that they, once active, constrain the extraction of water to the available water supply from each source. An option in the model allows to simulate the sustainable use of water for each water source, whereby 'sustainable' refers to the use of water at recharge levels. In addition, sustainable water management assumes that the minimum runoff required for biological integrity remains available at any point, throughout the year.

2.1.5 Agriculture module

The agriculture module provides information about the extent of agricultural land, irrigation water demand, total fertilizer application and runoff as well as crop production by type of crop. Further, it provides an overview of irrigated and rainfed agricultural land, the shares of irrigation technologies installed and their efficiency. Key parameters in the agriculture module are the water demand by crop and the total area planted by crop, both of which are required to estimate the total water demand for irrigation. Other key indicators are crop production, N fertilizer application, the share of organic agricultural land and the agriculture water balance. The latter plays an important role in determining the amount of water available for irrigation as well as the potential water stress risk, which is done in the water demand module. Stakeholder consultations revealed that switching to organic farming methods may lead to reduced agricultural yields in the short-term as land productivity declines, but higher yields are expected in the medium-term (five years onwards) as soil nutrients are re-established. The causal loop diagram for the agriculture sector is illustrated in Figure 5.

The agriculture sector is dominated by two balancing loops. The first balancing loop captures the adjustment of cropland to the desired level. The second balancing loop captures the impacts of water scarcity on productive agricultural land and production. The subsequent increase in agricultural land, implies a directly proportional increase in water being required for irrigation purposes and hence total sector water demand. The growth of water demand increases the risk of water scarcity and causes productive agricultural land to become stranded temporarily if insufficient water for irrigation is available. There are other balancing loops such as the adjustment process between conventional and organic agriculture production. However, these dynamics are not represented in this CLD (Figure 5) to highlight the interconnections between only key indicators and to keep the level of complexity at a manageable level.

Population is assumed as the driving factor behind the expansion of agricultural land, which implies that cropland increases proportional to population. If cropland grows over time, this leads to an increase in irrigation water requirements and the application of fertilizers. Water demand for irrigation depends on the type of irrigation technology installed (the model considers flood, sprinkler, and drip irrigation) and the respective efficiency of irrigation systems. Depending on water supply, the growth in irrigation water demand may trigger or increase water stress, reduce productive cropland, and cause negative impacts on GRP.

Crop production depends on the amount of productive agricultural land and the average yield per hectare per crop type. The current model uses crop yields on provincial level (Grain-SA, 2019), which are assumed to be constant after 2019.[8] This indicates that crop yields are identical for all four developed provincial models.

[8] New data 2020 Grain SA report shows a small increase in crop yields at the provincial level: https://www.grainsa.co.za/pages/industry-reports/production-reports.

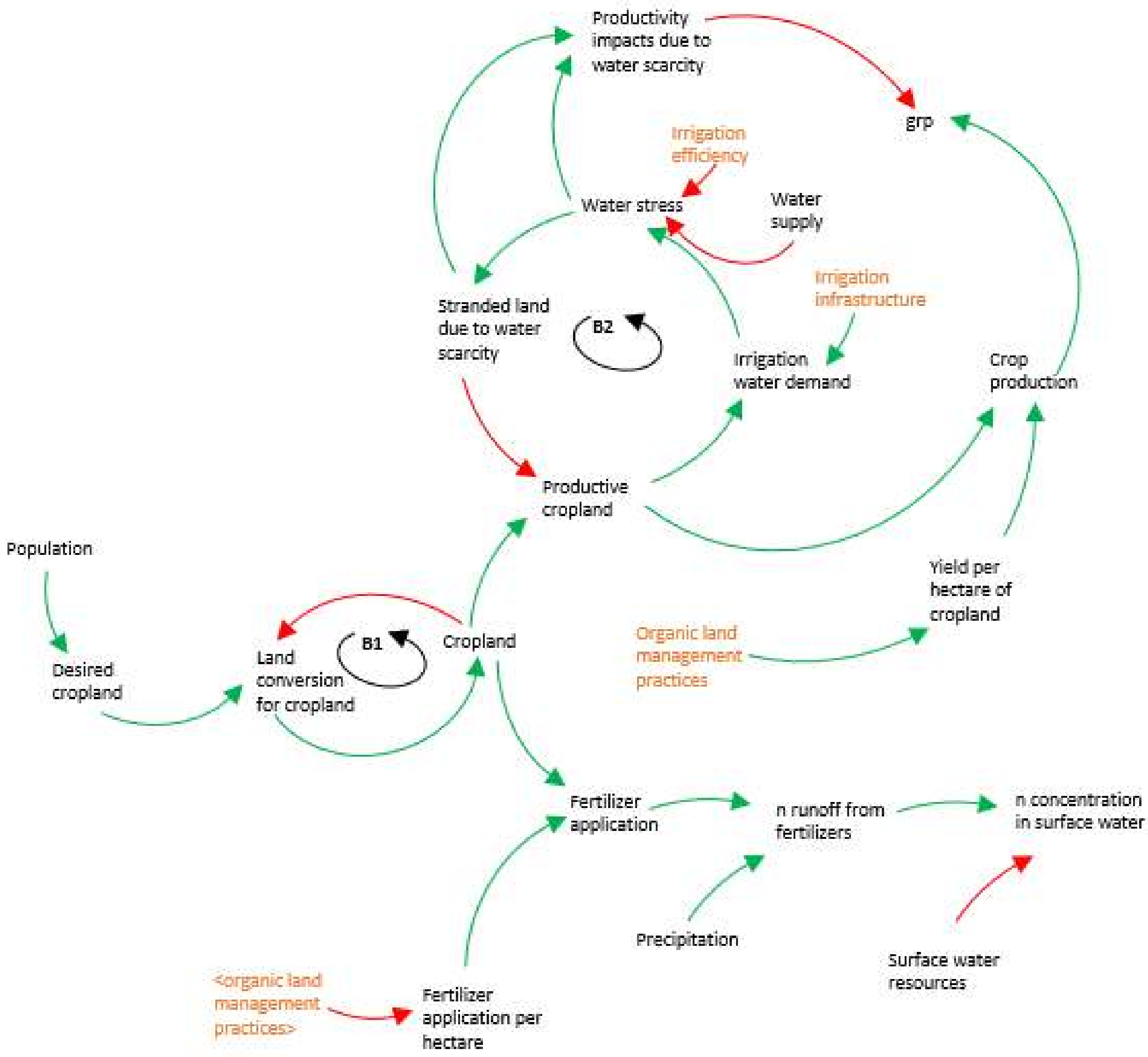


Figure 5.: Causal loop diagram illustrating the dynamics of the agriculture module.

The application of N fertilizer per hectare is based on a report concerning the fertilizer use by crop, in South Africa (FAO, 2005). According to the FAO (2005), chemical N fertilizer application ranged from 7kg to 92kg of N applied per hectare for field crops and from 50kg to 180kg N per hectare for horticulture cultivation. In the models, the average application of N fertilizer per hectare per year is based on the average N fertilizer use for specific crops (FAO, 2005) and the crop mix obtained from provincial databases (Grain-SA, 2019). In case of organic agricultural land, the use of chemical N fertilizers is assumed to be zero.

It must be stated that some applied fertilizer may be washed into surface water bodies, due to rainfall. The N runoff into the rivers increases the N concentration in surface water bodies and contributes to excess algae growth (eutrophication) in lakes and rivers as soon as the concentration of nutrients becomes too high (Rast, Lee, & G.F., 1978; Peters, 1986; Håkanson, Bryhn, & Biencker, 2007). The concentration of nutrients depends on the nutrient loads reaching the surface water and the amount of surface water, at any given point in time. An increase in nutrient concentration can be observed if loadings remain constant while surface water flow decreases, or when water becomes stagnant and only limited exchange of water is possible.

Eutrophication may degrade ecosystem health and biodiversity, as it can lead to a shift in species composition, secondary impacts which may be observed range from reduced amount of sunlight received by bottom water and an increased decomposition of organic matter (dead algae) that causes an oxygen deficient impacting fauna. Biodiversity impacts will have socio-economic impacts such as reduction in fish (for fishery industries) and harmful algal blossoms that can lead to human health impacts.

2.1.6 Wastewater and Nitrogen (N) loadings module

The causal loop diagram of the wastewater and N loadings module is illustrated in Figure 6. The wastewater and N loadings module provides information about wastewater treatment capacity and related nutrient removal efficiency, the amount of treated and untreated wastewater and how sewage overflows disrupt wastewater treatment by ejecting sewage out of sewers, potentially directly into surface water streams. Furthermore, Figure 6 illustrates total annual N loadings as the sum of N loadings from wastewater, fertilizer, and livestock.

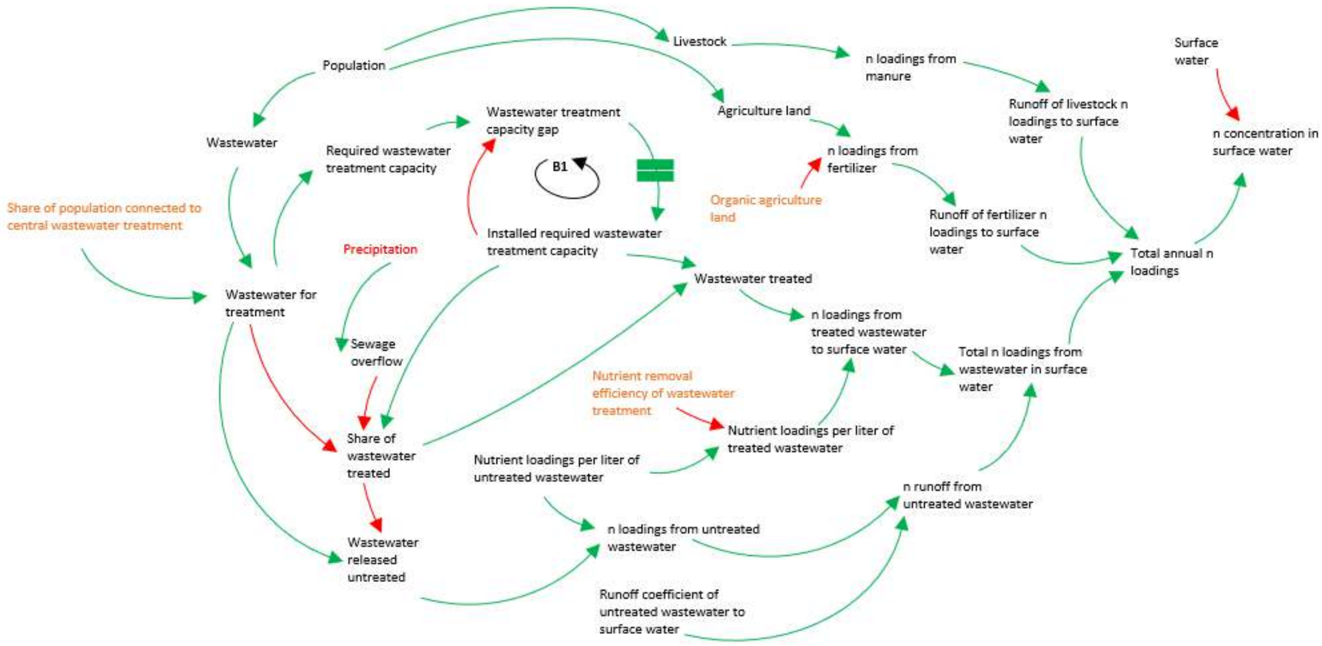


Figure 6.: Causal loop diagram illustrating the dynamics of the wastewater and Nitrogen (N)-loadings module.

The total amount of wastewater for treatment is driven by the wastewater from population and the share of population that is connected to a centralized wastewater treatment system. Wastewater treatment facility (WWTF) capacity is assumed to adjust based on expected wastewater loads. Balancing loop B1 illustrates the adjustment process during which the installed WWTF capacity is compared to the required WWTF capacity to determine whether there is a WWTF capacity gap. In case of a gap, B1 ensures that installed capacity adjusts over time towards the required capacity. The delay sign from the variable WWTF gap and installed wastewater treatment capacity indicate that there is a time lag between the commissioning and completion of new WWTF infrastructure.

The share of wastewater treated represents the percentage of sewage that is treated at wastewater treatment plants, which is affected by total WWTF capacity, accounting for wastewater for treatment and occasional sewage overflows. Sewage overflows typically occur during heavy rainfall events during which there is excess water in the sewage system. This in turn reduces the amount of sewage that reaches the treatment plants and hence reduces the percentage of wastewater treated.

The amount of wastewater being treated, depends on the total installed amount of WWTF capacity installed and the current share of wastewater treated. Both, N loadings from treated and untreated wastewater constitute the N loadings from wastewater that reach the surface water. Runoff from untreated wastewater uses a delivery coefficient, if only a small fraction of sewage stored in decentralized sewage systems reaches surface water bodies. Together with N loadings from fertilizer application and livestock, N loadings from wastewater constitute the total annual N loadings to surface water. Together with the total amount of surface water, total N loadings are used to estimate the N concentration in surface water.

BOX 1: KZN FLOODS – SEWAGE WASTEWATER SPILLAGE TO WATERCOURSES

In April 2022, Kwa-Zulu Natal (KZN) experienced consecutive days of heavy rain. This event resulted in floods, which caused damage to wastewater infrastructure leading to a massive contamination of rivers across the KZN province. eThekwini Municipality was one municipality which was extensively affected by the flood.

Extensive effluent flow to wastewater treatment plants, coupled with the damage to infrastructure, resulted in waste matter spillages on water courses causing river and consequentially ocean pollution. Spillages to water courses resulted in a decline in water quality throughout the province. The most affected rivers were the uMbilo, Umkhumbane, uMngeni, Isipingo and uThongathi.

Water quality testing that was conducted in August 2022 at beaches and rivers in the eThekwini Municipality, indicated high levels of *Escherichia coli* (E. coli), this has resulted in the prohibition of water activities such as swimming, surfing, fishing, bathing, and canoeing at 13 beaches.

For the water sector, "flood resilience", is an important concept. Wastewater treatment utilities can build resilience by implementing mitigation measures such as emergency planning activity, equipment modification/upgrade or alteration in its structure. All these interventions require planning and investment, which can prevent costly future damage and enable the utility to provide a more reliable service to customers to mitigate climate related impacts.

Sources: Iol (2022). State of eThekwini rivers dire after sewage spills. Available at: https://www.iol.co.za/mercury/news/state-of-ethekwini-rivers-dire-after-sewage-spills-ad37bebb-04cd-434e-9522-370949ccf45c

News24 (2022) Swimming, surfing, fishing prohibited at 13 Durban beaches after high levels of E. coli found. Available at: https://www.news24.com/news24/southafrica/news/swimming-surfing-fishing-prohibited-at-13-durban-beaches-after-high-levels-of-ecoli-found-20220824

2.2 PROVINCIAL MODELS SCENARIOS AND ASSUMPTIONS

The provincial assessments of water and biodiversity are conducted using scenario analysis. The scenarios simulated are the business-as-usual (BAU) scenario and a Green Economy (GE) scenario. The BAU scenario assumes a continuation of observed trends without the implementation of any water efficiency or biodiversity-related interventions. It serves as the baseline for assessing the impacts of GE policy interventions on key indicators. A description for each of the simulated scenarios, together with underlying assumptions are provided in Table 3.

Table 3.: Summary of the provincial models' scenarios and assumptions.

Scenario	Description
Business-as-Usual (BAU)	The BAU scenario constitutes the baseline for the assessment of policy impacts in the policy scenarios. This scenario extrapolates current trends observed for population, GRP, water consumption, agriculture expansion, and others into the future. It further assumes climate change impacts that affect annual precipitation and precipitation variability. The BAU scenario assumes that no policy interventions concerning water use efficiency, wastewater treatment or land management practices are implemented, which allows for assessing the impacts of policy interventions assuming everything else equal.
BAUec (ex climate)	The BAUec (ex climate) scenarios is based on the same assumptions as the BAU scenario, but does not assume climate change impacts. This indicates that the BAUec scenario does not consider potential changes in water availability due to climate change and that a status quo of precipitation persists.
Green Economy (GE)	The GE scenario assumes the simultaneous implementation of the following interventions. A linear implementation of the ambition is assumed for the period 2020 to 2030, after which the ambitions are achieved and maintained. The policy goals are: ➢ +20% water efficiency for municipalities and industry ➢ +20% of cropland shifted to sustainable practices ○ Yields of organic land are 10% higher than for conventional practices ○ No fertilizer application is assumed on organic agricultural land ➢ Shift in irrigation technologies ○ -10% flood irrigation ○ -10% sprinkler irrigation ○ +20% drip irrigation One third (33.3%) of current land covered by IAS cleared, by 2030.

Source: Authors' elaboration

Climate change impacts included in the models cover changes in precipitation, and an increase in evapotranspiration due to rising temperatures. Information concerning the impacts of climate change on water demand and supply are calibrated using information obtained from the Department of Water and Sanitation's (DWS) National Integrated Water Information System. It should be noted that the climate trends for precipitation are assumed to occur from the beginning of the simulation. The climate trends applied to precipitation are as follows:

- Eastern Cape: -0.027% per year[9]
- Limpopo: -0.016% per year
- Northern Cape: -0.102% per year
- Western Cape: 0.109% per year

In addition to the indicated trends in annual precipitation, the simulations assume a 0.5% increase in precipitation variability per year. By the year 2040, precipitation variability in the BAU and GE scenario is 22.1% higher than in the BAUec scenario without climate change impacts.

2.3 PROVINCIAL MODELS ANALYSIS RESULTS

2.3.1 Climate change impacts on the business as usual (BAU) projections

Climate impacts in the BAU scenario cause precipitation to decline across all provinces, except for the Western Cape, for which climate change forecast data utilized in the model indicate a slight increase in precipitation. Information about annual precipitation for the years 2000, 2019 and 2040 for the BAU and the BAUec scenario is summarized in Table 4. By 2040, the net reduction in annual rainfall ranges from -0.7% in Limpopo to -4.1% in Northern Cape. These reductions are equivalent to 4.8mm and 12.3mm less rainfall per year. In Western Cape, annual precipitation is approximately 4.5% higher because of climate impacts.

[9] The assumptions used on climate variability and trends should be utilized in relative, rather than absolute terms. The most important outcome of the model, even when using different climate scenarios, is the difference that intervention options generate in the alternative scenario when compared to the BAU case. It results that the use of assumptions that do not fully reflect current trends or expectations does not negatively impact the quality of the results of the model, when two simulations are compared. Future work may include the use of different climate scenarios, applied to all simulations created with the model. According to the latest Annual State of Climate Report (2021), all provinces have observed an increase in percentage of annual rainfall. Source: https://www.weathersa.co.za/Documents/Corporate/Annual%20State%20of%20the%20Climate%202021_04042022114230.pdf.

Table 4.: Climate impacts on annual precipitation.

Province	Scenario	Unit	2000	2019	2040
Eastern Cape	BAUec	mm/Year	708.6	708.6	708.6
	BAU	mm/Year	708.6	704.8	700.7
	CC impact on BAU	***%***	***0.0%***	***-0.5%***	***-1.1%***
Limpopo	BAUec	mm/Year	719.0	719.0	719.0
	BAU	mm/Year	719.0	716.7	714.2
	CC impact on BAU	***%***	***0.0%***	***-0.3%***	***-0.7%***
Northern Cape	BAUec	mm/Year	301.6	301.6	301.6
	BAU	mm/Year	301.6	295.6	289.3
	CC impact on BAU	***%***	***0.0%***	***-2.0%***	***-4.1%***
Western Cape	BAUec	mm/Year	509.0	509.0	509.0
	BAU	mm/Year	509.0	519.9	531.9
	CC impact on BAU	***%***	***0.0%***	***2.1%***	***4.5%***

Changes in rainfall and evapotranspiration further affect the total amount of available renewable freshwater resources on a provincial level, despite the increasing trend in precipitation in the Western Cape. A decline in total renewable freshwater resources is observed in all provinces, as presented in Table 4. Figure 7 illustrates total available renewable water resources in the year 2040 for the BAU scenario (including CC impacts) and the BAUec scenario (without climate change impacts). The highest reduction in renewable water resources is observed in Eastern Cape. By 2040, climate change impacts reduce total renewable water resources by 42.2% compared to the BAUec scenario, which is equivalent to a reduction of 12,242 million m^3 per year. In terms of absolute reductions, Eastern Cape (EC) is followed by Northern Cape (NC), with reductions of 8,349 million m^3 in total renewable water resources per year, and Limpopo (LP), with reductions of 7,878 million m^3 per year. The projections for Western Cape (WC) indicate a decline of 2,513 million m^3 in annual renewable water resources by 2040, compared to the BAUec scenario.

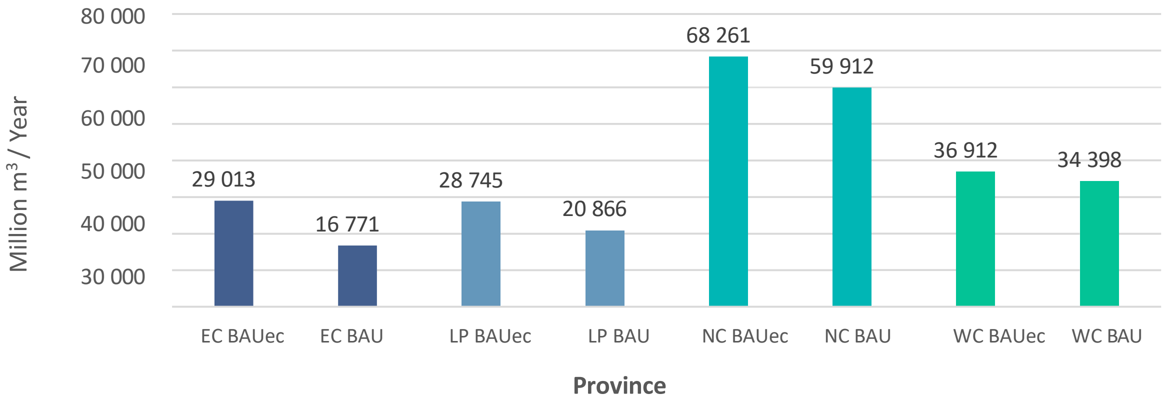


Figure 7.: Total renewable water resources on provincial level by 2040 (BAU vs BAUec) - Climate impacts.

The availability of water resources affects provincial value added if a shortage of water leads to reductions in GRP. Climate change impacts on GRP vary by province based on available water resources and the share of agriculture in total GRP. Reductions in GRP resulting from the simulation of climate impacts are observed in Eastern Cape and Northern Cape. Between 2019 and 2040, the projections indicate a cumulative reduction of ZAR 24.5 billion for Eastern Cape and ZAR 1.7 billion in Northern Cape (see Table 5). During the same period, no GRP impacts, were observed for Limpopo (due to the absence of water stress) and positive impacts of climate change are observed in Western Cape, where the increase in precipitation reduces the severity of water stress events in the future.

BOX 2: WESTERN CAPE GRP FOR AGRICULTURE

Agriculture is an important contributor to the South African economy, and a primary pillar at the provincial level in, for example, Western Cape. The Western Cape province has a different geographic conformation from the other provinces of South Africa, consequently, its agriculture is also distinguished in several ways. Stable and relatively adequate winter rainfall as well as well-developed infrastructure as well as and the diversity of agricultural enterprises contributes to the overall stability of agriculture.

Although the Province contributes 14% to the Country's Gross Domestic Product, it generates approximately 23% of the total value add of the agricultural sector in South Africa. Agricultural products account for approximately 34% of the total provincial exports and for 5.2 % of the province's GRP. Therefore, impacts of climate change in the availability of water resources and its effects in agriculture could have a severe impact in Western Cape's economy and mitigation measures should be prioritized at the provincial level.

Sources: The Agriculture and Agri-Business Sector Of The Western Cape (2005). Available at: https://www.elsenburg.com/wp-content/uploads/2022/02/Agriculture-and-Agri-Business-sector-of-the-Western-Cape.pdf.

Table 5.: Modelled GRP impacts of climate change.

Cumulative difference in GRP from 2019	Unit	2019	2030	2040
Eastern Cape	bn ZAR	0.0	-9.2	-24.5
Limpopo	bn ZAR	0.0	0.0	0.0
Northern Cape	bn ZAR	0.0	-0.7	-1.7
Western Cape	bn ZAR	0.0	0.1	0.3

2.4 PROVINCIAL WATER-BIODIVERSITY ANALYSIS RESULTS

2.4.1 Provincial macroeconomic drivers

Population and GRP are considered as the key drivers of water demand and environmental pressures. The substantial increase in population is observed for Western Cape, where total population is projected to increase by 1.79 million people or 27.6% between 2016 and 2040. Eastern Cape, Limpopo and Northern Cape see their population increase by 18.4%, 22.3% and 23.8% respectively, which is equivalent to an increase of 1.2 million, 1.28 million and 0.29 million people. Population projections are identical in the GE and the BAU scenario. An overview of population by province for 2030 and 2040, is provided in Table 6.

Table 6.: Summary of population results by province.

Province	Unit	2016 (data)	2030	2040	2040 vs 2016
Eastern Cape	Million people	6.51	7.17	7.71	18.4%
Limpopo	Million people	5.74	6.53	7.02	22.3%
Northern Cape	Million people	1.21	1.39	1.50	23.8%
Western Cape	Million people	6.48	7.69	8.27	27.6%

Source: UN Population division for South Africa

The development of GRP is affected by the level of water stress experienced by the provinces.[10] Western Cape and Eastern Cape exhibit the most economic growth across the four provinces. In the BAU scenario, GRP

[10] Corroborating the model results of expected impacts of climate change in water resources in South Africa, a recent study concluded by CSIR demonstrates that in parts of South Africa that dependent on groundwater, either entirely or partially, the combination of decreasing groundwater recharge potential and increasing population pressure will affect water supply as water supply decreases and demand increases. 41 settlements were identified as being at extreme risk of groundwater depletion, while another 156 were identified as being highly vulnerable (CSIR, 2022).

between 2016 and 2040 increases by 25.1% in Western Cape and 20.2% in Eastern Cape. Total GRP by 2040 in the BAU scenario is ZAR 546.3 billion in Western Cape and ZAR 280.7 billion in Eastern Cape. During the same period, GRP in Limpopo and Northern Cape experience increases by 9.9% and 2.2% in GRP respectively. Information about the development of provincial GRP in the BAU and GE scenario is provided in Table 7 for the years 2016, 2030 and 2040, respectively.

Table 7.: Gross Regional Product by province.

Province	Unit	2016 (data)	2030	2040	2040 vs 2016
Eastern Cape					
GE	Billion ZAR	233.40	266.28	287.31	23.1%
BAU	Billion ZAR	233.40	260.32	280.65	20.2%
GE vs BAU	*%*	*N/A*	*2.29%*	*2.37%*	
Limpopo					
GE	Billion ZAR	219.70	240.05	247.49	12.6%
BAU	Billion ZAR	219.70	234.20	241.45	9.9%
GE vs BAU	*%*	*N/A*	*2.50%*	*2.50%*	
Northern Cape					
GE	Billion ZAR	67.40	73.05	74.15	10.0%
BAU	Billion ZAR	67.40	67.91	68.90	2.2%
GE vs BAU	*%*	*N/A*	*7.58%*	*7.61%*	
Western Cape					
GE	Billion ZAR	436.50	516.97	567.39	30.0%
BAU	Billion ZAR	436.50	497.98	546.26	25.1%
GE vs BAU	*%*	*N/A*	*3.81%*	*3.87%*	

As illustrated in Table 7, in the GE scenario, the reduction in water stress from increased water efficiency and improved irrigation systems improve economic performance by between 2.4% (Eastern Cape) and 7.6% (Northern Cape). Productivity gains from GE interventions in Western Cape cause provincial GRP in the GE scenario to be 3.9% higher in 2040 compared to the baseline. In Limpopo, no changes in GRP are observed in the GE scenario, which, due to abundant groundwater resources[11], does not experience water stress in the BAU or GE scenario.

[11] Abundant water resource does not always equal fit for use water, as water may be of saline quality that requires pretreatment prior to use.

2.4.2 Provincial water demand

Information about projected total water demand for selected years is provided in Table 8. In the baseline, total water demand increases between 14% and 21% during the period between 2019 and 2040, across all provinces. In the BAU scenario, the largest increase in annual water demand relative to 2019 is observed in Western Cape with 21% (315.66 million m^3), followed by Eastern Cape with 17% (104.95 million m^3). In Limpopo and Northern Cape, water demand is projected to increase by 14% compared to 2019, which is equivalent to an increase of 76.85 million m^3 and 84.69 million m^3 respectively by 2040.

In the GE scenario, water efficiency interventions reduce total water demand below 2019 levels in all provinces. The reductions in total water demand compared to 2019 range from 2% in Northern Cape and Western Cape, to 6% in Eastern Cape and 7% in Limpopo. The highest net reductions in annual water demand by 2040 is achieved in Western Cape, where water efficiency measures contribute to saving 341.92 million m^3 per year in 2040 compared to the BAU scenario. In Eastern Cape, Limpopo and Western Cape, GE interventions contribute to reducing annual water demand in 2040 by 143.04 million m^3 (-20%), 114.44 million m^3 (-18.2%) and 95.01 million m^3 (-13.8%), respectively.

Table 8.: Summary of water demand results by province.

Province	Unit	2019 (Model)	2030	2040	2040 vs 2019
Eastern Cape					
GE	Million m^3/Year	611.24	534.07	573.15	-6%
BAU	Million m^3/Year	611.24	667.07	716.19	17%
GE vs BAU	*%*	*0.00%*	*-19.94%*	*-19.97%*	
Limpopo					
GE	Million m^3/Year	552.39	480.56	514.80	-7%
BAU	Million m^3/Year	552.39	585.23	629.24	14%
GE vs BAU	*%*	*0.00%*	*-17.88%*	*-18.19%*	
Northern Cape					
GE	Million m^3/Year	605.33	558.60	595.01	-2%
BAU	Million m^3/Year	605.33	639.07	690.02	14%
GE vs BAU	*%*	*0.00%*	*-12.59%*	*-13.77%*	
Western Cape					
GE	Million m^3/Year	1,536.54	1,399.57	1,510.28	-2%
BAU	Million m^3/Year	1,536.54	1,710.07	1,852.20	21%
GE vs BAU	*%*	*0.00%*	*-18.16%*	*-18.46%*	

Water demand for irrigation differs significantly across the four provinces due to differences in cultivated agricultural land. In the baseline, annual water demand for irrigation in 2040 totals 2.22 million m^3 in Eastern Cape, 127.6 million m^3 in Limpopo, 481.1 million m^3 in Northern Cape and 319.2 million m^3 in Western Cape. In all provinces, the shift towards more efficient irrigation technologies in the GE scenario yields a reduction of 11.1% in irrigation water demand by 2040. Compared to the baseline, this reduction is equivalent to 0.25 million m^3 per year in Eastern Cape, 14.12 million m^3 per year in Limpopo, 53.23 million m^3 per year in Northern Cape and 35.32 million m^3 per year in Western Cape. Information on water demand in the BAU and GE scenario for all provinces and selected years is provided in Table 9.

Table 9.: Summary of irrigation water demand results by province.

Province	Unit	2019 (Model)	2030	2040
Eastern Cape				
GE	Million m^3/Year	4.38	3.54	1.98
BAU	Million m^3/Year	4.38	3.91	2.22
GE vs BAU	*%*	***0.0%***	***-9.3%***	***-11.1%***
Limpopo				
GE	Million m^3/Year	128.56	106.16	113.52
BAU	Million m^3/Year	128.56	117.23	127.64
GE vs BAU	*%*	*0.0%*	*-9.4%*	*-11.1%*
Northern Cape				
GE	Million m^3/Year	429.20	402.48	427.87
BAU	Million m^3/Year	429.20	443.91	481.10
GE vs BAU	*%*	***0.0%***	***-9.3%***	***-11.1%***
Western Cape				
GE	Million m^3/Year	276.79	268.01	283.88
BAU	Million m^3/Year	276.79	295.61	319.19
GE vs BAU	*%*	***0.0%***	***-9.3%***	***-11.1%***

2.4.3 Provincial water supply

The underlying climate trend information obtained from the Department of Water and Sanitation (DWS, 2019) show a net reduction in total renewable water resources when compared to 2016. Total renewable water resources between 2019 and 2040 decline by 7.5 billion m^3 per year in Eastern Cape (-30.9%), 7.3 billion m^3 per year in Northern Cape (-10.9%), 6.2 billion m^3 per year in Limpopo (-22.9%) and 2.2 billion m^3 per year in Western Cape (-6%). The clearing of invasive alien species leads to a net increase in total renewable water resources in all provinces but Northern Cape. The increase in total renewable water resources ranges from

0.19% in Limpopo to 1.83% in Eastern Cape. For Northern Cape, a net decrease of 0.03% in total renewable water resources is observed, which is caused by the reduction of water supply obtained from water supply interventions, specifically greywater recycling. While additional water resources are unlocked through the clearing of invasive alien species land (0.71 million m^3 per year), this additional water supply is insufficient to compensate for the reduction in recycled greywater (-28.6 million m^3 per year) which is caused through increased water efficiency – which, in turn, reduces the amount of water available for recycling – at the municipal level.

BOX 3: SOUTH AFRICAN GREEN AND BLUE DROP STATUS

The Department of Water and Sanitation (DWS) implemented the Blue Drop programme to encourage continuous progress and to acknowledge excellence in drinking water services management in South Africa.

The Green Drop certification programme was designed to serve as stimulus for change; a catalyst to establish a water-shed in the water sector regarding the management of wastewater services. The aim of the Green Drop programme is to create a paradigm shift within the manner in which wastewater operations, management and regulation is being approached. It promotes incentive-based regulation; establishing excellence as the benchmark for wastewater services.

Blue Drop Certification (BDC) programme is the regulation tool introduced by DWEA with the aim of restoring the trust of the general public in the quality of tap water, by certifying the water quality of a municipality. These assessments and audits are done annually to determine who qualifies for Blue Drop Certification.

The first Blue Drop Report compiled by the Department of Water and Sanitation in 2009 indicated that the national microbiological compliance for South African tap water was measured at 93.3% against the National Standard (SANS 241). DSW reports that there has been a regression since then as Blue Drop Score had changed from 87.6% in 2012 to 79.6%, in 2014.

The last Green Drop and Blue Drop reports were published in 2013 and 2014 respectively. The Department of Water and Sanitation aimed to undertake a full Blue Drop audit and a Green Drop partial assessment in 2022. The results of the initiative have been recently released: Report_DPW_Rev02_29Mar22_MN web.pdf (dws.gov.za).

In terms of the provincial breakdown, Gauteng achieved the highest score of 92% in 2014, although a decline was observed from the score of 98%, from 2012. The Western Cape was the second-best performer with a score of 89% in 2014, which decreased when compared to the score of 94% from 2012. The score in Kwa- Zulu Natal had decreased from 92% in 2012 to 86% in 2014. Free State declined by 7.2% from 82% in 2012 to 75% in 2014. Eastern Cape had a blue drop score that declined by 10% from 82% in 2012 to 72% in 2014. Mpumalanga experienced an increase in its score from 60.9% in 2012 to 69.9% in 2014. Northern Cape had no changes with a score of 68% in 2014. The blue drop score for North West declined from 79% in 2012 to 63% in 2014. Limpopo declined from 79% in 2012 to 62% in 2014.

Source: Blue Drop Green Drop Report: Department of Water and Sanitation briefing (2017) https://pmg.org.za/committee-meeting/23873/

Compared to the BAU scenario, the increase in total renewable water resources from GE interventions in Eastern Cape, Limpopo and Western Cape is equivalent to 307.6 million m^3 per year, 39.1 million m^3 per year and 77.7 million m^3 per year by 2040 respectively. In Northern Cape, total renewable water resources In the GE scenario are projected to decline by 20.1 million m^3 by 2040 compared to the baseline. Information concerning the development of total renewable water resources is summarized in Table 10.

Table 10.: Provincial total renewable water resources.

Province	Unit	2019 (Model)	2030	2040	Net change by 2040
Eastern Cape					
GE	Million m^3/Year	24,283.0	21,162.9	17,078.2	307.6
BAU	Million m^3/Year	24,283.0	20,911.7	16,770.6	
GE vs BAU	*%*	*0.00%*	*1.20%*	*1.83%*	
Limpopo					
GE	Million m^3/Year	27,098.2	25,318.7	20,905.4	39.1
BAU	Million m^3/Year	27,098.2	25,287.5	20,866.3	
GE vs BAU	*%*	*0.00%*	*0.12%*	*0.19%*	
Northern Cape					
GE	Million m^3/Year	67,239.5	65,779.4	59,891.7	-20.1
BAU	Million m^3/Year	67,239.5	65,799.1	59,911.8	
GE vs BAU	*%*	*0.00%*	*-0.03%*	*-0.03%*	
Western Cape					
GE	Million m^3/Year	36,602.1	35,682.0	34,476.1	77.7
BAU	Million m^3/Year	36,602.1	35,625.3	34,398.3	
GE vs BAU	*%*	*0.00%*	*0.16%*	*0.23%*	

The projections indicate water stress for all provinces except for Limpopo Province, which, due to abundant groundwater resources, seems unaffected by water stress in this analysis. An overview of water stress in the BAU and GE scenario is provided in Figure, 8 for all provinces.

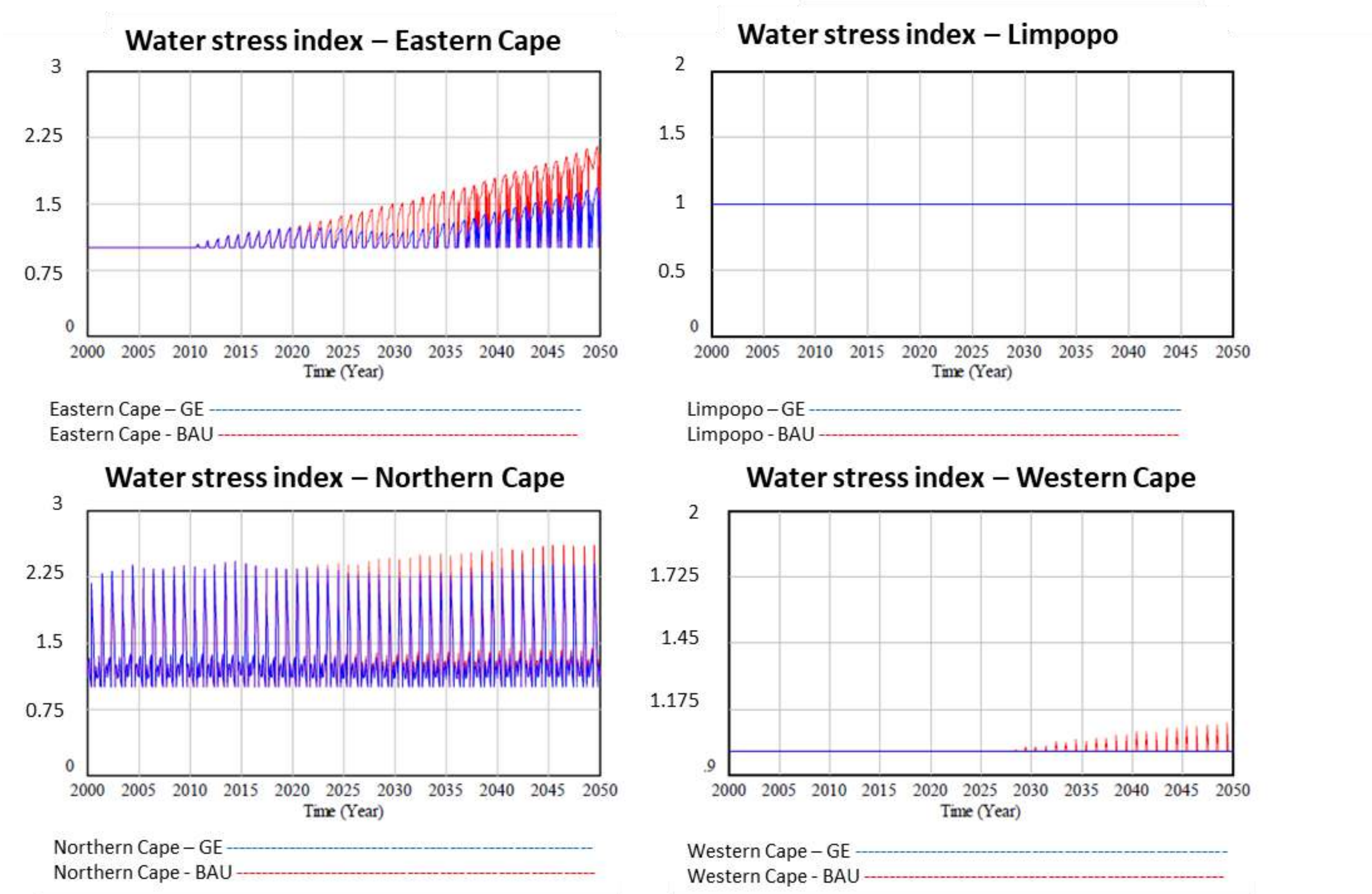


Figure 8.: Water stress by province - Eastern Cape, Limpopo, Northern Cape, and Western Cape.

As illustrated in Figure 8, all provinces except for Limpopo province, experience water stress in the BAU scenario. The projections indicate that Northern Cape already experiences competition for water resources from the beginning of the simulation. Water stress in Eastern Cape (top left) is projected to commence around the year 2011, while water stress in Western Cape is projected to commence by 2028. In the GE scenario, water efficiency interventions and the clearing of invasive alien species land contribute to preventing water stress in Western Cape, while alleviating water stress experienced by Eastern Cape and Northern Cape. The reductions in water stress in 2040 range from 0.7% in Western Cape to 18.3% in Eastern Cape. This indicates that especially the provinces of Eastern Cape and Northern Cape would benefit from the implementation of water efficiency measures (please refer to Table 11).

Table 11.: Summary of water stress results by province.

Province	Unit	2019 (Model)	2030	2040
Eastern Cape				
GE	Dmnl	1.09	1.06	1.27
BAU	Dmnl	1.09	1.26	1.55
GE vs BAU	*%*	*0.0%*	*-15.4%*	*-18.3%*
Limpopo				
GE	Dmnl	1.00	1.00	1.00
BAU	Dmnl	1.00	1.00	1.00
GE vs BAU	*%*	*0.0%*	*0.0%*	*0.0%*
Northern Cape				
GE	Dmnl	1.36	1.33	1.36
BAU	Dmnl	1.36	1.40	1.44
GE vs BAU	*%*	*0.0%*	*-5.0%*	*-5.2%*
Western Cape				
GE	Dmnl	1.00	1.00	1.00
BAU	Dmnl	1.00	1.00	1.01
GE vs BAU	*%*	*0.0%*	*-0.1%*	*-0.7%*

BOX 4: INVESTIMENTS FOR CLEARING OF INVASIVE SPECIES – THE CASE OF BERG RIVER DAM

An example of how interventions and the clearing of invasive alien species contribute to preventing water stress is the WfW (Working for Water) programme established by the South African Government in 1995 for the management of invasive alien plants (IAPs) to conserve water and to provide employment to marginalized sectors of South African society.

Some projects under the programme have resulted in previously heavily invaded ecosystems being returned to a state nearing pre-invasion conditions. In the case of the Berg River Dam, for example, the project covers 11,600 ha and commenced in 2001. An assessment conducted by CSIR, indicates that invasive species have been reduced significantly, resulting in increased water quantity and quality.

Source: CSIR (2022). Exploring Working for Water Success Stories. Available at: https://www.csir.co.za/exploring-working-water-success-stories

2.4.4 Provincial irrigation water losses

Water stress emerges as water demand exceeds water supply, indicating that water efficiency is crucial for sustainable development and avoiding competition of water in the future. Agriculture irrigation and the efficiency of irrigation systems play a key role in saving water and preventing water stress. Based on the BAU projections, annual water losses from irrigation in 2040 range between 1.1 million m^3 in Eastern Cape to 239.03 million m^3 in Northern Cape. The transition towards more efficient irrigation systems in the GE scenario contributes to reducing the losses from irrigation by 22.3% in all provinces compared to the BAU scenario. In 2040, water savings achieved from increasing efficient irrigation infrastructure total 0.25 million m^3 in Eastern Cape, 14.12 million m^3 in Limpopo, 53.23 million m^3 in Northern Cape and 35.32 million m^3 in Western Cape. An overview of simulated water losses from irrigation for all provinces and selected years is provided in Table 12.

Table 12.: Summary of irrigation water losses by province.

Province	Unit	2019 (Model)	2030	2040
Eastern Cape				
GE	Million m^3/Year	2.18	1.56	0.86
BAU	Million m^3/Year	2.18	1.92	1.10
GE vs BAU	%	**0.00%**	**-18.96%**	**-22.27%**
Limpopo				
GE	Million m^3/Year	63.88	47.18	49.29
BAU	Million m^3/Year	63.88	58.24	63.42
GE vs BAU	%	**0.00%**	**-19.00%**	**-22.27%**
Northern Cape				
GE	Million m^3/Year	213.25	179.12	185.81
BAU	Million m^3/Year	213.25	220.56	239.03
GE vs BAU	%	**0.00%**	**-18.79%**	**-22.27%**
Western Cape				
GE	Million m^3/Year	137.52	119.27	123.27
BAU	Million m^3/Year	137.52	146.87	158.59
GE vs BAU	%	**0.00%**	**-18.79%**	**-22.27%**

2.4.5 Provincial Water absorbed by invasive alien species

Water runoff reductions from land covered by invasive alien species (IAS) depends on the total amount of land covered with IAS and the average runoff reduction per hectare covered. The total amount of land covered by IAS is projected to slightly increase across all provinces in the BAU scenario. The GE scenario assumes that one third of land covered by IAS is cleared between 2020 and 2030.[12] The development of land covered by IAS in the BAU and GE scenario is summarized in Table 13.

Table 13.: Summary of land covered by invasive alien species by province.

Province	Unit	2019 (Model)	2030	2040
Eastern Cape				
GE	Ha	544,116	364,192	364,921
BAU	Ha	544,116	545,312	546,405
Limpopo				
GE	Ha	210,317	140,903	141,185
BAU	Ha	210,317	210,780	211,202
Northern Cape				
GE	Ha	27,960	18,666	18,689
BAU	Ha	27,960	27,998	28,033
Western Cape				
GE	Ha	173,641	115,968	116,189
BAU	Ha	173,641	174,004	174,335

Runoff reductions due to land covered by IAS are strongly affected by the amount of land covered by IAS and the respective species that are growing, in each province.

The clearing of IAS land in the GE scenario contributes to reducing water runoff reductions due to IAS compared to the baseline. In the BAU scenario, the projections indicate that, especially the Eastern Cape and Western Cape experience vast reductions in surface water runoff from IAS, with a total runoff reduction of 932.1 million m^3 and 414 million m^3 of water lost in 2040. The lost water is equivalent to 5.6% (Eastern Cape) and 1.2% (Western Cape) of total renewable water resources.

In the GE scenario, the clearing of IAS land reduces the amount of water absorbed by approximately 33% across all provinces. By 2040, the clearing of IAS land would contribute to unlocking renewable water

12 For the most current data on hectares of invasive plant species cleared, please refer to the Department of Forestry, Fisheries & the Environment Annual Performance Plan. Available at: https://www.dffe.gov.za/documents/annualreports

resources of 309.6 million m^3 in in Eastern Cape, 45.5 million m^3 in Limpopo, 8.6 million m^3 in Northern Cape and 138.1 million m^3 in Western Cape.

Table 14.: Summary of water absorbed from invasive alien species by province.

Province	Unit	2019 (Model)	2030	2040	*% of renewable water resources*	*GE and BAU difference by 2040*
Eastern Cape						
GE	Million m^3/Year	610.1	508.8	622.5	3.65%	-309.6
BAU	Million m^3/Year	610.1	761.8	932.1	5.56%	
GE vs BAU	*%*	*0.00%*	*-33.21%*	*-33.21%*		
Limpopo						
GE	Million m^3/Year	89.8	75.0	91.7	0.44%	-45.5
BAU	Million m^3/Year	89.8	112.1	137.2	0.66%	
GE vs BAU	*%*	*0.0%*	*-33.2%*	*-33.2%*		
Northern Cape						
GE	Million m^3/Year	16.9	14.0	17.2	0.03%	-8.6
BAU	Million m^3/Year	16.9	21.1	25.8	0.04%	
GE vs BAU	*%*	*0.0%*	*-33.3%*	*-33.3%*		
Western Cape						
GE	Million m^3/Year	271.0	225.5	275.9	0.80%	-138.1
BAU	Million m^3/Year	271.0	338.4	414.0	1.20%	
GE vs BAU	*%*	*0.0%*	*-33.4%*	*-33.4%*		

2.4.6 Provincial Agriculture

The amount of total agricultural land used for crop production in all provinces is illustrated in Figure 9. The highest increase in agricultural land is observed in the Western Cape province, while the projected expansion of agricultural land remains rather small in the Eastern Cape, Limpopo, and Northern Cape. While the amount of cropland is identical in the BAU and the GE scenario, the transition of 20% of cropland towards sustainable agriculture practices is assumed in the GE scenario. By 2040, the projections indicate that 20% of provincial agricultural land are managed sustainably, which is equivalent to approximately 3,900 hectares (Eastern Cape), 28,800 hectares (Limpopo), 21,700 hectares (Northern Cape) and 161,100 hectares (Western Cape), respectively.

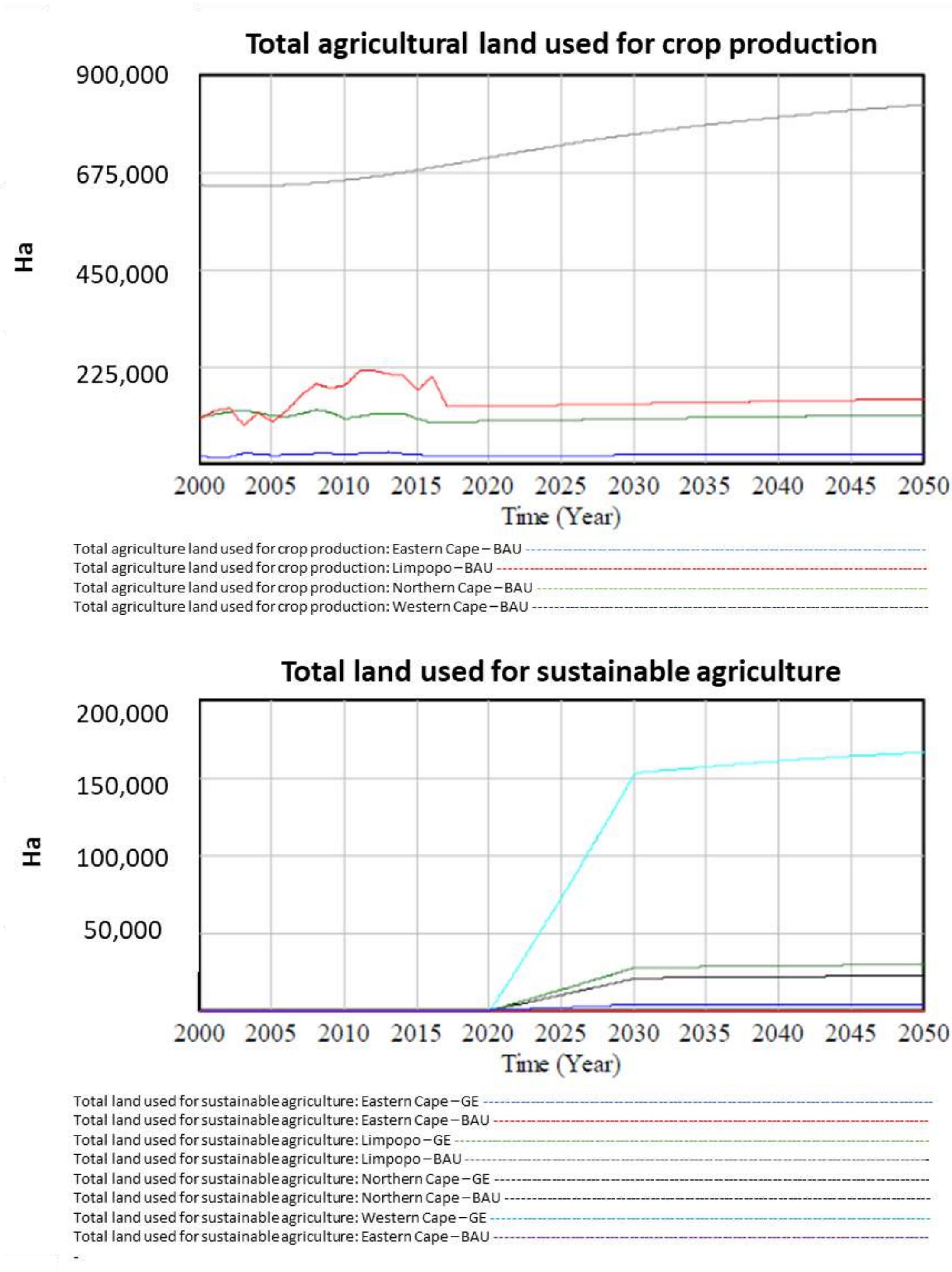


Figure 9.: Agricultural land used for crop production and organic agricultural land.

The transition towards sustainable agriculture practices in the GE scenario increases total agriculture production by 2% when compared to the BAU scenario, resulting from higher yields for organic crops. The projected increase in agriculture production ranges from 1,200 tonnes in Eastern Cape to 152,900 tonnes in Western Cape. A summary of agriculture production in the BAU and GE scenario is presented in Table 15.

Table 15.: Summary of agricultural production by provinces.

Province	Unit	2019 (Model)	2030	2040	Net change by 2040
Eastern Cape					
GE	Thousand	74.21	77.49	60.48	1.2
BAU	Thousand	74.21	75.97	59.30	
GE vs BAU	*%*	*0.00%*	*2.00%*	*2.00%*	
Limpopo					
GE	Thousand	426.00	441.55	460.35	12.0
BAU	Thousand	426.00	430.26	448.33	
GE vs BAU	*%*	*0.00%*	*2.62%*	*2.68%*	
Northern Cape					
GE	Thousand	1,064.52	1,150.06	1,203.16	23.6
BAU	Thousand	1,064.52	1,127.52	1,179.57	
GE vs BAU	*%*	*0.00%*	*2.00%*	*2.00%*	
Western Cape					
GE	Thousand	6,707.20	7,421.04	7,799.38	152.9
BAU	Thousand	6,707.20	7,275.61	7,646.45	
GE vs BAU	*%*	*0.00%*	*2.00%*	*2.00%*	

Information concerning the total amount of nitrogen (N) applied to agriculture cropland in all provinces is provided in Table 16, for the BAU and the GE scenario. The projections assume that the crop mix in all four provinces remains unchanged after 2017, and hence the baseline application of fertilizer remains constant into the future. Implementing sustainable agriculture practices lead to a 20% reduction in total fertilizer application in addition to increasing agriculture outputs. This reduces the total amount of nitrogen (N) that is applied on the fields by between 4,769 tonnes per year (Northern Cape) and 13,922 tonnes per year (Limpopo).

BOX 5: SOUTH AFRICAN IMPORTS OF FERTILIZER

South Africa is a global importer of fertilizers, importing mainly from Asia and Europe. Most of the Urea fertilizers imported into South Africa over the past decade were mainly from Asia. On average, South Africa imported 688 414 tonnes of Urea fertilizer from Asia over the past ten years.

The major supplier of LAN fertilizers into South Africa was primarily from Europe. On average, South Africa imported 93 416 tonnes of LAN fertilizers from Europe over the past ten years.

Most of the import volumes of MAP fertilizers from the world into South Africa were mainly from Europe, followed by Asia. On average, South Africa imported 62 869 tonnes of MAP fertilizers from Europe over the past decade.

The major supplier of potassium sulphate fertilizers from the world into South Africa was Europe, Americas surpassed Europe as the leading supplier of South African Potassium Sulphate on two occasions, in 2009 and 2012, while Asia claimed the top spot in 2014, 2016 and 2017.On average, South Africa imported 24 602 tonnes of potassium sulphate fertilizers from Europe over the past ten years.

The major supplier for potassium chloride fertilizers from the world into South Africa in the past ten years was from Europe, followed by Asia, Americas, and minimal import volumes from Africa. On average, South Africa imported 105 603 tonnes of potassium chloride fertilizers from Europe between 2008 and 2017 marketing seasons.

Source: DALRRD (2020) - South African Fertilizers Market Analysis Report. Available at: https://www.dalrrd.gov.za/doaDev/sideMenu/Marketing/Annual%20Publications/South%20African%20Fertilizer%20Market%20Analysis%20Report%202020.pdf

Table 16.: Summary of Nitrogen (N) fertilizer application from agriculture by province.

Province	Unit	201 (Model)	2030	2040
Eastern Cape				
GE	Tonne N/Year	57,215	46,875	48,494
BAU	Tonne N/Year	57,215	58,585	60,617
GE vs BAU	*%*	*0.00%*	*-19.99%*	*-20.00%*
Limpopo				
GE	Tonne N/Year	64,096	53,534	55,688
BAU	Tonne N/Year	64,096	66,909	69,610
GE vs BAU	*%*	*0.00%*	*-19.99%*	*-20.00%*
Northern Cape				
GE	Tonne N/Year	21,524	18,240	19,078
BAU	Tonne N/Year	21,524	22,797	23,848
GE vs BAU	*%*	*0.00%*	*-19.99%*	*-20.00%*
Western Cape				
GE	Tonne N/Year	60,003	52,067	54,705
BAU	Tonne N/Year	60,003	65,074	68,381
GE vs BAU	*%*	*0.00%*	*-19.99%*	*-20.00%*

2.4.7 Provincial wastewater treatment and Nitrogen (N) loadings

2.4.7.1 Wastewater treatment

The projections of wastewater and wastewater treatment facility (WWTF) capacity assume that a percentage of the population is connected to wastewater treatment network (see Table 17). The current simulations assume that this percentage is maintained in the future, which leads to the construction of wastewater treatment capacity once wastewater loads exceed current treatment capacity.[13] In the BAU scenario, the construction of additional wastewater treatment capacity is observed for Limpopo and Western Cape. Additional treatment requirements by 2040 are 45.7 million m^3 per year (equivalent to a capacity of 125.08

13 Rural - urban populational shifts are not considered in the model. The United Nations projects that 68% of the global population will be in cities by 2050. As the cities grow in these provinces, in size and density, if no better urban wastewater is in place and current treatment facilities are overwhelmed, wastewater may be discharged into existing natural water bodies, compromising health and food security in these urban areas.

ML/day) for Western Cape and 2.63 million m^3 per year (equivalent to a capacity of 7.21 ML/day) in Limpopo. In the GE scenario, the amount of wastewater is reduced because of the water efficiency interventions. This reduction prevents wastewater loads in Limpopo and Western Cape to exceed current capacity. This indicates that, given the reduction in wastewater loads, current capacity levels are projected to be sufficient until 2040, which prevents the necessity to construct additional wastewater treatment plants in both provinces.

Table 17.: Summary of wastewater treatment capacity by province.

Province	Unit	2019 (Model)	2030	2040
Eastern Cape				
GE	Million m^3/Year	178.7	178.7	178.7
BAU	Million m^3/Year	178.7	178.7	178.7
GE vs BAU	*%*	*0.00%*	*0.00%*	*0.00%*
Limpopo				
GE	Million m^3/Year	54.9	54.9	54.9
BAU	Million m^3/Year	54.9	54.9	57.5
GE vs BAU	*%*	*0.00%*	*-0.03%*	*-4.60%*
Northern Cape				
GE	Million m^3/Year	54.9	54.9	54.9
BAU	Million m^3/Year	54.9	54.9	54.9
GE vs BAU	*%*	*0.00%*	*0.00%*	*0.00%*
Western Cape				
GE	Million m^3/Year	423.1	445.7	446.1
BAU	Million m^3/Year	423.1	495.7	541.3
GE vs BAU	*%*	*0.00%*	*-10.08%*	*-17.60%*

In the BAU scenario, N concentration in wastewater treatment effluent is projected between 2.6 (Limpopo) and 16.2 mg/L (Eastern Cape) of effluent. The development of N concentration in WWTF effluents in all provinces is summarized in Table 18. In the GE scenario, the concentration of N is slightly higher compared to the BAU scenario. The N concentration per litre of effluent ranges from 3 mg/L in Limpopo to 20.2 mg/L in Eastern Cape.

This increase in effluent N concentration is caused by the reduction of total wastewater loads. While N loadings from population remain the same, the reduction in water use leads to less wastewater and hence an increased concentration of N in the water reaching the WWTF. Assuming that N removal efficiency of wastewater treatment remains constant leads to an increase in N concentration in WWTF effluent by between 16.4% and 25%.

Table 18.: Summary of wastewater treatment effluent Nitrogen (N) concentration by province.

Province	Unit	2019 (Model)	2030	2040
Eastern Cape				
GE	mg N/L	16.4	20.5	20.2
BAU	mg N/L	16.4	16.4	16.2
GE vs BAU	*%*	*0.00%*	*25.00%*	*25.00%*
Limpopo				
GE	mg N/L	2.5	3.1	3.0
BAU	mg N/L	2.5	2.5	2.6
GE vs BAU	*%*	*0.00%*	*23.61%*	*16.35%*
Northern Cape				
GE	mg N/L	9.4	11.8	11.7
BAU	mg N/L	9.4	9.4	9.3
GE vs BAU	*%*	*0.00%*	*25.00%*	*25.00%*
Western Cape				
GE	mg N/L	13.3	13.7	13.9
BAU	mg N/L	13.3	12.4	12.0
GE vs BAU	*%*	*0.00%*	*10.44%*	*16.39%*

3.4.7.2 Provincial Nitrogen (N) loadings

Total N loadings in the model are calculated as the sum of N loadings from wastewater treatment, N loadings from agriculture fertilizer application and N loadings from livestock (cattle). The development of total N loadings in the baseline and the GE scenario is summarized in Table 19 , for all provinces. Total N loadings in the GE scenario are between 2.9% (Eastern Cape) and 8.1% (Limpopo) lower when compared to the baseline scenario.

Table 19.: Summary of total annual Nitrogen (N) loadings by province.

Province	Unit	2019 (Model)	2030	2040
Eastern Cape				
GE	Tonne N/Year	21,209.5	21,346.3	22,116.1
BAU	Tonne N/Year	21,209.5	22,019.5	22,782.1
GE vs BAU	*%*	*0.00%*	*-3.06%*	*-2.92%*
Limpopo				
GE	Tonne N/Year	17,260.6	17,402.1	17,296.8
BAU	Tonne N/Year	17,260.6	18,961.4	18,815.4
GE vs BAU	*%*	*0.00%*	*-8.22%*	*-8.07%*
Northern Cape				
GE	Tonne N/Year	4,401.0	4,602.0	4,697.1
BAU	Tonne N/Year	4,401.0	4,860.5	4,949.7
GE vs BAU	*%*	*0.00%*	*-5.32%*	*-5.10%*
Western Cape				
GE	Tonne N/Year	23,926.8	24,784.3	26,565.6
BAU	Tonne N/Year	23,926.8	26,632.2	28,277.5
GE vs BAU	%	0.00%	-6.94%	-6.05%

The reduction of loadings is caused mainly through the transition towards sustainable agriculture practices and the assumed reduction in N fertilizer applications that comes with it. Across all provinces, the share of N loadings from fertilizer in total N loadings, declines. Table 20 provides information about the contribution of each polluter (municipalities, fertilizer, and livestock) to total N loadings for the BAU and the GE scenario in 2040. While the contribution of fertilizer to total N loadings is lower across all provinces, the share of loadings from wastewater and livestock manure runoff increases.

Table 20.: Summary of share of Nitrogen (N) loadings by polluter group in 2040 per province.

Province	Unit	N loadings from fertilizer	N loadings from livestock	N loadings from Municipalities
Eastern Cape				
GE	%	11.7%	42.3%	46.0%
BAU	%	14.1%	41.1%	44.8%
GE vs BAU	*%*	*-2.4%*	*1.2%*	*1.2%*
Limpopo				
GE	%	27.6%	20.6%	51.8%
BAU	%	31.7%	19.0%	49.2%
GE vs BAU	*%*	*-4.1%*	*1.6%*	*2.5%*
Northern Cape				
GE	%	20.9%	38.2%	41.0%
BAU	%	24.7%	36.3%	39.0%
GE vs BAU	*%*	*-3.8%*	*1.9%*	*1.9%*
Western Cape				
GE	%	19.4%	24.0%	56.6%
BAU	%	22.7%	22.6%	54.7%
GE vs BAU	*%*	*-3.3%*	*1.5%*	*1.9%*

The N concentration in surface water is used as water quality indicator in the models. It is estimated based on the total amount of surface water and total N loadings.[14] Concerning wastewater, it is assumed that both a share of loadings from decentralized wastewater treatment systems and WWTF effluents are released into surface water. In the BAU scenario, the N loadings in surface water is 1.05 mg/L (Western Cape), 1.59 mg/L (Eastern Cape) and 1.74 mg/L (Limpopo). For Northern Cape, additional information about water quality and loadings are required, as the current results indicate a surface water N concentration of 0.09 mg/L.

In the GE scenario, the reduction in total N loadings due to GE interventions causes the average N concentration in surface water to decline in all provinces. The lowest decline is observed for Northern Cape, with a reduction of 4.7% (-0.004 mg/L). In Eastern Cape, Limpopo and Western Cape, the N concentration in surface water in 2040 declines on average by 5.4% (-0.08 mg/L), 6.6% (-0.12 mg/L) and 5.8% (-0.06 mg/L) respectively.

[14] The models assume that a share of N loadings from fertilizer and livestock manure run off into surface water bodies.

Table 21.: Summary of Nitrogen (N) concentration in surface water by province.

Province	Unit	2019 (Model)	2030	2040
Eastern Cape				
GE	mg N/L	1.00	1.17	1.51
BAU	mg N/L	1.00	1.23	1.59
GE vs BAU	*%*	*0.00%*	*-4.52%*	*-5.35%*
Limpopo				
GE	mg N/L	1.19	1.35	1.62
BAU	mg N/L	1.19	1.44	1.74
GE vs BAU	*%*	*0.00%*	*-5.89%*	*-6.60%*
Northern Cape				
GE	mg N/L	0.07	0.08	0.09
BAU	mg N/L	0.07	0.08	0.09
GE vs BAU	*%*	*0.00%*	*-4.90%*	*-4.71%*
Western Cape				
GE	mg N/L	0.83	0.87	0.99
BAU	mg N/L	0.83	0.94	1.05
GE vs BAU	*%*	*0.00%*	*-6.76%*	*-5.81%*

2.4.8 Provincial Cost of interventions[15]

The cost of interventions is estimated for the shift in irrigation technologies and the clearing of land covered by invasive alien species (IAS). The costs of intervention were calculated from a combination of ambition (simulated and expressed in table 3) and the unit cost of the intervention. Combined, Western Cape requires the highest investment to realize the GE ambitions for irrigation and IAS. The required investment in Western Cape totals ZAR 12.55 billion between 2020 and 2040. In terms of total required investment, Western Cape is followed by Limpopo (ZAR 2.94 billion), Eastern Cape (ZAR 2.12 billion), and Northern Cape (ZAR 1.92 billion), respectively.

The cost of shifting towards more sustainable irrigation systems are the highest in Western Cape, where ZAR 624.6 million in additional capital and operations and maintenance (O&M) expenditure are required by 2040.This is more than twice as much investment required by 2040 as in Northern Cape (ZAR 300.6 million) and Limpopo (ZAR 215.5 million), and almost thirty times more than the required investment indicated for Eastern Cape (ZAR 21.1 million).

[15] The ambitions are included in Table 3 and the references for unit costs in annex VII, table VII.

Realizing the desired ambition for the clearing of IAS land requires between ZAR 90.2 million and ZAR 1.82 billion. These costs assume a one-time clearing of an area and continuous annual maintenance of cleared land following the initial clearing. It should be noted that the total amount of IAS land plays a significant role for the costs of the GE scenario, which is indicative of the effort that provinces need to put into realizing a one third reduction in IAS land. The highest cost is projected for Eastern Cape where additional investment of ZAR 1.84 billion is required between 2020 and 2040 for realizing the ambition. In terms of total additional investment required by 2040, Eastern Cape is followed by Limpopo (ZAR 683.5 million) and Western Cape (ZAR 592.4 million). The lowest cost for clearing IAS land is projected for Northern Cape, where an additional ZAR 90.2 million are required by 2040 to clear and maintain IAS land.

Table 22.: Integrated cost benefit analysis for Green Economy (GE) scenario by province.

Overview cost and Benefit	Unit	Eastern Cape	Limpopo	Northern Cape	Western Cape
Investment and O&M					
Cost of installing	**Million ZAR**	**21.1**	**215.5**	**300.6**	**624.6**
Investment required	Million ZAR	19.5	199.2	277.8	577.4
O&M Costs	Million ZAR	1.6	16.3	22.8	47.2
Cost of clearing IAS land	**Million ZAR**	**1,819.7**	**683.5**	**90.2**	**592.4**
Initial Clearing	Million ZAR	408.1	138.9	17.5	140.1
O&M Expenditure	Million ZAR	1,411.6	544.6	72.7	452.3
Cost of Organic Farming	**Million ZAR**	**277.9**	**2,043.3**	**1,529.7**	**11,331.8**
Investment Required	Million ZAR	28.0	207.1	155.7	1,157.6
O&M Costs	Million ZAR	249.9	1,836.2	1,374.0	10,174.2
Required GE Investment	**Million ZAR**	**2,118.8**	**2,942.4**	**1,920.5**	**12,548.8**
Added Benefits					
Additional GRP from	Million ZAR	93,545.5	90,408.1	79,270.3	298,521.4
Average per year in 2040	*Million ZAR/Year*	*93,545.5*	*90,408.1*	*79,270.3*	*298,521.4*
Net benefits from GE	**Million ZAR**	**91,426.7**	**87,465.7**	**77,349.9**	**285,972.6**
Non-discounted benefit		44.2	30.7	41.3	23.8

Additional investments and O&M required to achieve the GE ambitions range from ZAR 277.9 million in Eastern Cape to ZAR 11.33 billion in Western Cape between 2020 and 2040. Investment required for Limpopo and Northern Cape are projected at ZAR 2.94 billion and ZAR 1.92 billion. The projected costs in Table 22 indicated that total O&M costs required are between eight and nine times higher than the original capital investment.

In addition to alleviating water stress, the interventions in the GE scenario contribute to higher productivity in the agriculture sector. Both, unlocking additional water resources and improved productivity of organic cropland increase the GRP in the GE scenario compared to the baseline scenario. As illustrated in Table 7, the GE projections indicate that GRP in 2040 increases for all provinces, whereby increases in the individual provinces are 7.6% (Northern Cape), 3.9% (Western Cape), 2.5% (Limpopo) and 2.4% (Eastern Cape) respectively. Between 2020 and 2040, the additional cumulative GRP generated is 298.52 billion in Western Cape, 93.55 billion in Eastern Cape, 90.41 billion in Limpopo and 79.27 billion in Northern Cape. The increase in GRP across all provinces is projected to far outweigh the required investment for realizing the GE ambitions, with high benefit to cost ratios across all provinces.[16]

3. KEY AREAS FOR ACTIONS AND GUIDING PRINCIPLES

This section begins with a discussion to help guide decisionmakers to understand the key goals a green economy intervention should target. Following this, the key areas and the corresponding guiding principles that can be implemented by policy- and decision-makers to respond to the results outlined in the model and the discussion are presented in Table 23. To maintain and improve levels of biodiversity, the intervention should broadly focus on four goals:

3.1 MANAGING WATER DEMAND

Through increasing consumption efficiency and widening network coverage. Households, industry, and agriculture should have sufficient and reliable access to water, but should also be appropriately incentivised to not waste excessive amounts.

3.2 INCREASING WATER SUPPLY

Through improvements in water infrastructure, holding water utilities and service providers to account for high levels of service, and encouraging the development of non-conventional water supply, such as rainwater harvesting and the recycling of treated wastewater.

3.3 IMPROVING THE EFFICIENCY OF THE AGRICULTURAL SECTOR

Ensuring farmers are incentivised to upgrade to more efficient irrigation infrastructure and drought-resistant crops, whilst dissuading the sector from excessive use or waste of water. Meanwhile, infrastructure investments to encourage the re-use of treated wastewater across the sector, should be considered.

[16] The costs and benefits associated with these ratios have not been discounted to present value. Doing so would result in a decline in the benefit-cost ratio, although it would still be greater than one as, even with time discounts applied, the benefits of intervention greatly outweigh the costs.

3.4 REDUCING NITROGEN (N) LOADINGS

Improving the coverage and quality of wastewater treatment and encouraging farmers to switch to sustainable, organic farming.

The system dynamics model of the Water-Biodiversity nexus has illustrated the importance of taking a holistic approach to any green economy intervention.

3.5 POLICY RECOMMENDATIONS

The policy recommendations suggested in Table 23 are at two levels. At the operational level, policies are stemmed from the current technological solutions that could immediately create impacts; meanwhile, at the strategic level, long-term efforts are needed to push for a paradigm shift. Table 23 comprehensively outlines what and how sustainable water management and biodiversity conservation should focus on.

Table 23.: Policy recommendations/ suggestions for prominent stakeholders.[17].

Key Area of Action	Guiding Principles
1. Water Demand	**1.1. Water efficiency** Water efficiency interventions can be simulated in the residential, industrial and agriculture sector. Increasing water efficiency unlocks additional water resources by reducing water demand below the baseline. Policy Recommendations/ Suggestions for prominent stakeholders 1.1.1. **Government:** Reduce per capita water consumption through water tariff reform, ensuring the tariff better reflects the true market and environmental cost of sourcing and supplying water. Empirical studies show increases in water tariff led to near instant improvements in household efficiency of water consumption. Meanwhile, the tariff system should be designed not to harm the most disadvantaged; the merits of various tariff systems – such as a step tariff or cross-subsidies – should be considered. **(Strategic Action)** 1.1.2. **Government and Civil Society:** Undertake public awareness campaigns to emphasise the importance of water conservation and avoid wasteful practices. **(Strategic Action)**

[17] Whilst policy recommendations and suggests for prominent stakeholders are being provided, the practical implementation therefor may need to be supported through relevant research and demonstration to support at scale efficacy

Key Area of Action	Guiding Principles
	1.1.3. **Academia:** Further investigate the causes of water losses and the variables that influence them (potential variables could be local customs and tariff structure) at both provincial and national levels. **(Strategic Action)** 1.1.4. **Industry:** Incentivize dematerialization (i.e., adopting water resource conservation strategies in the entire value-added chain) and/or circular approaches to water use (e.g., the use of brackish water, treated wastewater, and desalinated water, closed loops for cooling). **(Strategic Action)** **Government and International Organisations:** Empower the agricultural, industrial and mining sectors by knowledge transfer and incentives to change water use and water management behaviour and adopt existing and/or new technologies that improve water efficiency and productivity via capacity building and/or providing positive and negative incentives. **(Strategic Action)**
	1.2. Water supply network coverage This recommendation would increase the coverage of the water supply network and capture part of the population that currently has no access to the freshwater supply network. Due to various factors, the unserved areas in South Africa cannot be connected to a centralised water grid. For these areas, a decentralised water supply is favourable. Policy Recommendations/ Suggestions for prominent stakeholders 1.2.1. **Government:** Develop a national and provincial integrated water resource management diagnosis (e.g., the geographical distribution of wastewater treatment plants, the amount of water flowing over the pipelines in the network, the capacity at which the wastewater treatment plants should be operated, and designated wastewater reuse sites, volume, and quality) and an inventory of various uses of treated wastewater and demineralised brackish water. **(Operational Action)** **Government:** Allocate local renewable water resources based on the characteristics of the local landscape and availability of renewable resources in the province through decentralised water supply networks. **(Operational Action)**
	1.3. Change in cropping patterns / change of crops This recommendation allows switching the composition of the crops that are grown on the provincial level. Some crops are more water-intensive than others, and irrigation water demand varies depending on the growing season (more water is

Key Area of Action	Guiding Principles
	required for irrigation during the dry season). Policy Recommendations/ Suggestions for prominent stakeholders 1.3.1. **Farmers:** Widely adopt irrigation warning systems for optimising soil moisture, volumes and timing for crops, and reducing evaporation losses. **(Operational Action)** 1.3.2. **Government:** Promote diverse, adapted, and innovative agricultural practices (e.g., plot diversification, crop rotation, sustainable grazing and pasture management, transhumance, hydroponic technology) with incentives and capacity building. (**Operational Action)** **Government/civil society organizations:** Support farming communities through capacity building and knowledge sharing to optimise cropping patterns for higher water productivity and encourage farmers' behavioural change to reduce water consumption. **(Strategic Action)**
2. Water Supply	**2.1. Water efficiency** Increasing water efficiency may unlock additional water resources by reducing water demand below the baseline for residential and industrial consumers. Policy Recommendations/ Suggestions for prominent stakeholders 2.1.1. **Government:** Explore responsible disposal of saline brines by conducting relevant research projects and creating pilot schemes in designated provinces. **(Operational Action)** 2.1.2. **Financial institutions:** Strengthen the enabling environment for the investment of water infrastructure through improving the disclosure of the exposure to water-related risks of their investment, declaring the nature and size of their portfolios of water-related investment, and expediting internal decision-making procedures on water-related investment. **(Strategic Action)** 2.1.3. **Government:** Incentivise Public-Private Partnerships (PPPs) for desalination and wastewater treatment projects. **(Strategic Action)** 2.1.4. **Government:** Broaden the national water pricing systems (currently reviewed by the DWS) from households to all sectors (e.g., agricultural sectors and industry), with an extra emphasis on the price elasticity of demand, alongside exploring the possibility of establishing a grey water rebate system to incentivise households and industry to install grey water irrigation system. **(Strategic Action)**

Key Area of Action	Guiding Principles
	Government: Develop a strategy to deal with non-revenue water (water supply that does not generate income for utilities, either due to pipe leakages, unpaid bills etc.) estimated at 41% (Water Resource Group, 2019). This could involve linking key performance indicators (KPIs) of water utilities to financial incentives.
	2.2. Stormwater collection Stormwater collection schemes have an impact on the total water supply. Collected stormwater quantities are estimated based on precipitation, urban area, and the share of stormwater collected. Policy Recommendations/ Suggestions for prominent stakeholders 2.2.1. **Government:** Provide property tax incentives for those properties switching to decentralised solutions to address the issue of the lack of finance for developing relevant infrastructure while creating high-value multi-functional urban space. **(Strategic Action)** **Academia and Government:** Protect public health under operational conditions by developing national monitoring systems and the corresponding guidelines for validating stormwater reuse schemes. **(Strategic Action)**
	2.3. Rainwater harvesting Rainwater harvesting refers to the immediate collection and storage of rainwater during precipitation events. The collection and storage of rainwater are assumed to increase the total water supply. Policy Recommendations/ Suggestions for prominent stakeholders **Government:** Identify the usage for harvested rainwater and the corresponding treatments (e.g., irrigation, toilet flushing, and heating and cooling). **(Operational Action)**
	2.4. (Grey) water recycling Water recycling, as defined in provincial planning documents, refers to the total amount of wastewater that is recycled. Water recycling is common across South Africa; however, approximately 8% of the current potential is used due to the implications of a dual bulk water infrastructure requirement and subsequent high costs to implement the dual system.

Key Area of Action	Guiding Principles
	Policy Recommendations/ Suggestions for prominent stakeholders 2.4.1. **Civil Society:** Minimising freshwater consumption and addressing the public perception, trust, and acceptance regarding the use of reclaimed water by developing an extensive greywater reuse strategy. **(Strategic Action)** 2.4.2. **Industry and Government:** Encouraging technologists to get involved in rural communities for facilitating access to piped water and supporting the application of the decentralised greywater treatment systems. (**Operational Action)** 2.4.3. **Government:** Conduct extensive monitoring to ensure that the decentralised greywater treatment systems can perform reliably in the long term. **(Operational Action)** **Government:** Providing attractive investment pay-backs for smaller installations. **(Strategic Action)**
	2.5. Clearing of invasive alien species land This recommendation assumes investments in the clearing of land covered by invasive alien species. In total, land covered by invasive alien species in South Africa absorbs between 1,444 million m^3 and 2,444 million m^3 of water per year (van Wilgen & Wilson, 2017). The clearing of land increases surface water runoff that feeds surface water bodies (and hence dams) and increases groundwater recharge. **Policy Recommendations/ Suggestions for prominent stakeholders** 2.5.1. **Academia and Government:** Disseminate information and enhance the public's awareness and attitude by developing informational documents (e.g., technical data sheets) for the public and for managers of natural resources. **(Operational Action)** **Government:** Develop cost-recovery mechanisms and/or fines to contribute to implementation costs, alongside attempting to share the costs more evenly between public and private sectors. **(Strategic Action)**
3. Agriculture	**3.1 Organic farming** This recommendation increases the share of agriculture premises that adopt sustainable agriculture practices. The use of sustainable agriculture is assumed to expand sustainable cropland, generate additional employment, and reduce the application of chemical fertilizers and pesticides.

Key Area of Action	Guiding Principles

Policy Recommendations/ Suggestions for prominent stakeholders

3.5.1. **Financial institutions and Academia:** Facilitate farmer support measures through multidisciplinary research and close partnership between universities and farmers. **(Strategic Action)**

3.5.2. **Civil Society and Government:** Assist farmers in the agroecological transition by sustaining the necessary investments through incentives and risk reduction, utilization of local know-how, and benchmarking of agroecological practices. **(Strategic Action)**

3.5.3. **Civil Society and Government:** Encourage the farming communities and associations from specific commodity sectors to upscale resource management efficiency and conservation solutions. **(Strategic Action)**

3.2 Water efficiency

The water efficiency policy targets the efficiency of irrigation systems. If the water efficiency policy is effective, water application efficiency of irrigation systems is assumed to increase.

Policy Recommendations/ Suggestions for prominent stakeholders

3.2.1. **Agricultural sector:** Procure smart agricultural systems that enhance irrigation efficiency and preserve resources, to optimize volumes and timing for crops and to reduce evaporation losses. **(Operational Action)**

3.2.2. **Agricultural sector:** Strengthen participatory agricultural water planning and self-management by giving Lebalelo – the existing water user association – the responsibility to operate parts of or the entire irrigation system via a pilot scheme. **(Operational Action)**

3.2.3. **Government:** Encourage water conservation and the efficient use of water through tariff reform that adequately incentivises farmers to upgrade equipment and improve efficiency. **(Strategic Action)**

Civil Society and Government: Encourage good environmental practices by incentivizing the use of locally manufactured materials for irrigation while providing adequate training for using, operating, and maintaining effective irrigation system. **(Strategic Action)**

Key Area of Action	Guiding Principles

3.3 Drought resilient crops

This recommendation increases the resilience of the agriculture sector to water shortages by assuming the use of drought resistant crops. If drought resistant varieties are assumed, crop production losses due to the lack of water during the dry season are reduced.

Policy Recommendations/ Suggestions for prominent stakeholders

3.3.1 **Government:** Provide financial incentives – for example through tax credits or insurance subsidies – to encourage farmers to trial drought resistant crops. **(Operational Action)**

Financial institutions and international organisations: Foster agribusiness and responsible investment in agriculture and food systems by developing preferential investment and loan programmes and establishing Voluntary Sustainability Standards (VSS) focused investment products. **(Strategic Action)**

3.4 Organic fertilizer application

The policies targeting organic fertilizers assume the increased use of manure in the fields for fertilization.

Policy Recommendations/ Suggestions for prominent stakeholders

3.4.1 **Government:** Directly provide farmers with organic fertilizers, subsidized, instead of providing money. **(Operational Action)**

3.4.2 **Government:** Incentivize the existing and/or potential farmers running larger farms by optimizing the rural land circulation policy. **(Strategic Action)**

3.5 Sustainable pasture practices

Soil erosion occurs in many pastures because of overgrazing. The sustainable use of pasture reduces overgrazing and contributes to soil improvements on land that was overgrazed in the past. For example, wetlands, soils and grasslands in the Matatiele area of the Eastern Cape are restored, bringing profitable spinoffs for livestock farmers in the area.

Policy Recommendations/ Suggestions for prominent stakeholders

3.5.1. **Agricultural sector:** Diversify the species of pasture while planting local pasture seeds. **(Operational Action)**

Key Area of Action	Guiding Principles
	3.5.2. **Agricultural sector and government:** Provide pasture management planning training events to enable pasture users to plan and manage their land in a sustainable manner. **(Operational Action)** 3.5.3. **Agricultural sector and government:** Encourage organic and traditional practices in conjunction with ecotourism and landscape conservation. **(Strategic Action)** **Government and international organisations:** Develop an online platform that allows quick access to a wide range of pasture management techniques. **(Strategic Action)**
	3.6 Irrigation coverage Irrigation coverage refers to the percentage of productive cropland covered by irrigation infrastructure. By increasing irrigation coverage, more land will be covered and potentially productive, even during water shortages from precipitation. On the other hand, more irrigation infrastructure bears the risk of increasing water stress and shortages during the dry season beyond the baseline. It exacerbates negative impacts, which in turn could facilitate the development of responsible usage of irrigation systems. Policy Recommendations/ Suggestions for prominent stakeholders 3.6.1 **Financial institutions:** Encourage patient capital (i.e., financial investment in a business with no expectation of turning a quick profit) and other innovative financial instruments that could help provide additional sources of finance for irrigation infrastructure. **(Operational Action)** 3.6.2 **Government:** Develop a national and/or provincial strategy to make solar irrigation more affordable while reducing the use of fossil-fuel-based irrigation and incorporating solar energy into rural development plans. **(Strategic Action)**
4. Wastewater and N loadings	**4.1 Sustainable agriculture** A share of agriculture land should be managed sustainably, helping to reduce levels of fertilizer runoff. As the share of sustainable agricultural land increases, fertilizer consumption and hence runoff from fertilizers will decline. Policy Recommendations/ Suggestions for prominent stakeholders 4.1.1. **Civil Society and Government:** Farming communities and

extension officers collaborate to develop local participatory strategies to encourage agricultural producers to work together to reduce agricultural non-point source pollution. **(Strategic Action)**

4.1.2. **Government:** Create incentives for commercial farmers to implement optimal management techniques at the farm level, such as barn waste reduction, animal waste management, diversions, and grazing land protection. **(Strategic Action)**

Government: Provide financial assistance to encourage the adoption of alternative management systems by establishing a wide range of water quality incentive projects. **(Strategic Action)**

4.2. Increase in wastewater treatment coverage

A larger share of people should be connected to central wastewater treatment plants, which reduces N loading runoff from decentralized or non-sewered population leaching into the rivers.

Policy Recommendations/ Suggestions for prominent stakeholders

4.2.1. **Government:** Encourage the investments in water recycling (i.e., use of alternate water supplies such as brackish water, as well as closed loops for cooling purposes) **(Strategic Action)**

Civil Society and Government: Improve inter-sectoral cooperation (e.g., agricultural, environment, and health) and consultation when creating wastewater treatment policies. **(Strategic Action)**

4.3. Change in wastewater treatment technology

The models assume three different treatment technologies, each with a different nutrient removal efficiency. A shift in technology allows to increase the efficiency of wastewater treatment, which reduces N concentration in wastewater treatment effluent.

Policy recommendations/ Suggestions for prominent stakeholders

Industry: Increase the adoption of non-conventional water resources through wastewater and drainage water treatment. (**Operational Action)**

4.4 Reduced leakage of untreated wastewater

Wastewater leakage occurs because of a) inefficient wastewater transport networks and b) potential sewage overflows in case of strong precipitation events. This policy allows for assuming improved wastewater transport and reducing sewage overflows, which reduces the amount of N leaked during wastewater transport and sewage overflows during precipitation events.

Policy Recommendations/ Suggestions for prominent stakeholders

4.4.1 **Academia and Government:** Explore the possibility to utilise the current SCADA system and/or machine learning of pattern recognition to detect untreated wastewater flows into watercourses. **(Operational Action)**

4.4.2 **Government:** Set KPIs for all provinces and municipalities regarding the response rate to any significant pollution occurrences and when violations are discovered. **(Operational Action)**

4.5 Wastewater treatment adjustment

The current setup of the models assumes the automatic adjustment of wastewater treatment capacity once currently installed capacity is insufficient to manage incoming wastewater loads. This recommendation allows to determine the adjustment of wastewater treatment capacity (central treatment).

Policy Recommendations/ Suggestions for prominent stakeholders

Government: Determine the treatment capacity and public space occupied by the infrastructure and its extension, alongside identifying the best potential sites of the wastewater treatment plant by using GIS-based analysis and mapping. **(Strategic Action)**

4. CONCLUSION

South Africa is a country with a rich fauna and flora, in which protection of biodiversity is secured in several legal documents. The country has one of the most comprehensive biodiversity regulatory frameworks, having a Biodiversity Act and a National Biodiversity Institute. Since nature conservation is a shared function, state regulation is complemented by regional regulatory acts. All four provinces analysed in this report, with very particular biological, geographical and economic characteristics, have their own supplementary regulatory framework.

As a simplified representation of the reality, the system dynamics models on the Water-Biodiversity nexus does not intend to predict all future environmental impacts of climate change in all provinces, and some recent empirical observations diverge from the modelling results completed in 2020. Still the model offers a useful analytical tool to understand the relationship between different variables, which can be complemented with more recent data, to base future policies intervention. Some of the conclusion presented in the model are summarized in the following paragraphs.

Firstly, the BAU and GE scenario results show that GRP growth will increase in both instances across all provinces by 2040. However, higher growth will be recorded under the GE scenario, where the water stress is reduced owing to usage efficiency and proper irrigation practices. The reductions in water stress by 2040 range from 0.7% in Western Cape to 18.3 in Eastern Cape. This indicates that the provinces would benefit from implementing water efficiency measures. Under the GE scenario, water efficiency measures reduce total water demand below 2019s level in all provinces. The Western Cape province will record the highest reduction in water demand in the absence of water stress.

Secondly, invasive alien species (IAS) affect surface water runoff. When IAS land is cleared under the GE scenario, the water runoff improves relative to the BAU scenario. Clearing IAS land reduced the amount of water absorbed by approximately 33% across all provinces. Clearing IAS land by 2040 would lead to water resources up to 309.6 million m^3 in Eastern Cape, 45.5 million m^3 in Limpopo, 8.6 million m^3 in Northern Cape, and 138.1 million m^3 in Western Cape. The move for more efficient irrigation systems in the GE scenario results in reduced losses from irrigation by 22.3% in all provinces compared to the BAU scenario.

Thirdly, from the projections of the GE scenario, 20% of provincial agricultural land will be managed sustainably by 2040, which is equivalent to approximately 3,900 hectares (Eastern Cape), 28,800 hectares (Limpopo), 21,700 hectares (Northern Cape) and 161,000 hectares (Western Cape). The Western Cape province will require the highest investment to realize the GE scenario target for irrigation and clearing IAS. This investment totals ZAR 12.55 billion between 2020 and 2040. The next highest are Limpopo (ZAR 2.94 billion), Eastern Cape (ZAR 2.12 billion), and Northern Cape (ZAR 1.92 billion).

Finally, this report provides some policy recommendations based on global best practices in the key areas of water demand, water supply, agriculture, and wastewater and N loadings. Specific policy options must be tailored and applicable to each province's individual circumstance Policy- and decision-makers, lawmakers, private sectors, academia, local communities, among other stakeholders shall continue to conduct collaborative actions to create co-benefits that aim to advance the provinces closer to the Green Economy scenario.

BIBLIOGRAPHY

African Development Bank. (2007). Assessment of Best Practises and Experience in Water Harvesting. Retrieved October7, 2022, from https://www.pseau.org/outils/ouvrages/bafd_rainwater_harvesting_handbook.pdf

Alberta Health Service. (2021). Public Health Guidelines for Water Reuse and Stormwater Use. Retrieved October 26, 2022, from https://open.alberta.ca/dataset/6a57d29c-d437-4dd9-94e3-d96bedc01bb4/resource/d533afcb-2933-43da-9199-eea030148c00/download/health-public-health-guidelines-water-reuse-stormwater-use-2021.pdf

Asian Development Bank. (2021). Five Lessons for Shaping Policies and Programs to Accelerate Urban Sanitation in Asia: A Case Study on the Beijing Gaobeidian Wastewater Treatment Plant. Retrieved October 7, 2022, from https://www.adb.org/sites/default/files/publication/734796/adbi-brief-five-lessons-shaping-policies-092421.pdf

Basson, M., & Rossouw, J. (2003a). Mzimvubu to Keiskamma Water Management Area - Overview of Water Resources Availability and Utilisation. DWAF report No: P WMA 12/000/00/203: Department of Water Affairs and Forestry, South Africa.

Basson, M., & Rossouw, J. (2003b). Limpopo Water Management Area - Overview of Water Resources Availability and Utilisation. DWAF report No: P WMA 01/000/00/0203: Department of Water Affairs and Forestry, South Africa.

Basson, M.S.; Rossouw, J.D. (2003c). Lower Orange Water Management Area - Overview of water resources availability and utilisation. DWAF Report No: P WMA 14/000/00/0203: Department of Water Affairs and Forestry.

Cai, X., Magidi, J., Nhamo, L., & van Koppen, B. (2017). Mapping Irrigated Areas in the Limpopo Province, South Africa. doi: 10.5337/2017.205: International Water Management Institute (IMWI), Working Paper 172.

CER. (2018). PROVINCIAL NOTICE 178. Retrieved from Centre for Environmental Rights (CER): https://cer.org.za/wp-content/uploads/2018/08/Draft-Eastern-Cape-Biodiversity-Conservation- Strategy-and-Action-Plan.pdf

CER. (2019). Draft Western Cape Biodiversity Bill, 2019. Retrieved from Centre for Environmental Rights (CER): https://cer.org.za/virtual-library/legislation/provincial/western-cape/draft-western-cape- biodiversity-bill-2019

CER. (2019). PROVINCIAL NOTICE 1. Retrieved from Centre for Environmental Rights: https://cer.org.za/wp-content/uploads/2004/09/Limpopo-bioregional-plans.pdf

Chalmers, Y. (N.D.). Relationships between yield and water in winegrapes. Australian Government, Department of Agriculture, Water & Vine.

CSIR (2022). Groundwater/ Retrieved from the web: https://pta-gis2web1.csir.co.za/portal/apps/GBCascade/index.html ?appid=73c7e05d7a1e4b0dbacc99b3709f7065

DFFE (2022), DFFE Annual report 2021-22)
(https://www.dffe.gov.za/sites/default/files/reports/dffe2021.2022annualreport.pdf)

DWAF. (2002). Animal Production - Livestock Production. Retrieved from Department of Agriculture, Forestry and Fisheries: https://www.daff.gov.za/Branches/Agricultural-Production-Health-Food-Safety/Animal-Production/Livestock-Production

DWAF. (2004a). Eastern Region Internal Strategic Perspectives - Mvoti to Mzimkulu Water Management Area. Prepared by Tlou & Matji (Pty) Ltd, WRP (Pty) Ltd, and DMM cc on behalf of the Directorate: National Water Resource Planning (East). DWAF Report No. P WMA 11/000/00/0304: Department of Water Affairs and Forestry, South Africa.

DWAF. (2004b). Fish to Tsitsikamma Water Management Area: Tsitsikamma to Coega internal strategic perspective. Department of Water Affairs and Forestry, South Africa.

DWAF. (2007). Western Cape Water Supply System: Reconciliation Strategy Study. DWAF Report No: P WMA 19/000/00/0507: Department of Water Affairs and Forestry.

DWAF. (2011). Western Cape Integrated Water Resources Management Action Plan: Status Quo Report Final Draft. https://www.westerncape.gov.za/other/2011/8/final_draft_exec_summary_report_2011.pdf: Department of Water Affairs and Forestry.

Department of Water and Sanitation. DWS. (2011a). Green Drop Report 2011 - Chapter 3 - Eastern Cape.

DWS. (2011b). Green Drop Report 2011 DWS- Chapter 7 - Limpopo.

DWS. (2011c). Green Drop Report 2011 - Chapter 10 - Northern Cape.

DWS. (2011d). Green Drop Report 2011 - Chapter 11 - Western Cape.

DWS. (2019, 09 13). National Integrated Water Information System (NIWIS). Retrieved from Department of Water Affairs and Sanitation: http://niwis.dws.gov.za/niwis2/?AspxAutoDetectCookieSupport=1

DWS. (2019, 09 13). Provincial dam capacity and average fill levels by province. Retrieved from South African Department of Water and Sanitation - Water is life, sanitation is dignity: http://www.dwa.gov.za/Hydrology/Weekly/Province.aspx

Environmental Commissioner of Ontario. (2016). Urban Stormwater Fees - How to Pay for What We Need. Retrieved October 26, 2022, from https://www.auditor.on.ca/en/content/reporttopics/envreports/env16/Urban-Stormwater-Fees.pdf

Environmental Protection Agency of the United States. (2008). Managing Wet Weather with Green Infrastructure. Retrieved October 7, 2022, from: https://www.epa.gov/sites/default/files/2015-10/documents/gi_munichandbook_harvesting.pdf

FAO. (2005). Fertilizer use by crop in South Africa. Rome: Food and Agriculture Organization of the United Nations.

FAO. (2022). Voluntary Guidelines on the Responsible Governance of Tenure. Retrieved October 26, 2022, from https://www.fao.org/3/i2801e/i2801e.pdf

Filali, H., Barsan, N., Souguir, D., Nedeff, V., Tomozei, C., & Hachicha, M. (2022). Greywater as an Alternative Solution for a Sustainable Management of Water Resources—A Review. Sustainability, 14(2), 665.

Forrester, J. (1961). Industrial Dynamics. Cambridge, MA: MIT Press.

Gilson, S., Cyre, H., Harrison, D., Reese, A., & Tucker, S. (2006). Guidance for Municipal Stormwater Funding. Retrieved October 26, 2022, from https://www.epa.gov/sites/default/files/2015-10/documents/guidance-manual-version-2x-2_0.pdf

Global Invasive Species Programme. (2003). Invasive Alien Species in South-Southeast Asia. Retrieved October 26, 2022, from https://www.gisp.org/downloadpubs/SOUTH_AN.pdf

Grain-SA. (2019). Grain SA - Report Documents. Retrieved from www.grainsa.co.za

Håkanson, L., Bryhn, A., & Biencker, T. (2007). Operational effect variables and functional ecosystem classifications - a review on empirical models for aquatic systems along with a salinity gradient. International Review of Hydrobiology , 326-357.

Institute for European Environmental Policy. (2009). Technical Support to EU Strategy on Invasive Alien Species (IAS): Recommendations on policy options to minimise the negative impacts of invasive alien species on biodiversity in Europe and the EU. Retrieved October 7, 2022, from: https://ec.europa.eu/environment/nature/invasivealien/docs/Shine2009_IAS_Final%20report.pdf

International Institute for Sustainable Development. (2022). Standards and investments in Sustainable Agriculture. Retrieved October 26, 2022, from https://www.iisd.org/ssi/reviews/standards-investment-sustainable-agriculture

Jovanovic, N., Mu, Q., Bugan, R., & Zhao, M. (2015). Dynamics of MODIS evapotranspiration in South Africa. Water SA 41, http://www.scielo.org.za/scielo.php?script=sci_arttext&pid=S1816- 79502015000100005.

Kettunen, M., Heikkilä, J., Underwood, E., & Vyliaudaite, L. (2014). Instruments for financing action on invasive alien species (IAS). Retrieved October 26, 2022, from https://ieep.eu/uploads/articles/attachments/d1b7abe7-75be-4aeb-8d82-b75194bf1272/Kettunen_at_al_2014_review_of_instruments_financing_IAS_action_FINAL_June_2014.pdf?v=63664509852

Khavhagali, V. P. (2010). Importance, threats, status and conservation challenges of biodiversity in Northern Cape. The Grassland Society of South Africa.

Marais, C., van Wilgen, B., & Stevens, D. (2004). The clearing of invasive alien plants in South Africa: a preliminary assessment of costs and progress. South African Journal of Science 100, 97-103.

Ministry of Ecology, Sustainable Development and Energy of France. (2015). Invasive Alien Species in Aquatic Environments. Retrieved October 7, 2022, from http://www.especes-exotiques-envahissantes.fr/wp-content/uploads/2016/10/EEEvol1-Complet-UKweb.pdf

Mwendera, E., & Atyosi, Y. (2018). A review of water storage for socio-economic development in South Africa. Journal of Water Resource and Protection, 10(03), 266.

Ng'ang'a, S., Miller, V., Essegbey, G., Karbo, N., Nautsukpo, K. S., & Girvetz. (2017). Cost and benefit analysis for climate-smart agricultural (CSA) practices in the coastal Savannah-Agro-Ecological Zone (AEZ) of Ghana. USAID , CIAT, CIGAR and CCAFS Working paper.

OECD. (2022). Water - the right price can encourage efficiency and investment. Retrieved October 7, 2022, from https://www.oecd.org/env/resources/water-therightpricecanencourageefficiencyandinvestment.htm

Peters, R. (1986). The role of prediction in limnology. American Association of Limnology and Oceanography 31, 1143-1159.

Pitman, W., Bailey, A., & Beater, A. (2002). Upper Orange Water Management Area - Water Resources Situation Assessment. DWAF Report No: P13000/00/0101: Department of Water Affairs and Forestry.

Probst, G., & Bassi, A. (2014). Tackling Complexity: A systematic approach for decision makers. Sheffield, UK: Greenleaf Publishing.

Probst, G., & Bassi, A. (2014). Tackling Complexity: A Systemic Approach for Decision Makers. Sheffield, UK: Addison Wesley.

Quantec. (2019). EasyData - South African macroeconomic, industry and trade. Retrieved from https://www.easydata.co.za/

Rast, W., Lee, & G.F. (1978). Summary analysis of the North American (US Portion) OECD eutrophication project. Paris: Organisation for Economic Co-operation and Development.

Roberts, N., Andersen, D., Deal, R., Garet, M., & Shaffer, W. (1983). Introduction to Computer Simulation.

SANBI. (2013). Life: the state of South Africa's biodiversity 2012. Pretoria: South African National Biodiversity Institute (SANBI).

SANBI. (2019). The 2018 National Biodiversity Assessment. Retrieved October 6, 2022, from http://biodiversityadvisor.sanbi.org/planning-and-assessment/national-biodiversity-assessment-nba-2018/

SASRI. (2019). Retrieved from South African Sugarcane Research Institute: https://sasri.org.za/storage/Information_Sheets/IS_5.8-Irrigation-systems-selection.pdf

STATS SA. (2005). South African Statistics, 2004/05. Retrieved from Statistics South Africa: https://www.statssa.gov.za/publications/SAStatistics/SAStatistics2004.pdf

Statistics South Africa (2022) – Mid year population estimates. Retrieved from Statistics South Africa: https://www.statssa.gov.za/publications/P0302/P03022022.pdf

Sterman, J. D. (2000). Business Dynamics - Systems Thinking and Modeling for a complex world. Irwin McGraw-Hill.

Stevens, J., & van Koppen, B. (2015). Trends and Outlook: Agricultural Water Management in Southern Africa - Country Report South Africa. USAID in collaboration with IMWI, ReSAKSS and NEPAD.

The NSW Department of Environment and Conservation. (2006). Managing Urban Stormwater. Retrieved October 7, 2022, from https://www.environment.nsw.gov.au/-/media/OEH/Corporate-Site/Documents/Water/Water-quality/managing-urban-stormwater-harvesting-reuse-060137.pdf

The NSW Department of Primary Industries. (2015). Recycled Water Management Systems. Retrieved October 7, 2022, from https://www.industry.nsw.gov.au/__data/assets/pdf_file/0010/180478/Section-60-NSW-Guildeines-for-Recycled-Water-Management-Systems.pdf

The System Dynamics Approach. MA: Addison-Wesley.

Toma, L. (2003). Policy recommendations for pursuing a sustainable agriculture in a small rural community in Romania. Retrieved October 7, 2022, from: https://www.ssoar.info/ssoar/bitstream/handle/document/11130/11130_1.pdf?sequence=1

UN Population Division. (2019). UN Population Division. Retrieved from United Nations Department of Economic and Social Affairs - Population: https://www.un.org/en/development/desa/population/index.asp

UNEP. (2014). Using models for Green Economy Policymaking. Available here: http://www.un-page.org/files/public/content-page/unep_models_ge_for_web.pdf: United Nations Environment Programme.

UNESCAP. (2015). Policy Guidance Manual on Wastewater Management with a Special Emphasis on Decentralised Wastewater Treatment System. Retrieved October 7, 2022, from: https://www.unescap.org/sites/default/d8files/knowledge-products/Policy%20Guidance%20Manual%20on%20Wastewater%20Management.pdf

United Nations Convention to Combat Desertification. (2019). Drought Resilience, Adaptation and Management Policy Framework. Retrieved October 7, 2022, from https://www.unccd.int/sites/default/files/relevant-links/2019-09/190906%20UNCCD%20drought%20resilience%20technical%20guideline%20EN.pdf

van Wilgen, B., & Wilson, J. (2017). The status of biological invasions and their 2 management in South Africa in 2017. South African National Biodiversity Institute (SANBI).

World Bank. (2019). The World Bank Data. Retrieved from https://data.worldbank.org/

ANNEXURES

ANNEXURE I: OVERVIEW OF DATA SOURCES

This Annexure provides an overview of key data sources used for the parameterization and calibration of key indicators in the provincial models. Key data sources and institutions for each of the modules are summarized in Annexure I, Table 1.

Annexure I Table 1.: Summary of data sources by module

Module	Data Sources
Macroeconomic drivers	Quantec UN Population division
Water demand	Department of Water Affairs and Forestry (DWAF) Department of Water and Sanitation
Water supply	Department of Water Affairs and Forestry (DWAF) Department of Water and Sanitation Statistics South Africa van Wilgen & Wilson (2017)
Land use	Quantec The World Bank Data Portal van Wilgen & Wilson (2017)
Agriculture	Quantec Food and Agriculture Organization of the United Nations Department of Water Affairs and Forestry
Wastewater and N loadings	Department of Water and Sanitation Department of Water Affairs and Forestry

ANNEXURE II: DATA SOURCES BY PROVINCE: EASTERN CAPE

Annexure II Table 2.: Data sources for the Eastern Cape province.

Key indicators by sector	Source(s)	Data point	Time series
MACROECONOMIC DRIVERS			
Total population	Quantec, 2019		x
Population growth rate	Quantec, 2019; UN Population Division, 2019		x
Gross Regional Product (GRP)	Quantec, 2019		x
GRP growth rate	Quantec, 2019		x
WATER DEMAND			
Residential water demand	Basson & Rossouw, 2003a; DWAF, 2004b	x	
Industry water demand	Basson & Rossouw, 2003a; DWAF, 2004b	x	
Agriculture water demand	Basson & Rossouw, 2003a; DWAF, 2004b	x	
WATER SUPPLY			
Precipitation	STATS SA, 2005		2000-2004
Trend in precipitation	DWS, 2019	x	
Evapotranspiration	Jovanovic, Mu, Bugan, & Zhao, 2015; DWS, 2019	x	
Percolation	Assumption / Calibration		
Water supply from surface water	Basson & Rossouw, 2003a; DWAF, 2004b	x	
Water supply from groundwater	Basson & Rossouw, 2003a; DWAF, 2004b	x	
Water supply from dams	Assumption / Calibration		
Efficiency of water transport	Assumption		
LAND USE			
Agricultural land (cropland)	Quantec, 2019; World Bank, 2019		x
Pasture	Quantec, 2019; World Bank, 2019		x
Conservation area	Quantec, 2019; World Bank, 2019		x
Forests	Quantec, 2019; World Bank, 2019		x
Settlement land	Quantec, 2019; World Bank, 2019		x

Key indicators by sector	Source(s)	Data point	Time series
INVASIVE ALIEN SPECIES (IAS)			
Land covered by IAS	van Wilgen & Wilson, 2017	x	
Water absorption per hectare covered by IAS	van Wilgen & Wilson, 2017	x	
Trend in water absorbed by IAS	van Wilgen & Wilson, 2017	x	
AGRICULTURE			
Cropland by crop	Quantec, 2019		x
Yield per hectare and crop	Quantec, 2019		x
Fertilizer application per hectare	Weighted average based on Quantec, 2019 and FAO,2005		
Irrigation requirements by crop	Assumption		
Growing season by crop	Assumption		
% of organic agriculture	Assumption		
Livestock (beef cattle)	DWAF, 2002	x	
WASTEWATER TREATMENT FACILITY (WWTF)			
Installed WWTF capacity	DWS, 2011a	x	
% of installed WWTF technologies	Assumption		
Efficiency of WWTF capacity	Assumption		
% of population connected to WWTF	Estimated based on DWS, 2011a		
Wastewater transport efficiency	Assumption		
Impact of precipitation of overflow	Assumption		
N LOADINGS AND WATER QUALITY			
N loadings per capita		x	
N loadings from livestock	Estimate	x	
N loadings from fertilizer	Estimate	x	
N concentration in surface water	Estimated based on DWS, 2019		
COSTS AND INVESTMENT			
Cost of clearing IAS land	Marais, van Wilgen, & Stevens, 2004	x	
Cost of organic farming	Ng'ang'a, et al., 2017	x	
Cost of irrigation systems	SASRI, 2019		

ANNEXURE III: DATA SOURCES BY PROVINCE: LIMPOPO

Annexure III Table 3.: Data sources for the Limpopo province.

Key indicators by sector	Source(s)	Data point	Time series
MACROECONOMIC DRIVERS			
Total population	Quantec, 2019		x
Population growth rate	Quantec, 2019; UN Population Division, 2019		x
Gross Regional Product (GRP)	Quantec, 2019		x
GRP growth rate	Quantec, 2019		x
WATER DEMAND			
Residential water demand	Basson & Rossouw, 2003b	x	
Industry water demand	Basson & Rossouw, 2003b	x	
Agriculture water demand	Basson & Rossouw, 2003b	x	
WATER SUPPLY			
Precipitation	STATS SA, 2005		2000-2004
Trend in precipitation	DWS, 2019	x	
Evapotranspiration	Jovanovic, Mu, Bugan, & Zhao, 2015; DWS, 2019	x	
Percolation	Assumption / Calibration		
Water supply from surface water	Basson & Rossouw, 2003b	x	
Water supply from groundwater	Basson & Rossouw, 2003b	x	
Water supply from dams	Assumption / Calibration		
Efficiency of water transport	Assumption		
LAND USE			
Agricultural land (cropland)	Quantec, 2019; World Bank, 2019		x
Pasture	Quantec, 2019; World Bank, 2019		x
Conservation area	Quantec, 2019; World Bank, 2019		x
Forests			x
Settlement land			x
INVASIVE ALIEN SPECIES (IAS)			
Land covered by IAS	van Wilgen & Wilson, 2017	x	

Key indicators by sector	Source(s)	Data point	Time series
Water absorption per hectare covered by IAS		x	
Trend in water absorbed by IAS		x	
AGRICULTURE			
Cropland by crop	Quantec, 2019		x
Yield per hectare and crop			x
Fertilizer application per hectare	Weighted average based on Quantec, 2019 and FAO,2005		
Irrigation requirements by crop	Assumption		
Growing season by crop	Assumption		
% of organic agriculture	Assumption		
Livestock (beef cattle)	DWAF, 2002	x	
WASTEWATER TREATMENT FACILITY (WWTF)			
Installed WWTF capacity	DWS, 2011a	x	
% of installed WWTF technologies	Assumption		
Efficiency of WWTF capacity	Assumption		
% of population connected to WWTF	Estimated based on DWS,2011a		
Wastewater transport efficiency	Assumption		
Impact of precipitation of overflow	Assumption		
N LOADINGS AND WATER QUALITY			
N loadings per capita		x	
N loadings from livestock	Estimate	x	
N loadings from fertilizer	Estimate	x	
N concentration in surface water	Estimated based on DWS, 2019		
COSTS AND INVESTMENT			
Cost of clearing IAS land	Marais, van Wilgen, & Stevens, 2004	x	
Cost of organic farming	Ng'ang'a, et al., 2017	x	
Cost of irrigation systems	SASRI, 2019		

ANNEXURE IV: DATA SOURCES BY PROVINCE: NORTHERN CAPE

Annexure IV Table 4.: Data sources for the Northern Cape province.

Key indicators by sector	Source(s)	Data point	Time series
MACROECONOMIC DRIVERS			
Total population	Quantec, 2019		x
Population growth rate	Quantec, 2019; UN Population Division, 2019		x
Gross Regional Product (GRP)	Quantec, 2019		x
GRP growth rate	Quantec, 2019		x
WATER DEMAND			
Residential water demand	Pitman, Bailey, & Beater, 2002; Basson, M.S.; Rossouw, J.D., 2003c	x	
Industry water demand		x	
Agriculture water demand		x	
WATER SUPPLY			
Precipitation	STATS SA, 2005		2000-2004
Trend in precipitation	DWS, 2019	x	
Evapotranspiration	Jovanovic, Mu, Bugan, & Zhao, 2015; DWS, 2019	x	
Percolation	Assumption / Calibration		
Water supply from surface water	(Pitman, Bailey, & Beater, 2002; Basson, M.S.; Rossouw, J.D., 2003c	x	
Water supply from groundwater		x	
Water supply from dams	Assumption / Calibration		
Efficiency of water transport	Assumption		
LAND USE			
Agricultural land (cropland)	Quantec, 2019; World Bank, 2019		x
Pasture			x
Conservation area			x
Forests			x
Settlement land			x
INVASIVE ALIEN SPECIES (IAS)			

Key indicators by sector	Source(s)	Data point	Time series
Land covered by IAS	van Wilgen & Wilson, 2017	x	
Water absorption per hectare covered by IAS		x	
Trend in water absorbed by IAS		x	
AGRICULTURE			
Cropland by crop	Quantec, 2019		x
Yield per hectare and crop			x
Fertilizer application per hectare	Weighted average based onQuantec, 2019 and FAO, 2005		
Irrigation requirements by crop	Assumption		
Growing season by crop	Assumption		
% of organic agriculture	Assumption		
Livestock (beef cattle)	DWAF, 2002	x	
WASTEWATER TREATMENT FACILITY (WWTF)			
Installed WWTF capacity	DWS, 2011a	x	
% of installed WWTF technologies	Assumption		
Efficiency of WWTF capacity	Assumption		
% of population connected to WWTF	Estimated based on DWS, 2011a		
Wastewater transport efficiency	Assumption		
Impact of precipitation of overflow	Assumption		
N LOADINGS AND WATER QUALITY			
N loadings per capita		x	
N loadings from livestock	Estimate	x	
N loadings from fertilizer	Estimate	x	
N concentration in surface water	Estimated based on DWS, 2019		
COSTS AND INVESTMENT			
Cost of clearing IAS land	Marais, van Wilgen, & Stevens, 2004	x	
Cost of organic farming	Ng'ang'a, et al., 2017	x	
Cost of irrigation systems	SASRI, 2019		

ANNEXURE V: DATA SOURCES BY PROVINCE: WESTERN CAPE

Annexure V Table 5.: Data sources for the Western Cape province.

Key indicators by sector	Source(s)	Data point	Time series
MACROECONOMIC DRIVERS			
Total population	(Quantec, 2019)		x
Population growth rate	(Quantec, 2019; UN Population Division, 2019)		x
Gross Regional Product (GRP)	(Quantec, 2019)		x
GRP growth rate	(Quantec, 2019)		x
WATER DEMAND			
Residential water demand	(DWAF, 2007)	x	
Industry water demand		x	
Agriculture water demand		x	
WATER SUPPLY			
Precipitation	(STATS SA, 2005)		2000-2004
Trend in precipitation	(DWS, 2019)	x	
Evapotranspiration	(Jovanovic, Mu, Bugan, & Zhao, 2015; DWS, 2019)	x	
Percolation	Assumption / Calibration		
Water supply from surface water		x	
Water supply from groundwater		x	
Water supply from dams	Assumption / Calibration		
Efficiency of water transport	Assumption		
LAND USE			
Agricultural land (cropland)	(Quantec, 2019; World Bank, 2019)		x
Pasture			x
Conservation area			x
Forests			x
Settlement land			x
INVASIVE ALIEN SPECIES (IAS)			
Land covered by IAS	(van Wilgen & Wilson, 2017)	x	
Water absorption per hectare covered by IAS		x	

Key indicators by sector	Source(s)	Data point	Time series
Trend in water absorbed by IAS		x	
AGRICULTURE			
Cropland by crop	(Quantec, 2019)		x
Yield per hectare and crop			x
Fertilizer application per hectare	Weighted average based on (Quantec, 2019) and (FAO, 2005)		
Irrigation requirements by crop	Assumption, Wine calibrated		
Growing season by crop	Assumption		
% of organic agriculture	Assumption		
Livestock (beef cattle)	(DWAF, 2002)	x	
WASTEWATER TREATMENT FACILITY (WWTF)			
Installed WWTF capacity	(DWS, 2011a)	x	
% of installed WWTF technologies	Assumption		
Efficiency of WWTF capacity	Assumption		
% of population connected to WWTF	Estimated based on (DWS, 2011a)		
Wastewater transport efficiency	Assumption		
Impact of precipitation of overflow	Assumption		
N LOADINGS AND WATER QUALITY			
N loadings per capita		x	
N loadings from livestock	Estimate	x	
N loadings from fertilizer	Estimate	x	
N concentration in surface water	Estimated based on (DWS, 2019)		
COSTS AND INVESTMENT			
Cost of clearing IAS land	(Marais, van Wilgen, & Stevens, 2004)	x	
Cost of organic farming	(Ng'ang'a, et al., 2017)	x	
Cost of irrigation systems	(SASRI, 2019)		

ANNEXURE VI: SUMMARY OF THE PROVINCIAL DATA GAPS

Annexure VI Table 6.: Provincial data gaps.

Module and key indicator	Description of current approach
MACROECONOMIC DRIVERS	
Population growth rate	Time series from the UN Population division for South Africa. Province-level data would improve the validation of results.
GRP growth rate	Last data point (2016) obtained from Quantec.
WATER DEMAND	
Residential water demand	Due to the lack of time series data, the models currently assume a constant water use per capita based on available data. Time series information on water use would allow for observing trends in water use per capita.
Industry water demand	Due to the lack of time series data, the models currently assume that water demand per Rand remains constant. This means that industry water demand is currently only affected by changes in GRP itself, but does not account for potential improvements in water efficiency that have occurred. Time series information on industry water use would allow for observing trends in water use per Rand generated.
AGRICULTURE	
Crop water demand per month	The current setup of the models is based on water demand data used for other studies in the African context, such as the Southern Agricultural Growth Corridor of Tanzania assessment (UNEP TEEB, 2018). Country- or province-level data on crop water requirements per month would increase the customization of the models to the provincial context.
Seasonality of irrigation demand	Growing seasons (and hence crop water demand) are currently calibrated to overlap with the rainy season to the extent possible.
Share of installed irrigation technologies	Detailed information concerning the share of installed irrigation systems on provincial level would improve the customization of the model to the local context. Currently, the average share of irrigation technologies installed in South Africa (Stevens & van Koppen, 2015) is used for the provincial models.

Module and key indicator	Description of current approach
Efficiency of water conveyance infrastructure	The efficiency of water conveyance infrastructure is part of the weighted average irrigation efficiency in that it determines the amount of water lost during transport to the fields. Currently, an efficiency of 95% is assumed.
WATER SUPPLY	
Water extraction by source	Time series information about the extraction of water by source was not available. Obtaining this information would improve the customization of the model to the provincial context.
Water supply from mountain aquifers	The structure for water supply from mountain aquifers has been developed, but not operationalized due to the lack of data. If data on water supplied from mountain aquifers would be available, the structure could be operationalized.
Water supply interventions	While these interventions were mentioned in relation with the provincial water sector, no data on the actual scale at which such interventions are applied is available. Information on the water supply obtained from different water supply interventions (storm water collection, rainwater harvesting and greywater recycling) would contribute to improved customization of the models.
WASTEWATER AND N LOADINGS	
Wastewater treatment capacity and efficiency	Information about wastewater treatment capacity was only available on aggregate provincial level, and information about installed technologies could not be obtained. Additional information about wastewater treatment capacity (and planned expansion) and the N removal efficiency of installed technologies would contribute to capturing wastewater treatment and wastewater treatment effluent quality more accurately.
N concentration in wastewater treatment effluents	Data concerning the N concentration in wastewater treatment effluents would contribute to validating the projections of wastewater treatment (and its efficiency) on provincial level.
N concentration in surface water	Some information concerning the concentration of N in surface water were obtained from the NIWIS website (DWS, 2019), for certain rivers. Province level averages on N concentration in surface water would contribute to improving the calibration of N loadings in the models.
INVESTMENTS AND COST	
Cost of wastewater treatment	Data would contribute to improving projections on wastewater related costs.
Cost of water supply network	Data would contribute to improving projections on water supply related costs.

ANNEXURE VII: POLICY INTERVENTIONS

Annexure VII Table 7.: Policy intervention by module.

WATER DEMAND	
Water efficiency	Water efficiency policies can be simulated in the residential, industrial and agriculture sector. Increasing water efficiency unlocks additional water resources by reducing water demand below the baseline. A fraction of water efficiency implemented is assumed for residential and industrial consumers.
Water supply network coverage	This policy would allow to increase the coverage of the water supply network to also capture part of the population that currently has no access to the freshwater supply network. Total water demand is expected to increase if water supply network coverage increases.
Change in cropping patterns/change of crops	This policy allows to switch the composition of the crops that are grown on provincial level. Some crops are more water intensive than others, and irrigation water demand varies depending on the growing season (more water required for irrigation during the dry season).
WATER SUPPLY	
Water efficiency	Water efficiency policies can be simulated in the residential, industrial and agricultural sector. Increasing water efficiency unlocks additional water resources by reducing water demand below the baseline. A fraction of water efficiency implemented is assumed for residential and industrial consumers.
Stormwater collection	This policy allows to examine the effect of stormwater collection schemes on total water supply. Collected stormwater quantities are estimated based on precipitation, urban area and a share of stormwater collected.
Rainwater harvesting	Rainwater harvesting refers to the immediate collection and storage of rainwater during precipitation events. The collection and storage of rainwater is assumed to increase total water supply.
(Grey-)water recycling	Water recycling, or usable return flows how they are defined in provincial planning documents, refers to the total amount of wastewater that is recycled. Water recycling is common across South Africa, however on approximately 8% of the current potential are used.

Clearing of invasive alien species land	This policy assumes investments in the clearing of land covered by invasive alien species. In total, land covered by invasive alien species in South Africa absorb between 1,444 million m^3 and 2,444 million m^3 per year (van Wilgen & Wilson, 2017). The clearing of land increases surface water runoff that feeds surface water bodies (and hence dams) and increases groundwater recharge.
AGRICULTURE	
Organic farming	This policy increases the share of agriculture premises that use sustainable agriculture practices. The use of sustainable agriculture is assumed to expand sustainable cropland, generate additional employment, reduce the application of chemical fertilizers and pesticides.
Water efficiency	The water efficiency policy targets the efficiency of irrigation systems. If the water efficiency policy is active, water application efficiency of irrigation systems is assumed to increase.
Drought resilient crops	This policy increases the resilience of the agriculture sector to water shortages by assuming the use of droughts resistant crops. If drought resistant varieties are assumed, crop production losses due to the lack of water during the dry season are reduced.
Organic fertilizer application	This policy targeting organic fertilizers assumes the increased use of manure on the fields for fertilization.
Sustainable pasture practices	Soil erosion is occurring on many pastures as a consequence of overgrazing. The sustainable use of pasture reduces overgrazing and contributes to soil improvements on land that was overgrazed in the past.
Irrigation coverage	Irrigation coverage refers to the percentage of productive cropland that is covered by irrigation infrastructure. By increasing irrigation coverage, more land will be covered by irrigation and potentially productive even in case of water shortages from precipitation. On the other hand, more irrigation infrastructure bears the risk to increase water stress and shortages during the dry season beyond the baseline and hence exacerbate negative impacts.
WASTEWATER AND N LOADINGS	
Sustainable agriculture	This policy assumes that a share of agriculture land is managed sustainably, assuming that there is no fertilizer runoff from sustainably managed agriculture land. As the share of sustainable agriculture land increases, fertilizer consumption and hence runoff from fertilizers will decline.

Increase in wastewater treatment coverage	This policy assumes that a larger share of people is connected to central wastewater treatment plants, which reduces N loading runoff from decentralised or non-sewered population leaching into the rivers.
Change in wastewater treatment technology	The models assume three different treatment technologies, each with a different nutrient removal efficiency. A shift in technology allows to increase the efficiency of wastewater treatment, which reduces N concentration in wastewater treatment effluent.
Reduced leakage of untreated wastewater	Wastewater leakage occurs as a result of a) inefficient wastewater transport networks and b) potential sewage overflows in case of strong precipitation events. This policy allows for assuming improved wastewater transport and reducing sewage overflows, which reduces the amount of N leaked during wastewater transport and sewage overflows during precipitation events.
Wastewater treatment adjustment	The current setup of the models assumes the automatic adjustment of wastewater treatment capacity once currently installed capacity is insufficient to manage incoming wastewater loads. This policy allows to determine the adjustment of wastewater treatment capacity (central treatment).

Publication: **MODELING THE WATER-BIODIVERSITY NEXUS IN FOUR SOUTH AFRICAN PROVINCES: NORTHERN CAPE, EASTERN CAPE, WESTERN CAPE, & LIMPOPO**