



# **Exploring water supply economics, opportunity costs and cost of unserved water in the context of various water augmentation considerations – using the Western Cape water supply system as a case study**

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A report to the Water Research Commission

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# EXECUTIVE SUMMARY

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## BACKGROUND

South Africa is a water-stressed country facing increased dry spells and weather variability. From a climate change adaptation perspective, the country needs to urgently increase its resilience specifically in the ability to manage its water resources. The concept of the water-energy-food nexus concerns the pressures being put on water resources by climate change and reduced water availability, brought about by economic development including population growth and globalization. These are presenting communities and regulators with an increasingly complex number of trade-offs and potential conflicts. Whilst the demand for water is increasing, the global water cycle is changing (part of a wider phenomenon referred to as climate change), where the effects are expected to vary across areas and seasons. The need to maintain a sustainable environment, for economic growth and to increase agricultural production to meet global food requirements, has increased the demand for the world's water resources. This has raised concerns about increasing the efficiency of water use. In the last decade, the number of countries facing the problem of water scarcity and insufficient water supply has increased sharply. At the global level, while per capita water availability is declining, withdrawals are projected to increase more rapidly, especially in developing countries.

## AIMS OF THE PROJECT

The aims of the project were as follows:

1. To conduct a literature review to gather relevant information that would enable refinement of the project methodology document and updating of the respective models.
2. To upgrade the SA Water SAM for inclusion of alternative supply sources specifically water reuse and desalination to an Alternative Water SAM.
3. To develop an expanded computable general equilibrium (CGE) model which accommodates stochastic elements to enable evaluation of certainty of supply and supply elasticity.
4. To develop a dynamic version of the CGE model to reflect the dynamic nature of economy.
5. To demonstrate the model as an assessment framework by conducting a scenario analysis for the Berg River WMA.
6. To undertake modelling of tariff structures with parallel evaluation of opportunity cost and cost of unserved water.
7. To undertake a National and regional/sectoral analysis by considering the impacts of different sets of policy interventions.

## APPROACH

The objective was to develop an assessment framework which would allow the evaluation of bulk water supply investments and regulatory options required for demand-side management in a socioeconomic perspective that captures the macroeconomic value of bulk freshwater. The assessment framework was to have a particular focus on scenarios where conventional water resources have been fully subscribed and alternative sources need to be considered as supply options in the face of current constraints and variability in supply.

The approach was to develop a standard methodology based on a country-wide water economy model with specific consideration of the competition between municipal, industrial and agricultural water use, water resource contributions and certainty of supply considerations. The country-wide model was proposed to be demonstrated within the Berg River WMA (currently one of South Africa's most stressed water management areas which also includes the City of Cape Town Metropolitan Municipality) where the model was resolved to a high level of detail and further developed to cater for different levels of supply certainty and resource elasticity.

## TECHNO-FINANCIAL EVALUATION OF ALTERNATIVE WATER SUPPLY OPTIONS

In this study, a number of alternative water supply options were considered, and a comprehensive analysis was undertaken on the options shown in the table below. Cost comparisons and hydrological assessment of alternative water supply options were carried out for the following: desalination, water reuse, aquifer recharge, farming under netting, agrivoltaics, precipitation augmentation, and alien invasive plant removal. A cost of supply was determined for each of the supply interventions for input into the economic analysis.

Modelling Scenarios	Description	Intervention volume WCWSS Total Mm <sup>3</sup> /a	Intervention/ alternative supply cost (R)
<b>Alternative Supply Options</b>			
Desalination			
a) Municipal	Desalination to supply municipal use	50	12.82
b) Agricultural	Desalination to supply agricultural use	50	12.82
Water Reuse	Water reuse for municipal supply (WCWSS discharges most suitable to recovery of potable water due to geographic location of discharge)	25	5.39
Farming under netting	Different irrigation crops respond differently under netting and not all crops can be cost effectively provided with netting (different water use reduction and different yield improvements)		
	Citrus	6	6.49
	Table Grapes	9	12.64
	Pome	2	24.15
Alien Invasive Plant Removal	Removal of alien vegetation through labour intensive processes - increased availability to municipal users	25	2.13
Agri PV	Different irrigation crops respond differently under PV and not all crops can be cost effectively provided with PV (different water use reduction and different yield improvements)	9.45	5.11



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#### Summary of findings:

- Desalination was, one of the more expensive water supply alternatives. This expense may be justified where the cost of unserved water is greater than the cost of water produced through desalination.
- In the farming under netting analysis, different irrigation crops responded differently under netting and not all crops could be cost effectively provided with netting due to different water use reduction and different yield improvements. Farming under netting was shown to be most cost effective for citrus crops and least cost effective for pome.
- Removal of alien invasive plants was found to be the most cost-effective of the interventions.

The modelling indicated that the cost of water realised from AgriPV was similar to costs achieved for water reuse. The water savings and electricity generation potential results potential are also significant enough to warrant further exploration of the technology. Unlike the use of netting to protect farming under cover which has already proven to be commercially viable in the production of a number of crops, we reasonably cannot expect agricultural fields be covered by solar canopies anytime soon without a concerted effort to establish commercial test utilities at scale and as integral to the production of specific crops. In order to provide the necessary proof-of-concept before market entry, we need to compare further techno-economical applications of AgriPV, demonstrate the transferability to other regional areas, and also realize larger systems.

### **ECONOMIC ANALYSIS OF WATER SUPPLY OPTIONS**

#### **a. Development Of The 2016 Water Social Accounting Matrix (SAM)**

The SAM is a comprehensive, disaggregated, consistent and complete data system that captures the interdependence that exists within a socioeconomic system. The SAM can be used as a conceptual framework to explore the impact of exogenous changes in such variables as exports, certain categories of government expenditures, and investment on the whole interdependent socioeconomic system, e.g. the resulting structure of production, factorial and household income distributions. As such the SAM becomes the basis for simple multiplier analysis and the building and calibration of a variety of applied general equilibrium models.

The basic structure of an agricultural and water-focused social accounting matrix (SAM) for South Africa that was developed in 2002 was used as base to develop a Water SAM for 2016. The treatment of water within the supply and use tables published by Statistics South Africa, as well as the national water accounts published by the Water Research Commission, which forms the core data of a SAM, has changed since 2002, with the implication that structural changes to the SAM were required. The 2016 SAM represents the nine 2012 water management areas while retaining the more detailed former WMAs for the Western Cape, resulting in 11 WMAs in total. The developed 2016 water SAM was used to calibrate a static and a recursive dynamic computable general equilibrium (CGE) model.

The SAM contains 40 sectors/commodities assumed to be at national market level, including 17 agricultural (including forestry and fishing), 15 industrial and 8 service sectors. Field crop production activities are further disaggregated in the SAM into irrigated and rainfed production per crop, while all horticultural production activities are assumed to be irrigated. All sectors are further disaggregated to capture production within each of the 11 water management areas. Beside capital, labour, and land, the SAM also includes three types of water (irrigation, bulk and municipal) per WMA as production factors. The institutions included in the 2016 SAM are enterprises, one representative household per WMA and the government. Further disaggregation of households were not possible due to lack of sufficiently detailed data. Irrigation water is incorporated in the model through the estimation of the shadow price of water per crop irrigated. Non-agricultural water use, in the form of bulk water and municipal water, is captured via the water distribution system. Irrigation and non-agricultural water used by industries is treated as a factor of production and water used by households is treated as a commodity.

#### **b. The Static Computable General Equilibrium (CGE) Model And Key Results**

CGE models are useful whenever we wish to estimate the effect of changes in one part of the economy upon the rest. CGE models fit economic data to a set of equations which aim to capture the structure of the economy

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and behavioural response of agents (industry, households, government). This provides a framework to simulate policy changes and trace the impact on key economic variables, including income and expenditure flows. The static dynamic computable general equilibrium model as developed by the International Food Policy Research Institute (IFPRI) was used as base model and was adjusted for purposes of this project to allow for policy options related to a water focus, notably the inclusion of water tariffs.

#### ***Change in irrigation water tariff – national level***

Modelling of changes in irrigation water tariffs where water is not transferred to other users indicated minimal indirect impact on the use of bulk water, municipal water used by industry and water used by households. Irrigated field crops are most affected by a change in water tariffs since these crops can be more easily switched to dryland conditions than horticultural products and field crops are often lower value crops and would be moved out of irrigation more readily than horticultural products. In general the impacts of the irrigation water tariff changes are small on a regional GDP level, but one can expect that the impact on individual irrigation farms are much more pronounced. A 10% increase in the irrigation water tariff leads to national job losses of 1600. The biggest negative impact of the irrigation water tariff increase is on the exports of horticultural products.

#### ***Change in municipal water rate – national level***

The modelling of changes to the municipal water tariff rate showed that although municipal water use decreases by up to 9.4% when the municipal water rates changes, there is little indirect effect on other water usage. In general that the production of horticulture increases when municipal water rates increase, whereas production of field crops decrease. This could be because an increase in municipal water rates has a dampening effect on industry and since a larger share of field crops is used as intermediate product compared to horticultural products, the demand for field crops is likely to decline. Changes in regional GDP for agriculture and non-agriculture impacts are more pronounced compared to that of the changes in irrigation water tariff rates. A 10% increase in the municipal water tariff leads to national job losses of 10 000.

#### ***Transfer of water from use in irrigation to municipal use for industries – national level***

The transfer of 50 million m<sup>3</sup> from irrigation to municipal use resulted in a 0.6% decrease in irrigation water used and a 4.6% increase in the use of municipal water, while household use increased by 0.8%. The 0.8% increase in water used by households for domestic purposes reflects a positive impact on the economy as a result of an expansion of industries and hence household income. There is also an increase in employment of 5 800 on a national level.

#### ***Reduction in water supply in the Berg - Olifants/Doorn WMA***

The volume of water available in the Berg - Olifants/Doorn WMA was assumed to decrease as follows: irrigation water by 50%; bulk and municipal water each by 40%. This led to a decrease in household's use of municipal water of 37%, which is endogenously determined, and therefore also captures some of the indirect impacts of the reduction in water as part of the imposed shock; it also captures some of the effects of the general contraction of the economy. In the Berg - Olifants/Doorn WMA the reduction in the volume of water available for irrigation is reflected by a reduction in production output under irrigation that is more pronounced for field crops (31.3%) than for horticulture (7.8%). GDP in the Berg – Olifants/Doorn WMA decreases by 0.35% and the decrease in GDP at a national level is 0.22%, with similar but slightly smaller impacts on households. Employment in the directly affected WMA decreases by 6 900 and on a national level 26 800 job opportunities are lost.

#### ***Water transfer between sectors in the Berg - Olifants/Doorn WMA***

The transfer of 25 million m<sup>3</sup> water from irrigation to bulk and municipal use and the transfer of a similar volume of water from bulk and municipal use to irrigation in the Berg - Olifants/Doorn WMA was investigated. The results of the two simulations are almost mirror images, but the magnitudes of the changes are slightly smaller when the water is transferred from industry to irrigation.

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When 25 million m<sup>3</sup> irrigation water is transferred to industries, field crop production in the Berg - Olifants/Doorn WMA decreases by 1.14%, while the use of irrigation water for field crops decreases by 2%. On a national level results are small as it reflects only the indirect effects of the changes in the Berg - Olifants/Doorn WMA. GDP increases by 0.036% in the Berg - Olifants/Doorn WMA and by 0.022% on a national level. Although employment in agriculture is negatively impacted, the net effect is that 300 job opportunities are created in the Berg - Olifants/Doorn WMA; and 2 440 job opportunities are created on a national level. Household income increases by 0.034% in the Berg - Olifants/Doorn WMA and by 0.02% on a national level.

***Desalination as alternative water supply option in the Berg - Olifants/Doorn WMA - same volumes, different payment options***

When an additional 50 million m<sup>3</sup> water is allocated to industry, the expansion in the economy is sufficiently large to stimulate further use of water, as observed by the increased water use of all water categories in all WMAs. It is only in the case where costs are recovered by users in the Berg - Olifants/Doorn WMA that there is a reduction in the use of water by households of 13.8%, with a net negative effect of 0.49% on the WMA level. Indirect effects on agricultural production, area and irrigation water use are small but positive throughout. The net national impact is small but positive. It is only the Berg - Olifants/Doorn WMA that shows a decrease in GDP because the cost of desalination is covered by either industries or users in this WMA. Tax on users have a more positive outcome compared to when industries absorb the cost. All WMAs show an increase in employment, with the exception of non-agricultural industry in the directly affected WMA. Households in the Berg - Olifants/Doorn WMA are worse off, indicating that the benefit of the additional water is outweighed by the cost thereof. Households are better off when the cost of desalination is recovered via a tax paid by users of the water rather than by the industries.

***Desalination as alternative water supply option in the Berg - Olifants/Doorn WMA - different volumes, same payment option***

Simulations were run in which additional desalination water of 25, 50, 75 and 100 million m<sup>3</sup> was made available to industries that use bulk and municipal water in the Berg - Olifants/Doorn WMA. In all four simulations it was assumed that the users of municipal water (including households) cover the increased cost of the more expensive desalination water and this is recovered as a tax on water.

When additional water is allocated to industry the expansion in the economy is sufficiently large to stimulate further use of water. The exception is the reduction in the use of water by households in the Berg - Olifants/Doorn WMA, which declines by between 6.5% and 37.4%. Households water use is endogenously determined and it declines substantially because of the substantial cost increase. The cost that needs to be recovered from water consumers (industries and households) for the additional desalination water at R12.8/kl, amounts to between R320 million and R1.28 billion depending on the additional amount of water.

GDP of industry in the directly affected WMA decreases by between 0.03% and 0.13% and the positive impacts on agriculture is not sufficient to offset it, giving a net negative impact on GDP in the Berg - Olifants/Doorn WMA. Employment in the Berg - Olifants/Doorn WMA increases for additional desalination water volumes of up to 50 million m<sup>3</sup> but decreases for higher volumes, because at lower volumes that positive impact on employment in the agricultural sector outweighs the negative impacts in industry. The GDP and employment impacts in the other WMAs are however positive.

***Reuse as alternative water supply option in the Berg - Olifants/Doorn WMA***

In this scenario an additional 25 million m<sup>3</sup> reuse water is made available for industries and households, with either industries paying, or all users of the water (including households) covering the additional cost. Economic benefits tend to be larger when all the users of water cover the additional cost. Also, since the cost is borne only by users in the directly affected Berg - Olifants/Doorn WMA, the net positive impact on GDP in this WMA is smaller compared to the positive indirect impact on GDP in the other WMAs.

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When an additional 25 million m<sup>3</sup> reuse water is made available for industries, the bulk and municipal water use within the Berg - Olifants/Doorn WMA increases by 7.28% and 6.79% respectively regardless who covers the cost. Household use increases by 5.54% when households are not responsible for the cost of the treatment of water, but when households cover the cost of water treatment via a tax, their use of water increases by only 0.77%. This effect also drives the national results. The effects of the additional reuse water on WMAs not directly affected are small positive indirect effects.

#### ***Alien invasive plant removal for additional water in the Berg - Olifants/Doorn WMA***

In this scenario there alien invasive plant removal provides an additional 25 million m<sup>3</sup> for industries that use bulk and municipal water in the Berg - Olifants/Doorn WMA. It is assumed that the users of municipal water (including households) cover the increased cost of the alien invasive plant removal and this is recovered as a tax on water.

#### ***Summary***

Within the Berg - Olifants/Doorn WMA total volume of water used increased by 2.29%, but indirect effects in the other WMAs are minimal. The positive impact of additional water available to industry outweighs the negative impact of the regional tax to cover the cost, leading a small positive impact on GDP in the Berg – Olifants/Doorn WMA. Employment in the directly affected WMA increases by 390 job opportunities and on a national level by 3 170. Impacts on the directly affected Berg - Olifants/Doorn WMA is relatively small because it covers the cost of the plant removal, whereas the expansionary effects of the increase in water availability to industries has a positive indirect effect on a national level.

#### **c. The Dynamic Computable General Equilibrium (CGE) Model And Key Results**

In order to be able to assess the impact of water policies over time a dynamic recursive model was configured along-side the static version. The dynamic version would provide the capability to evaluate policy options relating to water supply volume and tariff adjustments. However, it requires calibration of economic variables and parameters that go beyond the static version's requirements. The dynamic recursive model produces time series information which can be used in the techno-economical evaluation of proposed supply-side projects. In order to demonstrate its capability, the recursive dynamic model was configured to simulate three scenarios over a 9-year period following on the base year of 2016:

- Determine the compound impact of annual increases in the price of irrigation water,
- Determine the compound impact of annual increases in municipal water tariffs, and
- Estimation of the compound impact of annual increases in the transfer of water between application sectors.

#### ***Irrigation Water Tariff Increase***

A 5% annual increase in the irrigation water tariff will eventually lead to a 15% reduction in irrigation water consumption by 2025, with minimal indirect impact on the use of bulk (~ 0,09%) and municipal water (~ 0,005%). There is a negative impact on GDP in the long term.

#### ***Municipal Water Tariff Increase***

An annual increase of 10% in municipal water tariffs would result in a 39% reduction in expected consumption, with a slight increase in irrigation water consumption (~0,34%), supplied from a transfer from the municipal sector. The bulk water consumption is expected to be reduced indirectly by ~2,1%. There is a negative impact on GDP in the long term. Although crop production is expected to increase, a reduction in municipal water consumption affects both households and industrial consumption rates, and the economic losses in industrial economic activity will more than offset the slight gains to be made in agriculture.

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### ***Volume transfer of water between the application sectors***

The annual transfer of water from irrigation to municipal consumers, beginning with a volume of 50 million m<sup>3</sup> in the first year, and increasing by 50 million m<sup>3</sup> in every subsequent year, results in a significant reduction (~17%) in irrigation consumption (against the BAU case) while municipal consumption increases by 146% from the expected BAU case. A slight indirect increase (~0,9%) can also be expected for the bulk water consumption. There is a negative impact on GDP in the long term.

### ***Climate Change Simulation***

An attempt to simulate water availability subject to drought cycles was thought to be a useful test to further demonstrate the dynamic model capabilities. The model was forced to accept a hypothetical “drought-normal-drought” cycle spanning a 10-year period, in order to observe changes in water availability and costing, macro-economic conditions, employment and household income. The imposed drought cycle was built on the recent dry spell of 2015 to 2017 experienced in the Western Cape Water Management Areas (WCWMAs). The hypothetical test scenario commences in 2016, which was right in the middle of the Western Cape drought period.

The drought cycle was introduced to two water management areas (WMAs) only, i.e., Breede–Gouritz and Berg–Olifants/Doorn; these being representative of the WCWMAs. No water availability impingement in any of the other WMAs was allowed. The dynamic general equilibrium model was allowed to generate economic balances subject to constrained water availabilities. The outcomes correlated well with the actually recorded GDP and employment impacts of the drought experienced in the WCWMAs.

It became evident that, although water volume changes and pricing can be substantial, it does have a rather subdued impact on the macro-economic measures of GDP, employment and household income. This is manifested due to the overwhelming role of non-agricultural activity in the South African economy.

## **CONCLUSIONS AND RECOMMENDATIONS**

The project developed an assessment framework to allow for the evaluation of bulk water supply investments and regulatory options required for demand-side management in a socioeconomic perspective. The majority of the project aims were achieved. Notably a literature review related to project methodology and updating of the respective models were conducted; the SA Water SAM was updated and modified to allow for analysis of impacts of alternative supply sources, amongst other water reuse and desalination; a computable general equilibrium (CGE) model was expanded to accommodate different supply options; a dynamic version of the CGE model was developed to reflect the dynamic nature of economy; scenario analysis for the Berg River WMA was conducted; the impact of different irrigation and municipal water tariff were modelled, although different tariffs for household could not be modelled at a detailed level; the impacts of different sets of policy interventions at national and regional/sectoral level were analysed and presented.

The greatest challenge with regard to SAM development is the availability of up to date and detailed data at the level of disaggregation that is required. For the 2016 water SAM this was no exception since very little data in the public domain is published on a water management area level. Detailed agricultural and household data proved particularly difficult to find and time consuming to construct. In the case of household the level of detail in the data that would have allowed for more interesting institutional results was simply not available.

Cost comparisons and hydrological assessment of alternative water supply options were carried out for the following: desalination, water reuse, aquifer recharge, farming under netting, agrivoltaics, precipitation augmentation, and alien invasive plant removal. The estimated costs of some of these augmentation strategies were subsequently used in the analysis of policy interventions using the CGE static model to ensure that the cost recovery of additional water supply is taken into account in the analysis. Interventions that were not considered further in the economic analysis (Part B) were AgriPV and farming under cover as these are better suited to be modelled on a farm-level basis. Economic impacts from these interventions would be lost due the granularity of the model being at WMA level. The dynamic CGE model analysis focused on estimating the

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impacts of changes in municipal water tariffs and transfers of irrigation water to industry on a national level, as well as cyclical droughts due to climate change in the Western Cape over a ten year period.

Some key results from national policy interventions using the static CGE model are mentioned here. The biggest negative impact of the irrigation water tariff increase is on the exports of horticultural products. When municipal tariffs increase changes in regional GDP for agriculture and non-agriculture impacts and job losses are more pronounced compared to that of the changes in irrigation water tariff rates because the agricultural sector is substantially smaller and less integrated with the rest of the economy compared to industry. For the same reason, additional water (regardless the source) to industry rather than irrigation agriculture, typically lead to greater economic benefit in terms of GDP.

Different alternative water supply options with different cost recovery options were also simulated using the static CGE model. The CGE modelling provided valuable insight that can be used to inform policy with regard to who is best placed to pay for desalinated water. When additional water is allocated to industry the expansion in the economy is sufficiently large to stimulate further use of water, as observed by the increased water use of all water categories in all WMAs. The exception is the reduction in the use of water by households in the Berg - Olifants/Doorn WMA.

Modelling of desalination as an alternative supply option in the Berg - Olifants/Doorn WMA by varying the supply volumes with the cost of the water borne by the municipal users (including households) and the additional water made available to industry indicated negative impacts on GDP and these negative impacts became more pronounced as the desalination supply volumes increased. A positive effect was observed for employment numbers at lower supply volumes coming from the industries that benefit from the additional water. However, there was a tipping point between 50 million m<sup>3</sup> and 75 million m<sup>3</sup> when the impact to employment numbers became negative due to the increasing costs to produce the additional water for industry, which started to outweigh the indirect benefits to the agricultural industry in the directly affected WMA. Therefore, care should be taken in the sizing of a desalination project.

The idea to provide additional water to agriculture by means of desalination and having other users paying for it would not be sound policy and those costs will not be recovered from the rest of the economy as the agricultural sector is somewhat insular. In terms of payment options impacts on the economy tend to be more positive when the consumers of municipal water (industry and households) pay for the desalinated water compared to when only industry absorbs the cost.

With regard to the water supply options such as reuse of water and alien plant removal, the positive impacts of the additional water availability is often subdued due to the additional costs that need to be recovered, hence the macro-economic impacts in terms of GDP, employment and household incomes are generally small but positive.

The recursive dynamic model enables the testing of the impact of policy options affecting water regulation over time. Despite this, the Western Cape economy is quite diversified and although agriculture features highly in the economy, there is a level of resilience in the economy and the dynamic CGE model may not always be the best model to model the economic impact of a longer and severe drought, where the drought is of such a dimension that it eclipses the inherent resilience of the communities in making do with the bare minimum of water.

It is evident from the climate change simulation, as well as from the actually recorded historic macro-economic measures, that although water volume changes and pricing can be substantial, it does have a rather subdued impact on the macro-economic measures of GDP, employment and household income.

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## ACRONYMS & ABBREVIATIONS

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Capex	Capital Expenditure
CAPRI	Common Agricultural Policy Regional Impact
CES	Constant Elasticity of Substitution
CET	Constant Elasticity of Transformation
CFA	Atlantis and Cape Flats Aquifers
CGE	Computable General Equilibrium
CMA	Catchment Management Agency
CoCA	Census of Commercial Agriculture
CoCT	City of Cape Town
DAFF	Department of Agriculture, Forestry and Fisheries
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
FAO	Food and Agricultural Organization of the United Nations
GDP	Gross Domestic Product
IAP	Invasive Alien Plants
IBs	Irrigation Boards
MAE	Mean Annual Evapotranspiration
MAP	Mean Annual Precipitation
MAR	Mean Annual Runoff
MED	thermal / multi-effect distillation
MENA	Middle East and North Africa
MLD	million liters per day
NWA	National Water Act, No. 36 of 1998
NWRS	National Water Resource Strategy
O&M	Operating and maintenance costs
PPP	Public Private Partnership
PV	Photovoltaic
RO	Reverse Osmosis
SAM	Social accounting matrix
SASID	South Africa Standard Industrial Database
SU Tables	Supply and Use Tables
THI	Temperature Humidity Index
TDS	Total dissolved solids
UF	Ultrafiltration
URV	Unit Reference Value
USD	United States Dollar
USDA	United States Department of Agriculture

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UV	Ultraviolet
VMP	Value of Marginal Product
WBs	Water Boards
WCWSS	Western Cape Water Supply System
WEAP	Water Evaluation and Planning System
WfGD	Water for Growth and Development
WIM	Water impact model
WMA	Water Management Area
WRC	Water Research Commission
WRPM	Water Resource Planning Model
WRYM	Water Resources Yield Model
WUA	Water User Association
WUE	Water use efficiency
WWTP	Wastewater Treatment Plant
WWTW	Wastewater Treatment Works
ZAR	South African Rand

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**PART A:**

**TECHNICAL AND FINANCIAL EVALUATION OF  
WATER SUPPLY OPTIONS**

---

# CHAPTER 1: BACKGROUND

---

## 1.1 INTRODUCTION

South Africa is a water-stressed country facing increased dry spells and weather variability. From a climate change adaptation perspective, the country needs to urgently increase its resilience specifically in the ability to manage its water resources.

The concept of the water-energy-food nexus concerns the pressures being put on water resource by climate change and reduced water availability brought about by economic development including population growth and globalization. These are presenting communities and regulators with an increasingly complex number of trade-offs and potential conflicts. Whilst the demand for water is increasing, the global water cycle is changing (part of a wider phenomenon referred to as climate change), where the effects are expected to vary across areas and seasons.

The need to maintain a sustainable environment, economic growth and to increase agricultural production to meet global food requirements has increased the demand for the world's water resources. This has raised concerns about increasing the efficiency of water use. In the last decade, the number of countries facing the problem of water scarcity and insufficient water supply has increased sharply. At the global level, while per capita water availability is declining, withdrawals are projected to increase more rapidly, especially in developing countries. Generally, water scarcity raises two questions:

- to what extent can water resources be efficiently, equitably and sustainably allocated and used?
- what are the possible ways and means by which water scarcity can be alleviated or mitigated in support of further development?

The answers to these questions enable water managers to design appropriate water development policies and allocation strategies.

The ultimate objective of the project was to develop an assessment framework which would allow the evaluation of bulk water supply investments and regulatory options required for demand-side management in a socio-economic perspective that captures the macro-economic value of bulk freshwater. The assessment framework had a particular focus on scenarios where conventional water resources have been fully subscribed and alternative sources need to be considered as supply options in the face of current constraints and variability in supply.

## 1.2 PROJECT AIMS

The following were the aims of the project:

1. To conduct a literature review to gather relevant information that would enable refinement of the project methodology document and updating of the respective models.
2. To upgrade the SA Water SAM for inclusion of alternative supply sources specifically water reuse and desalination to an Alternative Water SAM.
3. To develop an expanded computable general equilibrium (CGE) model which accommodates stochastic elements to enable evaluation of certainty of supply and supply elasticity.
4. To develop a dynamic version of the CGE model to reflect the dynamic nature of economy.

- 
5. To demonstrate the model as an assessment framework by conducting a scenario analysis for the Berg River WMA.
  6. To undertake modelling of tariff structures with parallel evaluation of opportunity cost and cost of unserved water.
  7. To undertake a National and regional/sectoral analysis by considering the impacts of different sets of policy interventions.

### **1.3 SCOPE OF THIS REPORT**

The project aimed to develop an assessment framework which would allow the evaluation of bulk water supply investments and regulatory options required for demand-side management in a socio-economic perspective that captures the macro-economic value of bulk freshwater.

The approach was to develop a standard methodology based on a country-wide water economy model with specific consideration of the competition between municipal, industrial and agricultural water use, water resource contributions and certainty of supply considerations. The country-wide model is proposed to be demonstrated within the Berg River WMA (currently one of South Africa's most stressed water management areas which also includes the City of Cape Town Metropolitan Municipality) where the model will be resolved to a high level of detail and further developed to cater for different levels of supply certainty and resource elasticity. In this respect, it is worth noting that although traditional water supplies are characterised as highly uncertain and inelastic (a finite resource) whereas alternative supply options, such as seawater desalination, have significantly higher certainty levels and are elastic in supply potential.

For this study, various interventions in groundwater utilisation, conventional run of river and dam infrastructure, water reuse, desalination, as well as demand-side management that supplement the effort to minimise non-revenue water interventions were considered. The intent was to develop a standard methodology, which will not be limited to the Berg River WMA case study, but which may be applied as standard to evaluate alternative water resources in all WMAs, and indeed bulk water on a national scale. The standardised methodology will provide due consideration to cost, the certainty of supply and supply elasticity.

There is increasing pressure to prioritise water allocation between urban residential and rural agricultural consumers. The issue is exacerbated by increased water demand due to a significant urbanization drive, increasing living standards, as well as industrialization. An appropriate general equilibrium model was developed to address the fairness of such resource allocation.

The disaggregation of different supply sources, costs and certainty of supply profiles will be key factors to consider when optimising water source allocation and tariff design. It will ultimately inform water resources management and policy institutions appropriately. Accordingly, the economic model needed to be resolved to account for the water, agricultural, industrial and domestic water consumption. Such resolution was achieved by means of a computable general equilibrium (CGE) model which was calibrated by a suitable social accounting matrix (SAM).

In order to be able to assess the impact of water policies over time and to allow lifecycle-based techno-economic evaluations of proposed supply-side infrastructure, the static CGE was converted to a dynamic general equilibrium model that could generate impulse response functions. Such a variant will enable the tracking of the evolution of economic parameters over time.

The assessment framework will be demonstrated within one of South Africa's most stressed water management areas, the Berg River WMA which includes the City of Cape Town Metropolitan Municipality, with specific consideration of the competition between municipal and agricultural water use. For this study, we will consider

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various interventions in ground water utilisation, dam infrastructure, water re-use, desalination, as well as demand-side management that supplement the minimisation of non-revenue water interventions. The intent is to develop a standard methodology, which will not be limited to the Berg River WMA case study but which may be applied as standard to evaluate all WMA's, and indeed bulk water on a national scale.

## CHAPTER 2: WATER MANAGEMENT AREA SCENARIO ANALYSIS

### 2.1 WATER MANAGEMENT AREAS AND AREAS UNDER IRRIGATION

The Department of Water and Sanitation (DWS) previously divided the country into 19 Water Management Areas (WMAs), each containing a large river system (DWAf, 2004). The Berg River catchment supplies areas outside of its natural boundaries (Cape Town for example), and the boundary of the Berg WMA includes the supply area, and several smaller catchments. With the second revision of the National Water Resources Strategy (DWA, 2013), 19 WMAs were reduced to nine through an amalgamation of areas. As such, the Berg no longer constitutes an individual WMA and is now part of the Berg-Olifants WMA. The changes to the WMAs are shown in Figure 2-1.

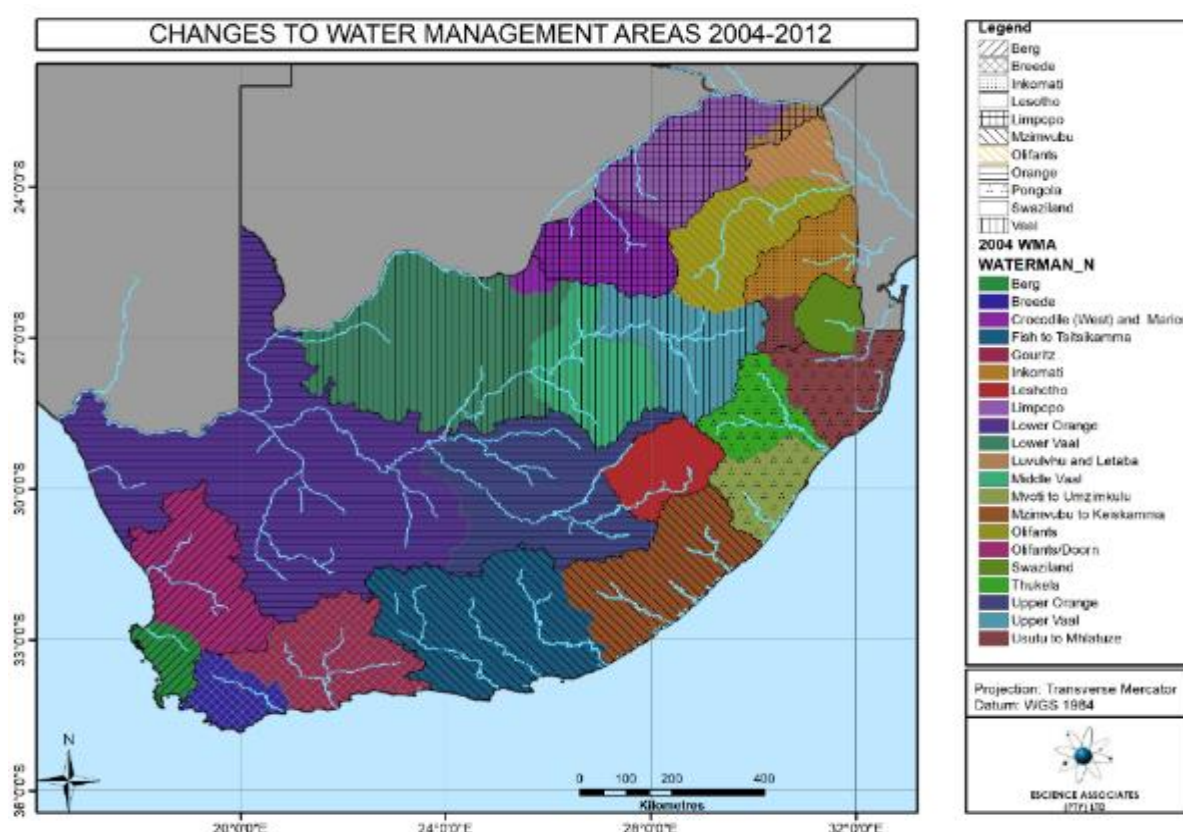


Figure 2-1: Changes to WMAs 2004-2012

While irrigated agriculture is certainly the main user of surface and groundwater resources in South Africa, the estimations of the area of irrigated crops are outdated and vary greatly. In a study conducted by Stellenbosch University for the WRC, the volume of water used by irrigated agriculture has been estimated to be between 51% and 63% of total water available (WRC, 2017). The study irrigation data was used in conjunction with National Landcover 2000 (NLC 2000) data to determine the area under irrigation for the new WMAs. Table 2-3 shows a comparison between the 2004 and 2012 WMAs, and indicates the areas under irrigation as of 2012 with which the Thurlow Hassan model was updated from the 19 2004 WMAs to the current nine WMAs via their common elements.

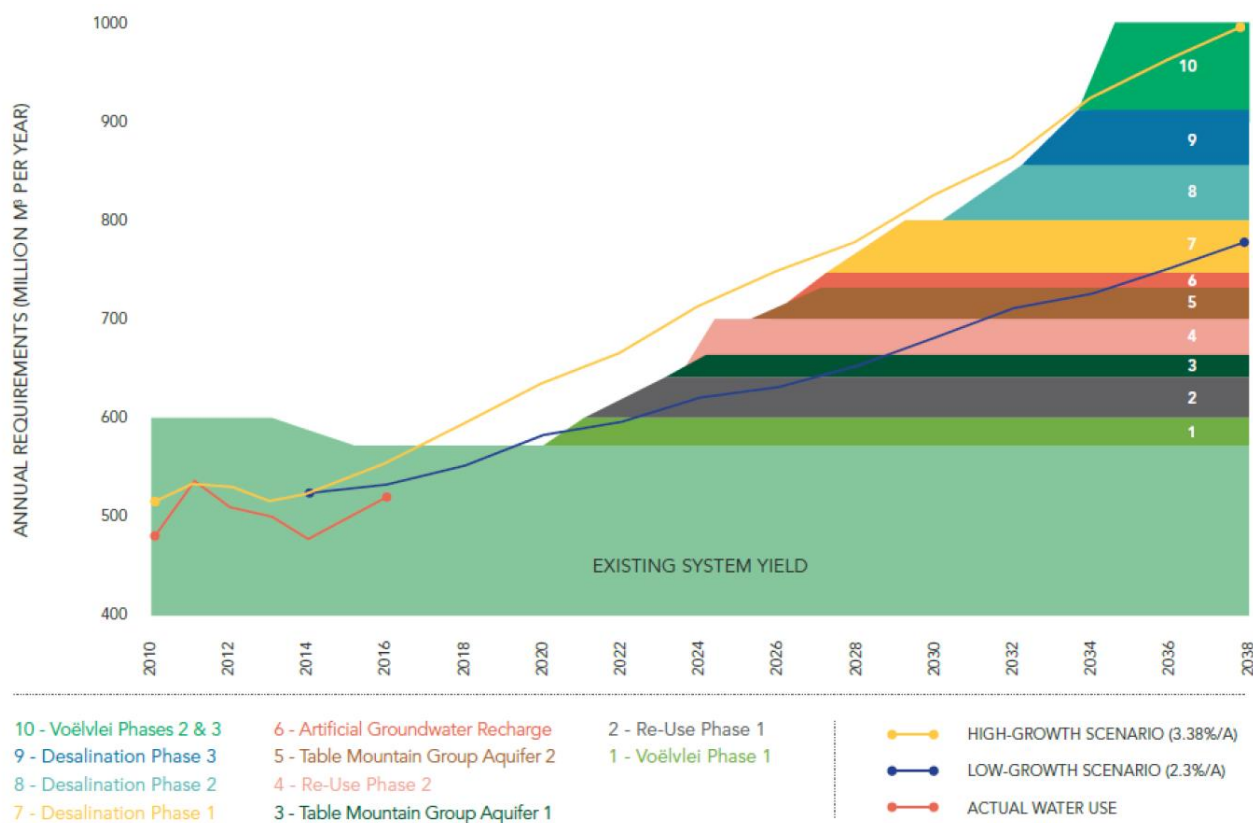


**Table 2-1: Area under irrigation – comparison old and new WMAs**

Old WMA 2004			Common elements			New WMA					
		Area irrigated ha 2012*	Total Area Irrigated ha			Area irrigated ha 2012*			Area irrigated ha 2012*	Irrigated Sugarcane	Total Area Irrigated ha
Limpopo	Area 1	59 698.7	73 408.7	Limpopo	Area 1	59 698.7	Limpopo	Area 1	153 870.7		178 837.0
Luvuvhu and Letaba	Area 2	54 829.6	90 735.6	Luvuvhu and Letaba	Area 2a	19 427.8					
Crocodile (West) and Maric	Area 3	77 650.2	88 458.5	Crocodile (West) and Maric	Area 3a	74 744.5					
Olifants	Area 4	91 121.5	124 603.7	Luvuvhu and Letaba	Area 2b	35 401.8	Olifants	Area 2	126 512.6		195 243.6
				Olifants	Area 4a	91 121.5					
Inkomati	Area 5	31 844.4	100 195.0	Inkomati	Area 5a	31 844.4	Inkomati-Usuthu	Area 3	34 486.9	62 058.1	104 421.9
				Usutu to Mhlatuze	Area 5b	2 631.9					
Usutu to Mhlatuze	Area 6	38 433.1	130 758.8	Usutu to Mhlatuze	Area 6	35 801.3	Pongola-Mtamvuna	Area 4	119 060.3	387 415.7	451 915.6
Thukela	Area 7	53 526.1	53 114.1	Thukela	Area 7	53 526.1					
Mvoti to Umzimkulu	Area 11	29 733.0	272 274.6	Mvoti to Umzimkulu	Area 11	29 733.0					
Upper Vaal	Area 8	45 396.7	62 471.7	Crocodile (West) and Maric	Area 3b	2 905.7	Vaal	Area 5	181 321.7		267 434.6
				Upper Vaal	Area 8	45 396.7					
Middle Vaal	Area 9	42 884.4	100 421.6	Middle Vaal	Area 9	42 884.4					
Lower Vaal	Area 10	90 133.6	101 436.3	Lower Vaal	Area 10	90 133.6					
Mzimvubu to Keiskamma	Area 12	39 143.4	27 528.2	Mzimvubu to Keiskamma	Area 12	39 143.4	Mzimvubu-Tsitsikamma	Area 7	155 827.7	12.1	165 660.1
Fish to Tsitsikamma	Area 15	116 684.4	138 130.5	Fish to Tsitsikamma	Area 15	116 684.4					
Upper Orange	Area 13	98 291.5	169 504.3	Upper Orange	Area 13	98 291.5	Orange	Area 6	172 388.2		260 711.9
Lower Orange	Area 14	74 040.0	91 102.0	Lower Orange	Area 14	74 040.0					
Gouritz	Area 16	44 364.1	71 705.5	Gouritz	Area 16	44 364.1	Breede-Gouritz	Area 8	152 362.9		176 403.2
Breede	Area 18	107 998.7	104 690.6	Breede	Area 18	107 998.7					
Berg	Area 19	65 254.5	69 536.7	Berg	Area 19	65 254.5	Berg-Olifants	Area 9	116 834.2		150 008.8
Olifants/Doorn	Area 17	51 579.8	80 469.6	Olifants/Doorn	Area 17	51 579.8					
		1 212 607.6	1 950 546.1						1 212 665.4		

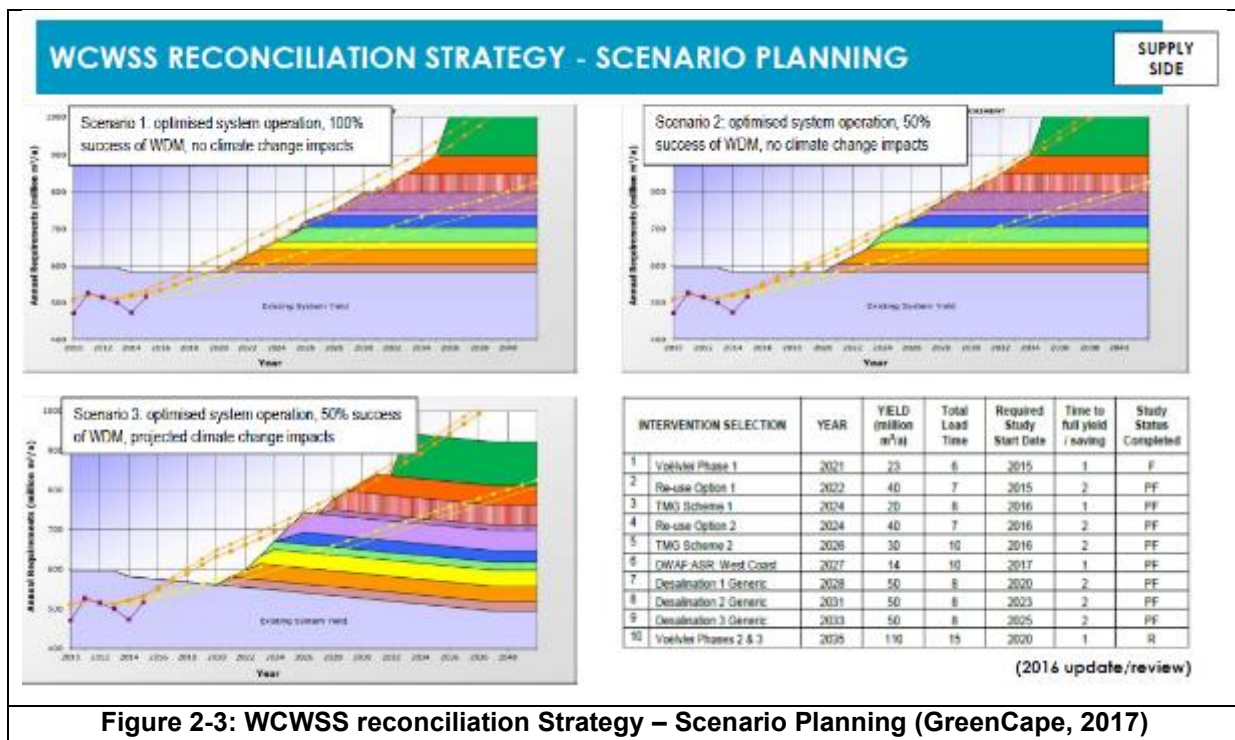
## 2.2 CURRENT STATE AND PLANNED WATER SUPPLY OPTIONS OF BERG BREED RIVER WATER MANAGEMENT AREAS AND WESTERN CAPE WATER SUPPLY SYSTEM

The DWS planning scenario (based on high water requirement growth, 50% success of water conservation and water demand management measures and no impact of climate change) indicated that the WCWSS's water requirements would exceed the system yield in 2019. The first possible supply augmentation scheme (Voëlvlei Augmentation Scheme) will increase the system yield by 23 million m<sup>3</sup>/a, and may come online in 2021 (due to the current drought, this scheme has been prioritised and may be online earlier than previously reported). However, as this brings the system yield to 605 million m<sup>3</sup>/a, the system will still be over-allocated. Thereafter, several new supply schemes will need to be implemented to meet the continued growth demands of the system. Feasibility studies are underway by the City of Cape Town (CoCT) for large-scale desalination, water reuse and groundwater use, and implementation of one of these schemes would have to commence imminently. Short-term schemes are being planned by the City of Cape Town that are effectively piloting the Table Mountain Aquifer Group and large-scale reuse schemes, yet also form part of the City's drought emergency supply schemes. (GreenCape, 2017)



**Figure 2-2: WCWSS reconciliation of supply and demand for the Planning Scenario (GreenCape, 2017)**

The WCWSS is therefore highly constrained according to existing allocations (Figure 2-2 and Figure 2-3). New supply options largely rely on non-surface augmentation (excluding Voëlvlei) and are therefore expected to be far more expensive to develop than previously built dams



## 2.3 ALTERNATIVE WATER SUPPLY OPTIONS AND THEIR INVESTIGATION

In the past, the Western Cape Water Supply System (WCWSS) has almost exclusively relied on rain-fed dams for its water supply. Cape Town's water supply will become more resilient through the development of diverse water sources including groundwater, water reuse and desalination. In combination, a mix of sources will be more reliable and more resilient in the context of climate change. The City of Cape Town, the system's largest water user, will build substantial water supply schemes of its own, as opposed to relying almost entirely on the WCWSS. Moreover, water schemes with very different costs and technical characteristics (for example, desalination plants and artificial aquifer recharge) now need to be considered for the first time.

### 2.3.1 Alternative water supply options considered

Given the changes in technologies, costs, and relationships between users, it is necessary to consider what arrangements would be best suited to manage the WCWSS and its interface with other bulk water production and storage systems, such as those that the City plans to build, in the future.

Scenarios considered in the technical analysis include the following alternative water options:

- Desalination
  - (a) Colocation cost benefit
  - (b) Yield implications
- Water Reuse
  - (c) Treatment to potable standards and offset of raw water and water treatment
  - (d) Treatment to industrial standards and offset of raw water and water treatment
  - (e) Yield implications
- Aquifer Recharge
  - (f) Recharge with stormwater

- (g) Yield implications
- Precipitation Augmentation
  - (h) Glaciogenic processes
  - (i) Yield implications
- Improved irrigation efficiency
  - (j) Farming under cover
  - (k) Yield implications
- Removal of alien vegetation
  - (l) Areas invaded
  - (m) Yield implications

### 2.3.2 Cost comparison of alternative water supply options

The committed programme of CCT (Table 2-2) as set out in the Water Management Strategy (City of Cape Town, 2020) is designed to balance risk and cost. The proposed accelerated supply schemes implemented between June 2018 and December 2019 is shown in Table 2-3 (City of Cape Town, 2020).

**Table 2-2: CCT committed new water programme over ten years – provisional costs (2018 costs)**

Intervention +	First Water	Effective yield		Total Capex	Unit Capex ++	Operating Cost +++
		ML/day	Million kl pa			
				R million	Rm /MLD	R/kl
Demand Management	2019	70	26	410	6	3
Alien Vegetation Clearing	2019	55	20			~1 - 2
Management of WCWSS	N/A	27	10			~0.2 – 0.5
Cape Flats Aquifer P1	2020	20	7.3	800	40	5
Table Mountain Group P1	2020	15	5.5	375	25	5
Cape Flats Aquifer P2	2021	25	9.1	1200	48	9
Atlantis Aquifer	2021	10	4	290	29	8
Table Mountain Group P2	2022	15	5.5	335	23	5
Table Mountain Group P3	2022	20	7.3	326	16	2
Berg River Augmentation	2023	40	15			~3-5
Water Re-Use P1	2024	70	26	1360	20	5
Desalination Phase 1	2026	50	18	1650	33-40	9
<b>Total including WDM</b>		417	154	6746		
<b>Total new supply</b>		347	128	6336		

Notes: +Timing and capital and operating costs are best available engineering estimates. All schemes subject to outcomes of ongoing investigations (to determine optimal yield, siting and timing) and relevant approvals.

++ Rounded to the nearest million Rand. +++ Rounded to the nearest Rand.

**Table 2-3: Proposed accelerated supply schemes – to be implemented June 2018 to December 2019**

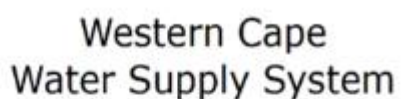
<b>Scheme</b>	<b>(Yield ML/day)</b>	<b>Detail</b>	<b>Cost</b>	<b>First Water Available</b>
TMG Aquifer	10	Incremental expansion of the wellfields constructed as emergency scheme	R90m	Jun-18
Seawater Desalination Package Plant	2.5	Expansion of the emergency plant package plant. Primarily for sea water quality data acquisition	R30m	Jun-18
Wastewater Re-Use (Drinking Water)	10	Treatment of effluent from Zandvliet WWTW for direct or indirect injection into bulk water supply system	R120m	Jun-18
Cape Flats Aquifer	5	Incremental drilling of boreholes abstracting water from the aquifer in Mitchells Plain / Khayelitsha	R40m	Jun-18
WC/WDM Strategy	100	Intensification of demand management measures: <ul style="list-style-type: none"> <li>• Water restrictions,</li> <li>• Pressure management,</li> <li>• Water saving incentive schemes,</li> <li>• Regulation of plumbing fittings and water using appliances,</li> <li>• informative water billing,</li> <li>• communication</li> </ul>	R10m	Jun-18
Voelvlei Augmentation (Phase 1)	60	DWS Scheme - Pumped transfer of water from Berg River to Voelvlei Dam	R275m	Dec-19

### 2.3.3 Hydrological assessment of alternative water supply options

A myriad of data sources and associated models exist to support this analysis of which the following are a few key examples:

- Western Cape Water Supply System Reconciliation Strategy - DWS, 2018.
- Cape Town Water Strategy – January 2019
- City of Cape Town Water Outlook 2018 - December 2018
- The Assessment of Water Availability in the Berg Catchment by means of Water Resource Related Models – Groundwater Model – Cape Flats Aquifer Model – DWS, 2008.
- The impacts of different degrees of alien plant invasion on yields from the western cape water supply system – Aurecon/CSIR, 2016s

Three models were used as sources of data during this assessment, i.e. the WRSM2000-Pitman hydrological model, the Water Resources Yield Model (WRYM) and the Water Resources Planning Model (WRPM) as configured for the WCWSS (Figure 2-4). The WRSM2000-Pitman was used to assess any impacts on the hydrological flow regime or water use patterns that certain alternative water supply options will have. The WRYM & WRPM was used to assess the assured yield and water balance impacts of the system. The primary tool for assessing the impacts during this assessment was the WRYM model. The latest version of the WRYM configuration for the WCWSS was sourced from consultants that made recent improvements to the model. As far as possible, the WRYM model was improved to include variable demands, and not the typical fixed annual demands, to include the impacts of higher demands in drier periods and vice versa. The yield from the system will also be constrained by the current and future projected treatment plant and transfer capacities.



**Figure 2-4: Western Cape Water Supply System (WCWSS) (DWS, 2018)**

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## CHAPTER 3: TECHNO-FINANCIAL EVALUATION OF ALTERNATIVE WATER SUPPLY OPTIONS

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### 3.1 DESALINATION

The main benefit of implementing desalination as an alternative source of bulk water or potable water supply is that it is rainfall independent. It does not rely on rainfall for assured supply and can be used to supplement traditional water supplies that are rainfall dependant. This is true for all types of desalination.

Desalination is, however, one of the more expensive water supply alternatives. This expense may be justified where the cost of unserved water is greater than the cost of water produced through desalination. What this would mean is that the cost of the desalinated water, which is more expensive than water from traditional bulk water supplies, would be justified by the fact that the economic costs associated with not having access to water are significantly more. For example, the Western Cape has substantial tourism and agricultural sectors with the capacity to pay different prices for water; their willingness to pay will vary substantially, with agriculture best placed to forego water and wait through the drought rather than to be faced with higher water costs. The tourism sector is the exact opposite and may be willing to pay a higher cost for assured water supply, provided through desalination.

It is likely that the desalination technology that would be implemented in South Africa is seawater reverse osmosis (SWRO) due to limited access to free, waste energy in the form of heat that would make MED cost effective. The most significant potential threat to this is the interruption of electrical power supply to the facility, which would result in the inability to run the facility and produce water.

Numerous recommendations regarding desalination plants have been made to the City of Cape Town. The following salient points are agreed upon in this regard:

- The need for construction of three separate seawater desalination plants of capacity between 100 and 150 MLD, for the following reasons (Water Globe Consultants, 2017), (Water Consultants International, 2018):
  - Environmental impacts – the concentrated discharge of large volume of brine in one location may pose a significant threat to the surrounding aquatic environment.
  - The total capital cost for construction of three 150 MLD plants will be lower than that of the construction of one 450 MLD plant due to diseconomy of scale associated with construction of plants larger than 200 MLD.
- The three construction sites are proposed to be at Table Bay Harbour (due to the pre-existence of the site), False Bay (due to lower salinity levels caused by cape flats aquifer's discharge into the bay) and on the Atlantic coast at or near Koeberg (to utilise existing infrastructure) or at another location in the vicinity of existing large fresh water delivery pipeline in order to avoid construction of water supply infrastructure in highly urbanized environment (Water Globe Consultants, 2017).

#### 3.1.1 Desalination Technology

The process of desalination can be broken down into two main types, namely; thermal / multi-effect (MED) distillation and reverse osmosis (RO). There are variations of both, but the general principals can be described as follows:



### 3.1.1.1 Thermal / Multi-effect distillation (MED)

Multi-effect distillation is a process consisting of multiple stages or “effects” (Figure 3-1), where the input/feed water is heated by an external heat source causing it to evaporate and leave the undesirable salts and impurities behind. In subsequent stages, the steam produced in the previous stage is used to heat and evaporate more input feed water. This occurs at successively lower pressures and temperatures at each stage; the lower pressure resulting in a lower temperature required for the feed water to boil. This reuses energy from the previous stage and aids in increasing the energy efficiency of the process. This type of desalination is often coupled to an industrial process where the heat required can be sourced directly.

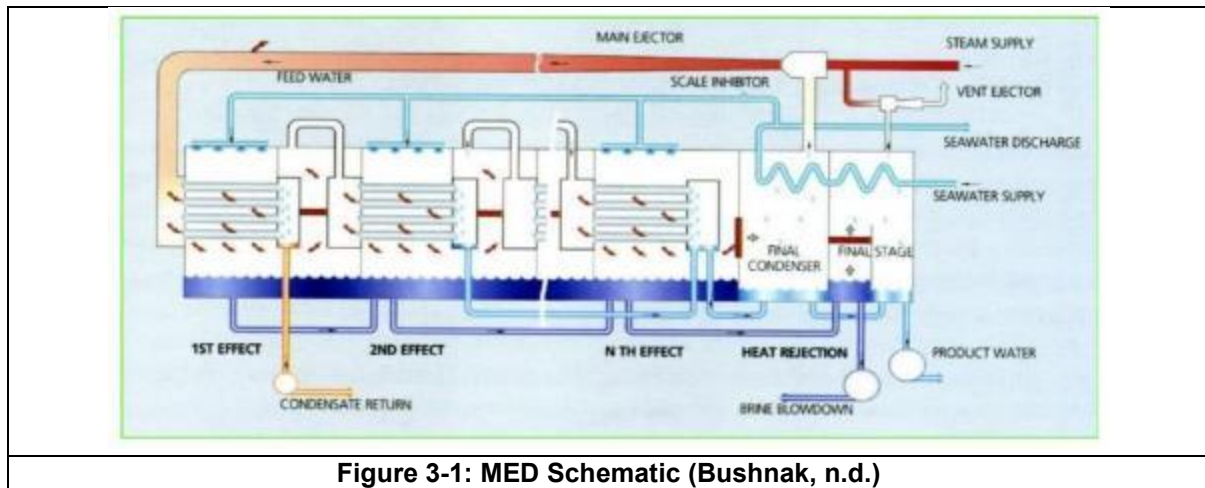


Figure 3-1: MED Schematic (Bushnak, n.d.)

### 3.1.1.2 Reverse osmosis (RO)

Reverse osmosis is a process where the input/feed water is forced through a semi-permeable membrane at high pressure, removing the salts and undesirable impurities (Figure 3-2). This is the reverse of the natural process of osmosis whereby solvent molecules will move from a less concentrated solution to a more concentrated solution through a semi-permeable membrane.

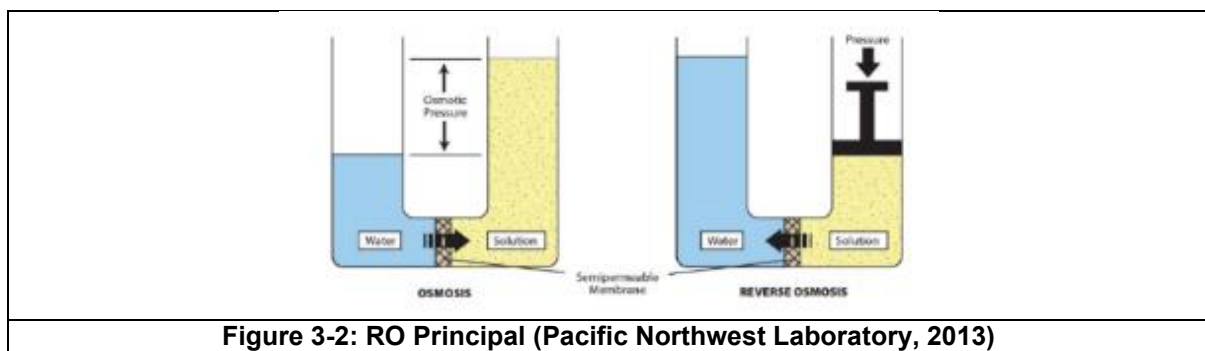
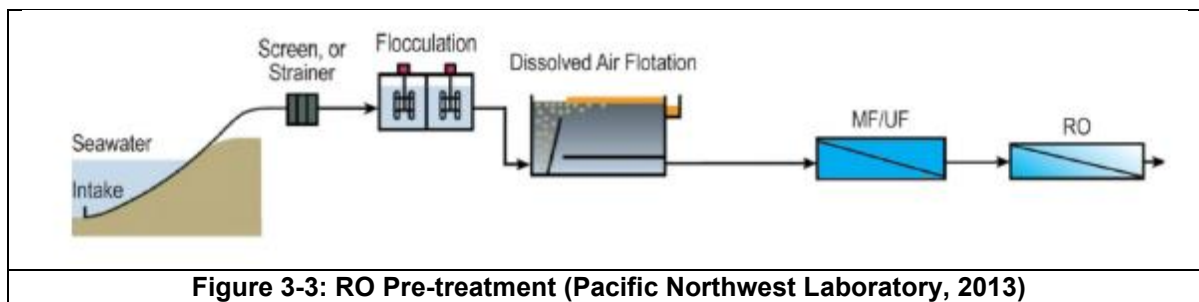


Figure 3-2: RO Principal (Pacific Northwest Laboratory, 2013)

Reverse osmosis membranes prevent the passage of dissolved solids, but are susceptible to fouling by suspended solids and organics in certain instances. Pre-treatment of the feed water may therefore be necessary, depending on the feed water quality (Figure 3-3).





### 3.1.2 Desalination Costing

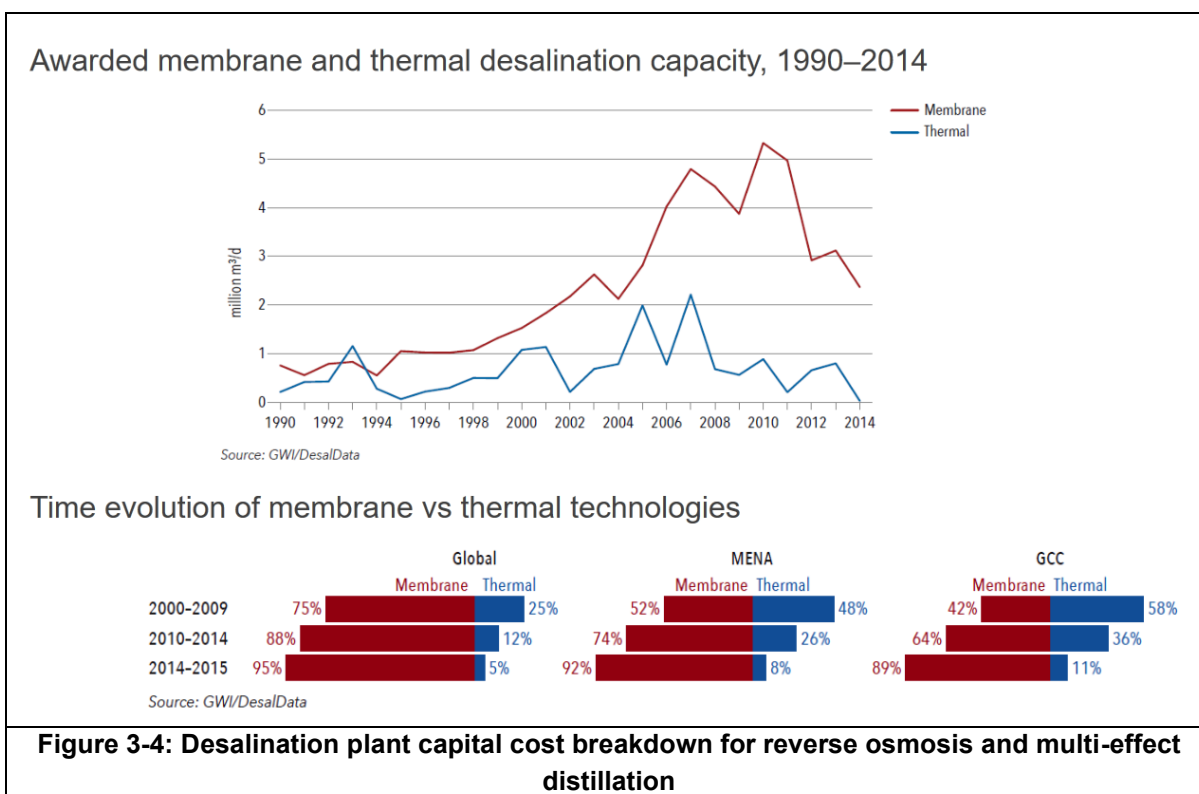
The below costing (Table 3-1) is assumed for modelling of the reference case facilities of 100 Ml/day, standalone plants.

**Table 3-1: Reference Case cost estimates - 100 Ml/day facility**

	SWRO	MED/Thermal
Overnight capital costs, ZAR/Ml/day	21 000 000	24 500 000
EPC costs	72.5%	84.5%
Owner's costs	15.5%	8.0%
Contingencies	12.0%	7.5%

Source: GWI, Desaldata, Almar Water and author's calculations

Capital costs for RO and MED are comparable, but the cost of RO has dropped to below MED costs and the market share of RO has subsequently increased, as illustrated in Figure 3-4.



Capital costs were found to be fairly insensitive to scale for plants larger than 50 Ml/day, except when diseconomy of scale occurs as a result of excessively large equipment and piping, and increased construction windows. This typically occurs with plants with capacity larger than 200 Ml/day (Water Globe Consultants, 2017).

### 3.1.2.1 Desalinated Water Cost Breakdown for Reverse Osmosis and Multi-effect Distillation

Unitary water costs are reported in Table 3-2 for the 100 Ml/day reference case facilities, including SWRO, natural gas-fired MED, and MED using waste heat.

**Table 3-2: Unitary water costs for 100 Ml/day reference case facilities**

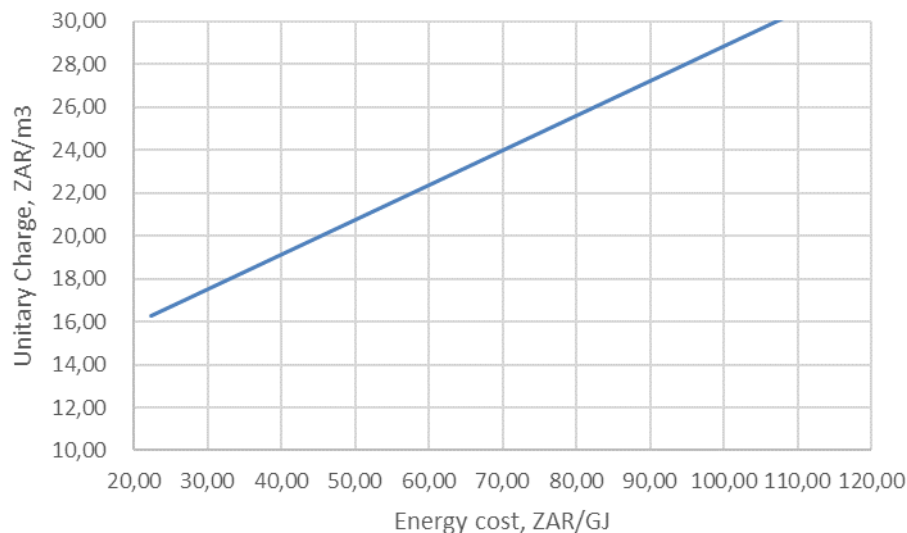
Project type	SWRO, with energy recovery device	MED – waste heat, free	MED/MSF, heat from natural gas at 56 ZAR/GJ (4 USD/GJ and 14 ZAR/USD)
Capital costs, ZAR/m <sup>3</sup>	7,97	8,96	8,96
Total operating costs, ZAR/m <sup>3</sup>	4,86	3,70	12,77
Thermal energy costs	0%	0%	71%
Electrical energy costs	47%	62%	18%
Other operations and maintenance costs	53%	38%	11%
Thermal energy consumption, kWh <sub>th</sub> /m <sup>3</sup>	0	45	45
Electrical energy consumption, kWh <sub>e</sub> /m <sup>3</sup>	2,7	1,75	1,75
Unitary charge, ZAR/m <sup>3</sup>	12,82	12,66	21,73

**Source: GWI, Desaldata, Veolia, Almar Water and author's calculations**

The calculations in Table 3-2 assume an average electricity cost of 0.85ZAR/kWh.

In the case of MED, the sensitivity of desalinated cost to the cost of energy is illustrated in Figure 3-5. It is shown that at scoping level, RO is essentially more cost-effective than MED, unless a free source of low-grade waste heat is used as the thermal energy input.

MED is more prevalent in MENA due to the availability of large amounts of associated natural gas production at low gas prices. In MENA it is often applied as part of the bottoming cycle of an integrated power and water generation facility. South Africa currently does not have access to low-cost natural gas. MED may be an option for South Africa in future if paired with low-grade waste heat from e.g., solar-thermal and nuclear power generation plants. However, solar-thermal/MED is not yet cost-competitive with grid/RO desalination because of the cost of thermal energy storage and the need for MED to operate at high load factors.



**Figure 3-5: Influence of energy cost on desalinated water cost, multi-effect distillation**

#### 3.1.2.2 Benefits of co-location with existing seawater intakes and outfalls

Co-locating the seawater intakes and outfalls of desalination plants with coastal power plant cooling systems may be beneficial and result in reduced water production costs. Apart from the obvious benefit of shared infrastructure, a new design could carry the added benefit of utilising lower grade waste heat for e.g., RO water preheating or hybrid MED-RO desalination, which can reduce energy consumption.

A qualitative analysis was conducted based on a co-locational capital cost benefit of 15%. On this basis, the impact on water cost is given in Table 3-3.

**Table 3-3: Impact on water cost**

Scenario	Water cost, ZAR/m <sup>3</sup>
Reference case SWRO plant, standalone	12.82
Reference case SWRO plant, co-located intake and outfall	11.78

The analysis is hypothetical based on a typical intake/outfall cost contribution and shared costs between co-located developments. Intake and outfall construction costs vary significantly and are highly site-specific and dependent on brine disposal and other environmental requirements.

Co-location of desalination with e.g., gas-to-power and nuclear energy at a coastal location should be considered, ideally during the planning stages of these projects.

#### 3.1.2.3 Desalination and Water Storage, including Aquifer Recharge

Natural water supply is intermittent and variable. Its additional buffer capacity (classically dam and groundwater storage) allows for a smaller reserve margin between water supply and demand. Pairing desalination with appropriately sized and cost-effective storage in theory makes it possible to provide more dispatchable water per unit of desalination capacity (implying a relatively smaller desalination plant).

Desalination requirements should be determined considering existing raw and bulk water storage capacity, future water storage potential and the ability to integrate with storage, as well as raw water treatment and purification capacity and the load factor.

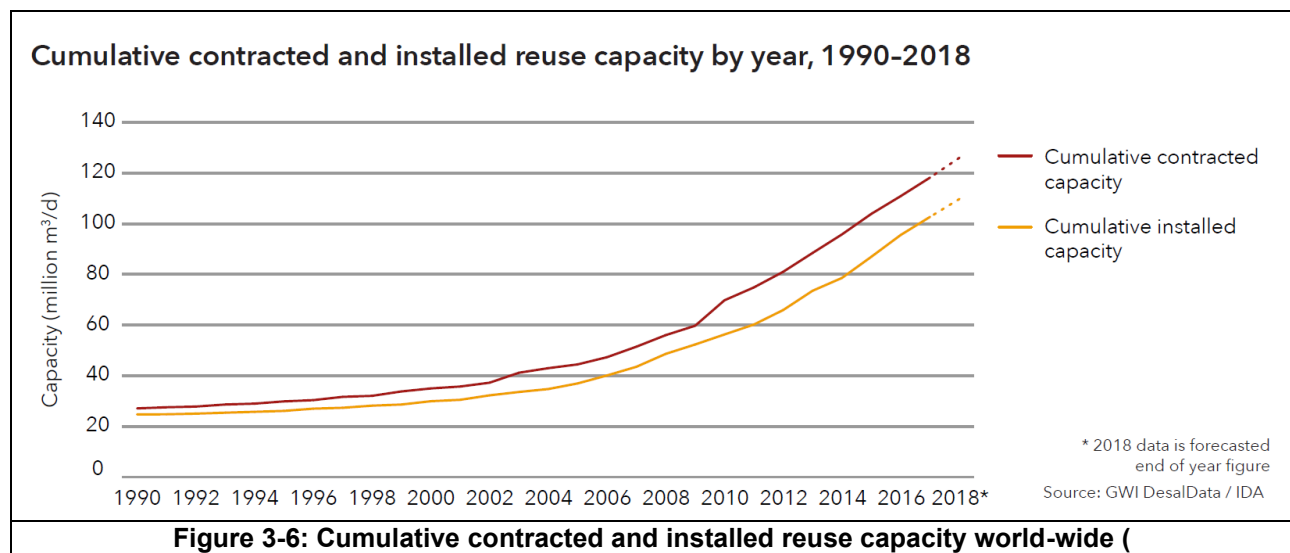
Such an analysis has to be conducted on a case-by-case basis within a specific water management area and is beyond the scope of this study.

### 3.1.3 Hydrological modelling of desalination

The interplay between treated wastewater, stormwater, desalinisation and aquifer recharge was built into the WRYM for different scenarios to assess the impact on supply reliability. Implications such as reduced reuse in times of restrictions will have to be considered.

## 3.2 WATER REUSE

Water reuse is the process by which wastewater, or effluent, is treated and repurposed. It should be noted that this is planned reuse of water from an erected treatment plant rather than indirect water reuse that is already prevalent in the agricultural sector. The use of this technology has been steadily increasing in recent years and has almost doubled since 2010 (IDA, 2018-2019) as shown in Figure 3-6.



The standard to which the water is treated for reuse depends on what the treated water is intended to be used for. This can broadly be broken into the following two categories:

- Potable use (water for fit for human consumption).
- Non-potable use such as agricultural irrigation or the recharge groundwater after extraction (aquifer recharge).

In addition to this, the manner in which the water is used can also be broken down into two categories:

- Direct use: where the treated water is directly used as potable water and fed directly from the output of the reuse treatment facility to the “tap”.
- Indirect use: where the treated water is used as raw feed water to an existing potable water treatment facility.

At present the direct use of reuse water is limited. In most cases the reuse water is blended with “conventional” potable water supplies being made available for consumption.

Typically, the input water intended to be reused has already undergone treatment at a WWTP or equivalent. The City of Cape Town has identified numerous WWTW’s as possible feed water sources for reuse. Table 3-4 details the sites as well as their potential yields and uses.

**Table 3-4: Potential yields for use of treated effluent from selected CCT wastewater treatment works (million m<sup>3</sup>/a)**

WWTW	Rated Hydraulic Capacity	Average annual flow <sup>3</sup>	Identified Potential Yield <sup>4</sup>					Total identified potential yield	Existing re-use
			Irrigation/ Industrial <sup>5</sup>	Local agriculture <sup>6</sup>	Commercial Agriculture <sup>7</sup>	Aquifer recharge <sup>8</sup>	Potable <sup>9</sup>		
Bellville	19.9	19.6	4.7	0.0	0.0	0.0	0.0	4.7	2.1 <sup>10</sup>
Kraaifontein	6.4	2.7	0.5	2.0	0.0	0.0	0.0	2.5	2.3
Scottsdene	4.4	2.8	0.5	1.8	0.0	0.0	0.0	2.3	1.9
Athlone	38.3	30.4	10.2	0.0	0.0	0.0	0.0	10.2	1.5
Cape Flats	73.0	54.6	2.5	0.0	0.0	0.0	40.0	42.5	0.8
Borcherds Quarry	12.8	10.2	3.4	0.0	0.0	0.0	0.0	3.4	0.0
Parow	0.4	0.6	0.3	0.0	0.0	0.0	0.0	0.3	0.2
Gordons Bay	1.1	0.9	0.3	0.0	0.0	0.0	0.2	0.3	0.0
Macassar	19.7	13.7	2.2	0.0	1.8	0.0	8.9	13.0	0.6 <sup>11</sup>
Zandvliet	22.6	17.5	0.8	0.0	3.3	0.0	16.3	20.4	0.0
Mitchell's Plain	17.5	11.3	1.1	0.0	0.0	0.0	9.3	10.4	0.0
Melkbos	2.0	0.7	0.7	0.0	0.0	0.0	0.0	0.7	0.4
Potsdam	11.7	11.7	6.5	4.1	0.0	0.0	0.0	10.6	1.7 <sup>12</sup>
Wesfleur (Domestic)	2.9	2.2	0.0	0.0	0.0	2.1	0.0	2.1	0.6
Wesfleur (Industrial)	2.2	1.8	0.4	0.0	0.0	0.0	0.0	0.4	0.0
Simons Town	1.8	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wildevöel Vlei	5.1	3.1	0.9	0.0	0.0	0.0	0.0	0.9	0.0
<b>Total</b>	<b>242.8</b>	<b>171.9</b>	<b>35.1</b>	<b>7.9</b>	<b>5.1</b>	<b>2.1</b>	<b>74.6</b>	<b>124.7</b>	<b>11.6</b>

<sup>3</sup> This represents the true potential yield as opposed to the identified potential yield.

<sup>4</sup> This represents yields of schemes that have already been identified and therefore does not equal the average annual flow.

<sup>5</sup> The source of information for the identified potential for local irrigation and industrial use in the Bvi Study "Investigation into the Distribution of Treatment Effluent" of 2003/04. However, where the industrial potential as determined in the IWRPS exceeds that determined in the Bvi Study, the greater value has been used.

<sup>6</sup> The source of information for the potential for local agriculture is based on the Bvi study (small-scale) agricultural demand).

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<sup>7</sup> The source of information for the potential for commercial agriculture is based on the IWRPS study by CCT. These are large-scale stand-alone schemes.

<sup>8</sup> The source of information for the potential for aquifer recharge is based on the Bvi Study.

<sup>9</sup> The source of information for the potential for potable use is based on the work undertaken in the Reconciliation Strategy Study. Based on comments recently received, the range for potable use varies from 22 million m<sup>3</sup>/a to 70 million m<sup>3</sup>/a. This differs from the figures in the table because they are based on average summer return flows as opposed to annual average flows. The figures in the table are effluent volumes (not reclaimed/portable water volumes) and there is usually a loss in volumes due to the need to treat the effluent.

<sup>10</sup> A project to use treated effluent from the Bellville WWTW, for industrial purposes, has just been completed. Current usage is however unknown at this stage.

<sup>11</sup> A project to convey treated effluent from the Macassar WWTW, to a proposed housing development (old AECl property), has recently been initiated.

<sup>12</sup> A project to use treated effluent from the Potsdam WWTW, for agricultural and industrial purposes, has just been completed. Current use is unknown at this stage.

**Source:** (Ninsham Sahnd Consulting Services; UWP Consulting, 2007)

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### **3.2.1 Water Reuse Technology**

Reuse is the process of treating wastewater bound for a typical wastewater treatment works (WWTW) and rather than treating it in the conversional manner, treating it to potable or raw water standards depending on whether its purpose is direct or indirect use. It therefore has the advantage of being rainfall independent but does rely on a consistent wastewater supply as feed water. If this supply of wastewater was to decrease for any number of reasons, the ability of the reuse facility to produce treated water for either direct or indirect consumption would also decrease. For this reason, reuse cannot be considered an assured water supply. The cost of production of reuse water depends largely on the quality of the waste feed water, but it is typically significantly less expensive than desalinated water.

The major concern associated with reused water is the perception that it may not be safe for human consumption. The result of this being a general negative public view of the technology and potentially a reluctance to consume the water. Both wastewater and water reuse represent areas of the water value chain where Public Private Partnership (PPP) potential is high. However, it is also the case that most municipalities in South Africa are not PPP suitable at present. Implemented correctly, wastewater is a business that has a number of revenue streams. Revenue options include treatment charges, the use of nutrients in fertilisers, the generation of biogas and opportunities for water reuse. The challenge with addressing wastewater is thus not largely a financing issue. Rather, the key challenges are centred around infrastructure, governance and institutional capacity.

There are substantial opportunities to finance wastewater infrastructure through securing purchasing agreements with industrial and agricultural users for reuse water. There are also good cost savings and revenue flows to be found in improved energy efficiency and biogas production at wastewater plants. Due to the variable nature of the effluent, which is intended to be treated, numerous treatment options are available, depending on the intended use of the output water.

For the CCT, one benefit of a water reuse initiative making use of membrane treatment by ultrafiltration (UF) to produce either potable water or raw water that could be delivered to surface drinking water plants (provided the input water is of adequate quality), is that this could be implemented faster than desalination plants. These indirect or direct water reuse projects have the potential to deliver 20 to 50 MLD to the City of Cape Town (Water Globe Consultants, 2017).

If reverse osmosis and advanced oxidation treatment of the effluent is necessary after UF in order to produce water of potable quality, then the time needed for construction of a 50 MLD water reclamation plant for potable reuse will be comparable to that of the construction of a SWRO plant. Added to this, the overall costs for the production of potable water through this process would likely be half that of desalinated water (Water Globe Consultants, 2017).

### **3.2.2 Water Reuse Costing**

#### **3.2.2.1 Faure WWTP Reference Case**

The below costing is assumed for modelling of a reference case, the Faure WWTW as the source of feed water. The reuse plant will make use of membrane bioreactor technology and produce potable water for direct use.

The following yields options (Table 3-5) of direct reuse potable water have been considered 166ML/day, 113ML/day and 60ML/day:

**Table 3-5: Overnight CapEx costs**

	166ML/day Potable	113ML/day Potable	60ML/day Potable
Overnight capital costs, ZAR/ML/day	9 289 750	11 933 489	6 525 644

Source: Ninham Shand, UWP and author's calculations

### 3.2.2.2 Unitised Cost Breakdown for Variable Yields:

**Table 3-6: Unitary water costs for variable yield reference case facilities**

Project type	166ML/day Potable	113ML/day Potable	60ML/day Potable
Capital Cost, ZAR/m <sup>3</sup>	3,58	4,60	2,51
Fixed O&M Cost, ZAR/m <sup>3</sup>	0,13	0,07	0,08
Variable O&M Cost, ZAR/m <sup>3</sup>	0,70	0,38	0,27
Electricity Cost, ZAR/m <sup>3</sup>	1,51	0,35	0,35
Unitary charge, ZAR/m <sup>3</sup>	5,92	5,39	3,22

Source: Ninham Shand, UWP and author's calculations

**Table 3-7: Faure New Water Scheme Operating Cost Estimate**

Description	R/Year	R/m <sup>3</sup>	%
Plant M&E cost (Amortised @ 15 years)	R44 232 154	R1.76	20.60%
Plant Civil cost (Amortised @ 20 years)	R40 710 056	R1.62	18.90%
Electricity	R37 549 153	R1.35	15.90%
Chemicals	R28 332 346	R1.12	13.20%
Membrane Replacement	R5 127 273	R0.20	2.40%
Labour	R13 050 000	R0.52	6.10%
Maintenance	R25 728 269	R1.02	12.00%
Insurance	R10 678 478	R0.42	4.90%
Additional Faure Treatment	R13 074 602	R0.51	6.00%
Total (excluding capital amortisation)	R133 540 121	R5.15	100%
Total (including capital amortisation)	R218 482 331	R8.53	100%

**Table 3-8: Faure New Water Scheme: Base Figures**

Updated 2019-05-30 (Based on Preliminary Design Report Cost Estimate)						
Item	Civil Work	Structural Work	Installed Equipment	Electrical Work	Electronic Work	Total
Construction Costs	398 432 001.03	381 726 281.46	470 058 904.19	121 862 625.63	43 819 692.24	1 415 899 504.55
Estimate base dated January 2019 (from Preliminary Design Report)						
Total of priced items excluding Preliminary & General costs	287 414 863.66	275 420 763.50	373 512 220.76	97 060 000.00	34 440 000.00	1 067 847 847.92
Preliminary & General costs	101 200 000.00	96 900 000.00	84 964 700.00	21 800 000	8 300 000.00	313 164 700.00



Sub-total including Preliminary & General costs	388 614 863.66	372 320 763.50	458 476 920.76	118 860 000	42 740 000.00	1 381 012 547.92
Contingencies (15%)	58 292 229.55	55 848 114.53	68 771 538.11	17 829 000.00	6 411 000.00	207 151 882.19
Total	446 907 093.21	428 168 878.03	527 248 458.87	136 689 000.00	49 151 000.00	1 588 164 430.11

### 3.2.2.3 Chapultepec Reference Case

The below costing shown in Table 3-9 and Table 3-10 is assumed for modelling of a reference case, the Chapultepec WWTW in Mexico City as the source of feed water. The reuse plant will make use of membrane bioreactor technology as well as a polishing plant consisting of UF, RO and ultraviolet (UV). The plant is intended to be used for aquifer recharge and has a production capacity of 14.7ML/day

**Table 3-9: Overnight CapEx Cost**

	14,7ML/day Potable, with UF RO & UV Polishing
Overnight capital costs, ZAR/ML/day	13 336 798

Unitised Cost Breakdown for Chapultepec:

**Table 3-10: Unitary water cost for Chapultepec**

Project type	14,7ML/day Potable, with UF RO & UV Polishing
Capital Cost, ZAR/m <sup>3</sup>	5,14
Fixed O&M Cost, ZAR/m <sup>3</sup>	0,43
Variable O&M Cost, ZAR/m <sup>3</sup>	0,86
Electricity Cost, ZAR/m <sup>3</sup>	1,51
Unitary charge, ZAR/m <sup>3</sup>	7,94

### 3.2.2.4 Unitised cost comparison

On comparison of the Faure and Chapultepec reuse schemes, there is not an excessively large unitised cost discrepancy. The Faure variable cost per m<sup>3</sup> increases with plant yield. This is likely due to a diseconomy of scale that occurs as a result of excessively large equipment and piping, and increased construction windows. The Chapultepec unitised cost is greater than all of the Faure costs at R7.94 /m<sup>3</sup>. This is because of the polishing facility the plant possesses as well as the input feed water having high TDS's.

On comparison of the unitised costs of reuse as compared to SWRO & MED desalination, it can be seen that the reuse costs are less, even for the largest capacity plant analysed. This is because the capex and O&M costs of a reuse plant are directly related to total dissolved solids (TDS) of the input water and therefore these costs are significantly lower for effluent as opposed to sea water (Ninham Shand Consulting Services; UWP Consulting, 2007).

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### 3.2.3 Hydrological modelling of water reuse

The interplay between treated wastewater, stormwater, desalinisation and aquifer recharge was built into the WRYM model through different scenarios to assess the impact on supply reliability. Implications such as reduced reuse in times of restrictions was considered.

## 3.3 AQUIFER RECHARGE

### 3.3.1 Overview

Artificial recharge is the process whereby surface water is transferred underground to be stored in an aquifer. The most common methods used involve injecting water into boreholes and transferring water into spreading basins where it infiltrates the subsurface. Underground water storage is an efficient way to store water because it is not vulnerable to evaporation losses and it is relatively safe from contamination. Artificial recharge schemes commonly involve surface or wastewater capture, treatment, pumping, water quality monitoring and clogging control. Careful planning and management is required to ensure that these processes are efficient.

The technology is not solely dependent on surface water as desalination and re-use can be used as sources for storage. Although this is an effective storage mechanism, it can only be applied in areas that have aquifers. Aquifer recharge can be cost effective when compared with high capital and infrastructure costs of other technologies. By optimising conjunctive use of surface and groundwater, and by using artificial recharge principles, expansion of surface water facilities can be deferred, with substantial cost savings. Aquifer recharge projects have the added advantage that they can be rapidly deployed, and development can be staged to reduce the upfront financial burden.

The main environmental concerns associated with artificial recharge schemes relate to the lowering and raising of water tables (or piezometric levels) over and above those of existing use, and issues associated with water quality changes within the aquifers. Artificial recharge schemes need to be licensed because storing water underground is defined as a “water use” in the National Water Act 36 of 1998.

It is also important to note that there is a risk that water stored cannot be extracted when needed because of infrastructure, water quality or water level, politics, and institutional or contractual provision. Based on the review of existing pertinent information, the COCT groundwater aquifers are expected to have water storage capacity that could provide sustainable water supply of 100 to 200 MLD for a period of 3 to 5 years. During years of low rainfall (“dry years”), the rate of aquifer drawdown could be increased to the maximum, while during wet years, and the winter season when drinking water demand subsides, the aquifers would need to be recharged with reclaimed wastewater and desalinated water. Which water would be used for aquifer recharge will depend on what type of plant (water reuse or desalination) is closest to the recharge field of a given aquifer and the specific water quality requirements of the receiving aquifer (Water Globe Consultants CCT study 2017).

Global international experience suggests that the recharge facilities located within 5 to 10 km of the seacoast should be designed such that they create a freshwater barrier to prevent seawater intrusion and the associated deterioration of aquifer water quality. Such seawater intrusion barriers have been successfully used in the US, Spain, Australia and other parts of the world. Since the safe yield of the groundwater aquifers targeted for immediate use is unknown at this time, the first priority of the water extraction projects is to establish their safe yield by standard pumping tests. Once the safe rate of groundwater extraction is known, the groundwater recharge fields, and water reuse and desalination plants, should be designed with adequate capacity to be capable of recharging the exploited aquifers at a rate equal to the safe groundwater extraction yield or the respective aquifers (Water Globe Consultants CCT study 2017).

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### **3.3.2 Hydrological modelling of aquifer recharge – treated wastewater**

Reuse of treated effluent typically must be stored and cannot be directly injected to the supply system. One of the main mechanisms for storage of the water is through artificial aquifer recharge which is currently being done for the Atlantis aquifer where about 30% of the groundwater used is supplemented by treated effluent. In fact, currently, the short-term supply solutions for the COCT is groundwater abstraction, and abstraction from the Atlantis and Cape Flats Aquifers (CFA) are being done at a non-sustainable rate. As part of the water use license conditions, these aquifers need to be artificially recharged. Investigations are underway to supplement the CFA Aquifer from various sources. The interplay between treated wastewater, stormwater, desalinisation, and aquifer recharge, was built into the scoping level model through different scenarios to assess the impact on supply. Implications such as reduced reuse in times of restrictions was considered.

## **3.4 FARMING UNDER NETTING - IMPROVED IRRIGATION EFFICIENCY**

Improving irrigation efficiency aims at minimizing water use within the agricultural sector while continuing to maintain optimal crop productivity rates. Water (and energy) efficient irrigation also provides a number of environmental and socio-economic benefits.

### **3.4.1 Farming under netting/Improved irrigation efficiency**

The intention of erecting shade netting over crops is to alter the micro-climatic conditions under the nets and to protect the fruit from adverse and extreme climatic events such as high solar radiation, hailstorms, and high wind speeds. The desired end objective being an increased return on investment due to reduced irrigation costs, higher produce yields and production of fruit of a higher quality (Prims, 2018).

Recent research has shown mixed results when it comes to reduced irrigation requirements and increased crop yields when grown under shade netting. The results seem to vary for different types of crops and climatic conditions. The use of screens and under-cover farming is constantly increasing, especially in arid and semi-arid regions. One of the reasons for the wide use of screens is the potential increase in water use efficiency, which is a crucial environmental issue in such regions. Screenhouses modify the crop microclimate and thus may reduce the atmospheric water demand and lead to water saving.

In Limpopo and in the South Cape, production has been seen to increase for citrus production (especially nartjies). Table grapes are very susceptible to the types of netting used and may not contribute towards water savings, but crop yields seem to increase due to the protection of the netting against birds, insects and the wind.

Water use efficiency is an important agricultural parameter because it tells the farmer the expected yield per plant water consumption. Water use efficiency (WUE) can be defined as the ratio between yield and applied irrigation. Figure 3-7 below illustrates the difference in WUE for navel oranges produced in Egypt at different irrigation levels (100%, 80% and 60%) under screen nets vs. in an open field for two consecutive seasons.

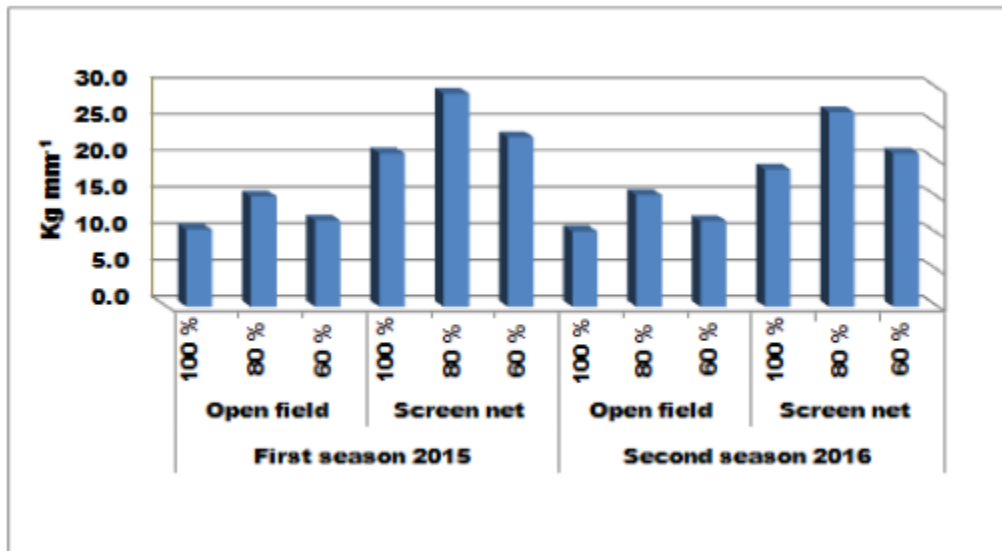


Figure 3-7: WUE at different irrigation levels (Mohamed, 2017)

### 3.4.2 Shade net costs and model considerations

In order to quantify the potential benefit of producing crops under shade netting, a number of aspects need to be considered. These can be broken down into a number of main categories, namely, capital costs, operations costs (including water costs) and yield.

#### 3.4.2.1 Capital costs:

The initial investment costs of shade netting are significant, ranging from R150 000/ha to R170 000/ha for grapes, about R200 000/ha for citrus (Ferreira, 2016) and about R250 000/ha for apples (FruitSA, 2018), but this may vary depending on the type of netting used. The nets and/or support structures may need to be replaced at some point, with the nets having an approximate lifespan of 15 years and the structures 30 years (Oosthuizen, 2019). In order for the erection of shade netting to be a viable water saving initiative, these costs need to be factored in, with the water (and/or other) savings being sufficient to justify the initial capital expenditure.

#### 3.4.2.2 Operations costs:

The erection of shade netting will have numerous effects on the day to day operational cost of running a farm. Some of these may be beneficial, such as the potential water saving; a 20% to 30% saving for table grapes in the Berg River area (Ferreira, 2016), fertiliser reduction by as much as 10 to 15% in table grapes due to better shoot elongation as a result of higher humidity (Ferreira, 2016), and labour cost reductions due to increased fruit quality. Others may be detrimental such as the need for maintenance on the nets and structures and the erection of supporting structures for fruit bearing branches (Mohamed, 2017).

#### 3.4.2.3 Yield:

For grapes there is a potential productivity increase of 20%-50% (Ferreira, 2016) and for navel oranges a potential yield increase of 30% (Mohamed, 2017). In addition to the potential increase in yield, the nets can result in decreased time to first fruit production in newly established orchards. For a citrus orchard not under nets the time from establishment to harvest may be as much as four years compared to 30 months for citrus crops under nets (Oosthuizen, 2019).

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It must be noted that for different crops in different climatic zones and soil conditions, the potential yield increases, and operational cost decreases, may vary significantly. This would have a distinct impact on the bottom line of the farm and would affect the viability of the use of shade netting as a water saving initiative significantly.

In order to combine all the above-mentioned potential effects of the erection of shade netting, it is necessary to perform a simulation to compare the base case of a farm without shade netting to a farm with shade netting for the same set of input variables. For this desktop study it is assumed that the orchards are already established when the nets are erected and that the nets are financed through a loan. The method of this study is as follows: model the best case scenario of a farm without shade netting with a fixed water tariff, model the case of a farm that erects shade netting, equate the value of the two different scenarios and solve for the water tariff the farm that erects shade netting can afford and still be on equal standing as the base case farm. What this will enable is a comparison between the water price paid by the base case farm and the water price the farm with nets can afford to pay, assuming both farms are of equal financial standing.

This simulation was performed for both a farm producing citrus and a farm producing grapes for wine production. The simulation showed that farming under netting is only economically viable in cultivars that are high paying, either being high value cultivars or having high yields per hectare. In this case, it was not economically viable for the farm producing grapes and borderline viable for the farm producing citrus. This is because even though citrus has a lower profit before tax percentage of revenue and requires a greater capital expenditure for the erection of netting compared to grapes, the significantly higher yield per hectare results in more cash available to service the debt incurred through the erection of the netting. In both the citrus farm and the grape farm, the profits after tax are insufficient to completely cover the interest and principal repayments of the loan. The citrus farm, however, is able to pull itself out of overdraft soon after the debt has been repaid while the grape farm is not. It is likely that for higher yielding and more valuable crops farming under netting will be economically viable. This will need to be investigated further to assess whether that is the case and, if it is the case, what water tariff this farm can then afford.

### **3.4.3 Hydrological modelling of improved irrigation efficiency**

The WCWSS WRYM model has an extensive and detailed network modelling all Cape Town and the surrounding areas' domestic and scheme irrigation water requirements, as well as the interconnectivity of a multitude of dams connected with tunnels, pipelines, canals and river releases. At the time of the WCWSS WRYM configuration in 2007, the detailed irrigation functionality was not available in the WRYM as it is today. A map of the irrigation areas for which the WCWSS WRYM is providing water to is also not available, nor is the actual sized of irrigated areas. Furthermore, irrigation requirements for the WCWSS area currently modelled as a static historical pattern in the WRYM/WRPM, barring the effects of rainfall of irrigation demand the WRYM and WRPM however to account for losses in supplying the irrigation water requirements to the different Irrigation Boards.

For the purpose of this analysis, the 1998 approved irrigation areas' sizes of Irrigation Boards (IBs) supplied by the WCWSS were used as well as the legal quotas for the IBs, which might differ from the currently approved scheme irrigation areas. Comparisons were however made between the 1998 approved irrigation water requirements, and what is currently used in the WRYM.

To assess the monthly irrigation water requirements the SAPWAT software was used to estimate the variability of irrigation water requirements (due to variability in daily climatic conditions) and subsequently the water balance benefits of using shaded netting and the integrated effect on the yield of the WCWSS.

Two main sources of information were used to derive the crop requirements for irrigation sub-areas in the WCWSS:

- The verified listed irrigation areas and quotas for IBs serviced by the WCWSS obtained from Mr. W. Enright. These values are the legal water rights as approved in 1998 and which was verified during the recent Validation and Verification Study done by the Breede-Gouritz Catchment Management Agency. A summary of the total field sizes under irrigation from the WCWSS sub-areas is provided in Table 3-11.
- A recent detailed aerial survey of irrigated fields in the Western Cape Province by the Department of Agriculture of the Western Cape Provincial Government provided per field data on crops, field sizes, irrigation methods and other data as observed during the winter of 2017 (ref).

The Irrigation Board irrigation area sizes and quotas for the Western Cape Water Supply System (WCWSS) obtained from Mr. W. Enright were compared with the Western Cape Government Department of Agriculture's detailed crop survey from 2017 (Enright pers comms Date).

**Table 3-11: Verified legal irrigation areas in the WCWSS.**

<b>WUA or Irrigation Board</b>	<b>Verified allocated area (ha)</b>	<b>Quota (m<sup>3</sup>/ha/a)</b>	<b>Maximum Allocated water use (10<sup>6</sup>m<sup>3</sup>/a)</b>
<b>Upper Berg River (G10A to G10D)</b>			
Berg River Subdistrict 1	3571	4000	14.29
Berg River Subdistrict 2	4227	5000	21.13
Berg River Subdistrict 3	3003	6000	18.02
Groenberg Ward 2	119	5000	0.60
Groenberg Ward 1	211	5000	1.06
Noord-Agter Paarl	970	5000	4.85
Perdeberg	1324	5000	6.62
Simondium	243	4 000	0.97
Simonsberg	125	4 000	0.50
Suid-Agter Paarl	867	4 000	3.47
<b>Sub-Total</b>	<b>14661</b>		<b>71.50</b>
<b>Lower Berg River (G10E to G10K)</b>			
Riebeeck Kasteel	224	6000	1.34
Riebeek West Ward 2	135	6000	0.81
Riebeek West Ward 1	115	6000	0.69
Lower Berg River Summer	3657	3000	10.97
Lower Berg River	1648	7000	11.54
<b>Sub-Total</b>	<b>5779</b>		<b>25.35</b>
<b>Jonkershoek River Transfer and Eerste River (G22E to H)</b>			
Wynland WUA	6 531	4 000	26.12
<b>Sub-Total</b>	<b>6531</b>		<b>26.12</b>
<b>Upper Riversonderend River (H60A to H60C)</b>			
Elandskloof	1 909	6860	13.10
Upstream Elandskloof Dam	457	6860	3.14
Vygeboom	1 863	7 100	13.23
Theewaterskloof Dam direct	1 564	7 100	11.11
<b>Sub-Total</b>	<b>5793</b>		<b>40.56</b>
<b>Lower Riversonderend River (H60D to H60L)</b>			
Zonderend	6 017	6 000	36.10
<b>TOTAL WCWSS</b>	<b>38781</b>		<b>199.64</b>

The analysis shows that in the Berg and Winelands sub-areas, the total amount of fields under irrigation from the 2017 Survey was nearly 4 times as much as the verified allocated areas as in Table 3-11. This might be due to several reasons:

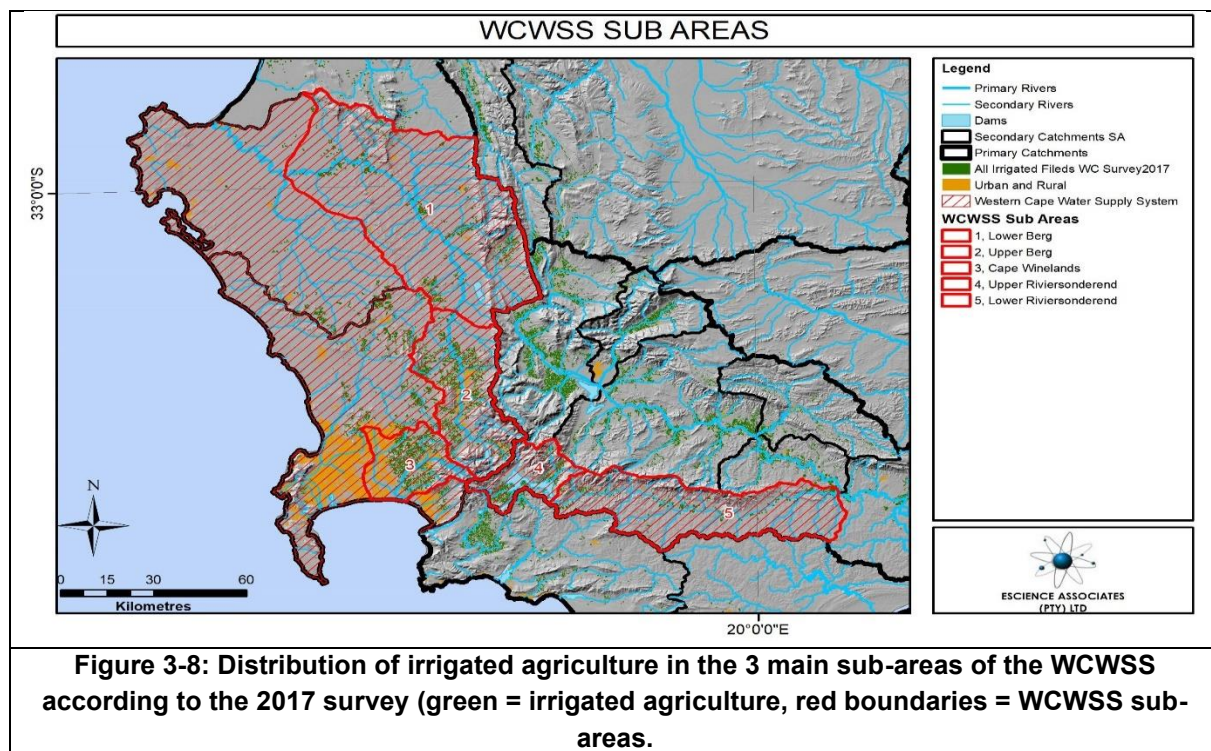
- The 2017 Survey's assessment of fields that are irrigated was inaccurate. The primary assessment was done in winter when rains occur in this area, which might result in wrongly assuming that a field is irrigated or not. A summer assessment, when most of the irrigation takes place, was also done, but only in terms of differences from the winter survey.
- Some of the fields identified during the 2017 Survey might have been irrigated from other sources such as farm dams or groundwater.
- Some of the fields identified might be from illegal use.

None the less, the 2017 Survey crop type and irrigation method spatial distributions (based on aerial photographic and ground truthing) were assumed to be accurate and indicative of the relative distribution of crops per irrigation sub-area for 2017.

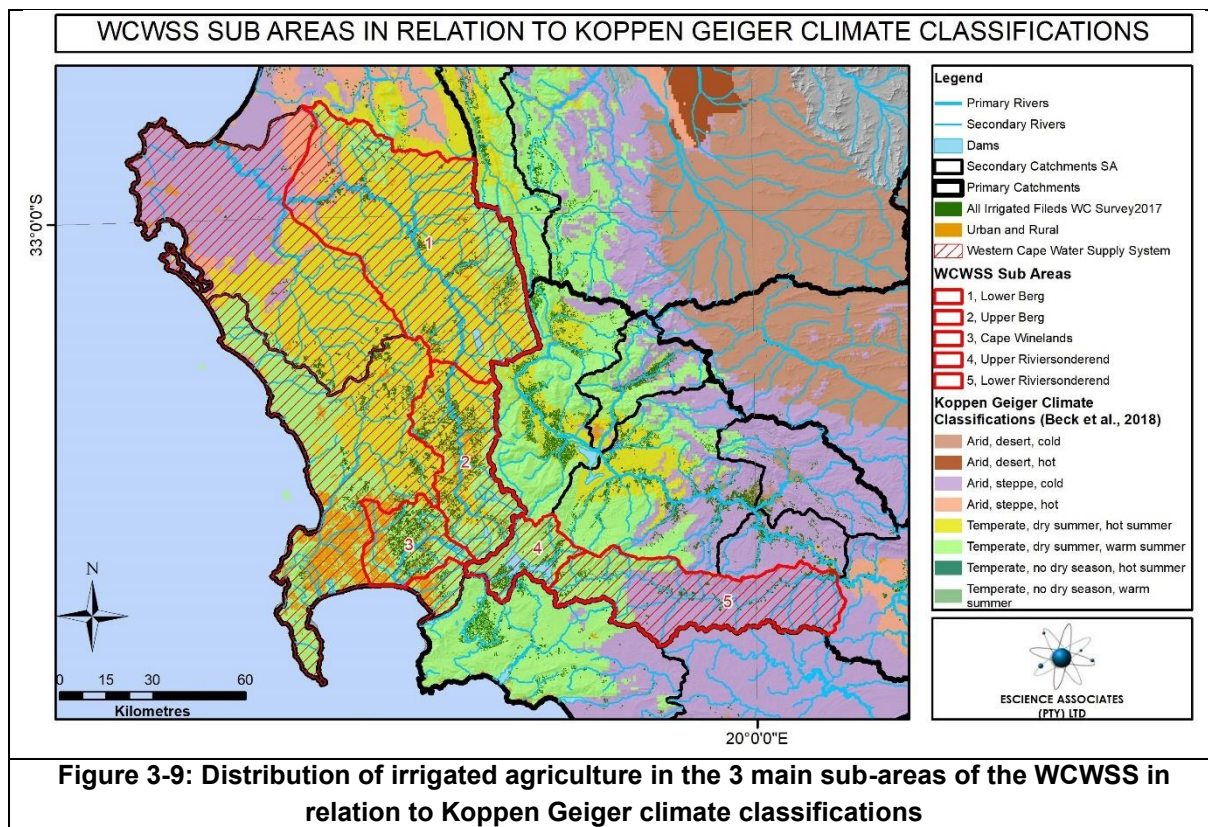
To assess the variable irrigation requirements in different climatic areas of the WCWSS, the crop type and irrigation method distributions were aggregated into 5 distinct irrigation sub-areas, namely:

- Upper Berg
- Lower Berg
- Winelands
- Upper Riviersonderend
- Lower Riviersonderend

Figure 3-8 shows the distributions of irrigated fields according to the 2017 Survey in the 5 irrigation sub-areas and Figure 3-9 shows the distribution in relation to the Koppen Geiger climate classifications.







The average monthly irrigation requirement for each of the 5 irrigation sub-areas were then calculated as follows:

- Determine an irrigation sub-area representative crop requirement:
  - The unique crops' distributions from the 2017 Survey for each sub-area was determined from the approximate quaternary catchment areas in which the IBs are situated. This had to be done since no detailed map of the IB locations existed. Table 3-13 provides a breakdown of the crop-groupings that makes up the distribution in each of the main 5 irrigation sub-areas.
  - In order to minimize the number of SAWPAT runs, the top 7 WCWSS crop groupings was identified to define a single representative crop requirement for each sub-area. The top 7 crop groupings represented 94.3% of all the crops that are irrigated in the WCWSS.
  - For each irrigation sub-area, different hydro-climatic zones were determined based on the quaternary MAP/MAE ratios. Where there were diverse hydro-climatic zones, two or more quaternaries were selected to represent the total spread of conditions and therefore the variation in crop water requirements.
  - For each of the crops within the 7 top crop groupings, the irrigation requirement was then determined using SAPWAT for each applicable quaternary and its hydro-climatic conditions. For an initial assessment, the crop requirement considered the quaternary long-term rainfall and evaporation data during the 50-year+ daily crop requirement simulation in SAPWAT. All irrigation systems were set as Drip irrigation and each quaternary' soil type was also considered in the calculation of the monthly crop irrigation water requirement.
  - Average crop requirements were then determined for each irrigation sub-area, with their individual hydro-climatic conditions. Using the 2017 Survey's crop area sizes per irrigation sub-area, a single area weighted monthly and annual crop requirement was determined for each irrigation sub-area.



- Calculating the WCWSS sub-area irrigation water requirement.
  - The single sub-area specific crop requirement was then multiplied by the legal crop areas for all the IBs and WUA per sub-area.
  - The annual total volumetric crop requirement per sub-area was then compared with the assigned irrigation quota.

Table 3-12 provides the sub-area representative average annual crop requirement for the 5 sub-areas in the WCWSS, taking into account rainfall provided in SAPWAT. Table 3-13 also provides a comparison between the total irrigation requirement per sub-area in comparison to the legal irrigation quotas in the areas. It can be seen from Table 3-12 that the SAPWAT water requirements in the Berg and the Winelands is still more than the surface water quotas for the IBs and WUA. The irrigation requirement considered Drip Irrigation efficiency and is therefore conservative, and no distribution losses were included in the comparison. It is possible that the rest of the gap between irrigation quota and total irrigation requirements is made up with groundwater and other resources. In contrast, the Breede River sections' total irrigation requirement is lower than the allowed quotas. For a reason that is not clear to the project team, the irrigation quotas in the Upper Riviersonderend is substantially higher than the annual crop requirement and double that of the rest of the WCWSS and it is to be clarified as a matter of urgency.

**Table 3-12: Crop requirements and total irrigation requirements per WCWSS sub-area for 2017 distribution of crops.**

Crop Group	Crop	Average annual crop requirement (mm/a)				
		Upper Berg	Lower Berg	Winelands	Upper RSE	Lower RSE
Grapes	Wine and Table	564	635	469	559	576
Pome fruit	Pear	578	525		613	444
Pome fruit	Apple		734		297	508
Grains	Wheat		251		154	256
Grains	Barley		161		148	186
Grains	Canola		188		148	
Stone fruit	Plums	432	556	328	401	
Stone fruit	Peach	578	738	453	533	
Stone fruit	Nectarine	429	551	326	398	
Stone fruit	Apricot	370	482		346	
Stone fruit	Cherries	435	470		434	
Citrus fruits	Citrus (unspecified)	688	798	565		810
Planted pastures	Planted pastures	245	293		242	307
Planted pastures	Lucern/Medics	714	837		686	759
Planted pastures	Planted pastures (perennial)	844	1000		862	995
Olives	Olives	388	459	278		
<b>Representative area weighted gross crops requirement (mm/a)</b>		<b>548</b>	<b>580</b>	<b>464</b>	<b>373</b>	<b>547</b>
IB and WUA legal area under irrigation (ha)		14661	5779	6531	5793	6017
2017 Irrigation Water Requirement (million m <sup>3</sup> /a) (drip irrigation with no distribution losses)		80.4	33.5	30.3	21.6	32.9
Allocated SW Quota (million m <sup>3</sup> /a)		71.5	25.4	26.12	40.56	36.10
Current irrigation water requirement as % of surface water quota		112%	132%	116%	53%	91%

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Using the annual representative crop requirements that accounts for rainfall for each irrigation sub-area generated from SAPWAT, three scenarios were defined in estimating the impact of shade netting on irrigation water requirement:

- Base scenario – this is the total irrigation demand as provided in Table 3-12 for the 2017 crop distribution.
- Scenario 1 – this scenario estimates the impact of current shade netting on total crop requirements, based on the total areas under shade netting provided in the 2017 Crop Survey.
- Scenario 2 – this scenario estimates the impact on total irrigation requirements if selected crops are covered with shade netting for 75% of the area under irrigation currently.

**Table 3-13: Distribution of major crop groupings in each of the sub-areas of the WCWSS**

Crop Grouping	2017 Survey Irrigated fields (ha)	% of total fields	Upper Berg		Lower Berg		Winelands		Upper RSE		Lower RSE	
			Crop areas (ha)	% of total area	Crop areas (ha)	% of total area	Crop areas (ha)	% of total area	Crop areas (ha)	% of total area	Crop areas (ha)	% of total area
Grapes	32291.0	55.2%	14629.0	73.6%	5756.9	39.6%	11693.9	91.0%	115.4	2.1%	95.7	1.7%
Pome fruit	8154.6	13.9%	167.7	0.8%	1072.6	7.4%	51.2	0.4%	4954.9	88.7%	1908.3	33.4%
Grains	3848.7	6.6%	77.9	0.4%	2376.4	16.4%	0.0	0.0%	53.4	1.0%	1341.0	23.5%
Stone fruit	3721.7	6.4%	1851.6	9.3%	1292.5	8.9%	223.1	1.7%	307.8	5.5%	46.7	0.8%
Citrus fruits	2687.5	4.6%	829.5	4.2%	1404.2	9.7%	150.9	1.2%	29.6	0.5%	273.3	4.8%
Planted pastures	2548.6	4.4%	223.0	1.1%	503.1	3.5%	65.9	0.5%	57.4	1.0%	1699.2	29.7%
Olives	1932.2	3.3%	1170.1	5.9%	496.3	3.4%	226.3	1.8%	4.1	0.1%	35.3	0.6%
Vegetables	1331.9	2.3%	131.8	0.7%	825.6	5.7%	194.3	1.5%	21.9	0.4%	158.3	2.8%
Sub-tropical fruit	565.2	1.0%	283.9	1.4%	207.3	1.4%	73.7	0.6%	0.2	0.0%	0.0	0.0%
Tree fruit - other	533.1	0.9%	171.4	0.9%	222.7	1.5%	28.0	0.2%	4.2	0.1%	106.8	1.9%
Other	321.2	0.5%	165.2	0.8%	70.8	0.5%	41.1	0.3%	6.4	0.1%	37.7	0.7%
Berries	271.7	0.5%	79.4	0.4%	110.1	0.8%	53.2	0.4%	29.0	0.5%	0.0	0.0%
Nuts	134.5	0.2%	55.8	0.3%	66.1	0.5%	3.1	0.0%	0.0	0.0%	9.5	0.2%
Flowers	99.0	0.2%	29.3	0.1%	31.5	0.2%	37.8	0.3%	0.0	0.0%	0.4	0.0%
Pepo	86.2	0.1%	0.0	0.0%	86.2	0.6%	0.0	0.0%	0.0	0.0%	0.0	0.0%
Herbs/Essential oils	19.1	0.0%	13.9	0.1%	2.7	0.0%	2.2	0.0%	0.3	0.0%	0.0	0.0%
Prickly pears	1.8	0.0%	0.9	0.0%	0.6	0.0%	0.0	0.0%	0.0	0.0%	0.3	0.0%
<b>Total</b>	<b>58547.9</b>		<b>19880.5</b>		<b>14525.4</b>		<b>12844.7</b>		<b>5584.7</b>		<b>5712.6</b>	

Reductions in irrigation requirements are distributed according to the quaternary MAP/MAEs ratios and based on the relatively little empirical evidence that is available on increased irrigation efficiency. Table 3-14 provides some illustrative reduction in irrigation requirements without loss in crop yields that has been shown internationally.

**Table 3-14: International findings on reduction in irrigation requirements under shaded netting without loss in crop yields.**

Crop	Reduction in irrigation requirement without influencing yield	Country	Relative evaporation or ET	Source
Bananas	20 – 30%	Jordan Valley, Israel	Very high (3300 mm/a evaporation)	Institute of Soil, Water & Environmental Sciences, Agricultural Research Organization, The Volcani Center, Israel
Apples	15%			
Citrus	50%	Sous Massa, Morocco	High (1800 mm/a ET and 2600 mm/a evaporation)	Equipe de Génie de l'Environnement et Biotechnologie, ENSA, Université Ibn Zohr, BP1136 Agadir, Morocco.
Capsicum	33%	India, Rajasthan	Medium (800 mm/a ET)	Indian Institute of Technology Kharagpur, Kharagpur, 721302, West Bengal, India

It is expected that wetter areas will see fewer overall savings in irrigation water requirements than drier areas. SAPWAT already considers the hydro-climatic conditions when determining the irrigation water requirements, meaning that there will be lower requirement in wetter areas.

To counter the expected savings in wet and dry areas, a relationship between a catchment's climatic conditions, expressed in terms of the MAP/MAE (or Wetness Index), and the expected savings per crop type was developed as an initial assessment of potential savings in the irrigation water requirements.

The seasonality of the highest rainfall and highest evaporation, is however out of phase in the WCWSS area, meaning that rainfall does not contribute substantially to the reduction in irrigation requirements due to the highest irrigation demands occurring in the driest time of year. There is however some wet summer months and some overlap in transitional months that does affect the irrigation water requirements.

The proposed relationship considers the effects of crop water requirements as generated by SAPWAT for different Wetness Indices generated during this analysis. Table 3-15 shows the assumed savings in irrigation requirements depending on the sub-area Wetness index.

**Table 3-15: Wetness index for sub-areas and the assumed irrigation water saving for different types of crops.**

Crop type	Irrigation water savings*		Wetness index (Catchment MAP/MAE)							
	Max	Min	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6
Grapes and pome	30	15	30	28	26	24	21	19	17	15
Stone	25	10	25	23	21	19	16	14	12	10
Citrus	40	20	40	37	34	31	29	26	23	20

Note: \* - Based on limited finding provided in Table 3-11.

Table 3-16 provides a breakdown of the reduction in annual total irrigation requirement per sub-area for each Scenario.

**Table 3-16: Total irrigation requirements and per WCWSS sub-area for 3 scenarios.**

	Scenario	Upper Berg	Lower Berg	Winelands	Upper RSE	Lower RSE	WCWSS Total
Legal area under irrigation (ha)	Current	14661	5779	6531	5793	6017	38781
Allocated SW Quota (million m <sup>3</sup> /a)	Current	71.5	25.4	26.1	40.6	36.1	199.6
Water Requirement - no distribution losses and drip irrigation (million m <sup>3</sup> /a)	Base	80.4	33.5	30.3	21.6	32.9	198.7
	Scenario 1	78.7	31.7	30.3	21.6	32.7	195.0
	Scenario 2	66.8	27.2	24.7	18.5	30.1	167.4
Reduced water requirements (million m <sup>3</sup> /a)	Base	0.0	0.0	0.0	0.0	0.0	0.0
	Scenario 1	1.7	1.8	0.0	0.0	0.2	3.8
	Scenario 2	13.6	6.3	5.6	3.1	2.8	31.3
Water requirement as % of Quota	Base	112%	132%	116%	53%	91%	100%
	Scenario 1	110%	125%	116%	53%	91%	98%
	Scenario 2	93%	107%	94%	46%	83%	84%

As can be seen from Table 3-16 there is already an estimated 3.8 million m<sup>3</sup>/a saving in irrigation water requirements throughout the WCWSS due to shade netting application, which is only 10% of the total potential saving that could be achieved if 75% of all grapes, pome fruit, stone fruit and citrus are place under shade netting. The biggest savings that could potentially be achieved will be in the Berg and Winelands regions.

To assess the impact of the (a) variable monthly irrigation requirements and (b) the reduction of these requirements due to the use of shade netting on some of the crops on the WCWSS, the following steps were taken undertaken:

- A recent version of the WCWSS WRYM model was obtained from AURECON.
- The SAPWAT annual representative crop requirements as shown in Table 3-19 was regenerated to exclude rainfall available in SAPWAT and the average monthly representative crop requirements for each of the irrigation sub-areas were calculated in the same way as before.
- Since it was assumed that the rainfall data in the WRYM model is directly related to the streamflow, irrigation sub-area representative rainfall distributions from the WRYM was used to calculate the monthly WRYM rainfall timeseries for each sub-area.

- Timeseries of variable monthly irrigation water requirements for each sub-area was then calculated using the WRSM2000/Pitman model's irrigation sub-model with the following inputs per irrigation sub-area:
  - SAPWAT average monthly representative crop requirements (excluding rainfall) based on the 2017 Survey's crop type distributions,
  - WRYM rainfall timeseries and the area weighted WR2012 MAP for the sub-area, and,
  - effective monthly rainfall estimates as calculated from a FAO equation.
- Four scenarios of variable monthly irrigation water requirements for each sub-area were generated as follows:
  - Scenario 1: monthly variable requirements (partly due to rainfall) without any quota considerations,
  - Scenario 2: monthly variable requirements reduced due to the application of netting to all Citrus, Stone fruit, Pome fruit and Grapes, without any quota considerations,
  - Scenario 3: same as Scenario 1 limiting each year to the maximum quota, and
  - Scenario 4: same as Scenario 2 limiting each year to the maximum quota.
- The irrigation water requirements in the WRYM were then compared with the annual, and the monthly, distribution of the three scenarios of SAPWAT based irrigation water requirement per sub-area.
- Lastly, the three irrigation water requirements scenarios' effects on the integrated WCWSS WRYM model water balance were assessed.

Table 3-17 provides a summary of the 5 irrigation sub-area's parameters used for calculating the variable monthly irrigation requirement Scenarios, while Table 3-18 provides a summary of the reduction of crop requirements due to shade netting application in the different sub-areas, as well as an estimated area of netting application for Scenario 3.

**Table 3-17: Summary of rainfall files and MAPs used for the calculation of variable monthly irrigation requirements per irrigation sub-area.**

Irrigation Sub-Area	Approximate Quaternaries	WRYM		WR2012	Legal Verified		
		Ran file	RAN MAP (mm/a)	Area-weighted MAP applied (mm/a)	Irrigation Area (km <sup>2</sup> )	Weighted Quota (m <sup>3</sup> /ha/a)	Quota Volume (million m <sup>3</sup> /a)
Upper Berg	G10A- G10F	G1H20-S	799	916	146.6	4877	71.5
Lower Berg	G10J & G10K	G1H35	407	488	57.8	4386	25.4
Winelands	G22F-G22H	G2R01-S	1613	941	65.3	3999	26.1
Upper Riviersonderend	H60A&H60B	H6R02GW	1037	831	34.3	7100	24.3
Lower Riviersonderend	H60D-H60L	H6INCGW	532	489	60.2	6000	36.1
Total					364.2		183.4

**Table 3-18: Summary of crop requirement reductions and approximate total areas of netting on which it should be applied for Scenario 3 of the variable monthly irrigation requirements.**

Irrigation sub-area	Wetness Index (MAP/MAE)	Approximate area of netting (km <sup>2</sup> )	Assumed reduction in crop irrigation requirements (%)		
			Grapes and Pome	Stone	Citrus
Upper Berg	0.81	135.8	23.5	18.5	31.3
Lower Berg	0.28	42.7	29.1	24.1	38.8
Winelands	0.83	64.1	23.2	18.2	31.0
Upper Riviersonderend	1.08	33.4	20.6	15.6	27.4
Lower Riviersonderend	0.26	25.8	29.4	24.4	39.2
Total:		301.8			

Table 3-19 provides a summary of the annual irrigation water requirements for the 3 Scenarios compared to the WRYM model's requirements.

**Table 3-19: Annual irrigation water requirements for the 3 scenarios compared to the WRYM model's requirements.**

Irrigation Sub-Area	Legal Verified Quota Volumes (million m <sup>3</sup> /a)	Annual irrigation water requirements (million m <sup>3</sup> /a)				
		WRYM 2019 WRYM Irrigation	WRSM2000-SAPWAT (using WRYM rainfall distribution)			
			Scenario 1: Present-day, variable demand	Scenario 2: Present-day, variable demand, shade netted	Scenario 3: Present-day, variable demand and quota limited	Scenario 4: Present-day, variable demand, shade netted, and quota limited
Upper Berg	71.5	68.1	87.4	64.1	71.3	63.7
Lower Berg	25.4	25.8	36.4	25.6	25.4	24.8
Winelands	26.1	26.2	36.2	31.2	26.1	26.0
Upper Riviersonderend	24.3	29.0	12.0	9.3	12.0	9.3
Lower Riviersonderend	36.1	28.5	20.3	16.6	20.3	16.6
Total	183.4	177.6	192.3	146.8	155.1	140.5

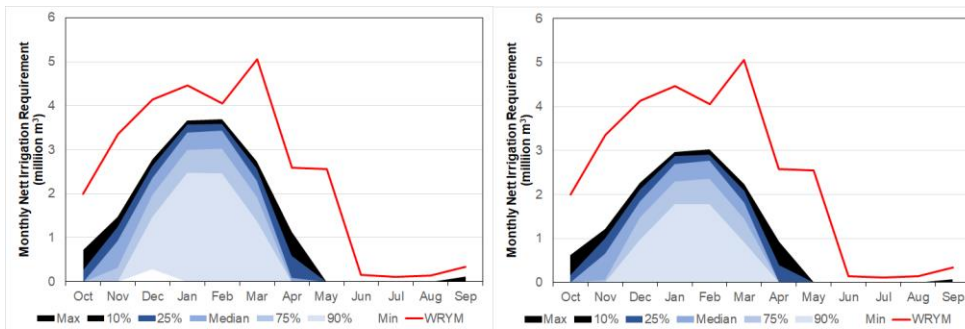
Please note the following regarding Table 3-19:

- The WRYM requirements are the end-of-pipe requirements after delivery losses have been accounted for.
- All WRYM irrigation requirements were provided as a fixed annual demand with a fixed monthly pattern.
- All the irrigation requirements were fully or 99% met in all of the scenarios and in the original system.
- No explanation could be obtained of how the WRYM annual and monthly distribution of irrigation requirements were calculated.
- It is uncertain if some of the WRYM irrigation requirements accounts for some canal and other distribution losses.
- The distribution of the SAPWAT-WRSM2000 variable irrigation water requirements for each sub-area compared to the fixed monthly requirements in the WRYM is illustrated in Figure 3-10.

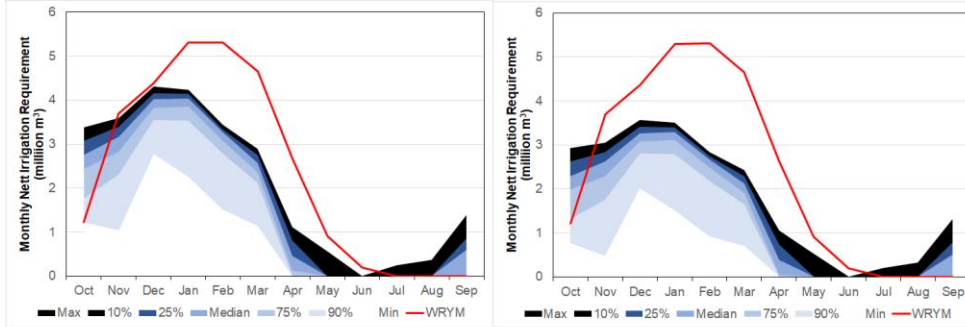
Scenario 3: Variable requirement from legal area using SAPWAT, quota limited

Scenario 4: Variable requirement from legal area using SAPWAT, shaded net and, quota limited

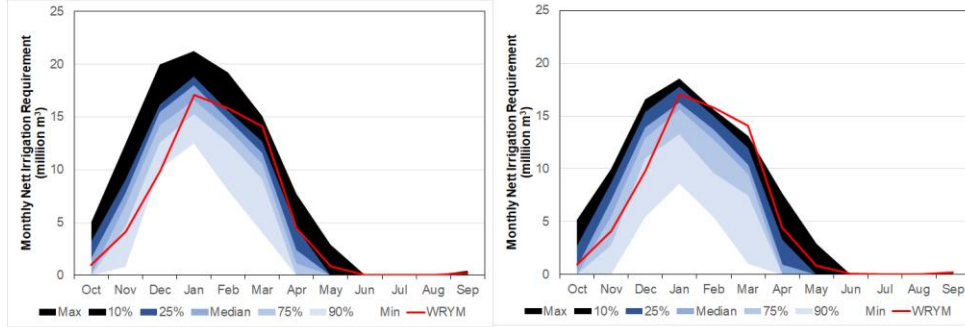
Upper  
Riviersonder  
-end



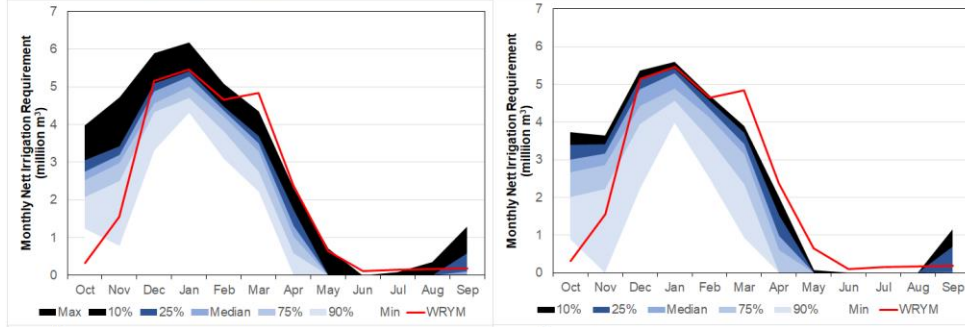
Lower  
Riviersonder  
-end



Upper Berg



Lower Berg



Winelands

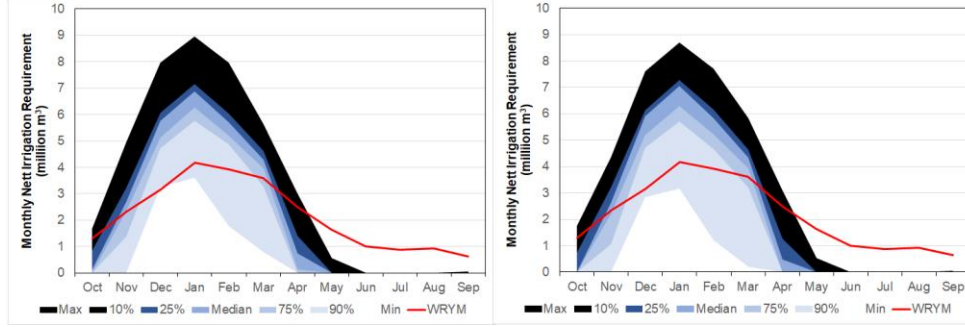


Figure 3-10: Exceedance probability of variable monthly irrigation requirements per sub-area compared to fixed monthly irrigation requirements in the WRYM Model.



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The following is observed from Table 3-19 and Figure 3-10:

- Figure 3-10 shows that even though there are limited rainfall in the highest irrigation requirement periods, the irrigation requirement varies considerably for each month. It is also apparent that the seasonal pattern of irrigating requirements in the WRYM differs considerably given the SAPWAT distribution of irrigation requirements for the crop types in the sub-areas, especially in the winelands. The apparent over-estimation of the irrigation requirements in the Riviersonderend end is also very evident. The Winelands does not show a reduction in irrigation requirements between Scenario 3 and 4 since even with shaded netting the demand is higher than the quota with which it is limited.
- The total WRYM scheme irrigation demand is 3% lower than the legal verified quota volumes.
- Upper Riviersonderend's WRYM irrigation requirements are slightly higher than the quota, while the Lower Riviersonderend WRYM requirements are 21% lower than their legal quota.
- The unconstrained Present-Day SAPWAT requirement (Scenario 1) shows that overall, the irrigation demand is only 5% over the quota and 8% over the WRYM requirement. However, all Upper Berg, Lower Berg and the Winelands SAPWAT unconstrained requirements are 22%, 43% and 39% more than their allocated quotas respectively. This means that the supply to these areas is significantly lower than the optimal water provision required for the schemes, even without considering canal and other distribution losses.
- Scenario 1 also shows that the Upper and Lower Riviersonderend SAPWAT variable demand is significantly lower than their quota. The quota for these areas is nearly double the quotas in the Berg River and the Winelands. The SAPWAT requirement for the Upper Riviersonderend was checked against the actual measured supply from the Vyeboom Pipeline and the values compared well. It is therefore uncertain why such a high quota is provided in this area.
- Scenario 2 shows that if the shade netting is applied over the 301 km<sup>2</sup>, the total irrigation requirement from with 24%, or 45.5 million m<sup>3</sup>/a. All the sub-areas then use less water than their quotas except for the Winelands, which require an additional 20% above their quota.
- Comparing Scenario 3 (SAPWAT variable monthly irrigation demand, limited to the annual quota for each year) with the current WRYM demand, there is a 22.5 million m<sup>3</sup>/a reduction in irrigation requirements, due to the inexplicably high Upper and Lower Riviersonderend requirements in the current WRYM model.
- Comparing Scenario 4 (SAPWAT variable monthly irrigation demand for shaded netting of indicated crops, limited to the annual quota for each year) with Scenario 3 it can be seen that there is a further 14.6 million m<sup>3</sup>/a reduction in irrigation demand (37.1 million m<sup>3</sup>/a against the current WRYM model irrigation requirement).

Incorporating the variable monthly irrigation requirements into the WRYM for Scenario 3 and Scenario 4 produced results summarised in Table 3-20. Table 3-20 shows that there is a 25.4 to 40.3 million m<sup>3</sup>/a difference in the irrigation water requirement between the current WRYM irrigation demands and the calculated SAPWAT variable irrigation requirements for the irrigation schemes, mostly due to the Riviersonderend's irrigation quotas. It is recommended that the irrigation requirements in the WRYM is checked against actual measured and supplied requirements from the system, as was done for the Vyeboom IB's pipeline in this assessment, and adapted. It is also recommended to implement a variable irrigation requirement that considers the variability of the requirements not to be over conservative.

The assessment shows that if 301 km<sup>2</sup> of potential irrigated areas are converted to shade netting, that there will be a 14.7 million m<sup>3</sup>/a addition to the yield of the WCWSS. At R170 000 per hectare this equated to:

- R231 per m<sup>3</sup> at a 10% interest rate
- R130 per m<sup>3</sup> at a 7.5% interest rate

**Table 3-20: WCWSS WRYM Results for Scenario 3 and Scenario 4 compared with Baseline (all values in million m<sup>3</sup>/a)**

Component	WRYM Baseline		Scenario 3		Scenario 4		Saving (Scen 3 & Baseline)	Saving (Scen 4 & Baseline)	Saving (Scen 4 and Scen 3)
	Require- ment	Supply	Require- ment	Supply	Require- ment	Supply			
Cape Town Supply from current WTW maximum capacities	660	265.2	660	290.3	660	300.9	25.1	35.7	10.6
Other Towns	34.8	34.6	34.8	34.6	34.8	34.6			
Compensation Releases	1.4	1.3	1.4	1.3	1.4	1.3			
Irrigation Schemes	177.6	176.4	156.0	155.1	141.3	140.5			
Possible additional supply to Cape Town from Berg Rivier Dam	Max	30.5	Max	28.9	Max	32.9	0.5*	4.6*	4.0
Total WCWSS Supply:		508.1		510.3		510.3	25.6	40.3	14.7

Note: \* - Additional Total WCWSS Supply added to these values

## 3.5 AGRIVOLTAICS

### 3.5.1 Introduction

Agrivoltaics (AV) is an emerging approach of harvesting energy and food together in a given land area that can maximize the land productivity, with additional potential benefits including reduced irrigation budget, improved crop yield, agricultural land preservation, and socioeconomic welfare of farmers. Agrivoltaics farming is rapidly attracting worldwide attention due to large scale spreading of solar photovoltaic (PV) energy systems, which is prompting the need to develop effective solutions for its landscape integration that can minimize ecological changes to the land and favour local communities. In AV approach, PV panel arrays are designed to partially cover the crops with optimal density, elevation, and tilt, which manipulates the desired balance for sharing sunlight intensity between energy and crop production. The PV covering could be leveraged to protect crop yield against adverse weather conditions, e.g., to minimize harmful thermal stress on plants in hot climate, and, to reduce leaching of soil due to excessive rain through water management. Moreover, PV coverage has shown a lower water evaporation, reducing the required water budget for irrigation by 20%. Similarly, by sharing water for irrigation with cleaning of PV panels, operational costs for the system could be reduced. From socioeconomic perspective, AV farming could make a significant improvement in the livelihood of farming communities and could accelerate solar energy investments to enable more sustainable economies.

Agrivoltaics is the co-developing of the same area of land for both solar PV power and agriculture. These systems leverage the colocation of energy and food production for mutual benefit. Crops are grown in the intermittent shade cast by the PV panels in agrivoltaic systems. The top three land covers associated with greatest solar PV power potential are croplands, grasslands and wetlands. Solar panels are most productive with plentiful insolation, light winds, moderate temperatures and low humidity. These are the same conditions that are best for agricultural crops, and vegetation has been shown to be most efficient at using available water under mesic conditions where atmospheric evaporative demand is balanced by precipitation supply. (Adeh, et al., 2019).

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The shade does not necessarily diminish agricultural yield. The reduction in yield due to shading varies per crop type due to crops having different radiation use efficiency. Researchers have successfully grown aloe vera (Ravi, 2016), tomatoes (Cossu, 2014), biogas maize (Amaducci, et al., 2018), pasture grass (Adeh, et al., 2018), and lettuce (Marrou, et al., 2013) in agrivoltaic experiments. When angled correctly, and when combined with shade tolerant crops, crops grown in agrivoltaic settings have been shown to provide similar yields to those grown in traditional agricultural settings, while simultaneously providing added revenue with the electricity being generated. (Dinesh & Pearce, 2016).

Advanced systems are able to determine the ideal tilt of the panels according to the sunshine and water requirements the crop, growth model of the crop, soil and weather conditions. This allows for additional shade, as and when required, such as during heatwaves or low rainfall periods.

### **3.5.2 Agrivoltaic Potential – Case Studies**

#### **3.5.2.1 Case study 1**

(Amaducci, et al., 2018) found that the shading under 4m high agrivoltaic systems in North Italy reduced radiation which affected mean soil temperature, and reduced evapotranspiration and associated water usage of maize, providing more favourable conditions for plant growth than in full light. The average grain yield was higher and more stable with varying rainfall under the agrivoltaic system than under full light. The maize yield under agrivoltaics increased proportionally with low water availability, which indicates that agrivoltaic systems could increase crop resilience to climate change.

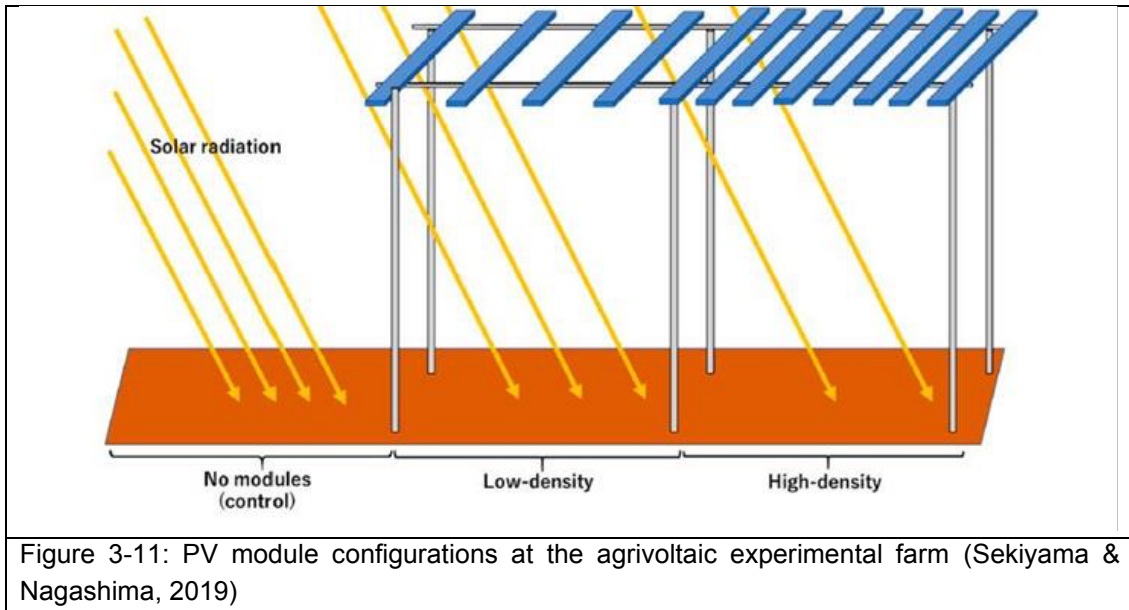
#### **3.5.2.2 Case study 2**

(Adeh, et al., 2018) describe a 6ha agrivoltaic solar farm and sheep pasture established at Oregon State University. The pasture was not irrigated, and experienced water stress. Areas under shade from PV solar panels maintained higher soil moisture throughout the period of observation. A significant increase in late season plant biomass was also observed under the PV panels (90% more biomass), and areas under PV panels were significantly more water efficient (328% more efficient), which suggests that plant growth may be sustained longer in the presence of PV panels in water-limited systems.

#### **3.5.2.3 Case study 3**

A Japanese study (Sekiyama & Nagashima, 2019) examined the yield, power output, and total revenue of an agrivoltaic system with maize, a shade intolerant crop. A 100m<sup>2</sup> area was divided into three sub-categories – no PV, low-density PV and high-density PV. In the high-density configuration, there were eight PV module arrays (48 modules) spaced at 0.71 m intervals. In the low-density configuration, there were four PV module arrays (24 modules) spaced at 1.67 m intervals. See Figure 3-11.

In each configuration, there were nine stalks per 1 m<sup>2</sup> spaced 0.5 m apart. The same soil, fertilizer, and water were used to grow all maize crops. The maize yield for each configuration is shown in Table 3-21. The low-density agrivoltaic system provided the highest yield (5% higher than the control).



**Table 3-21: Maize yields per square meter for different configurations (Sekiyama & Nagashima, 2019)**

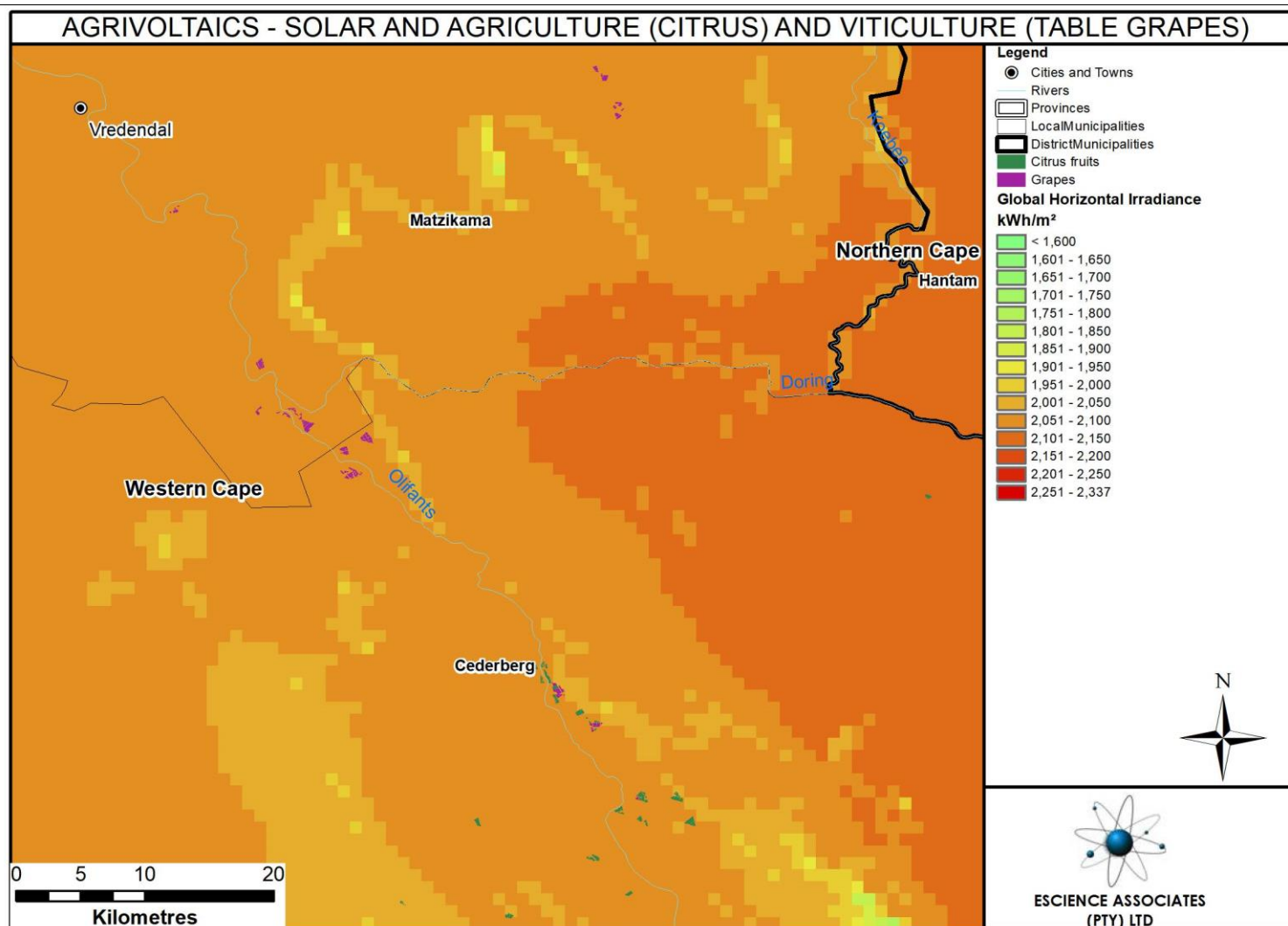
	Configurations		
	Control	Low-Density	High-Density
Maize yield (kg/m <sup>2</sup> )	3.35	3.54	3.23

### 3.5.3 Agrivoltaics Potential in the Western Cape

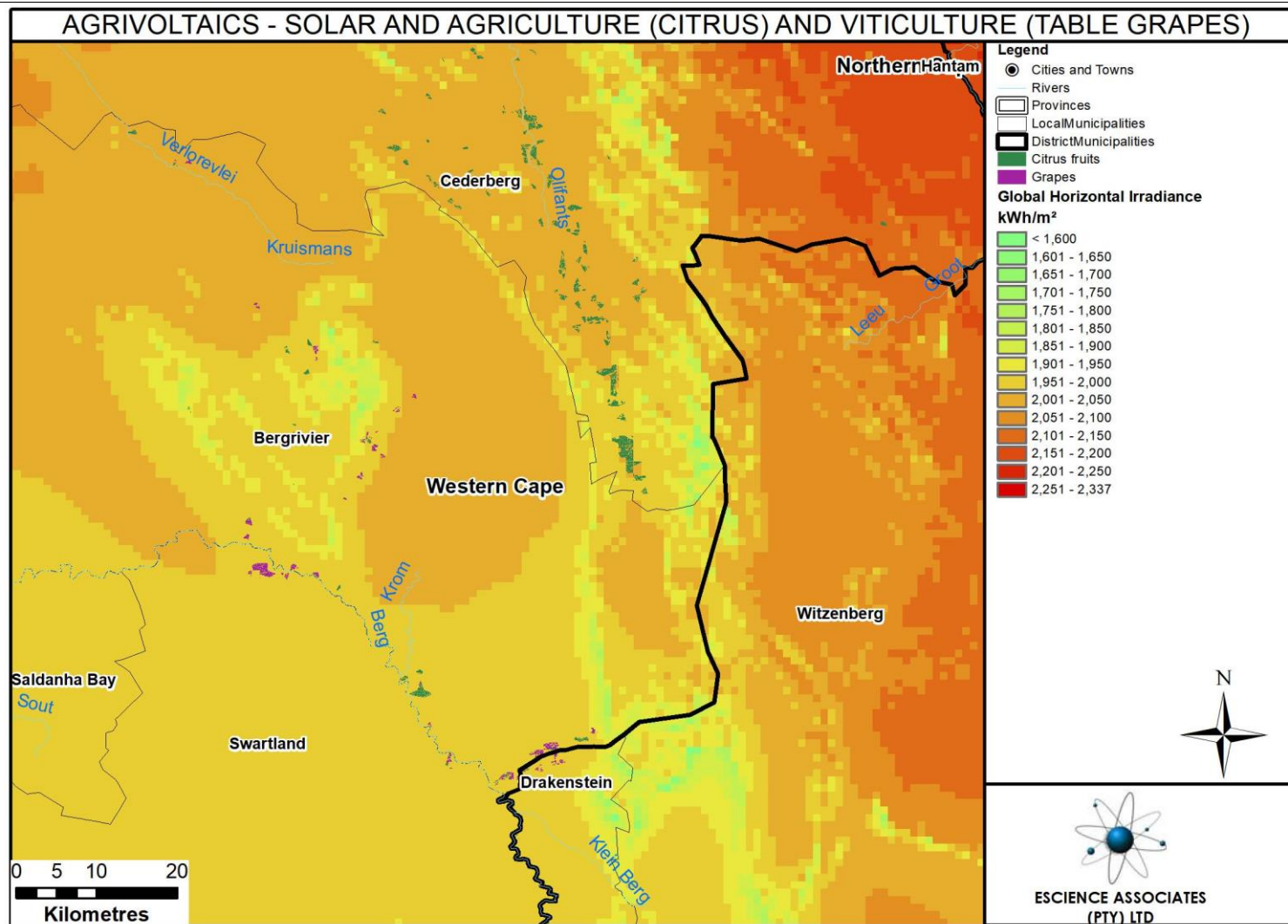
Figure 3-12 to Figure 3-14 show solar PV potential (GHI) and compatible land uses in the Breede and Olifants areas of the Western Cape. EScience undertook a modelling exercise to determine the potential for water saving and energy generation in the Western Cape by employing agrivoltaic systems on citrus and table grape cultivation areas. These areas were intersected with a 1 km proximity to the electrical grid. A system was designed with bifacial photovoltaic modules and a coverage density of 30% land area was assumed. Scenarios were run for a fixed tilt system and for a system employing single axis tracking. The following modelling assumptions were used:

- AgriPV PV support structure cost = Conventional PV cost + cost of agricultural structure (no increase in greenfield)
- AgriPV PV panels effectively shade netting as cover (shade net shading 30-50%)
- AgriPV PV panels have 30% coverage similar to conventional single axis tracking PV
- AgriPV PV panels use bifacial panels (panels for AgricPV taken as 14% higher CAPEX)
- AgriPV PV panels at 4 DegC lower temperature (increased electrical yield at lower Temp)
- AgriPV water saving is otherwise similar to netting.

A capacity factor of 22.5% was achieved for the fixed tilt system and a capacity factor of 29.8% achieved on the single axis tracking system. The LCOE achieved for the AgriPV system was 10% higher than a conventional PV system primarily driven by higher CAPEX. It should be noted that panel costs continue to fall due to technological improvements/learning rates and economies of scale in production of AgriPV components. The modelling indicated that the cost of water realised from AgriPV was similar to costs achieved for water reuse. The water savings and electricity generation potential results are presented in Table 3-22 to Table 3-25.

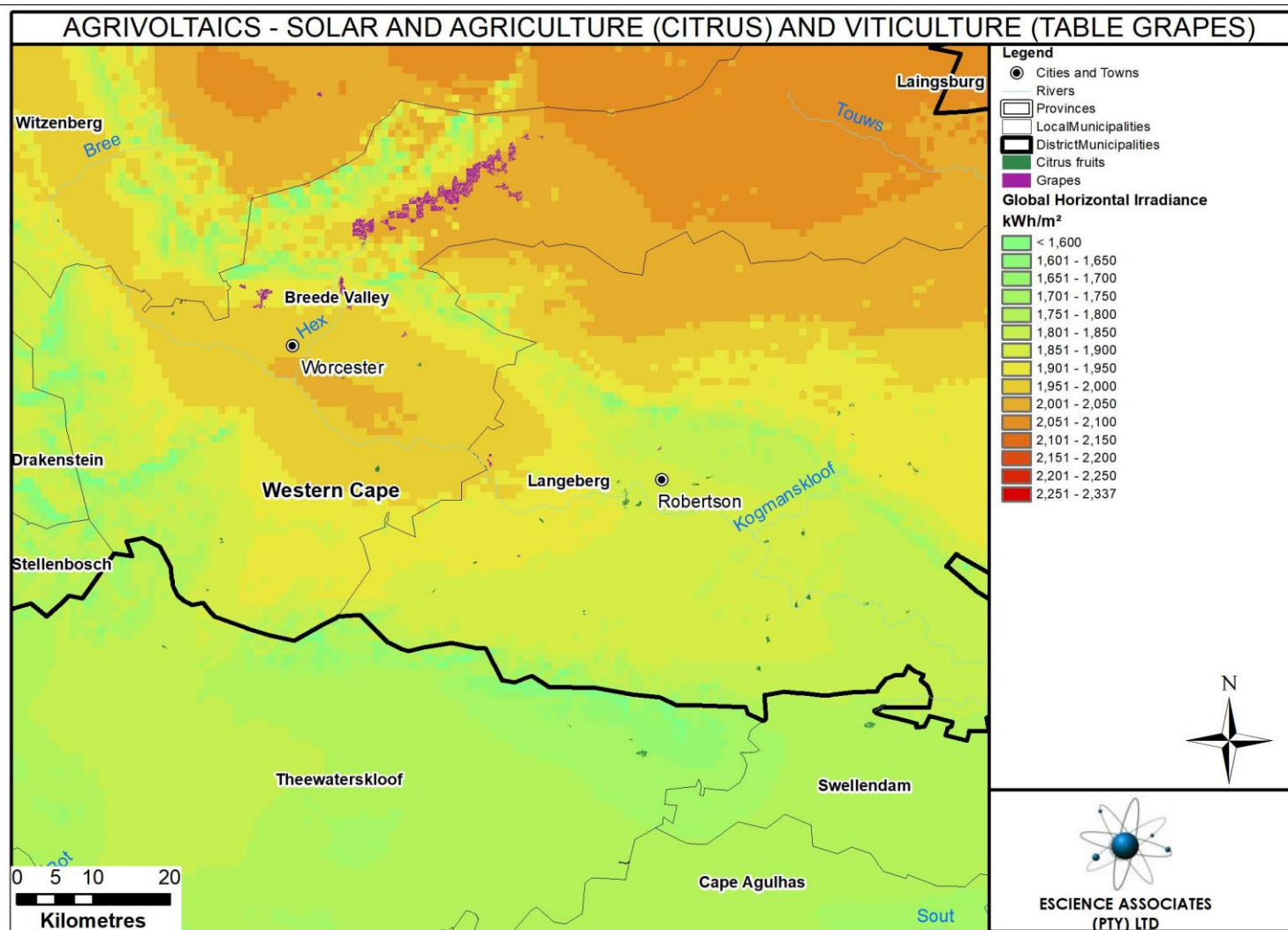


**Figure 3-12: Solar PV Potential (GHI) and compatible land uses (citrus and table grapes) – Olifants River**



**Figure 3-13: Solar PV Potential (GHI) and compatible land uses (citrus and table grapes) – Upper Olifants**





**Figure 3-14: Solar PV Potential (GHI) and compatible land uses (citrus and table grapes) – Breede**

**Table 3-22: Water Saving and Power Generation Potential - Table Grapes - Fixed Tilt Agrivoltaic System**

Table Grapes - Fixed Tilt Agrivoltaic System					
	Average GHI (kWh/m <sup>2</sup> )	Area (ha)	Water saving Potential (m <sup>3</sup> )	Energy Potential (GWh)	Power Generation Potential -Required Installed Capacity (GW)
<b>Provincial</b>					
Western Cape	1962	1379.3	3 273 048.7	27 060.0	13.729
<b>District Municipality</b>					
Cape Winelands	1942	535.1	1 269 793.7	10 392.5	5.273
West Coast	1977	844.2	2 003 255.1	16 689.1	8.467
<b>Local Municipality</b>					
Drakenstein	1942	535.1	1 269 793.7	10 392.5	5.273
Bergervier	1980	397.5	943 216.3	7 871.1	3.993
Swartland	1974	446.7	1 060 038.7	8 818.1	4.474
<b>WCWSS</b>					
Lower Berg	1980	819.6	1 944 875.4	16 225.5	8.232
Upper Berg	1940	559.7	1 328 173.4	10 857.6	5.509

**Table 3-23: Water Saving and Power Generation Potential - Table Grapes - Single Axis Tracking Agrivoltaic System**

Table Grapes - Single Axis Tracking Agrivoltaic System					
	Average GHI (kWh/m <sup>2</sup> )	Area (ha)	Water saving (m <sup>3</sup> )	Energy Potential (GWh)	Power Generation Potential -Required Installed Capacity (GW)
<b>Provincial</b>					
Western Cape	1962	1379.3	3 273 048.7	27 060.0	10.366
<b>District Municipality</b>					
Cape Winelands	1942	535.1	1 269 793.7	10 392.5	3.981
West Coast	1977	844.2	2 003 255.1	16 689.1	6.393
<b>Local Municipality</b>					
Drakenstein	1942	535.1	1 269 793.7	10 392.5	3.981
Bergervier	1980	397.5	943 216.3	7 871.1	3.015
Swartland	1974	446.7	1 060 038.7	8 818.1	3.378
<b>WCWSS</b>					
Lower Berg	1980	819.6	1 944 875.4	16 225.5	6.216
Upper Berg	1940	559.7	1 328 173.4	10 857.6	4.159



**Table 3-24: Water Saving and Power Generation Potential - Citrus - Fixed Tilt Agrivoltaic System**

Citrus - Fixed Tilt Agrivoltaic System					
	Average GHI (kWh/m <sup>2</sup> )	Area (ha)	Water saving (m3)	Energy Potential (GWh)	Power Generation Potential -Required Installed Capacity (GW)
<b>Provincial</b>					
Western Cape	1930	726.5	3 360 092.6	14 018.2	7.112
<b>Water Management Area</b>					
Berg-Olifants	1963	606.1	2 803 257.2	11 899.1	6.037
Breede-Gouritz	1758	120.4	556 835.4	2 116.3	1.074
<b>District Municipality</b>					
Cape Winelands	1937	199.7	923 741.8	3 869.6	1.963
West Coast	1978	406.4	1 879 515.4	8 037.3	4.078
Overberg	1758	120.4	556 835.4	2 116.3	1.074
<b>Local Municipality</b>					
Drakenstein	1945	160.2	740 976.1	3 115.4	1.581
Stellenbosch	1906	39.5	182 765.7	753.2	0.382
Bergrivier	1983	314.8	1 455 754.3	6 242.9	3.167
Swartland	1959	91.6	423 761.1	1 795.1	0.911
Swellendam	1792	56.3	260 455.3	1 009.4	0.512
Theewaterskloof	1727	64.1	296 380.1	1 106.5	0.561
<b>WCWSS</b>					
Cape Winelands	1913	18.9	87 578.8	362.2	0.184
Lower Berg	1981	400.1	1 850 597.4	7 928.4	4.023
Lower Riviersonderend	1749	111.6	515 934.0	1 951.3	0.990
Upper Berg	1932	187.0	865 081.1	3 614.4	1.834
Upper Riviersonderend	1838	8.8	40 901.4	162.5	0.082

**Table 3-25: Water Saving and Power Generation Potential - Citrus - Single Axis Tracking Agrivoltaic System**

Citrus - Single Axis Tracking Agrivoltaic System					
	Average GHI (kWh/m <sup>2</sup> )	Area (ha)	Water saving (m3)	Energy Potential (GWh)	Power Generation Potential -Required Installed Capacity (GW)
<b>Provincial</b>					
Western Cape	1930	726.5	3 360 092.6	14 018.2	5.370
<b>Water Management Area</b>					
Berg-Olifants	1963	606.1	2 803 257.2	11 899.1	4.558
Breede-Gouritz	1758	120.4	556 835.4	2 116.3	0.811
<b>District Municipality</b>					
Cape Winelands	1937	199.7	923 741.8	3 869.6	1.482
West Coast	1978	406.4	1 879 515.4	8 037.3	3.079
Overberg	1758	120.4	556 835.4	2 116.3	0.811
<b>Local Municipality</b>					
Drakenstein	1945	160.2	740 976.1	3 115.4	1.193
Stellenbosch	1906	39.5	182 765.7	753.2	0.289

Bergrivier	1983	314.8	1 455 754.3	6 242.9	2.391
Swartland	1959	91.6	423 761.1	1 795.1	0.688
Swellendam	1792	56.3	260 455.3	1 009.4	0.387
Theewaterskloof	1727	64.1	296 380.1	1 106.5	0.424
<b>WCWSS</b>					
Cape Winelands	1913	18.9	87 578.8	362.2	0.139
Lower Berg	1981	400.1	1 850 597.4	7 928.4	3.037
Lower Rivieronderend	1749	111.6	515 934.0	1 951.3	0.747
Upper Berg	1932	187.0	865 081.1	3 614.4	1.385
Upper Rivieronderend	1838	8.8	40 901.4	162.5	0.062

The tables above reflect a theoretical energy potential. If we assume that 25% of the power is evacuable then 5.2 GW is achievable with fixed tilt tracking and 3.9 GW with single axis tracking in the Western Cape.

### 3.5.4 Summary

Despite the promising results of trials and pilot AgriPV projects, the sheer capital cost associated with energy development demands prerequisites for funding that will require more than proof-of-concept, and that before significant uptake in the market, commercial demonstration projects of scale will be required. Unlike the use of netting to protect farming under cover which has already proven to be commercially viable in the production of a number of crops, we reasonably cannot expect agricultural fields be covered by solar canopies anytime soon without a concerted effort to establish commercial test utilities at scale and as integral to the production of specific crops.

In order to provide the necessary proof-of-concept before market entry, we need to compare further techno-economical applications of APV, demonstrate the transferability to other regional areas, and also realize larger systems.

The water savings and energy generation potential are however significant enough to warrant further exploration of the technology despite the 10% higher LCOE when compared with traditional PV systems.

## 3.6 PRECIPITATION AUGMENTATION

There have been two theories that have evolved concerning the potential to augment precipitation. One of the theories postulates that a natural cloud's efficiency in producing precipitation can be increased, while the second theory postulates cloud development can be enhanced by seeding, which leads to additional precipitation (Griffith, et al., 2016). The first theory has often been referred to as the static seeding hypothesis, while the second relies upon the dynamic effects of cloud growth. Both theories can occur in conjunction with each other, whereby a cloud's precipitation efficiency is increased, and the cloud is made to grow larger due to the seeding (Griffith, et al., 2016).

Cloud seeding has been used on both cold and warm clouds. Glaciogenic seeding is used in cold clouds to produce ice-phase precipitation, while hygroscopic seeding is used to promote coalescence of water droplets in warm clouds (World Meteorological Organization, 2010). Despite cloud seeding programmes being operated in more than 50 countries worldwide, the varieties of seeding materials being used, and the seeding methods being applied, the effect of cloud seeding in enhancing precipitation on the ground has until recently remained inconclusive (National Research Council, 2003) (Xue, et al., 2013) (French & Tessendorf, 2018). Until recently, scientific assessment invariably found that "cloud seeding probably have increased precipitation, but the increase could also be explained by natural variability in storm systems" (French & Tessendorf, 2018).

The difficulties in evaluating cloud-seeding effects are attributed to the following reasons: 1) the seeding signals are often very weak so that they are difficult to detect in natural precipitation with high variability; 2) the spatial and temporal scales of cloud-seeding effects may be different from those of seeding operations, especially in conjunction with significant dynamic effects; 3) the repeatability of real seeding activities under controlled environments is infeasible; and 4) the cost of programmes to evaluate the effects of cloud seeding is very high (e.g., randomized-seeding experiments) (Xue, et al., 2013).

However, recent advances in computer modelling tools and improved radar and airborne instrumentation have produced new insights confirming that glaciogenic seeding influences ice-phase precipitation. Unintended consequences of cloud seeding, such as changes in precipitation or other environmental impacts downwind of a target area, have not been clearly demonstrated, but neither can they be ruled out. In addition, cloud seeding materials may not be always successfully targeted and may cause their intended effects in an area different than the desired target area. This leads to the ethical concern that activities conducted for the benefit of some may have an undesirable impact on others. At times unintended effects may cross political boundaries. Weather modification programmes should be designed to minimize negative impacts. International cooperation may be needed in some regions.

### 3.6.1 Effects of Augmented Precipitation

The downwind effects experienced due to precipitation augmentation are caused by two mechanisms (1) the downwind transport of ice nuclei and ice crystals from the seeding source and (2) the invigoration of clouds by the release of latent heating or freezing and their subsequent propagation out of the target area (UCAR, 2019). A desktop review of augmented precipitation studies conducted by Long (2001) summarises previous studies findings as:

1. Downwind effects appear to increase precipitation in the area surrounding and downwind of the target location.
2. There is no substantial evidence that a decrease in precipitation occurs downwind from the target location.
3. Affected downwind distances vary from 80-300 km (as shown in Table 3-26).
4. The amount varies from 15 – 100%.

The studies researched by (Long, 2001) and the distance downwind effects were experienced are presented in Table 3-26. Table 3-27 shows the level of enhancement of precipitation augmentation was experienced downwind.

**Table 3-26: Case studies of the distance downwind the effects of precipitation augmentation are experienced (Long, 2001)**

Distance	Study Location	Reference
80 – 240 km	Colorado	Grant et al (1971)
80 – 250 km	Sierra Nevada, California	Warburton (1971)
100 – 250 km	Colorado	Brier et al (1973)
150 – 200 km	Santa Barbara, California	Elliot and Brown (1971)
150 – 250 km	Santa Barbara, California	Elliot et al (1976)
300 km	California	MacCracken and O’Laughlin (1996)

**Table 3-27: Case studies of the amount of enhancement was experienced downwind of precipitation augmentation (Long, 2001)**

Amount	Study Location	Reference
--------	----------------	-----------

10 – 20 %	Colorado	MacCracken and O’Laughlin (1996)
15 – 25 %	Sierra Nevada, California	Jannsen et al (1974)
50 – 100 %	Colorado	Elliot et al (1976)
100 %	Santa Barbara, California	Grant et al (1971)
200 %	Santa Barbara, California	Elliot and Brown (1971)

A study conducted in the Wasatch Plateau, Utah indicated that periods of cloud seeding produced about 20% more precipitation than periods of unseeding (Super & Heimbach, 2005). Furthermore the main findings of one investigation into randomized cloud seeding were (a) seeding increased snowfall in the intended target and sometimes downwind, when the ridge top (~2595m) temperature was less than -9° C; (b) the seeding increase was found for the entire 100 days which met this criterion over two seasons as well as when each season was analysed separately; (c) positive seeding effects were suggested in the target and in the valley downwind of the target, also mainly for the colder cases; (d) a seeding effect of about +15% was also found just a few kilometres from the seeding site, and (e) double ratios of target and control gage precipitation suggested seasonal increases of ~15% on seeded days, but increases as great as +50% were indicated when only the colder days were included in the analysis (Huggins, 2009)

### 3.6.2 Precipitation Enhancement through Glaciogenic Seeding

The World Meteorological Organisation (2010) states: “There is statistical evidence, supported by some observations, of precipitation enhancement from glaciogenic seeding of orographic supercooled liquid and mixed-phase clouds and of some clouds associated with frontal systems that contain supercooled liquid water”. There are two basic mechanisms that produce precipitation: collision coalescence and ice formation. Collision coalescence is defined as “The growth of raindrops by the collision and coalescence of cloud drops and or small precipitation particles” (Griffith, et al., 2016). Ice formation, also referred to as ice nucleation (as described in the Bergeron-Findeisen theory), consists of a process in which precipitation particles may form within a mixed cloud (clouds composed of both ice crystals and liquid water drops). In such clouds, the ice crystals will gain mass by sublimation (formation of a solid phase directly from a vapor phase) at the expense of the liquid drops surrounding the ice crystals. Upon attaining sufficient weight, the ice crystals (by this time they would be snowflakes) would fall to the ground as snow if the surface temperatures are at or below freezing or would melt and fall as raindrops if the surface temperatures are warmer than freezing. Of interest to this discussion is the fact that cloud droplets often exist in portions of clouds that are colder than freezing (Griffith, et al., 2016).

Clouds often have cloud droplets present at sub-freezing temperatures. These droplets are termed “super cooled” (North American Weather Modification Council, unknown) (Griffith, et al., 2016). The natural tendency is for these droplets to freeze, but to do so at temperatures warmer than -39° C they need to encounter an impurity (Griffith & Solak, 2006) (Griffith, et al., 2016).

Nucleation is the conversion of a supercooled water droplet into an ice crystal. The nucleating efficiency of these naturally occurring freezing nuclei increases with decreasing temperatures (Griffith & Solak, 2006). It is relatively rare that naturally occurring freezing nuclei are active in the temperature range of approximately -5 to -15° C (Griffith & Solak, 2006) (Griffith, et al., 2016).

Since a scarcity of natural ice nuclei commonly exists in the atmosphere at temperatures in the range of -5° to -15° C, the conversion of water droplets into ice crystals may be inefficient in many clouds. Silver iodide has been used as a glaciogenic agent for over half a century and despite its relatively high cost it remains a favourite cloud seeding agent (Griffith & Solak, 2006). The addition of silver iodide nuclei into these cloud can produce additional ice crystals, which, under the right conditions, grow through vapour deposition and possibly

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also aggregation to form snowflakes large enough to fall out of the cloud as either snow or rain and reach the ground (Griffith & Solak, 2006) (Griffith, et al., 2016). Rain is produced by the melting of such snowflakes when they fall through warmer air near the ground. The ice crystallisation temperature threshold for silver iodide is about  $-5^{\circ}\text{C}$ , which is significantly warmer than the threshold of most naturally occurring ice nuclei. Naturally occurring ice nuclei commonly have ice crystallisation temperature thresholds closer to  $-15^{\circ}\text{C}$ . Chemical formulations of silver iodide seeding agents can be modified further so that their resulting ice nuclei function at temperatures even warmer than  $-5^{\circ}\text{C}$  (Griffith & Solak, 2006).

Both orographic and convective clouds have been studied and research indicates that clouds whose tops are colder than  $-25^{\circ}\text{C}$  already have sufficiently large concentrations of natural ice crystals, such that seeding of these clouds will have little to no effect on precipitation. While there are no indications that there are warm temperature limits to seeding effectiveness (Griffith & Solak, 2006). Therefore, there appears to be an ideal “temperature window” of between  $-5$  and  $25^{\circ}\text{C}$  where clouds react favourably to the use of silver iodide seeding. Airborne cloud seeding, using frozen carbon dioxide (also known as dry ice), or with the venting of liquid propane can extend this temperature window to temperatures just between  $0$  and  $-2^{\circ}\text{C}$  (Griffith & Solak, 2006).

The dispersion of dry ice ( $\text{CO}_2$ ) pellets into the cloud with the use of an aircraft is a glaciogenic seeding technique that modifies the formation process of natural ice by rapidly transforming vapour and cloud droplets into ice (Griffith & Solak, 2006). The advantage of dry ice over silver iodide is that dry ice is a natural substance, however, the only effective delivery is using an aircraft which increases costs significantly.  $\text{CO}_2$  or dry ice is also difficult to store as sublimation (and therefore loss) is continuous. The use of dry ice is commonly used in conjunction with silver iodide seeding (Griffith & Solak, 2006).

An additional ground-based cloud seeding agent is liquid propane. Liquid propane produces almost the same number of ice crystals per gram as dry ice does, however its costs are lower due to not requiring an aircraft for release. Note, liquid propane cannot be dispensed from an aircraft as it is a flammable substance. Liquid propane can be dispensed from the ground if it is released in areas of elevation which are frequently within the supercooled clouds. The ground-based dispersion of liquid propane has been used by the United States Air Force for over thirty years to clear supercooled fog at military airports (Griffith & Solak, 2006).

Studies of orographic clouds within the mountainous western states of the United States of America have indicated that the preferred location for the formation of zones of supercooled liquid water (droplets in clouds that remain unfrozen at temperatures well below freezing) is over the windward slopes of the mountain barriers at relatively low elevations. Super (1990) reported that “there is remarkable similarity among research results from the various mountain ranges. In general, supercooled liquid water is available during at least portions of many storms. It is usually concentrated in the lower layers and especially in shallow clouds with warm tops”.

### **3.6.3 Glaciogenic Seeding of Orographic Precipitation**

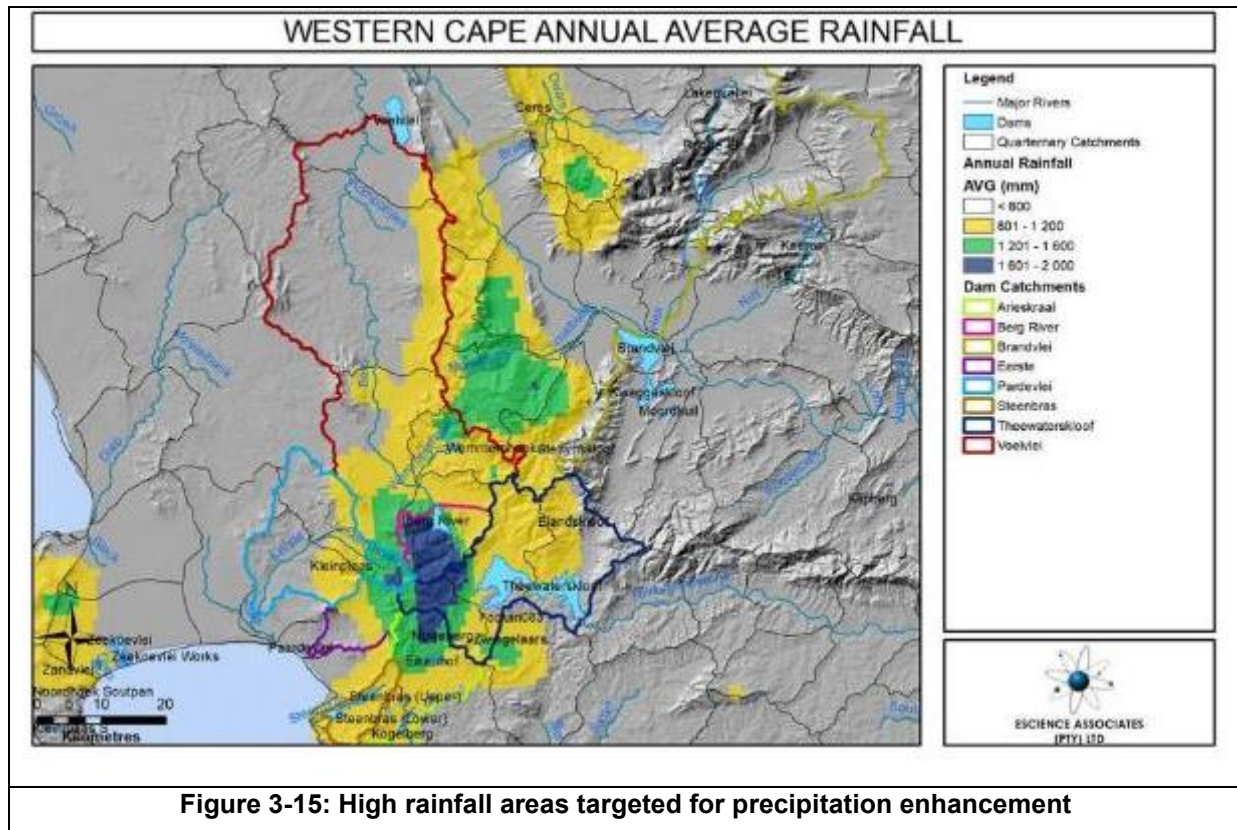
Precipitation augmentation of specific precipitation enhancement from glaciogenic seeding of orographic precipitation (typical of a significant portion of the Western Cape precipitation). The goal of this project is to enhance snowfall from winter storms through the application of wintertime cloud-seeding technology. Two technological approaches are proposed with respect to wintertime cloud seeding: (1) ground-based silver iodide (AgI) generators, and (2) airborne cloud seeding.

Technology (1) is considered essential to the project, whereas technology (2) is an option that can be employed to further extend the scope of seeding activities to several areas where ground-based silver iodide generators are not technically feasible or cost-effective. The hourly increases in the precipitation rate due to seeding, in the range of a few hundredths to greater than  $2\text{ mm per hour}$ , have been documented in historical research

results from ground-based cloud seeding projects (Desert Research Institute, 2016). Such values lead to estimates of approximately 10% overall water augmentation (Desert Research Institute, 2016).

As a conceptual intervention the alternative supply option assessment will investigate areas that:

1. Have rainfall in excess of 800mm average /annum (Figure 3-15 and Figure 3-16)
  - a. Drain into major water supply systems
  - b. Areas that provide to agriculture but not major water supply systems
2. Deviation from this was considered based on first order cost benefit analysis



The cost estimates that were estimated for a similar programme in Nevada (Desert Research Institute, 2014) are as follows:

**Table 3-28: Cost estimates – ground-based cloud seeding generators (Desert Research Institute, 2014)**

Option 1: Use of silver iodide solution with ground-based cloud seeding generators			
	Rate	Hours	Amount
Labor			
Programme Director	\$181.68	1320	\$239,818
Project Meteorologist	\$107.00	1520	\$162,640
Instrument Field Tech 1	\$109.41	1760	\$192,562
Instrument Field Tech 2	\$79.70	1760	\$140,272
Graduate Student	\$45.86	1200	\$55,032
Subtotal Labor			\$790,323
Operating	Rate	Units	Amount
Cloud seeding solution (100 gallons)	\$5,800	28	\$162,400

Propane and nitrogen	\$600	28	\$16,800
Supplies			\$5,000
Generator replacement parts	\$1,000	14	\$14,000
Data/communications lines (monthly rate)	\$150	12	\$1,800
Vehicle usage (4x4 truck) (daily rate)	\$112	45	\$5,040
Snowmobile usage (2)	\$60	16	\$960
Subtotal Operating			\$206,000
Total Project Costs			\$996,323

**Table 3-29: Cost estimates – using aircraft for cloud seeding (Desert Research Institute, 2014)**

Option 2: Use of Aircraft for cloud seeding for the Walker/Carson (aircraft only)			
	Rate	Hours	Amount
Labor			
Programme Director	\$181.68	80	\$14,534
Project Meteorologist	\$107.00	80	\$8,560
Instrument Field Tech 1	\$109.41		\$0
Instrument Field Tech 2	\$79.70		\$0
Graduate Student	\$45.86		\$0
Subtotal Labor			\$23,094
Operating			
Subcontract to Weather Modification Inc.			\$85,000
Subtotal Operating			\$85,000
Total Project Costs			\$108,094

A study by Griffith and Solak (2006) on the impact of new seeding programmes in the lower Colorado River Basin of Arizona found that “the approximate cost of the estimated additional water which could be produced through cloud seeding is estimated to average \$5.00/acre foot” of annual runoff generated. Furthermore, the benefit of conducting cloud seeding programmes are that they can be implemented and, if need be, terminated comparatively quickly as they do not generally involve the development of large permanent infrastructure. Additionally, these programmes can be suspended during periods of high rainfall and restarted when appropriate (Griffith & Solak, 2006).

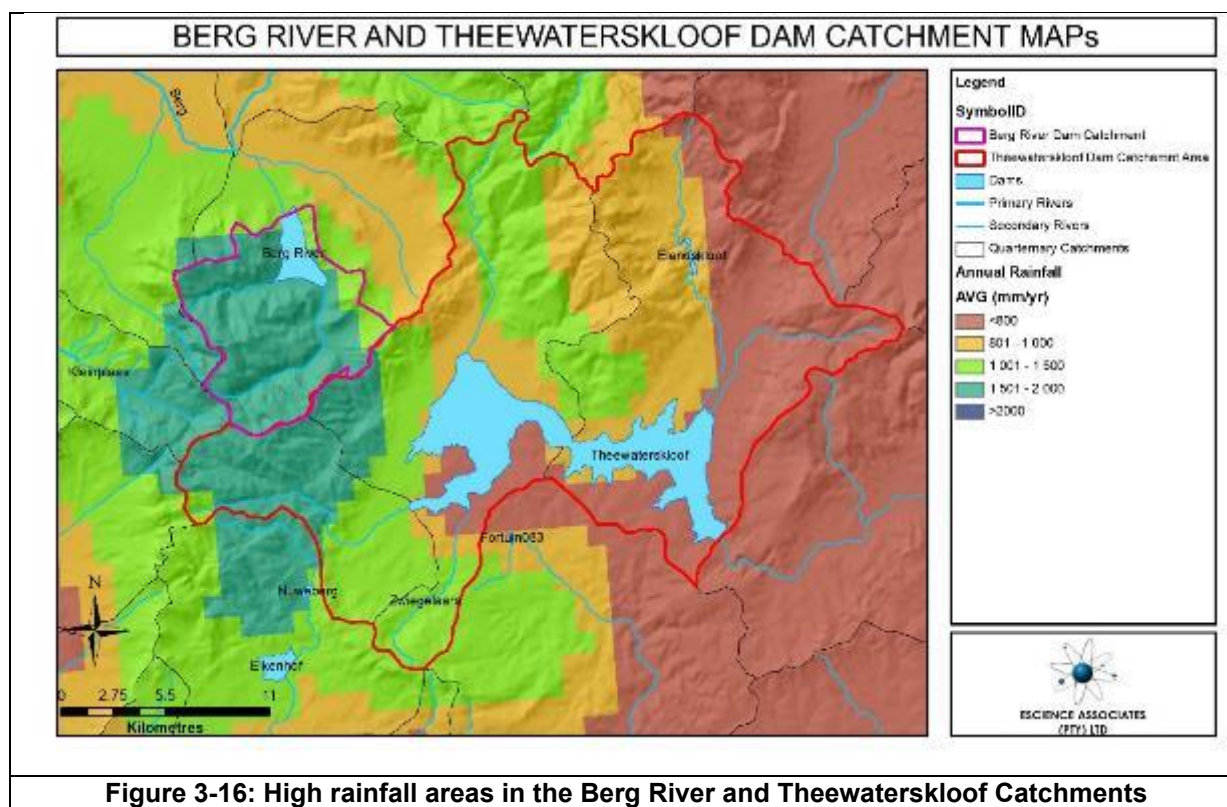
The use of certain cloud seeding programmes have advantages and disadvantages over other programmes, and these need to be taken into account when deciding on an appropriate cloud seeding programme. Ground-based cloud seeding can be manually operated by local residents or remotely operated from higher elevations at unmanned locations. Furthermore, silver iodide can be released from aircrafts using either liquid fuelled generators or pyrotechnics. However, in general, remotely controlled ground equipment or aircraft seeding may be more effective in some situations than lower elevation ground generators but they will be more costly (Griffith & Solak, 2006).

The Bureau of Reclamation, in the US, states that of all the options that have been considered to provide additional water supplies in the Colorado River Basin “precipitation management appears to be one of the most cost effective and economical means of providing additional fresh water supplies” (Griffith & Solak, 2006). Whilst the World Meteorological Organization’s policy statement indicates that “glaciogenic seeding of clouds formed by air flowing over mountains offers the best prospects from increasing precipitation in an economically-viable manner” (Huggins, 2009).



### 3.6.4 Hydrological Modelling of Precipitation Augmentation

As an initial attempt to quantify the potential benefits from precipitation augmentation in terms of overall WCWSS yield gains, a modelling simulation has been done for the high rainfall areas that supply the WCWSS's major reservoirs, i.e., the Berg River and Theewaterskloof Dams. The assumption of expected increases in monthly rainfall patterns was formulated and applied into a scenario using the WRSM2000 and the WRYM model. Figure 3-16 indicates the location of the high rainfall areas in the Berg River and Theewaterskloof Dam catchment areas. Due to the complexity of updating hydrological data in the WRYM, the integrated WRYM configuration for the entire WCWSS was not used to determine the effect of rainfall augmentation. A separate model was developed using simulated natural runoff generated during this analysis and the infrastructure configuration data as provided in the integrated WCWSS WRYM configuration. Comparisons were done on the natural runoff and yields between the two versions of the WRYM and differences explained.



The following steps were taken during this analysis:

- The WRSM2000 rainfall-runoff model setups for the 2007 DWS study on *The Assessment of Water Availability in the Berg Catchment by means of Water Resource Related Models* (WAAS Study) were sourced from Aurecon. The simulation period for this model configuration was for the period 1927 to 2004. The hydrological data from this study is still today the basis of all WRYM and WRPM model planning analyses for the WCWSS., including the Annual Operating Rule Analysis.
- A natural runoff simulation was done for the dam catchment areas using the WAAS Study WRSM2000 model configurations, using the calibration parameters obtained against streamflow gauging stations during the initial study. The resulting simulated natural runoff from this assessment was then compared to the naturalised runoff generated during the WAAS study in terms of Mean Annual Runoff (MAR).
- A WRYM model configuration was developed for the two dams using the simulated natural runoff from this analysis and the infrastructure configuration as defined in a recent WCWSS WRYM Model configuration.



- The WRYM was then used to determine the historical firm yield from each reservoir, as well as risk based stochastic assured yields.
- This process was repeated for a base and an adjusted scenario by first modifying the historical 1927 to 2004 rainfall records and subsequently simulating new natural runoff, incorporating the new natural runoff sequences into the WRYM and calculating yields.

During the analysis, the following scenarios were developed for this modelling analysis:

- Base Scenario: Simulated Present Day (2004) upstream development hydrology and yields for each dam to compare with original WAAS study results and used as the base for other Scenarios.
- Scenario 1: Simulated Present Day (2004) upstream development hydrology and yields where the historical monthly rainfall for May to September was increased by 10% for the whole simulation period.

#### Hydrological data

Table 3-30 provides a summary of the hydrological characteristics of the Berg River and Theewaterskloof Dams catchments, as well as the resulting Natural MAR.

**Table 3-30: Summary of the climatic and MAR for the Berg River Catchment for 2 Scenarios.**

<b>Berg River Dam</b>	<b>Reference*</b>	<b>Baseline</b>	<b>Scenario 1</b>
Area (km <sup>2</sup> )		68.9	68.9
MAP (mm/a)		2576	2748
Natural MAR (mm/a)		2067	2203
% NMAR/MAP		80%	80%
Natural MAR (10 <sup>6</sup> m <sup>3</sup> /a)	143.1	142.4	151.8
Forestry Reduction (10 <sup>6</sup> m <sup>3</sup> /a)		1.6	1.6
Net MAR (10 <sup>6</sup> m <sup>3</sup> /a)		<b>140.8</b>	<b>150.1</b>
<b>Theewaterskloof Dam</b>	<b>Reference*</b>	<b>Baseline</b>	<b>Scenario 1</b>
Area (km <sup>2</sup> )		441.2	441.2
MAP (mm/a)		1238	1292
Natural MAR (mm/a)		702	751
% NMAR/MAP		57%	58%
Natural MAR (10 <sup>6</sup> m <sup>3</sup> /a)	317.1	309.9	331.5
Forestry Reduction (10 <sup>6</sup> m <sup>3</sup> /a)		1.72	1.75
Net MAR (10 <sup>6</sup> m <sup>3</sup> /a)		<b>308.1</b>	<b>329.8</b>

\* - Values were obtained from a recent WRYM configuration for the WCWSS

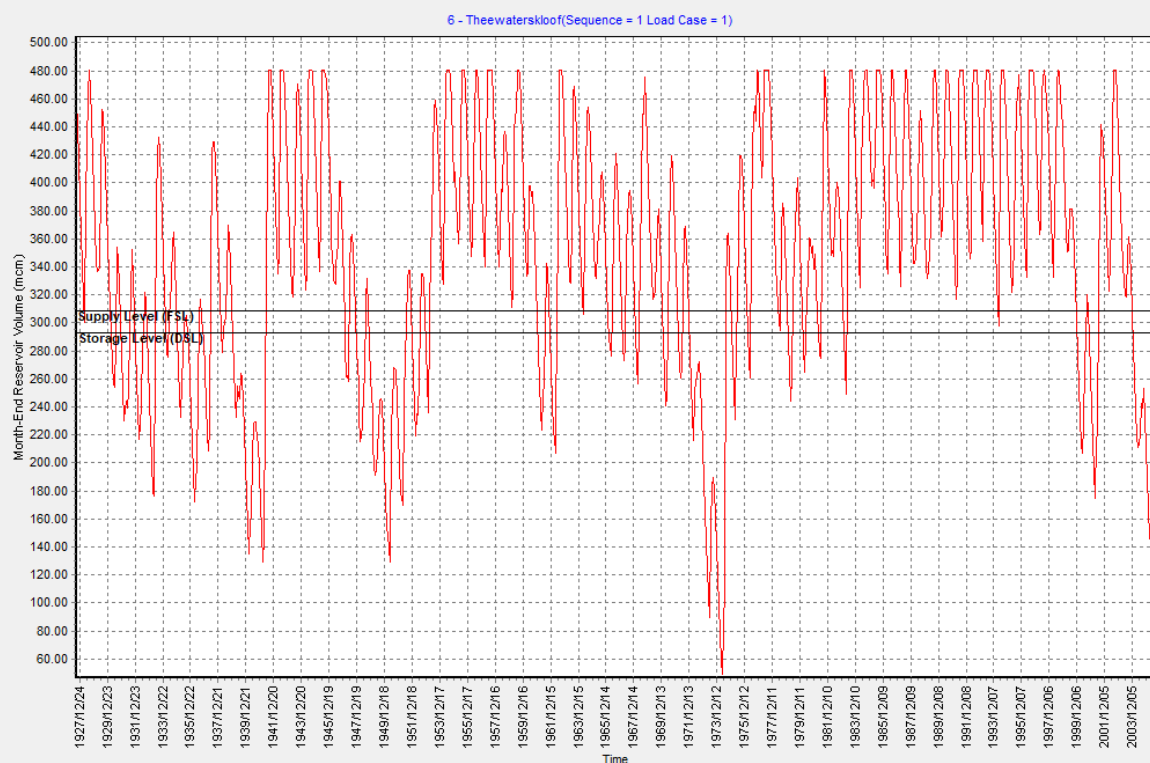
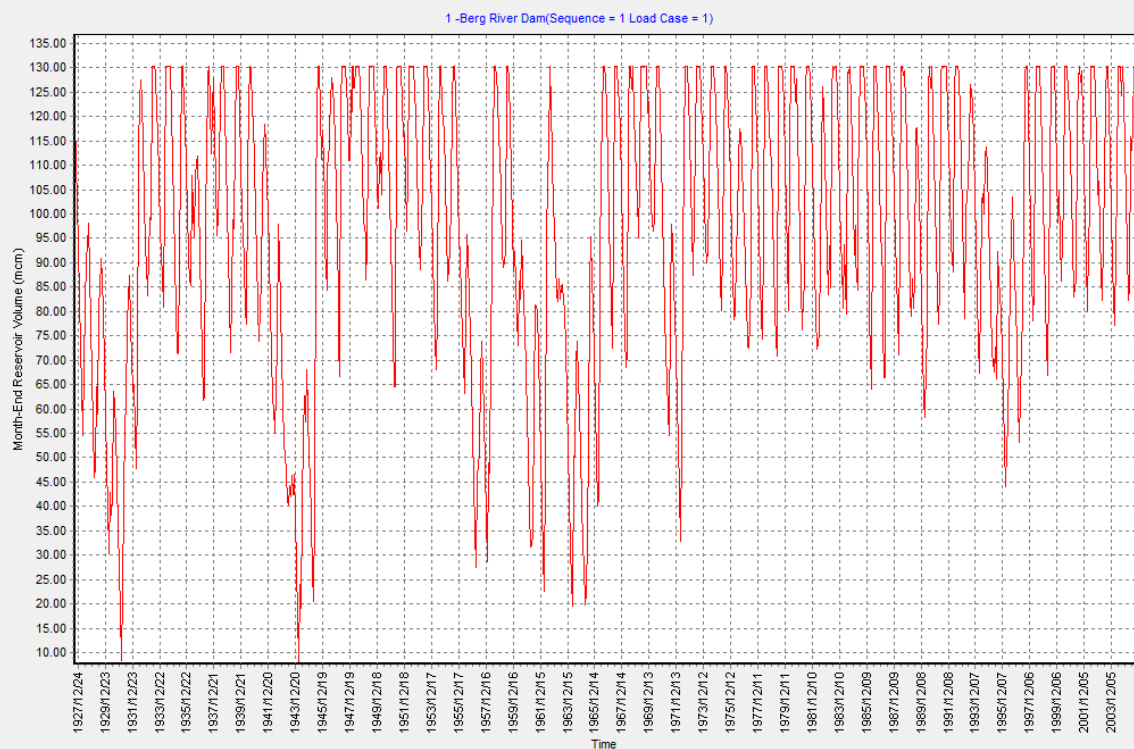
The differences between the WCWSS natural runoff and the runoff used in this analysis are due to the different methods that were used to generate the data with. The hydrology of the WCWSS was generated through a process called naturalisation where observed streamflow data was manipulated and extended to result in a natural timeseries, while this analysis made use of pure natural simulated timeseries. This was due to the time-consuming nature of the naturalisation process that is not conducive for a scoping scenario analysis.

The Berg River Catchment is one of the wettest catchments in South Africa and as can be seen from Table 3-30, the catchment has a very high unit runoff. Not only is the MAP above 2500 mm/a, but the amount of rainfall that is effectively converted to runoff is nearly 80%, which is extremely high compared to the rest of the Berg River catchments that range between 1 and 57%. Scenario 1 produces an average of 9.3 million m<sup>3</sup> per annum (6.6%) more net runoff over the period 1927 – 2004 (78-year monthly simulation).

#### Yield Analysis

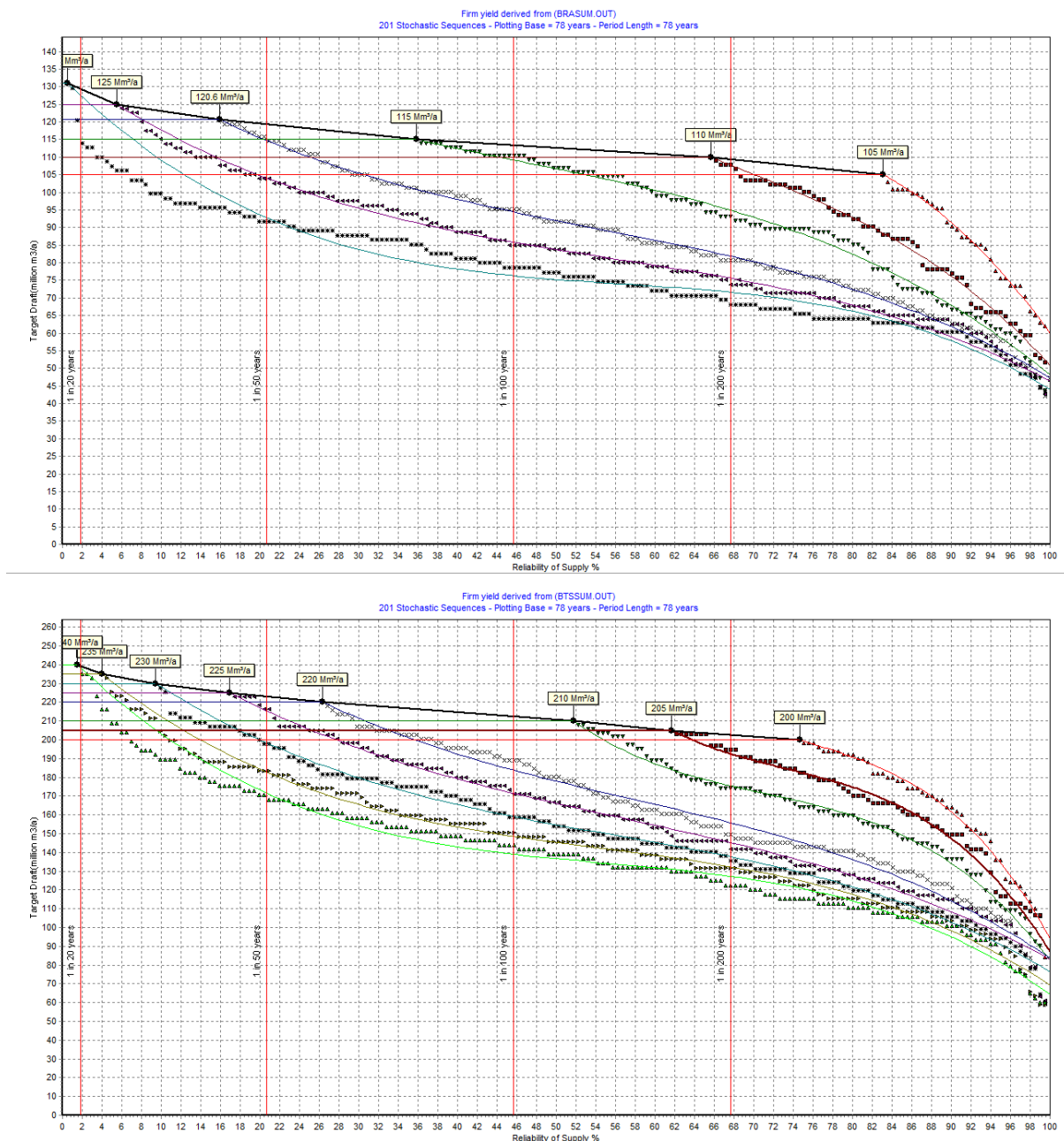
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The WRYM model was configured for the two scenarios. Figure 3-17 shows the Scenario 1 simulated reservoir levels over the 1927-2004 period if the historic firm yield would have been constantly abstracted over the entire simulation period. From Figure 3-17, the Berg River Dam's critical period is seen as between 1927 and 1931, and 1961 to 1976 for Theewaterskloof Dam. However, there seems to be a disjunct between the hydrological regime of the simulation between the periods 1927 to 1972, and 1972 to 2004. Limited and bad quality rainfall data is most probably to be blamed for this. Addressing this issue does not fall within the scope of this assignment.



**Figure 3-17: Simulated Berg River (top) and Theewaterskloof Dam (bottom) volumes from 1927 -2004 if the historical firm yield of the dam is constantly and abstracted**

Figure 3-18 provides Scenario 1 stochastic yield reliability curves for the Berg River and the Theewaterskloof Dams, for different target drafts and assurance bands.



**Figure 3-18: Scenario 1 stochastic yield reliability curves for the Berg River (top) and the Theewaterskloof Dams (bottom)**

Table 3-31 provides a summary of the yield comparisons between the Base and Scenario 1 for the Berg River Dam.

**Table 3-31: Base and Scenario 1 yields for the Berg River and Theewaterskloof Dams**

Type of Yield	Yield (10 <sup>6</sup> m <sup>3</sup> /a)			Diff (10 <sup>6</sup> m <sup>3</sup> /a)	% of Baseline
	Reference*	Baseline	Scenario 1		
Berg River Dam					
Historical Firm Yield (78 years)	105	120.2	125	4.8	104%
1:20 Assured yield		129.5	135.2	5.7	104%
1:50 Assured yield		119.7	124.3	4.6	104%
1:100 Assured yield		112.1	116.4	4.3	104%
1:200 Assured yield		106.7	110.5	3.8	104%
Theewaterskloof Dam					
Historical Firm Yield (78 years)	234	203.5	220.8	17.3	109%
1:20 Assured yield		221.2	238	16.8	108%
1:50 Assured yield		206.4	222.9	16.5	108%
1:100 Assured yield		196.5	212.2	15.7	108%
1:200 Assured yield		187.5	202.7	15.2	108%

\* - From report *Pre-Feasibility and feasibility studies for augmentation of the Western Cape Water Supply System by means of further surface water developments – Report 3 – Volume 1: Berg River-Voëlvlei Augmentation Scheme* by Department of Water Affairs December 2012.

There are significant differences between the historical firm yields from this analysis and the WCWSS analysis for both the Berg and the Theewaterskloof Dams. For the Berg River Dam, no upstream diversions were configured in this analysis as in the current WCWSS WRYM configuration, and for the Theewaterskloof Dam the upstream network for this analysis was changed so that the irrigators at Vyeboom did not have access to the spills from Elandskloof Dam and farm dams, as in the WCWSS WRYM configuration.

Urban water requirements are usually supplied at 1:50 (98%) assurance of supply, while irrigation is supplied at 1:20 (95%) assurance of supply. From Table 3-31 for Scenario 1 a gain of 4.6 million m<sup>3</sup> per annum is seen on average for a 1:50 assured supply, and 16.5 million m<sup>3</sup>/a for Theewaterskloof Dam for the same assurance. The analysis therefore showed that if a 10% improvement in the wet winter months is achieved, a 6.5% increase in 1:50 assured yield can be achieved between the two dams. For Scenario 1, the whole catchment area for Theewaterskloof Dam was included for rainfall augmentation, only the high runoff generating pristine mountainous catchments. Care was taken to avoid all areas with irrigation or areas with large amounts of downstream irrigation. In past experiments, farmers often blamed the rainfall augmentation activities for perceived increases in hail. Avoiding agricultural areas would attempt to avoid this situation.

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### 3.7 ALIEN INVASIVE PLANT REMOVAL

Invasive Alien Plants (IAPs) are widely considered to be a major threat to biodiversity, human livelihoods and economic development. IAPs cost South Africans tens of billions of rand annually in lost agricultural productivity and resources spent on management. Many IAPs are products of unwise and unintentional plant introductions, but if new invasions are discovered before they are well established, eradication is possible and management costs can be reduced. The economic benefits of clearing areas with high tourism, biodiversity, productivity, or water yield potential, are necessary to maintain the support for the continuation of the clearing project. In other words, the benefits of clearing, other than merely the cost, must be carefully considered.

Concerns about the impacts of alien plant invasions on streamflows were a key factor in the establishment of the Working for Water programme in October 1995, and in sustaining the programme since then (Le Maitre, et al., 2019). The streamflow reduction models used to estimate the flow reductions were based on long-term studies of the impacts of plantations on streamflows in catchments spread across South Africa, compared with natural vegetation, particularly fynbos. The invasions often involved the same or ecologically similar tree species as those in the plantation studies, strengthening the argument that the reductions caused by invasions could match those observed in plantation studies (Le Maitre, 2004). Ongoing research into water use by individual plants, and stands of invasives, has confirmed the original findings, and shown that invasions can have substantial impacts on streamflows (Le Maitre, et al., 2019).

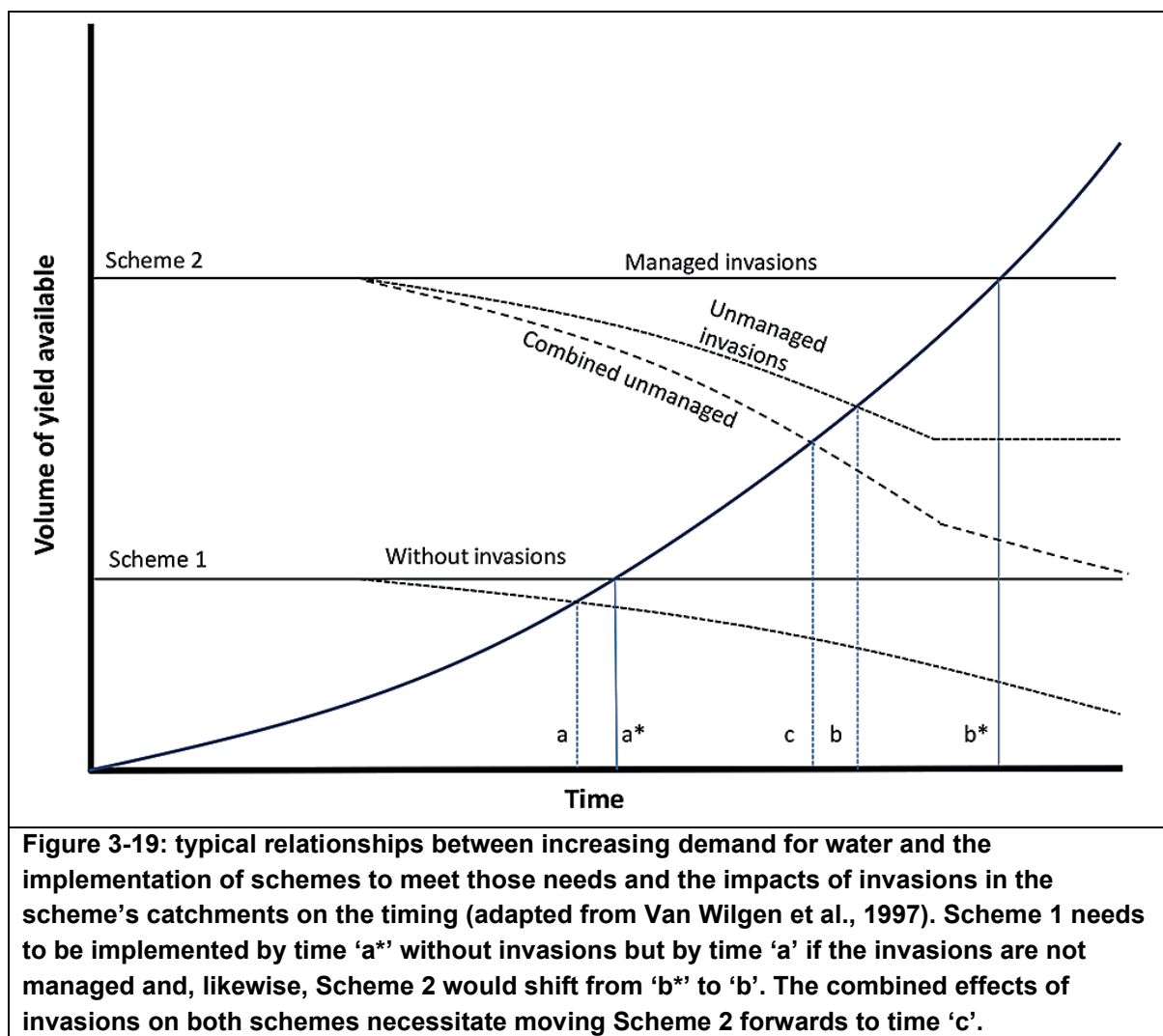
However, there is still an ongoing debate about the impacts of flow reductions on the yields from large water supply schemes (WSS). Yet, there is every indication that the reductions in flows will result in reductions in yields, for a given level of assurance of supply, even when the storage dams in the WSS are large relative to the mean annual runoff (Le Maitre & Gorgens, 2001); (Cullis, et al., 2007). These findings have not convinced some, who argue that it is more cost-effective to build additional storage or transfer schemes to supply additional water than to clear invasions. While WSS infrastructure is necessary, and WSS capacity does need augmenting to meet increases in demand (Muller et al., 2015), investments in additional infrastructure can be unwise if the reductions more than offset the gains provided by the infrastructure, or if alternative water resources are considerably more expensive to develop or inherently more costly, such as desalinisation. One way of comparing such investments is the unit reference value which calculates the net present value of the costs of different investments (e.g., in infrastructure) over the projected life-span of the infrastructure, and relates it to the volume of water yielded to derive a cost per m<sup>3</sup> of water (van Niekerk & du Plessis, 2013).

Although the unit reference value (URV) is a useful way of comparing investments in water supply infrastructure in relation to their yields, the way it is used in practice treats the decreased yields from the one option as being replaceable with yields from other options. A study presented a simple model to illustrate how the impacts of unmanaged invasions on water yields would affect water yields over time (van Wilgen, et al., 1997). This model was very similar to the one in Figure 3-19, and showed how the timing of the development of two water supply schemes was affected by invasions. The authors also showed that differing initial stages of invasion and differing proportions of non-invadable areas would affect the outcomes (van Wilgen, et al., 1997), illustrated here by the different rates of reduction of flows from the catchments in the two schemes and stabilisation of the reductions from Scheme 2. With invasions, Scheme 1 would have to be operational by year 'a' to meet the rising demand but with clearing could be postponed to year 'a\*'.

Likewise Scheme 2 could be delayed from 'b' to 'b\*'. However, their model failed to take into account the fact that without clearing, the ongoing decline in the yields from the original sources combined with the declining yield from Scheme 2, would require Scheme 2 to be operational by time 'c' and would also bring forward any future schemes. The WCWSS borders on the coast so desalination could be an option for meeting rising demand, but, if there really were no more land-based options for increasing yields, the only choice would be to clear the invasions. However, by the time that time 'c' arrives, the costs of clearing the invasions would also have increased significantly, a factor which also needs to be taken into consideration. The standard discounting

model used in estimating the net present values for the URV would discount those future costs, essentially assuming that some innovative technologies would drastically lower the clearing costs by time 'c', but this is highly unlikely to be the case. If anything, the costs are likely to be significantly higher because the currently lightly invaded rugged mountain areas, which comprise much of the WCWSS's catchments, would have become more densely invaded.

Clearing these areas is very expensive as it requires fit, able, and skilled people, and expensive safety equipment, as well as the costs incurred in supporting workers camping out for a week at a time where daily access is not efficient. The rate at which invaders are cleared is also low because the people have to use ropes for safety and moving between plants and safely securing themselves is very time consuming. In other words, if there is a finite yield of water from the current WSS, and this will be significantly reduced by allowing alien plants to invade the catchments, then clearing now would be the best option for securing overall yields in the long-term, even if the unit reference values are higher. Thus, clearing invasions now represents a much wiser investment of resources than deferring clearing. If this is so, then it provides a sound rationale for ensuring that a portion of the revenue realised from supplying water to users is dedicated to clearing the catchment and ensuring that invasions are cleared as rapidly as possible to as low a density as possible, and the catchment maintained in that state.



A key motivation for managing invasive alien plant (IAP) species is their impacts on streamflows, which, for the wetter half of South Africa, are about 970 m<sup>3</sup>/ha/annum or 1 444 million. m<sup>3</sup>/annum (2.9% of naturalised mean annual runoff), comparable to forest plantations. However, the implications of these reductions for the

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reliability of yields from large water supply systems are less well known. The impacts on yields from the WCWSS were modelled by (Le Maitre, et al., 2019) under three invasion scenarios: 'Baseline' invasions; increased invasions by 2045 under 'No management'; and under 'Effective control' (i.e., minimal invasions). Monthly streamflow reductions (SFRs) by invasions were simulated using the Pitman rainfall–runoff catchment model, with taxon-specific mean annual and low-flow SFR factors for dryland (upland) invasions and crop factors for riparian invasions.

These streamflow reduction sequences were input into the WCWSS yield model and the model was run in stochastic mode for the three scenarios. The 98% assured total system yields were predicted to be  $\pm 580$  million  $\text{m}^3/\text{annum}$  under 'Effective control', compared with  $\pm 542$  million  $\text{m}^3/\text{annum}$  under 'Baseline' invasions and  $\pm 450$  million  $\text{m}^3/\text{annum}$  in 45 years' time with 'No management'. The 'Baseline' invasions already reduce the yield by 38 million  $\text{m}^3/\text{annum}$  (two thirds of the capacity of the Wemmershoek Dam) and, in 45 years' time with no clearing, the reductions would increase to 130 million  $\text{m}^3/\text{annum}$  (capacity of the Berg River Dam). Therefore IAP-related SFRs can have significant impacts on the yields of large, complex water supply systems. A key reason for this substantial impact on yields is that all the catchments in the WCWSS are invaded, and the invasions are increasing. Invasions also will cost more to clear in the future. So, the best option for all the water-users in the WCWSS is a combined effort to clear the catchments and protect their least expensive source of water.

### 3.7.1 Areas invaded

*The DEA commissioned an investigation into the impacts of IAPs on simulated reservoir yields/ system yields and their related assurances in the WCWSS by means of the latest WRYM configuration during 2014. (DEA, 2015). The analysis involved the following steps:*

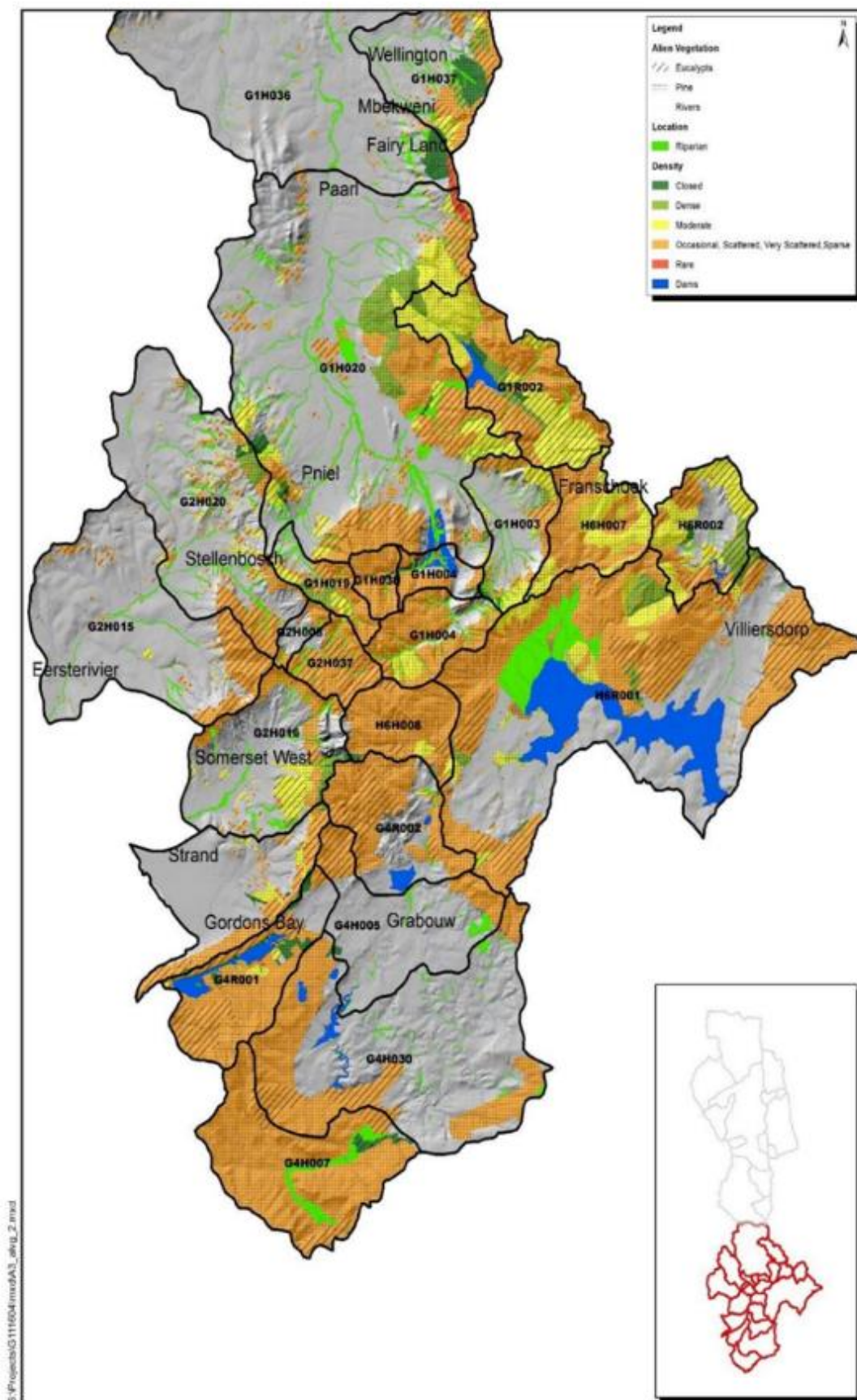
- updating the present-day IAP maps/coverages,
- defining areas considered as upland, riparian or having shallow groundwater access,
- defining IAP invasion scenarios,
- running the Pitman (WRSM2000) catchment model to determine long-term SFRs for the updated invaded areas,
- running the WCWSS WRYM system yield model for the different invasion scenarios, and
- generating system yield-assurance outputs for the different invasion scenarios.

The 2008 IAP infestation coverage used during the DWS's Water Availability Assessment Study for the WCWSS, were used as the baseline to which several improvements were done. Improvements included correction to species for certain areas, consideration of clearing activities, correcting plantations indicated as IAPs, and several other updates using Google Earth. The most important value addition to the original baseline infestation coverage was the sub-division of IAP areas that falls within upland, riparian and shallow groundwater zones. For each of the zones, factors for MAR and low flow reduction for different species were assumed based on previous research. Figure 3-20 and Figure 3-21 provide the resulting coverage of IAPs in the WCWSS. The total condensed areas per species of IAPs for the WCWSS is summarised in Table 3-32 as for the baseline scenario (2008).



**Table 3-32: Condensed areas of IAPs in the WCWSS**

Species	Condensed area (ha)			
	Upland	Groundwater	Riparian	Total per Species
Black Wattle	0	0	1182	1182
Eucalypts	8108	447	569	9124
Longleaf Wattle	0	0	110	110
Pine	11008	438	95	11540
Poplar	0	0	125	125
Port Jackson	0	0	99	99
Hakea	0	0	2	2
Rubus spp	0	0	8	8
Total per zone	19116	885	2190	22191



**Figure 3-20: IAPs mapped in the southern reaches of the Western Cape Water Supply System.**

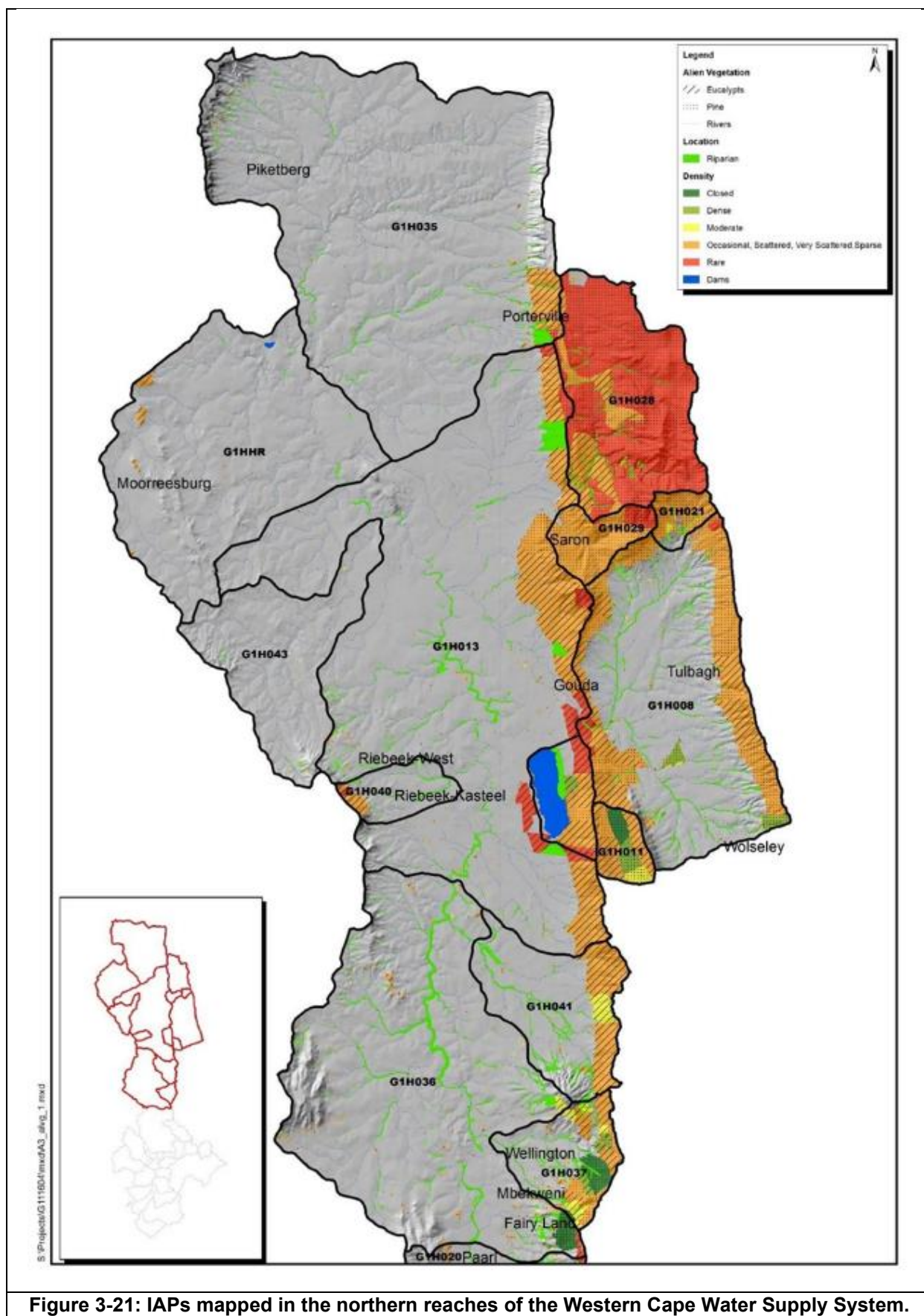


Figure 3-21: IAPs mapped in the northern reaches of the Western Cape Water Supply System.

### 3.7.2 Hydrological modelling of alien invasive plant removal

The total streamflow reduction caused by IAPs were simulated using the WRSM2000 model and is summarised in Table 3-33.

**Table 3-33: Streamflow reduction due to IAP in the WCWSS for baseline (2008) conditions.**

Area	Upland and Groundwater	Riparian	Total
	Reduced runoff ( $10^6\text{m}^3$ per annum)		
Berg River	36.5	4.78	41.28
Winelands/Eerste River/Palmiet	9.6	0.67	10.27
Breede River	24.9	0.05	24.95
Total	71	5.5	76.5

The detailed streamflow reduction activities were incorporated into the WRYM for the WCWSS for 3 scenarios.

- Baseline (2008): representing yield for present-day infestation.
- Good Management: representing yield if the present-day infestation is properly cleared and managed.
- No Management: representing the yield by 2045 if all IAP clearing is halted today.

A stochastic yield analysis was undertaken for the 3 scenarios and 1:50 year assurance of supply (98% assured yield) was determined for each scenario, provided in Table 3-34.

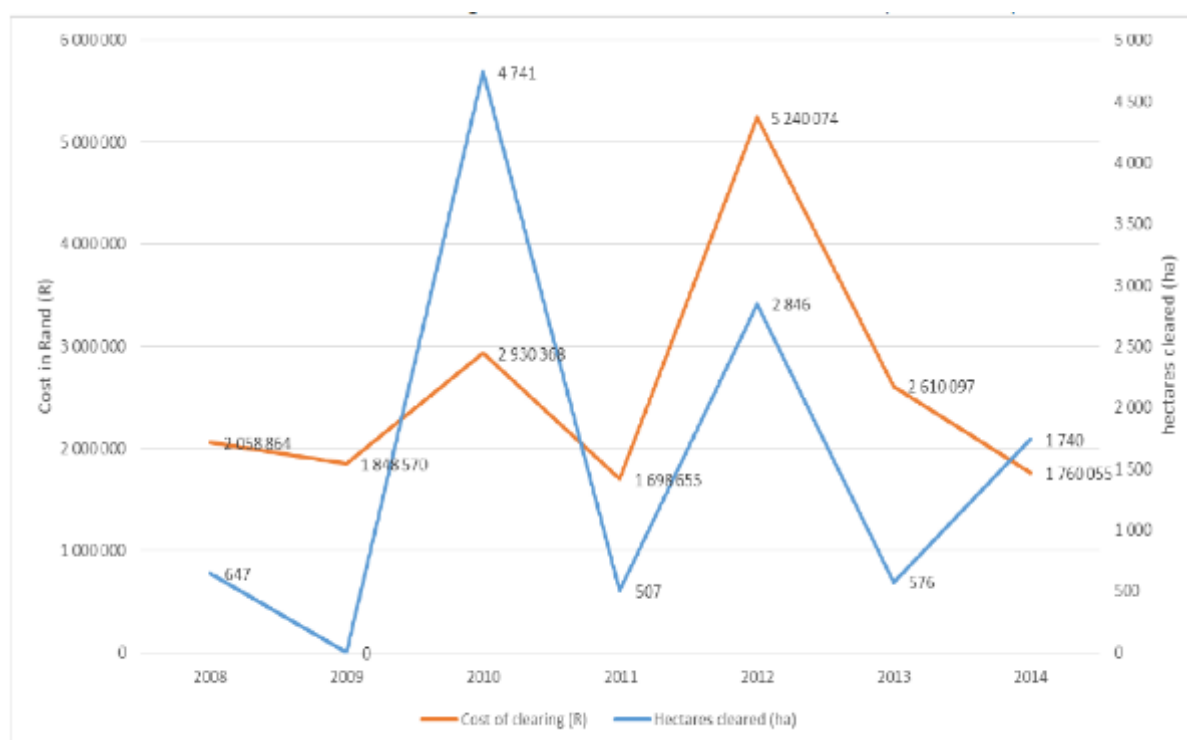
**Table 3-34: Yield of the WCWSS at 98% assurance for three IAP invasion scenarios**

Scenario	98% Assurance of Supply (million $\text{m}^3/\text{a}$ )
"Baseline" (~2008)	542
"No-Management" (2045)	450
"Good-Management"	580

The CSIR/Aurecon analysis (Le Maitre, et al., 2019) showed therefore that there is a potential gain of 38 million  $\text{m}^3/\text{a}$  at 98% assurance of supply for the WCWSS if IAPs are cleared and well-managed in the future.

### 3.7.3 Alien invasive plant removal costs

The spread of invasive alien plants is a dynamic phenomenon and requires investment in both ensuring that their spread is controlled and in managing the hectares invaded. In a study conducted by (Morokong, et al., 2016) for the Olifants River catchment area, and using data extracted from the DEA: NRM's WIMS data management system, cost and hectares cleared between 2008–2014 were determined. As Figure 3-22 indicates the investment in clearing IAPs has been fluctuating, affecting the hectares cleared.



**Figure 3-22: The investment in clearing IAPs at the Olifants River catchment (2008–2014) (Morokong, et al., 2016)**

A system dynamic modelling approach was adopted in the (Morokong, et al., 2016) study in order to investigate how well water catchment management by means of clearing IAPS compares in securing water, in comparison with the development of a new dam in the Olifants River catchment. Three sub-models were developed, a land-use model, a water-saved model, and an economic model, including the estimation of the Unit Reference Value (URV).

The Unit Reference Value (URV) is calculated to analyse the cost-effectiveness of water generation by clearing IAPs. The URV was developed by the Department of Water Affairs and Sanitation (van Niekerk, 2012) and is the cost per cubic metre of water over the lifetime of a water infrastructure (van Niekerk, 2013) (Preston, 2015) presented as follows:

*Unit Reference Value (R/m<sup>3</sup>) = Net present value NPV of lifecycle cost/Discounted yield of the dam over its life span*

*Lifecycle cost = PV of capital costs + PV of operating and maintenance cost*

The outcomes of this study indicate that clearing IAPs is a very cost-effective strategy. The URV of clearing IAPs is estimated at R1.44/m<sup>3</sup> as opposed to that of R2.93/m<sup>3</sup> for building the De Hoop Dam. Stated differently, the opportunity cost of not clearing the IAPs (R2.93/m<sup>3</sup>) is higher than that of clearing (R1.44/m<sup>3</sup>). This makes IAP clearing a socially desirable investment. Water consumed by IAPs is quite significant, so clearing the IAPs is an essential measure to ensure that less water is lost and is instead made available to support desirable economic activities like agricultural production and to support natural ecosystems, and the conservation of the water reserve.

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## 3.8 SUMMARY

### 3.8.1 Technology comparison

In order to perform a high-level comparison of the technologies considered in the report, it is necessary to determine categories in which they can be compared. This is not a straightforward exercise as the technologies considered are vastly different. In an attempt to perform this comparison, the following categories are considered:

- Type of Intervention – supply side or demand side?
- Quality of water produced – Potable water for human consumption or raw bulk water?
- Rainfall dependence – is the intervention dependant on precipitation? Or is it an assured supply?
- Barriers to Entry – what might impede the implementation of the intervention?
- Applicability of the Intervention – what external factors might limit where/how the intervention can be implemented?
- Cost – how expensive to implement is the intervention?
- Environmental – what environmental impacts/concerns are associated with the intervention?

It must be noted that the end result of this study is to develop an assessment framework which would allow the evaluation of bulk water supply investments and regulatory options required for demand-side management in a socioeconomic perspective that captures the macroeconomic value of bulk freshwater. For this reason, the socioeconomic and macroeconomic aspects have been included, but in a very limited capacity.



**Table 3-35: Technology Comparison**

	<b>Desalination</b>	<b>Reuse</b>	<b>Aquifer Recharge</b>	<b>Improved Irrigation Efficiency</b>	<b>Precipitation Augmentation</b>	<b>Alien Invasive Plant Removal</b>	<b>Non-Revenue Water (Leaks &amp; Unpaid Bills) Recovery</b>
<b>Demand or Supply Intervention</b>	Supply	Supply	Supply	Demand	Supply	Supply	Demand
<b>Quality of Water</b>	Potable or Raw	Potable or Raw	Raw	Raw	Raw	Raw	Potable
<b>Rainfall Dependence or Independence (assurance of supply)</b>	Independent – Seawater supply	Independent, but wastewater output dependant	Independent – recharged using desalinated or reused water	Dependant	Dependant	Dependant	Independent
<b>Barriers to Entry</b>		Social perception – hesitance to consume water produced from wastewater		Access to funding – large capital costs required by farmers	Difficulty in evaluating efficacy		Social compliance with regard to unpaid bills
<b>Applicability of Intervention</b>	For assured supply proximity to the coast is required		Applicable in areas with aquifers	Applicable to agricultural users		Applicable in catchment areas that have been invaded	Areas with poor payment compliance or significant water leaks
<b>Cost</b>	High	Medium	Medium	High			Low
<b>Environmental</b>	Concern surrounding disposal of hyper-saline effluent		Artificial recharge schemes need to be licensed because storing water underground is defined as a “water use” in the National Water Act.	decreased nutrient leaching and pollution of local watersheds due to decreased agricultural runoff	Unintended consequences such as changes in precipitation or other environmental impacts downwind of a target area have not been clearly demonstrated, but neither can they be ruled out.	Removal of alien vegetation will have a positive influence on local ecosystems	

### 3.8.2 Technology cost comparison

A number of alternative water supply options were considered, and a comprehensive analysis was undertaken on the options shown in the table below. A cost of supply was determined for each of the supply interventions for input into the economic analysis models.

**Table 3-36: Alternative Supply Options Volumes and Costs**

Modelling Scenarios	Description	Intervention volume WCWSS Total Mm <sup>3</sup> /a	Intervention/ alternative supply cost (R)
<b>Alternative Supply Options</b>			
Desalination			
a) Municipal	Desalination to supply municipal use	50	12.82
b) Agricultural	Desalination to supply agricultural use	50	12.82
Water Reuse	Water reuse for municipal supply (WCWSS discharges most suitable to recovery of potable water due to geographic location of discharge)	25	5.39
Farming under netting	Different irrigation crops respond differently under netting and not all crops can be cost effectively provided with netting (different water use reduction and different yield improvements)		
	Citrus	6	6.49
	Table Grapes	9	12.64
	Pome	2	24.15
Alien Invasive Plant Removal	Removal of alien vegetation through labour intensive processes - increased availability to municipal users	25	2.13
Agri PV	Different irrigation crops respond differently under PV and not all crops can be cost effectively provided with PV (different water use reduction and different yield improvements)	9.45	5.11



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Summary of findings:

- Desalination was, one of the more expensive water supply alternatives. This expense may be justified where the cost of unserved water is greater than the cost of water produced through desalination.
- In the farming under netting analysis, different irrigation crops responded differently under netting and not all crops could be cost effectively provided with netting due to different water use reduction and different yield improvements. Farming under netting was shown to be most cost effective for citrus crops and least cost effective for pome.
- Removal of alien invasive plants was found to be the most cost-effective of the interventions.
- The cost of water realised from AgriPV was similar to costs achieved for water reuse. The water savings and electricity generation potential results potential are also significant enough to warrant further exploration of the technology.

The estimated costs of some of these augmentation strategies were subsequently used in the analysis of policy interventions using the CGE static model to ensure that the cost recovery of additional water supply is taken into account in the analysis. Interventions that were not considered further in the economic analysis (Part B) were AgriPV and farming under cover as these are better suited to be modelled on a farm-level basis. Economic impacts from these interventions would be lost due the granularity of the model being at WMA level.

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**PART B:**

**ECONOMIC ANALYSIS OF WATER SUPPLY  
OPTIONS**

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## **CHAPTER 4: THE SOUTH AFRICAN ECONOMY AS PORTRAYED BY THE 2016 SOCIAL ACCOUNTING MATRIX**

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### **4.1 INTRODUCTION**

(Hassan, et al., 2008) constructed an agricultural and water-focused social accounting matrix (SAM) for South Africa in 2002 that was used as a basis for modelling water related policies and examining their economy-wide impacts on water use and allocation. The 2002 SAM had to be updated to consider the change in WMAs that took place in 2012 and also to reflect some of the key macro variable changes between 2002 and 2016. The 2016 version had to also consider the level of data granularity available for the 2002 SAM that was not available for the 2016 SAM. In this document we followed, where possible, the basic structure from (Hassan, et al., 2008) to construct an agriculture and water-focused SAM for South Africa for 2016. The 2016 SAM includes a new treatment of water and represents the 2012 water management areas. The developed 2016 water SAM is used to calibrate a static and a recursive dynamic computable general equilibrium (CGE) model. This document discusses the economy as portrayed by the SAM as well as some technical aspects of the development of the SAM. This is followed by results from the static and recursive dynamic CGE models.

### **4.2 DEVELOPMENT OF THE 2016 WATER SOCIAL ACCOUNTING MATRIX (SAM)**

The SAM is a comprehensive, disaggregated, consistent and complete data system that captures the interdependence that exists within a socioeconomic system. The SAM can be used as a conceptual framework to explore the impact of exogenous changes in such variables as exports, certain categories of government expenditures, and investment on the whole interdependent socioeconomic system, e.g. the resulting structure of production, factorial and household income distributions. As such the SAM becomes the basis for simple multiplier analysis and the building and calibration of a variety of applied general equilibrium models.

The basic structure of an agricultural and water-focused social accounting matrix (SAM) for South Africa that was developed in 2002 was used as base to develop a Water SAM for 2016. The treatment of water within the supply and use tables published by Statistics South Africa, as well as the national water accounts published by the Water Research Commission, which forms the core data of a SAM, has changed since 2002, with the implication that structural changes to the SAM were required. The 2016 SAM represents the nine 2012 water management areas while retaining the more detailed former WMAs for the Western Cape, resulting in 11 WMAs in total. The developed 2016 water SAM was used to calibrate a static and a recursive dynamic computable general equilibrium (CGE) model.

The SAM contains 40 sectors/commodities assumed to be at national market level, including 17 agricultural (including forestry and fishing), 15 industrial and 8 service sectors. Field crop production activities are further disaggregated in the SAM into irrigated and rainfed production per crop, while all horticultural production activities are assumed to be irrigated. All sectors are further disaggregated to capture production within each of the 11 water management areas. Beside capital, labour, and land, the SAM also includes three types of water (irrigation, bulk and municipal) per WMA as production factors. The institutions included in the 2016 SAM are enterprises, one representative household per WMA and the government. Further disaggregation of households were not possible due to lack of sufficiently detailed data. Irrigation water is incorporated in the model through the estimation of the shadow price of water per crop irrigated. Non-agricultural water use, in the form of bulk water and municipal water, is captured via the water distribution system. Irrigation and non-

agricultural water used by industries is treated as a factor of production and water used by households is treated as a commodity.

### 4.3 NEW BASE YEAR AND WATER MANAGEMENT AREAS

The table below (Table 4-1) indicates the structure of the South African economy in 2016 in terms of sectoral contribution to GDP and exports and imports. Import/export intensity refers to import/export share in total domestic demand/output. The tables in this document can be compared to the tables in (Hassan, et al., 2008), which are referred to in this document but not repeated here. From Table 4-1 it can be seen that agriculture, forestry and fishery's contribution to GDP declined from 4.32% in 2002 (Table 3 in (Hassan, et al., 2008)) to 2.55% in 2016. Although the employment share of agriculture remained stable between 7 to 8% from 2002 to 2016, there has been shift in employment from industry to services, with the service sector share of employment increasing by 10% to 73% over the period.

**Table 4-1: Structure of the South African economy (2016)**

	Share of total (%)				Export intensity	Import intensity
	GDP	Employment	Exports	Imports		
Total GDP	100.0	100.0	100.0	100.0	14.33	16.08
<b>Agriculture, forestry and fishery</b>	<b>2.55</b>	<b>7.59</b>	<b>2.35</b>	<b>0.81</b>	<b>12.03</b>	<b>5.00</b>
Field crops	0.71	2.06	0.32	0.56	5.94	10.95
Summer cereals	0.33	0.99	0.20	0.30	8.08	13.17
Winter cereals	0.09	0.27	0.01	0.10	1.16	13.09
Oils & legumes	0.14	0.42	0.01	0.07	1.37	7.67
Fodder crops	0.05	0.13	0.00	0.00	0.84	1.66
Sugarcane	0.08	0.17	0.00	0.00	0.00	0.00
Cotton & tobacco	0.02	0.08	0.10	0.08	56.18	47.99
Horticultural crops	0.62	2.02	1.60	0.14	33.99	4.83
Vegetables	0.11	0.35	0.09	0.03	10.92	4.10
Citrus fruits	0.18	0.63	0.61	0.00	45.14	0.39
Subtropical fruits	0.06	0.20	0.17	0.01	39.23	5.13
Deciduous fruits	0.25	0.78	0.63	0.01	32.46	0.48
Other horticulture	0.02	0.05	0.09	0.09	74.57	62.38
Livestock	0.87	2.36	0.26	0.09	3.71	1.38
Forestry and fishery	0.34	1.15	0.17	0.03	7.21	1.45
<b>Industry</b>	<b>30.71</b>	<b>19.21</b>	<b>75.88</b>	<b>84.77</b>	<b>28.27</b>	<b>30.16</b>
Mining	8.22	3.25	34.54	10.06	74.00	49.57
Manufacturing	15.31	9.40	41.01	74.64	24.50	34.32
Food processing	3.53	1.93	4.79	3.92	12.90	9.95
Textiles & clothing	0.40	0.73	1.62	5.11	20.53	43.39
Wood & paper	1.47	1.08	1.77	1.74	11.44	10.46
Chemicals & petroleum	2.97	1.19	9.33	17.80	24.90	34.36
Nonmetallic minerals	0.40	0.47	0.22	1.76	4.25	23.35
Machinery	2.41	2.03	13.94	14.82	42.61	41.26
Electrical machinery	0.33	0.33	1.84	10.87	23.16	63.12
Scientific equipment	0.08	0.14	0.20	1.95	28.15	75.69

	Share of total (%)				Export intensity	Import intensity
	GDP	Employment	Exports	Imports		
Transport equipment	3.04	0.85	5.50	14.50	31.10	50.17
Other manufacturing	0.69	0.65	1.80	2.17	34.76	37.48
Electricity generation	3.03	0.35	0.22	0.00	1.26	0.00
Water distribution	0.81	0.10	0.00	0.00	0.01	0.00
Construction	3.34	6.10	0.10	0.07	0.33	0.30
<b>Services</b>	<b>66.74</b>	<b>73.20</b>	<b>21.78</b>	<b>14.42</b>	<b>5.31</b>	<b>4.44</b>

Source: 2016 Water SAM for SA

Table 4-2 indicates the main changes in some of the key macro variables between 2002 and 2016. The 2002 values were taken from the final model version of the 2002 SAM developed by (Hassan, et al., 2008) and it is compared to the 2016 SAM compiled as part of this study.

**Table 4-2: Key economic changes in SA economy between 2002 and 2016 (R billion – nominal)**

	2002	2016	% change from 2002 value
<b>Supply</b>			
Value added at factor cost	1 042	3 814	266%
Labour	521	2 073	298%
Capital	506	1 712	238%
Land	9	10	19%
Water	7	19	181%
+Net industry taxes	22	77	258%
=Value added at basic prices	1 064	3 892	266%
+Net product taxes	105	468	347%
=GDP at purchaser prices	1 168	4 359	273%
+Intermediate consumption	1 571	4 572	191%
+Imports	338	1 310	287%
<b>=Total supply at purchaser prices</b>	<b>3 077</b>	<b>10 241</b>	<b>233%</b>
<b>Demand</b>			
Intermediate consumption	1 571	4 572	191%
Household consumption	733	2 584	252%
Government consumption	215	906	321%
Capital formation and stock changes	179	846	372%
Exports	379	1 333	252%
<b>Total demand at purchaser prices</b>	<b>3 077</b>	<b>10 241</b>	<b>233%</b>

Source: 2002 Water SAM (Hassan et al.) and 2016 Water SAM for SA

One of the unique features of the 2002 water SAM constructed by total domestic demand/output is the modelling of production and consumption activities by the 19 water management areas (WMAs) that were relevant in 2002. The WMAs in South Africa decreased from 19 to 9 in 2012. Three of the previous 19 WMAs are split across more than one of the new 9 WMAs, so it was initially decided to use 22 common areas in the most detailed version of the SAM, which would allow the SAM to be aggregated to either the 9 new WMAs or the old 19 WMAs, whichever was required. However, due to lack of more recent data at such a detailed level, it was decided to do a simple mapping of the 19 WMAs to the 9 WMAs, but to still retain the more detailed former WMAs for the Western Cape, resulting in 11 WMAs. The decision to retain more detail for the Western Cape was prompted by the fact that the Western Cape is the focus of the project. The decision to follow a

simple mapping for the other provinces was prompted by the fact that the developers of the new national water accounts for 2016 (Maila, et al., 2018) followed a similar approach. The discussion of the results from the 2016 SAM in this document follows the 11 WMAs as presented in Table 4-3.

**Table 4-3: Former, new and SAM water management areas**

<b>19 former WMA (2004)</b>		<b>9 new WMA (2012)</b>		<b>11 WMA for SAM</b>	
Limpopo	Area 1	Limpopo	Area 1	Limpopo	Area 1
Crocodile (West) and Marico	Area 3				
Luvuvhu and Letaba	Area 2	Olifants	Area 2	Olifants	Area 2
Olifants	Area 4				
Inkomati	Area 5	Inkomati-Usuthu	Area 3	Inkomati-Usuthu	Area 3
Usutu to Mhlatuze	Area 6	Pongola-Mtamvuna	Area 4	Pongola-Mtamvuna	Area 4
Thukela	Area 7				
Mvoti to Umzimkulu	Area 11				
Upper Vaal	Area 8	Vaal	Area 5	Vaal	Area 5
Middle Vaal	Area 9				
Lower Vaal	Area 10				
Upper Orange	Area 13	Orange	Area 6	Orange	Area 6
Lower Orange	Area 14				
Mzimvubu to Keiskamma	Area 12	Mzimvubu-Tsitsikamma	Area 7	Mzimvubu-Tsitsikamma	Area 7
Fish to Tsitsikamma	Area 15				
Gouritz	Area 16	Breede-Gouritz	Area 8	Gouritz	Area 16
Breede	Area 18			Breede	Area 18
Berg	Area 19	Berg-Olifants	Area 9	Berg	Area 19
Olifants/Doorn	Area 17			Olifants/Doorn	Area 17

#### 4.4 PRODUCTION AND EMPLOYMENT

The SAM contains 40 sectors/commodities, including 17 agricultural (including forestry and fishing), 15 industrial and 8 service sectors, as summarized in Table 4-4 below.

**Table 4-4: Sectors in the SAM**

<b>Agriculture</b>	<b>Non Agriculture (per WMA)</b>
<i>Field crops (irrigated and dryland, per WMA)</i>	18 Mining
1 Summer cereals (maize, sorghum)	19 Food & agricultural processing
2 Winter cereals (wheat, barley)	20 Textiles, clothing & footwear
3 Oil crops & legumes (groundnuts, beans)	21 Wood & paper products
4 Fodder crops (Lucerne, grain maize)	22 Chemicals & petroleum
5 Sugarcane	23 Non-metallic mineral products
6 Cotton & tobacco (incl. other field crops)	24 Metals & machinery
	25 Electrical machinery
<i>Horticultural crops (irrigated, per WMA)</i>	26 Scientific equipment
7 Vegetables	27 Transport equipment (incl. vehicles)
8 Citrus fruits	28 Other Manufacturing (incl. furniture)
9 Subtropical fruits	29 Electricity generation
10 Deciduous fruits and viticulture	30 <b>Bulk water distribution</b>
11 Other horticulture (tea, nuts)	31 <b>Municipal water distribution</b>
	32 Construction
<i>Livestock (per WMA)</i>	

12	Livestock sales (cattle, sheep, pigs)		
13	Dairy		
14	Poultry (chickens, eggs)		
15	Other livestock products (wool, game)		
	<i>Other agriculture</i>		
16	Fisheries ( <i>per WMA</i> )		
17	Forestry ( <i>dryland, per WMA</i> )		
		<b>Services (<i>per WMA</i>)</b>	
		33	Retail & wholesale trade
		34	Hotels & catering
		35	Transport
		36	Communication
		37	Financial & insurance services
		38	Business services & real estate
		39	Community & other private services
		40	Government services

The commodities are assumed to be at national market level, so they are not further disaggregated, hence the 40 commodities listed in the table above appear in the water SAM for 2016. Field crop production activities are further disaggregated in the SAM into irrigated and rainfed production per crop, while all horticultural production activities are assumed to be irrigated. Forestry is treated as dryland only, as was the case in the 2002 SAM. All sectors are further disaggregated to capture production within each of the 11 water management areas. Not all areas produce all products. For the 2016 SAM there were a total of 477 production activities; of which 224 were agricultural, forestry and fishery activities (62 dryland; 107 irrigated; 55 animal and animal product), 165 were industry (22 water related) and 88 were service activities.

(Hassan, et al., 2008) used the 2002 South African Census of Commercial Agriculture (CoCA) for detailed information on agricultural production. The 2017 South African CoCA was used for the 2016 SAM. There appears to be substantial missing information in the CoCA, hence the information was supplemented using various other sources. Other sources primarily include information published by the Department of Agriculture, Forestry and Fisheries (DAFF) in various reports, as well as publications and data supplied by various industry associations.

Detailed production data for the industrial sectors were obtained from the South Africa Standard Industrial Database (SASID) for 2016 from Quantec Easy Data Regional Services. The data is reported per district and could thus be mapped to the WMAs. Intermediate demands for non-agricultural production were taken from the national SU tables (StatsSA, 2017), and data for the production technologies across WMAs were based on data from the South Africa Standard Industrial Database (SASID) for 2016 from Quantec Easy Data Regional Services.

To capture differences in agricultural production technologies between sub-sectors and WMAs, intermediate demands for crops and livestock were derived from the 2002 CoCA as a starting point and then updated using the 2017 CoCA data where possible. In the CGE model production is governed by a nested constant elasticity of substitution (CES) production function. Table 4-5 indicates characteristics of WMAs as portrayed by the 2016 SAM. National population increased from 44.7 million in 2002 to 55.6 million in 2016; and national GDP (value added at factor cost) per capita increased from R23 282 to R68 580 over the same period. None of the water management areas in the 2016 SAM still have a larger regional GDP contribution from agriculture than industry (last two columns). In 2002 (not shown here), there were five regions: Middle Vaal, Lower Vaal, Lower Orange, Olifants/Doorn and Breede. In 2002, both Olifants/Doorn and Breede had agricultural contributions to

regional GDP of above 30%, but it decreased between 2002 and 2016 from 32.7% to 19.9% and from 36.2% to 2.4% for the two respective regions.

**Table 4-5: Summary characteristics of Water Management Areas (2016)**

	Population (1000)	GDP per capita (R)	Share of national GDP (%)			Share of region GDP (%)	
			Total	Agric	Industry	Agric	Industry
National	55 619.92	68 579.61	100.00	100.00	100.00	2.52	22.50
Limpopo	10 096.69	85 216.42	22.56	10.01	20.05	1.12	20.00
Olifants	6 641.47	63 178.27	11.00	7.28	10.37	1.67	21.21
Inkomati-Usuthu	1 928.46	46 657.37	2.36	5.35	2.43	5.71	23.14
Pongola-Mtamvuna	11 016.27	52 490.51	15.16	21.77	17.85	3.62	26.49
Vaal	11 461.29	79 562.70	23.91	18.28	24.50	1.93	23.06
Orange	1 835.46	64 477.62	3.10	7.91	2.07	6.42	15.00
Mzimvubu-Tsitsikamma	6 307.41	43 459.54	7.19	7.06	7.27	2.48	22.74
Gouritz	721.14	66 620.40	1.26	3.34	1.29	6.68	23.13
Olifants/Doorn	271.79	63 384.48	0.45	3.57	0.47	19.91	23.37
Breede	619.37	67 038.31	1.09	4.21	1.13	9.74	23.39
Berg	4 720.56	96 390.97	11.93	11.24	12.57	2.37	23.71

Source: 2016 Water SAM

The model identifies eight factors of production: capital, three types of labour (unskilled, skilled and highly skilled), agricultural land, and three types of water (water used by irrigation agriculture, bulk water supply and municipal water supply). The labour, land and water accounts are further disaggregated per WMA. The 2016 water SAM with 11 WMAs therefore includes 78 factor accounts (33 labour, 11 land, 33 water, 1 capital). The inclusion of these factors of production allows us to capture differences in production technology in the CGE model that was used for the analysis.

Table 4-6 shows land use per crop and WMA. The area has decreased from 7.6 million ha in 2002 to 6.8 million ha in 2016. Compared to 2002, the national shares of summer cereals, oilseeds and legumes, sugarcane and horticulture increased marginally; while that of winter cereals, fodder crops, and cotton and tobacco decreased marginally.

**Table 4-6: Agricultural land allocation by Water Management Areas (2016)**

	Agricultural land allocated to crops (percent)							
	All crops (1000 ha)	Summer cereals	Winter cereals	Oilseeds & legumes	Fodder crops	Sugar- cane	Cotton & tobacco	Horti- culture
National	6 778	43%	9%	20%	12%	5.3%	0.2%	10%
Limpopo	546	55%	6%	19%	7%	0%	0.1%	13%
Olifants	520	50%	3%	24%	3%	0%	1.0%	20%
Inkomati-Usuthu	256	46%	1%	28%	2%	11%	0.3%	11%
Pongola-Mtamvuna	662	18%	2%	5%	21%	50%	0.1%	4%
Vaal	2 977	58%	4%	27%	9%	0%	0.1%	3%
Orange	753	47%	10%	24%	11%	0%	0.1%	7%



	Agricultural land allocated to crops (percent)							
	All crops (1000 ha)	Summer cereals	Winter cereals	Oilseeds & legumes	Fodder crops	Sugar- cane	Cotton & tobacco	Horti- culture
Mzimvubu- Tsitsikamma	237	22%	3%	2%	58%	0%	0%	15%
Gouritz	114	1.4%	35%	12%	36%	0%	0%	15%
Olifants/Doorn	135	0.3%	20%	2%	9%	0%	0%	69%
Breede	341	0.1%	53%	12%	10%	0%	0%	24%
Berg	237	0.0%	48%	5%	16%	0%	0%	31%

Source: 2016 Water SAM

## 4.5 INSTITUTIONS

The institutions included in the 2016 SAM are enterprises, representative household groups and the government. Households are disaggregated according to each of the 11 WMAs. Income and expenditure household data per district were obtained from the South Africa Standard Industrial Database (SASID) for 2016 from Quantec Easy Data Regional Services, and mapped to the water management areas. The data were reconciled with national accounts data on incomes and expenditures for 2016 from the South African Reserve Bank. None of the more recent household surveys contain sufficient information to replicate the income quintiles that were included in the 2002 SAM. Sources consulted include the 2011 Population Census, the 2017 National Income Dynamics Survey (NIDS) Survey, the General Household Survey and the 2016 Community Survey.

Producers make payments to households for the use of their factors of production. With the income received from the factors of production as well as from enterprise, households consume products governed by a linear expenditure system (LES) of demand. Households also pay direct taxes to government (based on fixed tax rates) and save (based on marginal propensities).

The government receives income from five imposed taxes: water tariffs, other industry taxes, import tariffs, other sales taxes and direct income taxes. Government expenditures include government services and transfers made to households. The balance of government income is (dis)saved, and forms part of a savings pool which also collects the savings from households and the rest of the world (foreign savings). This savings is used to finance investment. Government income and expenditure data were obtained from the National Accounts for SA derived from the quarterly bulletin of statistics published by the South African Reserve Bank (South African Reserve Bank, 2018). Enterprises were not captured explicitly in the 2002 SAM, but is included as a separate institution in the 2016 SAM.

## 4.6 AGRICULTURAL WATER USE AND SHADOW PRICES

Irrigation water is incorporated in the model through the estimation of the shadow price of water per crop irrigated. In order to calculate the shadow price of water it is necessary to take the productivity effects of water on crop yields into account, i.e., to calculate the value of marginal product (VMP) of water. Compared to the

2002 data, the only component that was updated for the 2016 water SAM is the price of information to calculate the value of marginal product. The 2016 product prices were retrieved from the Food and Agricultural Organization of the United Nations (FAO) database for producer prices. The process described below therefore borrows from (Hassan, et al., 2008).

The first step to calculate the VMP is to estimate the water use. This is done by using the water-yield response functions based on experimental research trials' data from SA's Agricultural Research Council (ARC) that was estimated and used in the 2002 Water SAM by (Hassan, et al., 2008). According to the ARC, these water yield response functions are still valid (Reinders, 2019). The trial data measured the amount of water needed to achieve different yield levels for a variety of crops. Average crop yields were retrieved from various sources, including the CoCA (2002). The coefficients calculated with the trial data, together with the average yields were then applied to the water-yield response function by (Hassan, et al., 2008). Yield response functions were however not re-estimated.

Water-yield response function (Hassan, et al., 2008):

$$Y_i = \beta_{0i} + \beta_{1i}W_i + \beta_{2i}W_i^2$$

Where  $Y_i$  is the output of crop  $i$  per hectare of land (in kilograms) and  $W_i$  is the amount of water used to produce this level of output (in millimetres).

From this formula, the current water use was determined, which in turn were used to calculate the VMP for water using the following formula:

$$VMP_i = P_i \left( \frac{\partial Y_i}{\partial W_i} \right) = P_i (\beta_{1i} + 2\beta_{2i}W_i)$$

Where  $P_i$  is the producer price of crop  $i$  (with updated data for 2016 obtained from FAO).

Hassan et al. (2002) subtracted non-water irrigation costs from the VMPs to provide an estimate of the shadow price of water for different crops. This was a constant value for all industries, comprising the average irrigation costs incurred by farmers. The shadow price of water was then used in the estimate of the payment by irrigation agriculture to water as a production factor, by disaggregating the payment to water from the payments to capital (gross operating surplus). In 2016 the capital payments as share of total output are substantially lower compared to 2002 and the shadow prices ended up being relatively higher, causing negative capital payments for several agricultural sectors. Estimated shadow prices for the 2016 SAM were therefore scaled downward to avoid negative capital payments yet retaining the differentiation between areas and accurate water volumes.

Table 4-7 shows agricultural production and water use per crop. The average irrigation water use is 6.0 1000m<sup>3</sup>/ha, which is slightly greater compared to that which was reported in the (Hassan, et al., 2008) report. The volume of irrigation water used increased from 7.3 to 8.5 billion m<sup>3</sup> between 2002 and 2016. During the same period the area of productive agricultural land under irrigation increased from 20.5% to 20.9%.

**Table 4-7: Agricultural production and water use per crop (2016)**

	Production Quantity (1000 mt)	Land area		Yields		Irrigation water use	
		Total (1000 ha)	Irrigated (%)	Rainfed (mt/ha)	Irrigated (mt/ha)	Volume (mil m <sup>3</sup> )	(1000 m <sup>3</sup> /ha irrig)
<b>Total</b>	<b>-</b>	<b>6 778</b>	<b>20.85</b>	<b>-</b>	<b>-</b>	<b>8 483</b>	<b>6.00</b>
Summer cereals	15 858	2 941	8.38	4.98	9.89	1 580	6.41
Winter cereals	1 446	617	19.24	2.12	3.28	327	2.76
Oils & legumes	2 387	1 378	4.79	1.65	3.33	363	5.50
Fodder crops	4 207	808	30.75	2.79	10.65	2 006	8.07
Sugarcane	13 153	359	16.52	35.00	45.00	525	8.86
Cotton & tobacco	50	12	81.65	0.39	5.11	53	5.50
Vegetables	6 999	229	100.00	-	30.55	558	2.44
Citrus fruits	2 047	93	100.00	-	21.93	863	9.25
Subtropical fruits	993	69	100.00	-	14.36	521	7.53
Deciduous fruits	4 073	180	100.00	-	22.58	1 176	6.52
Other horticulture	104	93	100.00	-	1.12	512	5.53

Source: 2016 Water SAM

#### 4.7 NON-AGRICULTURAL WATER USE AND DISTRIBUTION SYSTEM

Non-agricultural water use, in the form of bulk water and municipal water, is captured via the water distribution system. Irrigation and non-agricultural water used by industries is treated as a factor of production and water used by households is treated as a commodity. In South Africa, the water distribution system charges different water tariffs to different sectors or users (Maila, et al., 2018). However, to simplify the system, the model only distinguishes between three groups: (i) agricultural ii) bulk water and (iii) municipal water. Households also use municipal water. For each of the three groups a new water production factor was created to separately capture the returns to water per group. The water production factors are used by industries according to the supply and use tables developed by (Maila, et al., 2018). The agricultural industry uses only 'agricultural water' while other industries use either bulk or municipal water, or in some cases both. Households use only municipal water. The distinction between agricultural, bulk and municipal water allows for more detailed water pricing in the model.

Water expenditures by industries and aggregate households are reported in the use table for 2016 (Statistics South Africa, 2017). The water values for non-agricultural use contained in the SAM are converted to volumes of water as part of the CGE model when water prices become explicit. The table below (Table 4-8) shows the water use by different groups, and these volumes per group are similar to what is reported in South Africa's Water Flow Accounts (Maila, et al., 2018).

**Table 4-8: Water use by WMA and water users (2016)**

	Water use, 2016 (million m <sup>3</sup> )				
	Irrigation	Bulk water (industries)	Municipal water (industries)	Municipal water (households)	Total water use
<b>National</b>	<b>8 483</b>	<b>3 923</b>	<b>1 079</b>	<b>3 741</b>	<b>17 226</b>
Limpopo	800	760	254	791	2 605
Olifants	971	441	151	397	1 959
Inkomati-Usuthu	455	121	29	96	701
Pongola-Mtamvuna	1 063	963	201	603	2 830
Vaal	931	896	247	891	2 965
Orange	1 224	138	35	114	1 511
Mzimvubu-Tsitsikamma	1 056	274	74	321	1 725
Gouritz	290	29	8	51	377
Olifants/Doom	558	20	3	16	597
Breede	665	27	7	40	738
Berg	469	255	70	422	1 216

Source: 2016 Water SAM

In summary, water is incorporated into the SAM by (i) separating agriculture in irrigated and rainfed production; (ii) disaggregating all production, labour markets and households across water management areas; (iii) estimating the shadow value of irrigation water for different crops; and (iv) distinguishing between the bulk and municipal water distribution systems.

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## CHAPTER 5: PREDICTING THE IMPACT OF CHANGES IN WATER TARIFFS AND TRANSFERS ON THE NATIONAL AND WESTERN CAPE ECONOMY USING THE STATIC COMPUTABLE GENERAL EQUILIBRIUM MODEL

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### 5.1 INTRODUCTION

The developed 2016 water SAM is used to calibrate a computable general equilibrium (CGE) model. The model is different to the static model used by (Hassan, et al., 2008). The recursive dynamic computable general equilibrium model, as developed by the International Food Policy Research Institute (IFPRI), was used as base model and was adjusted for purposes of this project to allow for policy options related to a water focus, notably the inclusion of water tariffs. Compared to the original water model, this model also allows for secondary production and the explicit treatment of enterprises. Secondary production implies that one industry can produce more than one product. This is of importance because the treatment of the production of water in the supply and use tables have changed over time. By retaining secondary production, fewer assumptions have to be made during data transformation, and the original supply and use values can be used. In the original water model, enterprises were aggregated with households, but a separation of the two allows for improved tracing of the flow of funds from factors of production to households, as well as improved modelling of household behaviour in terms of consumption vs savings.

### 5.2 PRELIMINARY RESULTS

As an initial example of model output, selected results from the static version of the model for the increase in the water tariff on irrigation agriculture by 50% is presented here. The static model results were tested first before the recursive dynamic CGE model was finalised. Table 5-1 shows that a 50% increase in the water tariff rate will lead to a 13.2% decrease in irrigation water used, with minimal indirect impact on the use of bulk and municipal water. In this scenario irrigation water is assumed to become more expensive, but the water is not necessarily transferred to other water users.

**Table 5-1: Change in volume of water used for a 50% increase in irrigation water tariff**

	Base (mil m3)	Change (%)
Irrigation water	8 483	-13.23
Bulk water	3 923	-0.09
Municipal water	1 079	-0.01
Domestic	3 741	-0.04
Total	17 226	-6.54

Table 5-2 shows that besides fodder crops, it is horticulture that is most affected by the hypothetical increase in the water tariff since these crops are produced under irrigation only. In terms of land area, there is the

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expected decrease in irrigated area, and an increase in dryland area, especially notable for fodder crops. Other horticulture and summer cereals show the greatest relative decrease in water use, but the greatest volume of water saved comes from fodder crops, which is a low value crop.

**Table 5-2: Change in production, area and water use for a 50% increase in irrigation water tariff**

	Production quantity		Agricultural irrigated area		Agricultural dryland area		Water use	
	Base (1000 mt)	Change from base (%)	Base (1000 ha)	Change from base (%)	Base (1000 ha)	Change from base (%)	Base (mil m <sup>3</sup> )	Change from base (%)
<b>All crops</b>	<b>51 316</b>	<b>-0.7</b>	<b>1 413</b>	<b>-2.8</b>	<b>5 365</b>	<b>0.7</b>	<b>8 483</b>	<b>-13.2</b>
Summer cereals	15 858	-0.4	247	-4.5	2 694	-0.1	1 580	-19.0
Winter cereals	1 446	-0.3	119	-1.9	498	0.2	327	-16.6
Oils & legumes	2 387	-0.2	66	-4.8	1 312	-0.5	363	-16.4
Fodder crops	4 207	-3.3	248	-3.7	559	8.9	2 006	-17.6
Sugarcane	13 153	-0.2	59	-3.7	300	-0.3	525	-10.3
Cotton & tobacco	50	-1.2	10	-1.5	2	-1.2	53	-13.5
Vegetables	6 999	-0.4	229	-0.3			558	-5.7
Citrus fruits	2 047	-1.0	93	-0.6			863	-6.1
Subtropical fruits	993	-1.6	69	-0.9			521	-5.3
Deciduous fruits	4 073	-0.9	180	-0.3			1 176	-6.7
Other horticulture	104	-14.8	93	-10.2			512	-20.1

Table 5-3 below indicates that agriculture comprises 2.55% of GDP at factor cost in the base case. The water tariff increase will lead to a 0.3% decrease in GDP at factor cost for the economy in general and a 0.44% decrease in agriculture's contribution to GDP at factor cost. The biggest negative impact of the water tariff increase is on the exports of horticultural products. The impacts on non-agriculture in terms of both GDP contribution and trade are only indirect effects and hence much less pronounced.

**Table 5-3: Macro economic effects (in real terms) of a 50% increase in irrigation water tariff**

	<b>Base contribution to GDP at factor cost (%)</b>	<b>Change in contribution based on values in real terms (%)</b>
GDP factor cost	100.00	-0.03
<b>Agriculture</b>	<b>2.55</b>	<b>-0.44</b>
Field crops	0.71	-0.46
Horticulture	0.62	-1.18
Livestock	0.87	-0.05
Other	0.34	-0.05
<b>Non-agriculture</b>	<b>97.45</b>	<b>-0.02</b>
Consumption	59.29	-0.04
Investment	19.40	-0.03
Government	20.79	0.00
Exports	30.58	-0.04
Agriculture	2.35	-2.04
Field crops	0.32	-1.28
Horticulture	1.60	-2.76
Non-agriculture	97.65	0.01
Processed foods	4.79	-0.30
Imports	-30.06	-0.04
Agriculture	0.81	0.56
Field crops	0.56	0.50
Horticulture	0.14	1.37
Non-agriculture	99.19	-0.04
Processed foods	3.92	0.06

### 5.3 IMPACT OF CHANGES IN WATER TARIFFS AND TRANSFERS ON THE NATIONAL ECONOMY

Selected results from the static CGE model are presented here. Scenarios include the following:

- Changes in the water tariff rate on irrigation agriculture ranging between -20% to +20% with 10% increments.
- Changes in the municipal water rate used by industries ranging between -20% to +20% with 10% increments.
- A transfer of 50 million m<sup>3</sup> from irrigation water to municipal water for industry



### 5.3.1 Scenario 1: Change in irrigation water tariff

Table 5-4 shows the changes in the different water volumes demanded for changes in the water tariff rate, ranging between -20% to +20% with 10% increments. The impact is mostly on irrigation water with minimal indirect impact on the use of bulk water, municipal water used by industry and water used by households.

**Table 5-4: Change in volume of different types of water used for changes in irrigation water tariff**

	<b>Base</b>	<b>Scenario: changes in irrigation water tariff</b>			
	<b>Quantity used</b>	<b>-20%</b>	<b>-10%</b>	<b>+10%</b>	<b>+20%</b>
	<b>(mil m<sup>3</sup>)</b>	<b>% change in quantity of water used from base</b>			
Irrigation water	8 483	6.551	3.152	-2.934	-5.674
Bulk water	3 923	0.046	0.022	-0.021	-0.042
Municipal (industry)	1 079	0.001	0.001	-0.001	-0.002
Municipal (hhholds)	3 741	0.017	0.008	-0.008	-0.016
Total	17 226	3.24	1.56	-1.45	-2.81

Table 5-4 above indicates that there is little indirect effect on other water usage when the tariff for irrigation water is changed, but water is not transferred to other users. The impact on irrigation water was explored further and presented at a more detailed water management level in Table 5-5 below.

**Table 5-5: Change in volume of irrigation water used in different WMAs for changes in irrigation water tariff**

	<b>Base</b>	<b>Scenario: changes in irrigation water tariff</b>			
	<b>Quantity used</b>	<b>-20%</b>	<b>-10%</b>	<b>+10%</b>	<b>+20%</b>
	<b>(mil m<sup>3</sup>)</b>	<b>% change in quantity of water used from base</b>			
WMAs 1 – 7	6 502	6.80	3.27	-3.04	-5.87
Breede – Gouritz	955	5.84	2.83	-2.66	-5.17
Berg – Olifants/Doorn	1 027	5.66	2.72	-2.52	-4.88
Total	8 483	6.55	3.15	-2.93	-5.67

Table 5-6 shows that irrigated field crops are more affected by a change in water tariffs since these crops can be more easily switched to dryland conditions than horticultural products and field crops are often lower value crops and would be moved out of irrigation more readily than horticultural products.

**Table 5-6: Change in production volume (irrigated), irrigated area, volume of irrigation water used in different WMAs for changes in irrigation water tariff**

			Scenario: changes in irrigation water tariff			
		Base	-20%	-10%	+10%	+20%
		Quantities	% change from base			
Production (1000 tons)						
WMAs 1 – 7	Field crops	7 749	3.202	1.572	-1.518	-2.986
	Horticulture	9 282	0.432	0.211	-0.203	-0.397
Breede – Gouritz	Field crops	539	7.269	3.538	-3.359	-6.552
	Horticulture	2 768	0.542	0.265	-0.254	-0.499
Berg - Olifants/Doorn	Field crops	122	2.830	1.397	-1.362	-2.691
	Horticulture	2 166	0.086	0.048	-0.057	-0.121
RSA	Irrigated production	22 625	1.537	0.754	-0.727	-1.429
Area (1000 ha)						
WMAs 1 – 7	Field crops	673	1.455	0.723	-0.713	-1.416
	Horticulture	400	1.116	0.536	-0.498	-0.963
Breede – Gouritz	Field crops	57	2.312	1.165	-1.178	-2.365
	Horticulture	97	0.335	0.159	-0.145	-0.279
Berg - Olifants/Doorn	Field crops	19	-0.020	0.020	-0.073	-0.191
	Horticulture	167	1.826	0.879	-0.819	-1.585
RSA	Irrigated area	1 413	1.341	0.658	-0.636	-1.252
Irrigated water (mil m³)						
WMAs 1 – 7	Field crops	4 384	8.338	4.002	-3.706	-7.151
	Horticulture	2 117	3.603	1.749	-1.657	-3.230
Breede – Gouritz	Field crops	375	10.106	4.863	-4.522	-8.737
	Horticulture	579	3.073	1.508	-1.454	-2.859
Berg - Olifants/Doorn	Field crops	94	7.948	3.824	-3.559	-6.881
	Horticulture	933	5.432	2.608	-2.420	-4.673
RSA	Irrigated water use	8 483	6.551	3.152	-2.934	-5.674

Table 5-7 below indicates selected macro-economic impacts on a regional level for changes in irrigation water tariffs. Changes in regional GDP for agricultural and non-agricultural sectors are presented.

**Table 5-7: Change in GDP in different WMAs for changes in irrigation water tariff**

			Scenario: changes in irrigation water tariff			
		BASE GDP	-20%	-10%	+10%	+20%
WMA / Region	Sectors	Value (Rbn)	% change from base			
WMAs 1 - 7	Region total	3 253	0.030	0.015	-0.015	-0.029
	Agriculture	75	0.085	0.041	-0.037	-0.072
	Non-agric	3 178	0.029	0.014	-0.014	-0.028
Breede - Gouritz	Region total	90	0.051	0.025	-0.024	-0.048
	Agriculture	7	0.230	0.112	-0.105	-0.204
	Non-agric	82	0.035	0.018	-0.017	-0.034
Berg - Olifants/Doorn	Region total	472	0.039	0.019	-0.019	-0.037
	Agriculture	14	0.214	0.102	-0.094	-0.181
	Non-agric	458	0.034	0.017	-0.016	-0.032
RSA	Total	3 814	0.032	0.016	-0.015	-0.030
	Agriculture	96	0.115	0.055	-0.051	-0.098
	Non-agric	3 718	0.030	0.015	-0.014	-0.029

In general, the impacts of the irrigation water tariff changes are small on a regional GDP level, but one can expect that the impact on individual irrigation farms are much more pronounced.

### 5.3.2 Scenario 2: Change in municipal water rate

Table 5-8 below shows the changes in the different water volumes demanded for changes in the municipal water rate, ranging between -20% to +20% with 10% increments.

**Table 5-8: Change in volume of different types of water used for changes in municipal water rate**

	Base	Scenario: changes in municipal water rate			
	Quantity used	-20%	-10%	+10%	+20%
	(mil m <sup>3</sup> )	% change in quantity of water used from base			
Irrigation water	8 483	0.07	0.03	-0.03	-0.06
Bulk water	3 923	0.72	0.34	-0.31	-0.60
Municipal (industry)	1 079	12.97	5.91	-5.04	-9.41
Municipal (hholds)	3 741	2.17	1.03	-0.94	-1.81
Total	17 226	1.48	0.69	-0.61	-1.15

Table 5-8 above indicates that although municipal water use decreases by up to 9.4% when the municipal water rates changes, there is little indirect effect on other water usage. The impact on municipal water is therefore explored further at a more detailed water management level as shown in Table 5-9.

**Table 5-9: Change in volume of municipal water used in different WMAs for changes in municipal water rate**

	<b>Base</b>	<b>Scenario: changes in municipal water rate</b>			
	<b>Quantity used</b>	<b>-20%</b>	<b>-10%</b>	<b>+10%</b>	<b>+20%</b>
	<b>(mil m<sup>3</sup>)</b>	<b>% change in quantity of water used from base</b>			
WMAs 1 – 7	991	12.87	5.87	-5.01	-9.34
Breede – Gouritz	14	14.04	6.39	-5.43	-10.11
Berg – Olifants/Doorn	74	14.21	6.46	-5.48	-10.21
Total	1 079	12.97	5.91	-5.04	-9.41

Table 5-10 below shows that in general, the production of horticulture increases when municipal water rates increase, whereas production of field crops decrease. This could be because an increase in municipal water rates has a dampening effect on industry and since a larger share of field crops is used as intermediate product compared to horticultural products, the demand for field crops is likely to decline. The impact on agriculture is indirect in this scenario.

**Table 5-10: Change in production volume (irrigated), irrigated area, volume of irrigation water used in different WMAs for changes in municipal water rate**

		Scenario: changes in municipal water rate				
		Base	-20%	-10%	+10%	+20%
		Quantities	% change in quantities from base			
Production (1000 tons)						
WMAs 1 - 7	Field crops	7 749	0.070	0.034	-0.033	-0.064
	Horticulture	9 282	-0.014	-0.007	0.006	0.012
Breede - Gouritz	Field crops	539	0.126	0.061	-0.059	-0.115
	Horticulture	2 768	-0.030	-0.014	0.014	0.027
Berg - Olifants/Doorn	Field crops	122	0.043	0.021	-0.020	-0.039
	Horticulture	2 166	-0.020	-0.010	0.009	0.019
<b>RSA</b>	<b>Irrigated production</b>	<b>22 625</b>	<b>0.016</b>	<b>0.008</b>	<b>-0.007</b>	<b>-0.015</b>
Area (1000 ha)						
WMAs 1 - 7	Field crops	673	0.051	0.025	-0.024	-0.047
	Horticulture	400	-0.016	-0.008	0.007	0.014
Breede - Gouritz	Field crops	57	0.085	0.041	-0.040	-0.077
	Horticulture	97	-0.015	-0.007	0.007	0.014
Berg - Olifants/Doorn	Field crops	19	0.085	0.042	-0.040	-0.078
	Horticulture	167	-0.042	-0.020	0.020	0.038
<b>RSA</b>	<b>Irrigated area</b>	<b>1 413</b>	<b>0.019</b>	<b>0.009</b>	<b>-0.009</b>	<b>-0.017</b>
Irrigated water (mil m <sup>3</sup> )						
WMAs 1 - 7	Field crops	4 384	0.110	0.053	-0.051	-0.100
	Horticulture	2 117	0.016	0.008	-0.008	-0.015
Breede - Gouritz	Field crops	375	0.153	0.074	-0.071	-0.139
	Horticulture	579	0.045	0.022	-0.021	-0.041
Berg - Olifants/Doorn	Field crops	94	0.106	0.051	-0.049	-0.096
	Horticulture	933	-0.020	-0.010	0.009	0.018
<b>RSA</b>	<b>Irrigated water use</b>	<b>8 483</b>	<b>0.070</b>	<b>0.034</b>	<b>-0.032</b>	<b>-0.063</b>

Table 5-11 below indicates selected macro-economic impacts on a regional level for changes in municipal water rates. Changes in regional GDP for agriculture and non-agriculture are presented. The impacts are somewhat more pronounced compared to that of the changes in irrigation water tariff rates.

**Table 5-11: Change in GDP in different WMAs for changes in changes in municipal water rate**

			Scenario: changes in municipal water rate			
		BASE GDP	-20%	-10%	+10%	+20%
WMA / Region	Sectors	Value (Rbn)	% change from base			
<b>WMAs 1 – 7</b>	<b>Region total</b>	<b>3 253</b>	<b>0.179</b>	<b>0.087</b>	<b>-0.083</b>	<b>-0.163</b>
	Agriculture	75	0.125	0.061	-0.058	-0.114
	Non-agric	3 178	0.180	0.088	-0.084	-0.164
<b>Breede – Gouritz</b>	<b>Region total</b>	<b>90</b>	<b>0.180</b>	<b>0.088</b>	<b>-0.084</b>	<b>-0.164</b>
	Agriculture	7	0.107	0.052	-0.050	-0.098
	Non-agric	82	0.187	0.091	-0.087	-0.170
<b>Berg - Olifants/Doorn</b>	<b>Region total</b>	<b>472</b>	<b>0.179</b>	<b>0.087</b>	<b>-0.083</b>	<b>-0.163</b>
	Agriculture	14	0.102	0.049	-0.047	-0.092
	Non-agric	458	0.181	0.088	-0.084	-0.165
<b>RSA</b>	<b>Total</b>	<b>3 814</b>	<b>0.179</b>	<b>0.087</b>	<b>-0.083</b>	<b>-0.163</b>
	Agriculture	96	0.120	0.059	-0.056	-0.110
	Non-agric	3 718	0.180	0.088	-0.084	-0.164

### 5.3.3 Scenario 3: Transfer of water from use in irrigation to municipal use for industries

A total of 50 million m<sup>3</sup> water is transferred. The transfer per region is calculated based on the pro rata use of irrigation water for that region in the base case.

Table 5-12 below shows that a 50 million m<sup>3</sup> transfer of irrigation water to municipal water will lead to a 0.6% decrease in irrigation water used and a 4.6% increase in the use of municipal water. The 0.8% increase in water used by households for domestic purposes reflects a positive impact on the economy as a result of an expansion of industries and hence household income.

**Table 5-12: Change in volume of water used for a 50 mil m<sup>3</sup> water transfer from irrigation to municipal use**

	Base (mil m <sup>3</sup> )	Change from base (%)
Irrigation water	8 483	-0.59
Bulk water	3 923	0.00
Municipal (industry)	1 079	4.63
Municipal (hholds)	3 741	0.76
Total	17 226	0.17

Table 5-13 below shows the general negative impact on agricultural production under irrigation due to the reduction in the volume of water available for irrigation. The reduction in production under irrigation

is also reflected in the reduction in area irrigated, although the reduction in areas is relatively smaller than the reduction in production.

**Table 5-13: Change in production, area and water use for a 50 mil m<sup>3</sup> water transfer from irrigation to municipal use**

		<b>Base</b>	<b>Scenario: 50 mil m<sup>3</sup> water transferred</b>
		<b>Quantities</b>	<b>% change in quantities from base</b>
<b>Production (1000 tons)</b>			
WMAs 1 - 7	Field crops	7 749	-0.280
	Horticulture	9 282	-0.088
Breede - Gouritz	Field crops	539	-0.365
	Horticulture	2 768	-0.125
Berg - Olifants/Doorn	Field crops	122	-0.055
	Horticulture	2 166	-0.017
<b>RSA</b>	<b>Irrigated production</b>	<b>22 625</b>	<b>-0.158</b>
<b>Area (1000 ha)</b>			
WMAs 1 - 7	Field crops	673	-0.082
	Horticulture	400	-0.087
Breede - Gouritz	Field crops	57	-0.096
	Horticulture	97	-0.036
Berg - Olifants/Doorn	Field crops	19	0.093
	Horticulture	167	-0.154
<b>RSA</b>	<b>Irrigated area</b>	<b>1 413</b>	<b>-0.087</b>
<b>Irrigated water (mil m<sup>3</sup>)</b>			
WMAs 1 – 7	Field crops	4 384	-0.507
	Horticulture	2 117	-0.760
Breede – Gouritz	Field crops	375	-0.501
	Horticulture	579	-0.647
Berg - Olifants/Doorn	Field crops	94	-0.243
	Horticulture	933	-0.624
<b>RSA</b>	<b>Irrigated water use</b>	<b>8 483</b>	<b>-0.589</b>

Table 5-14 below indicates selected macro-economic impacts on a regional level when water is transferred from irrigation to municipal use. Changes in regional GDP for agriculture and non-agriculture are presented. Impacts are relatively small, as can be expected when one sector benefits while another is disadvantaged.

**Table 5-14: Change in GDP in different WMAs for a 50 mil m<sup>3</sup> water transfer from irrigation to municipal use**

		<b>BASE GDP</b>	<b>Scenario: 50 mil m<sup>3</sup> water transferred</b>
<b>WMA / Region</b>	<b>Sectors</b>	<b>Value (Rbn)</b>	<b>% change from base</b>
<b>WMAs 1 – 7</b>	<b>Region total</b>	<b>3 253</b>	<b>0.049</b>
	Agriculture	75	0.040
	Non-agric	3 178	0.049
<b>Breede - Gouritz</b>	<b>Region total</b>	<b>90</b>	<b>0.062</b>
	Agriculture	7	0.031
	Non-agric	82	0.065

		<b>BASE GDP</b>	<b>Scenario: 50 mil m<sup>3</sup> water transferred</b>
<b>WMA / Region</b>	<b>Sectors</b>	<b>Value (Rbn)</b>	<b>% change from base</b>
<b>Berg - Olifants/Doorn</b>	<b>Region total</b>	<b>472</b>	<b>0.049</b>
	Agriculture	14	0.026
	Non-agric	458	0.050
<b>RSA</b>	<b>Total</b>	<b>3 814</b>	<b>0.049</b>
	Agriculture	96	0.038
	Non-agric	3 718	0.050

#### 5.3.4 Macro results for the three scenarios

Table 5-15 below compares macro-economic effects at a national level of the three scenarios that were discussed. The table below indicates that agriculture comprises 2.55% of GDP at factor cost in the base case. A 10% increase in the irrigation water tariff will lead to a 0.01% decrease in GDP at factor cost for the economy in general, and a 0.1% decrease in agriculture's contribution to GDP at factor cost. The biggest negative impact of the irrigation water tariff increase is on the exports of horticultural products. The impacts on non-agriculture in terms of both GDP contribution and trade are only indirect effects and hence much less pronounced.

An increase of 10% in the municipal water rate will lead to a 0.03% decrease in GDP at factor cost for the economy in general and a 0.1% decrease in agriculture's contribution to GDP at factor cost. Non-agricultural sectors are now directly affected and the decrease in the contribution to GDP at factor cost for the non-agricultural sector is 0.03%.

It is only the last scenario that assumes a transfer of water from irrigation to municipal water use that leads to a positive impact on GDP (0.02%), driven by the non-agricultural sector.

**Table 5-15: Macro economic effects (in real terms) – comparison of three scenarios**

		<b>Scenario: 10% increase in irrigation water tariff</b>	<b>Scenario: 10% increase in municipal water rate</b>	<b>Scenario: 50mil m<sup>3</sup> transfer from irrigation to municipal</b>
	<b>Base contribution to GDP at factor cost (%)</b>	<b>Change in contribution based on values in real terms (%)</b>		
GDP factor cost	100.00	-0.01	-0.03	0.02
<b>Agriculture</b>	<b>2.55</b>	<b>-0.10</b>	<b>0.01</b>	<b>-0.04</b>
Field crops	0.71	-0.10	0.02	-0.04
Horticulture	0.62	-0.28	0.02	-0.12
Livestock	0.87	-0.01	0.00	0.00
Other	0.34	-0.01	0.00	-0.01
<b>Non-agriculture</b>	<b>97.45</b>	<b>0.00</b>	<b>-0.03</b>	<b>0.02</b>
Consumption	59.29	-0.01	-0.03	0.02
Investment	19.40	-0.01	-0.08	0.05
Government	20.79	0.00	0.00	0.00
Exports	30.58	-0.01	-0.05	0.03



		Scenario: 10% increase in irrigation water tariff	Scenario: 10% increase in municipal water rate	Scenario: 50mil m <sup>3</sup> transfer from irrigation to municipal
	Base contribution to GDP at factor cost (%)	Change in contribution based on values in real terms (%)		
Agriculture	2.35	-0.49	0.08	-0.22
Field crops	0.32	-0.30	0.10	-0.13
Horticulture	1.60	-0.67	0.07	-0.28
Non-agriculture	97.65	0.00	-0.05	0.04
Processed foods	4.79	-0.06	0.09	-0.09
Imports	-30.06	-0.01	-0.05	0.03
Agriculture	0.81	0.13	-0.05	0.06
Field crops	0.56	0.11	-0.04	0.04
Horticulture	0.14	0.31	-0.05	0.12
Non-agriculture	99.19	-0.01	-0.05	0.03
Processed foods	3.92	0.01	-0.06	0.06

Table 5-16 below compares employment effects of the three scenarios that were discussed. There is a general negative effect on employment when there is a 10% increase in the irrigation water tariff and an increase of 10% in the municipal water rate, with national job losses of 1 600 and 10 000 for the two respective scenarios. It is only the last scenario, which assumes a transfer of water from irrigation to municipal water use, that leads to an increase in employment of 5 800.

**Table 5-16: Employment effects – comparison of three scenarios**

		Scenario: 10% increase in irrigation water tariff	Scenario: 10% increase in municipal water rate	Scenario: 50mil m <sup>3</sup> transfer from irrigation to municipal
	Base employment (‘000)	Change in employment (‘000)		
<b>WMAs 1 – 7</b>	<b>13 173</b>	<b>-1.3</b>	<b>-8.6</b>	<b>5.0</b>
Agriculture	921	0.1	-0.4	0.1
Non-agric	12 252	-1.4	-8.2	4.9
<b>Breede - Gouritz</b>	<b>533</b>	<b>-0.1</b>	<b>-0.3</b>	<b>0.2</b>
Agriculture	104	0.0	0.0	0.0
Non-agric	429	-0.1	-0.3	0.2
<b>Berg - Olifants/Doorn</b>	<b>1 926</b>	<b>-0.3</b>	<b>-1.1</b>	<b>0.6</b>
Agriculture	162	-0.1	0.0	0.0
Non-agric	1 764	-0.2	-1.1	0.6
<b>RSA</b>	<b>15 632</b>	<b>-1.6</b>	<b>-10.0</b>	<b>5.8</b>
Agriculture	1 186	0.1	-0.5	0.1
Non-agric	14 446	-1.7	-9.6	5.7

Table 5-17 below compares income effects of the three scenarios that were discussed. There is a general negative effect in income when there is a 10% increase in the irrigation water tariff and an increase of 10% in the municipal water rate, with aggregate national income decreasing by 0.01% and

0.07% for the two respective scenarios. In the last scenario, which assumes a transfer of water from irrigation to municipal water use, aggregate national income increases by 0.04%.

**Table 5-17: Welfare effects – comparison of three scenarios**

		Scenario: 10% increase in irrigation water tariff	Scenario: 10% increase in municipal water rate	Scenario: 50mil m <sup>3</sup> transfer from irrigation to municipal
	Base hhold income ('000)	Change in income (%)		
<b>WMAs 1 – 7</b>	2 632	-0.01	-0.07	0.04
<b>Breede – Gouritz</b>	74	-0.02	-0.07	0.05
<b>Berg - Olifants/Doorn</b>	366	-0.02	-0.07	0.04
<b>RSA</b>	<b>3 072</b>	<b>-0.01</b>	<b>-0.07</b>	<b>0.04</b>

## 5.4 IMPACT OF CHANGES IN WATER TARIFFS AND TRANSFERS ON THE WESTERN CAPE ECONOMY

Scenarios presented in this section focus on the Western Cape WMAs in terms of the implemented shocks. Results are still reported for the rest of South Africa as well, in order to retain context. Selected results from the static version of the model are presented here. Scenarios include the following:

**Scenario 1:** Reduction in water supply in the Berg - Olifants/Doorn WMA

Sim1: The volume of available irrigation, bulk and municipal water in the Berg - Olifants/Doorn WMA is assumed to decrease by 50%, 40% and 40% respectively. Volume decreases are shown in Table 5-18 below.

**Table 5-18: Scenario 1 assumed water volume changes in Berg - Olifants/Doorn WMA**

	Base (mil m <sup>3</sup> )	Decrease (mil m <sup>3</sup> )
Irrigation	1027	513.5
Bulk	275	110
Municipal (industry)	73	29.2
Municipal (households)	438	0
Total (Berg - Olifants/Doorn)	1813	652.7

Note that the use of water by households is endogenously determined by the model dependent on the price of water. In the case of industries, water is modelled as a constraining production factor, hence the volume available can be exogenously specified.

**Scenario 2:** Transfer of water between sectors in the Berg - Olifants/Doorn WMA

Sim1: Transfer of water from irrigation to bulk and municipal use

Sim2: Transfer of water from bulk and municipal use to irrigation

Volume changes are shown in Table 5-19.

**Table 5-19: Scenario 2 assumed water volume changes in Berg - Olifants/Doorn WMA**

	Base	Sim1	Sim2
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	<b>Water volumes (million m<sup>3</sup>) for Berg - Olifants/Doorn WMA</b>		
Irrigation	1027	-25	+25
Bulk	275	+20	-20
Municipal (industry)	73	+5	-5
Municipal (households)	438	0	0
Total (Berg - Olifants/Doorn)	1813	0	0

**Scenario 3a:** Desalination as alternative water supply option in the Berg - Olifants/Doorn WMA – same volume, different payment options

The same volume of water (50 million m<sup>3</sup>) is made available first to agriculture, and then to industry. The increased cost of desalination is borne alternatively by suppliers of water and then by users of bulk and municipal water.

Sim1: Desalination to supply agriculture with additional irrigation water at an increased cost borne by suppliers of bulk and municipal water.

Sim2: Desalination to supply agriculture with additional irrigation water at an increased cost borne by users of bulk and municipal water (industries and households).

Sim3: Desalination to supply industries with additional water at an increased cost borne by suppliers of bulk and municipal water.

Sim4: Desalination to supply industries with additional water at an increased cost borne by users of bulk and municipal water (industries and households).

Volume changes are shown in Table 5-20.

**Table 5-20: Scenario 3a assumed water volume changes and tariff increases in Berg - Olifants/Doorn WMA**

	<b>Base</b>	<b>Sim1</b>	<b>Sim2</b>	<b>Sim3</b>	<b>Sim4</b>
	<b>Water volumes (million m<sup>3</sup>) for Berg - Olifants/Doorn WMA</b>				
Irrigation	1027	+50	+50	0	0
Bulk	275	0	0	+40	+40
Municipal (industry)	73	0	0	+10	+10
Municipal (households)	438	0	0	0	0
Total (Berg - Olifants/Doorn)	1813	+50	+50	+50	+50
Cost borne by:		Water industry	Users of municipal water	Water industry	Users of municipal water
Tariff increase		12.8 R/kl	12.8 R/kl	12.8 R/kl	12.8 R/kl

**Scenario 3b:** Desalination as alternative water supply option in the Berg - Olifants/Doorn WMA – different volumes, same payment option

Different volumes of desalination water are made available to industry. In all four simulations the increased cost of desalination is borne by users of bulk and municipal water (industries and households).

Sim1: 25 mil m<sup>3</sup> additional desalination water to industry.

Sim2: 50 mil m<sup>3</sup> additional desalination water to industry.

Sim3: 75 mil m<sup>3</sup> additional desalination water to industry.

Sim4: 100 mil m<sup>3</sup> additional desalination water to industry.

Volume changes are shown in Table 5-21.

**Table 5-21: Scenario 3b assumed water volume changes and tariff increases in Berg - Olifants/Doorn WMA**

	Base	Sim1	Sim2	Sim3	Sim4
<b>Water volumes (million m<sup>3</sup>) for Berg - Olifants/Doorn WMA</b>					
Irrigation	1027	0	0	0	0
Bulk	275	+20	+40	+60	+80
Municipal (industry)	73	+5	+10	+15	+20
Municipal (households)	438	0	0	0	0
Total (Berg - Olifants/Doorn)	1813	+25	+50	+75	+100
Cost borne by:		Users of municipal water			
Tariff increase		12.8 R/kl			

**Scenario 4:** Reuse as alternative water supply option in the Berg - Olifants/Doorn WMA

Sim1: Additional treated water to supply industries and households at an increased tariff borne by suppliers of bulk and municipal water.

Sim2: Additional treated water to supply industries and households at an increased tariff borne by users of bulk and municipal water (industry and households).

Volume changes are shown in Table 5-22.

**Table 5-22: Scenario 4 assumed water volume changes and tariff increases in Berg - Olifants/Doorn WMA**

	Base	Sim1	Sim2
<b>Water volumes (million m<sup>3</sup>) for Berg - Olifants/Doorn WMA</b>			
Irrigation	1027	0	0
Bulk	275	+20	+20
Municipal (industry)	73	+5	+5
Municipal (households)	438	0	0
Total (Berg - Olifants/Doorn)	1813	+25	+25
Cost borne by:		Water industry	Users of municipal water
Tariff increase		5.4 R/kl	5.4 R/kl

**Scenario 5:** Alien invasive plant removal for additional water in the Berg - Olifants/Doorn WMA

Sim1: Alien Invasive Plant Removal with an increased tariff borne by suppliers of bulk and municipal water.

Volume changes are shown in Table 5-23.

**Table 5-23: Scenario 5 assumed water volume changes and tariff increases in Berg - Olifants/Doorn WMA**

	Base	Sim1
<b>Water volumes (million m<sup>3</sup>) for Berg - Olifants/Doorn WMA</b>		
Irrigation	1027	0

Bulk	275	+20
Municipal (industry)	73	+5
Municipal (households)	438	0
Total (Berg - Olifants/Doorn)	1813	+25
Cost borne by:		Water industry
Tariff increase		2.1 R/kl

Results of the five scenarios are discussed in the following sections.

#### 5.4.1 Scenario 1: Reduction in water supply in the Berg - Olifants/Doorn WMA

The volume of water available in the Berg - Olifants/Doorn WMA is assumed to decrease as follows: irrigation water by 50%; bulk and municipal water each by 40%.

Table 5-24 below indicates that on a national level the total volume of water used decreased by only 4.8% but within the Berg - Olifants/Doorn WMA it decreased on average by 45%. The decrease in household's use of municipal water of 37% is endogenously determined and therefore also captures some of the indirect impacts of the reduction in water as part of the imposed shock; it also captures some of the effects of the general contraction of the economy.

**Table 5-24: Model changes in volumes of water used for the water reduction scenario**

	National		Berg - Olifants/Doorn WMA	
	Base (mil m <sup>3</sup> )	Change (%)	Base (mil m <sup>3</sup> )	Change (%)
Irrigation	8 483	-6.1%	1 027	-50%
Bulk	3 923	-2.8%	275	-40%
Municipal (industries)	1 079	-2.7%	74	-40%
Municipal (hholds)	3 741	-4.7%	438	-37%
Total	17 226	-4.8%	1 813	-45%

Table 5-25 below shows the general negative impact on agricultural production under irrigation due to the reduction in the volume of water available for irrigation. The impacts in regions other than the Berg - Olifants/Doorn WMA are only impacted indirectly, mostly through price impacts, as indicated by the small changes. In the Berg - Olifants/Doorn WMA the reduction in production under irrigation is more pronounced for field crops (31.3%) than for horticulture (7.8%). The reduction in area irrigated is relatively smaller than the reduction in production for both field crops (8.3%) and horticulture (7.1%).

**Table 5-25: Change in production (irrigated), area (irrigated) and irrigation water use for the water reduction scenario**

		Base	Scenario: water
		Quantities	Change (%)
<b>Production (1000 tons)</b>			
WMAs 1 - 7	Field crops	7 749	0.2
	Horticulture	9 282	0.6
Breede - Gouritz	Field crops	539	-0.4
	Horticulture	2 768	1.1
Berg - Olifants/Doorn	Field crops	122	-31.3

		<b>Base</b>	<b>Scenario: water reduction</b>
		<b>Quantities</b>	<b>Change (%)</b>
	Horticulture	2 166	-7.8
<b>RSA</b>	<b>Irrigated production</b>	<b>22 625</b>	<b>-0.5</b>
<b>Area (1000 ha)</b>			
WMAs 1 - 7	Field crops	673	0.2
	Horticulture	400	-0.5
Breede - Gouritz	Field crops	57	-0.1
	Horticulture	97	1.1
Berg - Olifants/Doorn	Field crops	19	-8.3
	Horticulture	167	-7.1
<b>RSA</b>	<b>Irrigated area</b>	<b>1 413</b>	<b>-0.9</b>
<b>Irrigated water (mil m<sup>3</sup>)</b>			
WMAs 1 – 7	Field crops	4 384	0.3
	Horticulture	2 117	-0.7
Breede – Gouritz	Field crops	375	-0.6
	Horticulture	579	0.4
Berg - Olifants/Doorn	Field crops	94	-47.6
	Horticulture	933	-50.2
<b>RSA</b>	<b>Irrigated water use</b>	<b>8 483</b>	<b>-6.1</b>

Table 5-26 below indicates GDP impacts on a regional level when the volume of water available in the Berg - Olifants/Doorn WMA is assumed to decrease. Changes in regional GDP for agricultural and non-agricultural industries are presented. GDP in the Berg – Olifants/Doorn WMA decreases by 0.35% and the decrease in GDP at a national level is 0.22%.

**Table 5-26: Change in GDP in different WMAs for the water reduction scenario**

		<b>BASE GDP</b>	<b>Scenario: water reduction</b>
<b>WMA / Region</b>	<b>Sectors</b>	<b>Value (Rbn)</b>	<b>Change (%)</b>
<b>WMAs 1 – 7</b>	<b>Region total</b>	<b>3 253</b>	<b>-0.20</b>
	Agriculture	75	-0.13
	Non-agric	3 178	-0.20
<b>Breede - Gouritz</b>	<b>Region total</b>	<b>90</b>	<b>-0.18</b>
	Agriculture	7	0.37
	Non-agric	82	-0.22
<b>Berg Olifants/Doorn</b>	<b>Region total</b>	<b>472</b>	<b>-0.35</b>
	Agriculture	14	-1.10
	Non-agric	458	-0.33
<b>RSA</b>	<b>Total</b>	<b>3 814</b>	<b>-0.22</b>
	Agriculture	96	-0.23
	Non-agric	3 718	-0.22

Table 5-27 below indicates the impact of a water reduction on employment and income. Employment in the directly affected WMA decreases by 6 900 and on a national level 26 800 job opportunities are lost. Household income decreases by 0.31% in the Berg - Olifants/Doorn WMA and by 0.19% on a national level.

**Table 5-27: Employment and household income effects for the water reduction scenario**

	Base employment ('000)	Change in employment ('000)	Base income (Rmillion)	Change in income (%)
<b>WMAs 1 – 7</b>	<b>13 173</b>	<b>-19.6</b>	<b>2 632</b>	<b>-0.18</b>
Agriculture	921	-0.6		
Non-agric	12 252	-19.0		
<b>Breede - Gouritz</b>	<b>533</b>	<b>-0.3</b>	<b>74</b>	<b>-0.16</b>
Agriculture	104	0.4		
Non-agric	429	-0.7		
<b>Berg - Olifants/Doorn</b>	<b>1 926</b>	<b>-6.9</b>	<b>366</b>	<b>-0.31</b>
Agriculture	162	-3.5		
Non-agric	1 764	-3.4		
<b>RSA</b>	<b>15 632</b>	<b>-26.8</b>	<b>3 072</b>	<b>-0.19</b>
Agriculture	1 186	-3.7		
Non-agric	14 446	-23.2		

#### 5.4.2 Scenario 2: Water transfer between sectors in the Berg - Olifants/Doorn WMA

In simulation 1 there is a transfer of water from irrigation to bulk and municipal use and in simulation 2 the transfer of water is from bulk and municipal use to irrigation in the Berg - Olifants/Doorn WMA. A total of 25 million m<sup>3</sup> is transferred.

Table 5-28 below indicates that indirect effects of the water transfers on areas not directly affected by the water transfers are negligible. When 25 million m<sup>3</sup> of irrigation water is transferred away from agriculture towards industries (sim 1), then the total volume of water used within the Berg - Olifants/Doorn WMA increased by 1.36%. When 25 million m<sup>3</sup> of industry water (20m m<sup>3</sup> bulk and 5m m<sup>3</sup> municipal) is transferred away from industries towards agriculture (sim 2), then the total volume of water used within the Berg - Olifants/Doorn WMA decreased by 1.4%.

**Table 5-28: Model changes in volumes of water for the water transfer scenario**

	Base	Sim 1: Irrigation to industry	Sim 2: Industry to irrigation
	Volume (mil m <sup>3</sup> )	Change (%)	
<b>WMAs 1 – 7</b>	<b>14 298</b>	<b>0.01</b>	<b>-0.01</b>
Irrigation	6 502	0.00	0.00
Bulk	3 593	0.00	0.00
Municipal (industries)	991	0.00	0.00
Municipal (hholds)	3 212	0.05	-0.05
<b>Breede - Gouritz</b>	<b>1 116</b>	<b>0.00</b>	<b>0.00</b>
Irrigation	955	0.00	0.00
Bulk	56	0.00	0.00
Municipal (industries)	14	0.00	0.00
Municipal (hholds)	91	0.05	-0.05
<b>Berg - Olifants/Doorn</b>	<b>1 813</b>	<b>1.36</b>	<b>-1.40</b>
Irrigation	1 027	-2.43	2.43
Bulk	275	7.28	-7.28

	Base	Sim 1: Irrigation to industry	Sim 2: Industry to irrigation
	Volume (mil m <sup>3</sup> )	Change (%)	
Municipal (industries)	74	6.79	-6.79
Municipal (hholds)	438	5.63	-5.82
<b>RSA</b>	<b>17 226</b>	<b>0.15</b>	<b>-0.16</b>
Irrigation	8 483	-0.29	0.29
Bulk	3 923	0.51	-0.51
Municipal (industries)	1 079	0.46	-0.46
Municipal (hholds)	3 741	0.70	-0.73

Table 5-29 below shows the impacts of water transfers on the irrigation sector in the directly affected Berg - Olifants/Doorn WMA area. as well as on national level. When 25 million m<sup>3</sup> of irrigation water is transferred to industries (sim 1), field crop production in the Berg - Olifants/Doorn WMA decreases by 1.14%, while the use of irrigation water for field crops decreases by 2%. On a national level results are small as it reflects only the indirect effects of the changes in the Berg - Olifants/Doorn WMA.

When 25 million m<sup>3</sup> water is transferred from industries to irrigation in simulation 2 the results are almost a mirror image of those for simulation 1, but the magnitudes of the changes are slightly smaller. The indirect effects of the water transfers on water management areas not directly affected by the water transfers are negligible and therefore not reported.

**Table 5-29: Change in production (irrigated), area (irrigated) and irrigation water use for the water transfer scenario**

		Base	Sim 1: Irrigation to industry	Sim 2: Industry to irrigation
		Quantities	Change (%)	
<b>Production (1000 tons)</b>				
Berg - Olifants/Doorn	Field crops	122	-1.14	1.11
	Horticulture	2 166	-0.25	0.24
<b>RSA</b>	<b>Irrigated production</b>	<b>22 625</b>	<b>-0.01</b>	<b>0.01</b>
<b>Area (1000 ha)</b>				
Berg - Olifants/Doorn	Field crops	19	-0.18	0.17
	Horticulture	167	-0.29	0.29
<b>RSA</b>	<b>Irrigated area</b>	<b>1 413</b>	<b>-0.04</b>	<b>0.04</b>
<b>Irrigated water (mil m<sup>3</sup>)</b>				
Berg - Olifants/Doorn	Field crops	94	-1.99	1.96
	Horticulture	933	-2.48	2.48
<b>RSA</b>	<b>Irrigated water use</b>	<b>8 483</b>	<b>-0.29</b>	<b>0.29</b>

Results in Table 5-30 show that when 25 million m<sup>3</sup> of irrigation water is transferred to industries (sim 1), GDP increases by 0.036% in the Berg - Olifants/Doorn WMA and by 0.022% on a national level. It is only the agriculture industry in the Berg - Olifants/Doorn WMA that is negatively impacted. When 25 million m<sup>3</sup> water is transferred from industries to irrigation (sim 2) GDP decreases by 0.038% in the Berg - Olifants/Doorn WMA and by 0.024% on a national level.



**Table 5-30: Change in GDP in different WMAs for the water transfer scenario**

		<b>BASE GDP</b>	<b>Sim 1: Irrigation to industry</b>	<b>Sim 2: Industry to irrigation</b>
<b>WMA / Region</b>	<b>Sectors</b>	<b>Value (Rbn)</b>	<b>Change (%)</b>	
<b>WMAs 1 – 7</b>	<b>Region total</b>	<b>3 253</b>	<b>0.020</b>	<b>-0.021</b>
	Agriculture	75	0.027	-0.029
	Non-agric	3 178	0.020	-0.021
<b>Breede - Gouritz</b>	<b>Region total</b>	<b>90</b>	<b>0.022</b>	<b>-0.024</b>
	Agriculture	7	0.042	-0.043
	Non-agric	82	0.021	-0.022
<b>Berg - Olifants/Doorn</b>	<b>Region total</b>	<b>472</b>	<b>0.036</b>	<b>-0.038</b>
	Agriculture	14	-0.004	0.001
	Non-agric	458	0.037	-0.040
<b>RSA</b>	<b>Total</b>	<b>3 814</b>	<b>0.022</b>	<b>-0.024</b>
	Agriculture	96	0.024	-0.026
	Non-agric	3 718	0.022	-0.024

Table 5-31 below indicates the impact of water transfers on employment. The changes in employment in the directly affected WMA is less pronounced than in the rest of South Africa, reflecting that the impact on industries has greater national linkages through price changes compared to the agricultural sector. Although employment in agriculture is negatively impacted when 25 million m<sup>3</sup> of irrigation water is transferred to industries (sim 1), the net effect is that 300 job opportunities are created in the Berg - Olifants/Doorn WMA; and 2 440 job opportunities are created on a national level. When 25 million m<sup>3</sup> water is transferred from industries to irrigation (sim 2) 2 610 job opportunities are lost on a national level.

**Table 5-31: Employment effects for the water transfer scenario**

	<b>Base employment</b>	<b>Sim 1: Irrigation to industry</b>	<b>Sim 2: Industry to irrigation</b>
	<b>Quantity ('000)</b>	<b>Change ('000)</b>	
<b>WMAs 1 – 7</b>	<b>13 173</b>	<b>2.04</b>	<b>-2.18</b>
Agriculture	921	0.21	-0.23
Non-agric	12 252	1.82	-1.95
<b>Breede - Gouritz</b>	<b>533</b>	<b>0.10</b>	<b>-0.11</b>
Agriculture	104	0.04	-0.04
Non-agric	429	0.07	-0.07
<b>Berg - Olifants/Doorn</b>	<b>1 926</b>	<b>0.30</b>	<b>-0.33</b>
Agriculture	162	-0.09	0.08
Non-agric	1 764	0.38	-0.41
<b>RSA</b>	<b>15 632</b>	<b>2.44</b>	<b>-2.61</b>
Agriculture	1 186	0.17	-0.18
Non-agric	14 446	2.27	-2.43

When 25 million m<sup>3</sup> of irrigation water is transferred to industries (sim 1), household income increases by 0.034% in the Berg - Olifants/Doorn WMA and by 0.02% on a national level. When 25 million m<sup>3</sup> water is transferred from industries to irrigation (sim 2) household income decreases by 0.037% in the Berg - Olifants/Doorn WMA and by 0.022% on a national level. These results are shown in Table 5-32.

**Table 5-32: Household income effects for the water transfer scenario**

	Base income	Sim 1: Irrigation to industry	Sim 2: Industry to irrigation
	Value (Rmillion)	Change (%)	
<b>WMAs 1 – 7</b>	2 632	0.018	-0.020
<b>Breede - Gouritz</b>	74	0.021	-0.022
<b>Berg - Olifants/Doorn</b>	366	0.034	-0.037
<b>RSA</b>	3 072	0.020	-0.022

### 5.4.3 Scenario 3: Desalination as alternative water supply option in the Berg - Olifants/Doorn WMA

#### 2.4.3.1 Scenario 3a: Desalination – same volumes, different payment options

In simulations 1 and 2 there is additional water for irrigation derived from desalination, and in simulations 3 and 4 the additional desalination water is made available to industries that use bulk and municipal water in the Berg - Olifants/Doorn WMA. Desalination provides an additional 50 million m<sup>3</sup>. In simulations 1 and 3 the water industry pays the higher tariff to cover the cost of desalination, whereas in simulations 2 and 4 it is assumed that the users of municipal water (including households) cover the increased cost of the more expensive desalination water and this is recovered as a tax on water. Note that even though the agricultural sector is assumed to receive the additional water in simulation 1, it is still other industries that pay for it, not the agricultural sector.

Table 5-33 below indicates that the different payment options cause indirect effects in WMAs that do not receive water. The increased cost of water production is indirectly passed on to the users by industries in simulations 1 and 3, whereas the increased cost of water production is recovered directly from users in the form of a tax in simulations 2 and 4.

From the previous scenario on water transfers it became clear that GDP tends to be relatively greater when additional water is diverted to industrial use rather than irrigation agriculture. The same trend can be seen in the tables that follow: simulations 3 and 4 (when industry receives the desalination water) tend to yield more positive results compared to simulations 1 and 2 (when agriculture receives the desalination water). Results for different payment options are more mixed, but impacts are generally more favourable when the cost of desalination is recovered from users.

Focusing on simulations 1 and 2 in Table 5-33 below, it can be seen that the negative impact of the additional cost of desalination outweighs the positive impact of the additional water for irrigation in the Berg - Olifants/Doorn WMA. The results for other WMAs are smaller indirect effects.

When additional water is allocated to industry (simulations 3 and 4) the expansion in the economy is sufficiently large to stimulate further use of water, as can be seen by the increased water use of all water categories in all WMAs. It is only in the case where costs are recovered by users in the Berg - Olifants/Doorn WMA (simulation 4) that there is a reduction in the use of water by households of 13.8%, with a net negative effect of 0.49% on the WMA level.

**Table 5-33: Model changes in volumes of water for the desalination scenario— same volumes, different payment options**

	Base	Sim 1: Irrigation water & industry pays	Sim 2: Irrigation water & municipal users pay	Sim 3: Industry water & industry pays	Sim 4: Industry water & municipal users pay
	Volume (mil m <sup>3</sup> )	Change (%)			
<b>WMAs 1 – 7</b>	<b>14 298</b>	<b>0.47</b>	<b>0.03</b>	<b>0.04</b>	<b>0.07</b>
Irrigation	6 502	0.00	0.00	0.04	0.10
Bulk	3 593	2.19	0.23	0.00	0.00
Municipal (industries)	991	-1.12	-0.19	0.00	0.00
Municipal (hholds)	3 212	0.00	-0.07	0.10	0.12
<b>Brede – Gouritz</b>	<b>1 116</b>	<b>0.11</b>	<b>0.01</b>	<b>0.04</b>	<b>0.09</b>
Irrigation	955	0.00	0.00	0.04	0.09
Bulk	56	2.48	0.29	0.00	0.00
Municipal (industries)	14	-1.03	-0.19	0.00	0.00
Municipal (hholds)	91	0.04	-0.04	0.12	0.15
<b>Berg - Olifants/Doorn</b>	<b>1 813</b>	<b>-15.98</b>	<b>-13.08</b>	<b>5.07</b>	<b>-0.49</b>
Irrigation	1 027	4.87	4.87	0.07	0.14
Bulk	275	-46.50	-17.91	14.55	14.55
Municipal (industries)	74	-47.24	-47.85	13.59	13.59
Municipal (hholds)	438	-40.50	-46.33	9.44	-13.76
<b>RSA</b>	<b>17 226</b>	<b>-1.28</b>	<b>-1.35</b>	<b>0.57</b>	<b>0.02</b>
Irrigation	8 483	0.59	0.59	0.04	0.10
Bulk	3 923	-1.21	-1.04	1.02	1.02
Municipal (industries)	1 079	-4.27	-3.44	0.93	0.93
Municipal (hholds)	3 741	-4.74	-5.49	1.20	-1.50

Table 5-34 below shows the impact on agricultural production under irrigation due to additional desalination water available for irrigation (simulations 1 and 2) and industry (simulations 3 and 4). The impacts in regions other than the Berg - Olifants/Doorn WMA are only impacted indirectly, mostly through price impacts, as indicated by the small changes.

In the Berg - Olifants/Doorn WMA the production under irrigation is stimulated because of the increase in irrigation water (simulations 1 / 2), for both field crops (2.21% / 2.24%) and horticulture (0.66% / 0.71%), with resultant increases in area and irrigation water used. On aggregate, production of horticulture in WMAs 1 – 7 decreases, but area and volume of irrigation water used increase, which appears as a contradiction. It should be noted however that on a more disaggregated commodity level (not presented here), there is consistent increase or decrease in production, area and volume of irrigation water used per commodity.

When additional desalination water is allocated to industry (simulations 3 and 4), indirect effects on agricultural production, area and irrigation water use is small but positive throughout.

**Table 5-34: Change in production (irrigated), area (irrigated) and irrigation water use for the desalination scenario— same volumes, different payment options**

		<b>Base</b>	<b>Sim 1: Irrigation water &amp; industry pays</b>	<b>Sim 2: Irrigation water &amp; municipal users pay</b>	<b>Sim 3: Industry water &amp; industry pays</b>	<b>Sim 4: Industry water &amp; municipal users pay</b>
		<b>Quantities</b>	<b>Change (%)</b>			
<b>Production (1000 tons)</b>						
WMAs 1 – 7	Field crops	7 749	-0.06	-0.02	0.03	0.08
	Horticulture	9 282	-0.08	-0.04	0.01	0.05
Breede – Gouritz	Field crops	539	0.01	0.04	0.04	0.09
	Horticulture	2 768	-0.15	-0.10	0.01	0.06
Berg - Olifants/Doorn	Field crops	122	2.21	2.24	0.02	0.06
	Horticulture	2 166	0.66	0.71	0.01	0.06
<b>RSA</b>	<b>Irrigated production</b>	<b>22 625</b>	<b>0.01</b>	<b>0.05</b>	<b>0.02</b>	<b>0.06</b>
<b>Area (1000 ha)</b>						
WMAs 1 – 7	Field crops	673	-0.10	-0.02	0.04	0.10
	Horticulture	400	0.01	0.09	0.04	0.10
Breede – Gouritz	Field crops	57	-0.08	0.01	0.04	0.10
	Horticulture	97	-0.19	-0.11	0.03	0.09
Berg - Olifants/Doorn	Field crops	19	0.78	0.86	0.03	0.09
	Horticulture	167	1.09	1.19	0.07	0.15
<b>RSA</b>	<b>Irrigated area</b>	<b>1 413</b>	<b>0.08</b>	<b>0.16</b>	<b>0.04</b>	<b>0.10</b>
<b>Irrigated water (mil m<sup>3</sup>)</b>						
WMAs 1 – 7	Field crops	4 384	-0.05	-0.05	0.04	0.10
	Horticulture	2 117	0.11	0.09	0.04	0.11
Breede – Gouritz	Field crops	375	0.04	0.06	0.04	0.10
	Horticulture	579	-0.03	-0.04	0.03	0.09
Berg - Olifants/Doorn	Field crops	94	3.82	3.84	0.03	0.09
	Horticulture	933	4.97	4.97	0.07	0.14
<b>RSA</b>	<b>Irrigated water use</b>	<b>8 483</b>	<b>0.59</b>	<b>0.59</b>	<b>0.04</b>	<b>0.10</b>

Focusing on the first two simulations in Table 5-35 it can be seen that the negative impact of the additional cost of the desalination outweighs the positive impact of the additional water for irrigation in the Berg - Olifants/Doorn WMA. The GDP in the directly affected WMA decreases by 0.29% when industry pays, but the negative effect is slightly less when consumers pay (-0.23%). The GDP impacts on the other WMAs are indirect and less pronounced. When industry pays (sim 1) the net effect on national GDP is -0.11%, whereas the net effect on the national economy is almost negligible when consumers bear the cost (-0.03% in sim 2).

When industries receive the additional desalination water (simulations 3 and 4), the net national impact is small but positive. It is only the Berg - Olifants/Doorn WMA that shows a decrease in GDP because the cost of desalination is covered by either industries or users in this WMA. Tax on users have a more positive outcome compared to when industries absorb the cost.

**Table 5-35: Change in GDP in different WMAs for the desalination scenario— same volumes, different payment options**

		BASE GDP	Sim 1: Irrigation water & industry pays	Sim 2: Irrigation water & municipal users pay	Sim 3: Industry water & industry pays	Sim 4: Industry water & municipal users pay
WMA / Region	Sectors	Value (Rbn)	Change (%)			
<b>WMAs 1 – 7</b>	<b>Region total</b>	<b>3 253</b>	<b>-0.08</b>	<b>0.00</b>	<b>0.05</b>	<b>0.09</b>
	Agriculture	75	-0.10	0.00	0.04	0.10
	Non-agric	3 178	-0.08	0.00	0.05	0.09
<b>Breede Gouritz</b>	<b>Region total</b>	<b>90</b>	<b>-0.09</b>	<b>0.00</b>	<b>0.05</b>	<b>0.10</b>
	Agriculture	7	-0.15	-0.06	0.04	0.09
	Non-agric	82	-0.08	0.00	0.05	0.10
<b>Berg Olifants/Doorn</b>	<b>Region total</b>	<b>472</b>	<b>-0.29</b>	<b>-0.23</b>	<b>-0.08</b>	<b>-0.05</b>
	Agriculture	14	-0.01	0.08	0.04	0.10
	Non-agric	458	-0.30	-0.24	-0.08	-0.05
<b>RSA</b>	<b>Total</b>	<b>3 814</b>	<b>-0.11</b>	<b>-0.03</b>	<b>0.03</b>	<b>0.07</b>
	Agriculture	96	-0.09	0.00	0.04	0.10
	Non-agric	3 718	-0.11	-0.03	0.03	0.07

Table 5-36 below indicates the impact of different desalination options on employment. Employment for the agricultural sector in the Berg - Olifants/Doorn WMA increases between 190 (sim 1) and 320 (sim 2) job opportunities when water is allocated to irrigation. For all other sectors in the economy employment declines when industry covers the cost, leading to a net national job loss of 10 340. When costs are recovered via a tax, then the impact is less negative with a net national job loss of 1 290.

When desalination water is available to industry, all WMAs show an increase in employment, with the exception of non-agricultural industry in the directly affected WMA. Net national job opportunities increasing between 6 440 (sim 3) and 10 290 (sim 4).

**Table 5-36: Employment effects for the desalination scenario— same volumes, different payment options**

	Base employment	Sim 1: Irrigation water & industry pays	Sim 2: Irrigation water & municipal users pay	Sim 3: Industry water & industry pays	Sim 4: Industry water & municipal users pay
	Quantity ('000)	Change ('000)			
<b>WMAs 1 – 7</b>	<b>13 173</b>	<b>-7.73</b>	<b>0.84</b>	<b>5.23</b>	<b>9.79</b>
Agriculture	921	-0.75	-0.03	0.28	0.75
Non-agric	12 252	-6.99	0.87	4.95	9.04
<b>Breede - Gouritz</b>	<b>533</b>	<b>-0.39</b>	<b>-0.01</b>	<b>0.21</b>	<b>0.42</b>
Agriculture	104	-0.13	-0.06	0.03	0.08
Non-agric	429	-0.25	0.04	0.18	0.34
<b>Berg - Olifants/Doorn</b>	<b>1 926</b>	<b>-2.22</b>	<b>-2.12</b>	<b>1.00</b>	<b>0.08</b>
Agriculture	162	0.19	0.32	0.04	0.14
Non-agric	1 764	-2.41	-2.44	0.95	-0.06
<b>RSA</b>	<b>15 632</b>	<b>-10.34</b>	<b>-1.29</b>	<b>6.44</b>	<b>10.29</b>
Agriculture	1 186	-0.69	0.23	0.35	0.98
Non-agric	14 446	-9.65	-1.52	6.09	9.31

The household income effects in Table 5-37 below are quite mixed because households are the owners of all factors and receive incomes from these factors in different proportions. In all four simulations households in the Berg - Olifants/Doorn WMA are worse off, indicating that the benefit of the additional water is outweighed by the cost thereof. Households are better off when the cost of desalination is recovered via a tax paid by users of the water rather than by the industries.

**Table 5-37: Household income effects for the desalination scenario— same volumes, different payment options**

	Base income	Sim 1: Irrigation water & industry pays	Sim 2: Irrigation water & municipal users pay	Sim 3: Industry water & industry pays	Sim 4: Industry water & municipal users pay
	Value (Rmillion)	Change (%)			
<b>WMAs 1 – 7</b>	<b>2 632</b>	<b>-0.07</b>	<b>0.00</b>	<b>0.05</b>	<b>0.08</b>
<b>Breede – Gouritz</b>	<b>74</b>	<b>-0.08</b>	<b>-0.01</b>	<b>0.05</b>	<b>0.09</b>
<b>Berg - Olifants/Doorn</b>	<b>366</b>	<b>-0.28</b>	<b>-0.20</b>	<b>-0.13</b>	<b>-0.05</b>
<b>RSA</b>	<b>3 072</b>	<b>-0.10</b>	<b>-0.03</b>	<b>0.02</b>	<b>0.07</b>

#### 2.4.3.2 Scenario 3b: Desalination – different volumes, same payment option

In simulations 1 to 4 additional desalination water is made available to industries that use bulk and municipal water in the Berg - Olifants/Doorn WMA. Desalination provides additional water as follows: sim1: 25 million m<sup>3</sup>, sim2: 50 million m<sup>3</sup>, sim3: 75 million m<sup>3</sup> and sim4: 100 million m<sup>3</sup>. In all four simulations, it is assumed that the users of municipal water (including households) cover the increased cost of the more expensive desalination water and this is recovered as a tax on water.

Table 5-38 below indicates the impacts on use of different types of water in the different WMAs, for different volumes of additional desalination water to industry. When additional water is allocated to

industry the expansion in the economy is sufficiently large to stimulate further use of water, as can be seen by the increased water use of all water categories in all WMAs. The exception is the reduction in the use of water by households in the Berg - Olifants/Doorn WMA, which declines by between 6.5% (sim 1) and 37.4% (sim 4). Households water use is endogenously determined, and it declines substantially because of the substantial cost increase. The cost that needs to be recovered from water consumers (industries and households) for the additional desalination water at R12.8/kl, amounts to between R320 million (sim 1) and R1.28 billion (sim 4).

**Table 5-38: Model changes in volumes of water for the desalination scenario – industry water, municipal water users pay**

	Base	Sim 1: 25 mil m <sup>3</sup>	Sim 2: 50 mil m <sup>3</sup>	Sim 3: 75 mil m <sup>3</sup>	Sim 4: 100 mil m <sup>3</sup>
		<b>Industry water and municipal water users pay</b>			
	<b>Volume (mil m<sup>3</sup>)</b>	<b>Change (%)</b>			
<b>WMAs 1 – 7</b>	<b>14 298</b>	<b>0.04</b>	<b>0.07</b>	<b>0.11</b>	<b>0.14</b>
Irrigation	6 502	0.05	0.10	0.15	0.20
Bulk	3 593	0.00	0.00	0.00	0.00
Municipal (industries)	991	0.00	0.00	0.00	0.00
Municipal (hholds)	3 212	0.06	0.12	0.18	0.22
<b>Breede – Gouritz</b>	<b>1 116</b>	<b>0.05</b>	<b>0.09</b>	<b>0.14</b>	<b>0.19</b>
Irrigation	955	0.05	0.09	0.14	0.19
Bulk	56	0.00	0.00	0.00	0.00
Municipal (industries)	14	0.00	0.00	0.00	0.00
Municipal (hholds)	91	0.08	0.15	0.23	0.29
<b>Berg - Olifants/Doorn</b>	<b>1 813</b>	<b>-0.14</b>	<b>-0.49</b>	<b>-1.77</b>	<b>-3.36</b>
Irrigation	1 027	0.07	0.14	0.21	0.28
Bulk	275	7.28	14.55	21.83	29.11
Municipal (industries)	74	6.79	13.59	20.38	27.17
Municipal (hholds)	438	-6.45	-13.76	-24.95	-37.42
<b>RSA</b>	<b>17 226</b>	<b>0.02</b>	<b>0.02</b>	<b>-0.09</b>	<b>-0.22</b>
Irrigation	8 483	0.05	0.10	0.16	0.21
Bulk	3 923	0.51	1.02	1.53	2.04
Municipal (industries)	1 079	0.46	0.93	1.39	1.85
Municipal (hholds)	3 741	-0.78	-1.68	-3.08	-4.63

Table 5-39 below shows the impact on agricultural production under irrigation due to additional desalination water available for industry. All impacts are indirect because irrigation water is not directly affected in this scenario. The impacts are mostly price driven and national production under irrigation expands by between 0.03% (sim 1) and 0.13% (sim 4). Irrigated area and water use both increase by between 0.05% (sim 1) and 0.21% (sim 4).

**Table 5-39: Change in production (irrigated), area (irrigated) and irrigation water use for the desalination scenario – industry water, municipal water users pay**

		<b>Base</b>	<b>Sim 1: 25 mil m<sup>3</sup></b>	<b>Sim 2: 50 mil m<sup>3</sup></b>	<b>Sim 3: 75 mil m<sup>3</sup></b>	<b>Sim 4: 100 mil m<sup>3</sup></b>
		<b>Quantities</b>	<b>Change (%)</b>			
<b>Production (1000 tons)</b>						
WMAs 1 – 7	Field crops	7 749	0.04	0.08	0.12	0.16
	Horticulture	9 282	0.03	0.05	0.08	0.11
Breede – Gouritz	Field crops	539	0.05	0.09	0.14	0.18
	Horticulture	2 768	0.03	0.06	0.09	0.12
Berg - Olifants/Doorn	Field crops	122	0.03	0.06	0.10	0.14
	Horticulture	2 166	0.03	0.06	0.09	0.12
<b>RSA</b>	<b>Irrigated production</b>	<b>22 625</b>	<b>0.03</b>	<b>0.06</b>	<b>0.10</b>	<b>0.13</b>
<b>Area (1000 ha)</b>						
WMAs 1 – 7	Field crops	673	0.05	0.10	0.15	0.19
	Horticulture	400	0.05	0.10	0.15	0.20
Breede – Gouritz	Field crops	57	0.05	0.10	0.15	0.20
	Horticulture	97	0.04	0.09	0.13	0.18
Berg - Olifants/Doorn	Field crops	19	0.05	0.09	0.14	0.18
	Horticulture	167	0.08	0.15	0.22	0.30
<b>RSA</b>	<b>Irrigated area</b>	<b>1 413</b>	<b>0.05</b>	<b>0.10</b>	<b>0.16</b>	<b>0.21</b>
<b>Irrigated water (mil m<sup>3</sup>)</b>						
WMAs 1 – 7	Field crops	4 384	0.05	0.10	0.15	0.19
	Horticulture	2 117	0.06	0.11	0.17	0.22
Breede – Gouritz	Field crops	375	0.05	0.10	0.16	0.21
	Horticulture	579	0.05	0.09	0.14	0.18
Berg - Olifants/Doorn	Field crops	94	0.05	0.09	0.14	0.18
	Horticulture	933	0.07	0.14	0.22	0.29
<b>RSA</b>	<b>Irrigated water use</b>	<b>8 483</b>	<b>0.05</b>	<b>0.10</b>	<b>0.16</b>	<b>0.21</b>



In Table 5-40 below it can be seen that the negative impact of the additional cost of the desalination outweighs the positive impact of the additional water for industries in the Berg - Olifants/Doorn WMA. GDP of industry in the directly affected WMA decreases by between 0.03% (sim 1) and 0.13% (sim 4) and the positive impacts on agriculture is not sufficient to offset it, giving a net negative impact on GDP in the Berg - Olifants/Doorn WMA. The GDP impacts on the other WMAs are however positive, hence the national GDP increases by between 0.04% (sim 1) and 0.13% (sim 4).

**Table 5-40: Change in GDP in different WMAs for the desalination scenario – industry water, municipal water users pay**

		Base	Sim 1: 25 mil m <sup>3</sup>	Sim 2: 50 mil m <sup>3</sup>	Sim 3: 75 mil m <sup>3</sup>	Sim 4: 100 mil m <sup>3</sup>
			<b>Industry water and municipal water users pay</b>			
WMA / Region	Sectors	Value (Rbn)	Change (%)			
<b>WMAs 1 – 7</b>	<b>Region total</b>	<b>3 253</b>	<b>0.05</b>	<b>0.09</b>	<b>0.13</b>	<b>0.17</b>
	Agriculture	75	0.05	0.10	0.15	0.19
	Non-agric	3 178	0.05	0.09	0.13	0.17
<b>Breede – Gouritz</b>	<b>Region total</b>	<b>90</b>	<b>0.05</b>	<b>0.10</b>	<b>0.14</b>	<b>0.19</b>
	Agriculture	7	0.05	0.09	0.14	0.19
	Non-agric	82	0.05	0.10	0.14	0.19
<b>Berg Olifants/Doorn</b>	<b>Region total</b>	<b>472</b>	<b>-0.03</b>	<b>-0.05</b>	<b>-0.08</b>	<b>-0.12</b>
	Agriculture	14	0.05	0.10	0.15	0.20
	Non-agric	458	-0.03	-0.05	-0.09	-0.13
<b>RSA</b>	<b>Total</b>	<b>3 814</b>	<b>0.04</b>	<b>0.07</b>	<b>0.11</b>	<b>0.14</b>
	Agriculture	96	0.05	0.10	0.15	0.19
	Non-agric	3 718	0.04	0.07	0.10	0.13

Table 5-41 below indicates negative impacts on employment for industry in the Berg - Olifants/Doorn WMA, of up to 690 jobs lost (sim 4). All other WMAs show a net increase in employment, leading to net national job opportunities increasing by between 5 370 (sim 1) and 19 720 (sim 4).

**Table 5-41: Employment effects for the desalination scenario – industry water, municipal water users pay**

	Base	Sim 1: 25 mil m <sup>3</sup>	Sim 2: 50 mil m <sup>3</sup>	Sim 3: 75 mil m <sup>3</sup>	Sim 4: 100 mil m <sup>3</sup>
		<b>Industry water and municipal water users pay</b>			
	Quantity ('000)	Change ('000)			
<b>WMAs 1 – 7</b>	<b>13 173</b>	<b>5.09</b>	<b>9.79</b>	<b>14.70</b>	<b>19.28</b>
Agriculture	921	0.39	0.75	1.15	1.53
Non-agric	12 252	4.70	9.04	13.56	17.75
<b>Breede - Gouritz</b>	<b>533</b>	<b>0.22</b>	<b>0.42</b>	<b>0.64</b>	<b>0.84</b>
Agriculture	104	0.04	0.08	0.13	0.17
Non-agric	429	0.18	0.34	0.51	0.67
<b>Berg - Olifants/Doorn</b>	<b>1 926</b>	<b>0.07</b>	<b>0.08</b>	<b>-0.10</b>	<b>-0.40</b>
Agriculture	162	0.07	0.14	0.21	0.29

	Base	Sim 1: 25 mil m <sup>3</sup>	Sim 2: 50 mil m <sup>3</sup>	Sim 3: 75 mil m <sup>3</sup>	Sim 4: 100 mil m <sup>3</sup>
		<b>Industry water and municipal water users pay</b>			
	<b>Quantity (‘000)</b>	<b>Change (‘000)</b>			
Non-agric	1 764	-0.003	-0.06	-0.32	-0.69
<b>RSA</b>	<b>15 632</b>	<b>5.37</b>	<b>10.29</b>	<b>15.24</b>	<b>19.72</b>
Agriculture	1 186	0.50	0.98	1.49	1.99
Non-agric	14 446	4.87	9.31	13.75	17.73

Table 5-42 shows that in all four simulations households in the Berg - Olifants/Doorn WMA are worse off, indicating that the benefit of the additional water is outweighed by the cost thereof. In other WMAs household incomes increase as these households do not pay for the desalination, but indirectly reap the benefits of the industry expansion in the Berg - Olifants/Doorn WMA.

**Table 5-42: Household income effects for the desalination scenario – industry water, municipal water users pay**

	Base	Sim 1: 25 mil m <sup>3</sup>	Sim 2: 50 mil m <sup>3</sup>	Sim 3: 75 mil m <sup>3</sup>	Sim 4: 100 mil m <sup>3</sup>
		<b>Industry water and municipal water users pay</b>			
	<b>Value (Rmillion)</b>	<b>Change (%)</b>			
<b>WMAs 1 – 7</b>	2 632	0.04	0.08	0.12	0.16
<b>Breede – Gouritz</b>	74	0.04	0.09	0.13	0.17
<b>Berg - Olifants/Doorn</b>	366	-0.03	-0.05	-0.08	-0.10
<b>RSA</b>	3 072	0.03	0.07	0.10	0.13

#### 5.4.4 Scenario 4: Reuse as alternative water supply option in the Berg - Olifants/Doorn WMA

In simulations 1 and 2 there is additional water for industries that use bulk and municipal water in the Berg - Olifants/Doorn WMA derived by treating water for reuse. Reuse provides an additional 25 million m<sup>3</sup>. In simulation 1 the water industry covers the cost of treatment and passes this cost onto users, whereas in simulation 2 it is assumed that the users of municipal water (including households) cover the increased cost of the more expensive treated water and this is recovered as a tax on water. Detailed changes for the agricultural sector in terms of production of field crops and horticulture and respective areas irrigated are negligible and are not presented for this scenario.

Table 5-43 below indicates the direct impact of the additional 25 million m<sup>3</sup> reuse water available for industries, with use of bulk and municipal water use within the Berg - Olifants/Doorn WMA increasing by 7.28% and 6.79% respectively regardless of who covers the cost (simulations 1 and 2). Household use increases by 5.54% when households are not responsible for the cost of the treatment of water (sim 1), but when households cover the cost of water treatment via a tax (sim 2), their use of water increases by only 0.77%. This effect also drives the national results. The effects of the additional reuse water on WMAs not directly affected are small positive indirect effects.

**Table 5-43: Model changes in volumes of water for the water reuse scenario**

	Base	Sim 1: Industry water & industry pays	Sim 2: Industry water & municipal users pay
	Volume (mil m <sup>3</sup> )	Change (%)	Change (%)
<b>WMAs 1 – 7</b>	<b>14 298</b>	<b>0.02</b>	<b>0.03</b>
Irrigation	6 502	0.02	0.04
Bulk	3 593	0.00	0.00
Municipal (industries)	991	0.00	0.00
Municipal (hholds)	3 212	0.06	0.06
<b>Breede - Gouritz</b>	<b>1 116</b>	<b>0.02</b>	<b>0.04</b>
Irrigation	955	0.02	0.04
Bulk	56	0.00	0.00
Municipal (industries)	14	0.00	0.00
Municipal (hholds)	91	0.06	0.07
<b>Berg - Olifants/Doorn</b>	<b>1 813</b>	<b>2.73</b>	<b>1.59</b>
Irrigation	1 027	0.03	0.04
Bulk	275	7.28	7.28
Municipal (industries)	74	6.79	6.79
Municipal (hholds)	438	5.54	0.77
<b>RSA</b>	<b>17 226</b>	<b>0.31</b>	<b>0.19</b>
Irrigation	8 483	0.02	0.04
Bulk	3 923	0.51	0.51
Municipal (industries)	1 079	0.46	0.46
Municipal (hholds)	3 741	0.70	0.14

When industries receive an additional 25 million m<sup>3</sup> of treated water but pay the additional cost themselves (sim 1), the GDP increase in the Berg - Olifants/Doorn WMA is almost negligible at 0.008%, but it is slightly higher at 0.021% on a national level (Table 5-44). This is because the indirect positive effects of the additional water are positive throughout the economy, but the cost is borne only in the Berg - Olifants/Doorn WMA. When consumers in the Berg - Olifants/Doorn WMA pay for the water treatment via a tax (sim 2) the positive impacts on GDP in the Berg - Olifants/Doorn WMA as well as on a national level is slightly greater compared to simulation 1. This is because in simulation 2 the cost is more concentrated on the households rather than industries (because the volume of water used by households is larger than that of industry), so the expansion effect due to increased water availability is relatively greater for the industries, and the industries do not cover the cost of the water treatment.

**Table 5-44: Change in GDP in different WMAs for the water reuse scenario**

		BASE GDP	Sim 1: Industry water & industry pays	Sim 2: Industry water & municipal users pay
WMA / Region	Sectors	Value (Rbn)	Change (%)	Change (%)
<b>WMAs 1 – 7</b>	<b>Region total</b>	<b>3 253</b>	<b>0.023</b>	<b>0.032</b>
	Agriculture	75	0.023	0.037
	Non-agric	3 178	0.023	0.031
<b>Breede - Gouritz</b>	<b>Region total</b>	<b>90</b>	<b>0.024</b>	<b>0.034</b>

		<b>BASE GDP</b>	<b>Sim 1: Industry water &amp; industry pays</b>	<b>Sim 2: Industry water &amp; municipal users pay</b>
<b>WMA / Region</b>	<b>Sectors</b>	<b>Value (Rbn)</b>	<b>Change (%)</b>	<b>Change (%)</b>
	Agriculture	7	0.023	0.037
	Non-agric	82	0.024	0.034
<b>Berg - Olifants/Doorn</b>	<b>Region total</b>	<b>472</b>	<b>0.008</b>	<b>0.012</b>
	Agriculture	14	0.022	0.036
	Non-agric	458	0.008	0.012
<b>RSA</b>	<b>Total</b>	<b>3 814</b>	<b>0.021</b>	<b>0.029</b>
	Agriculture	96	0.023	0.037
	Non-agric	3 718	0.021	0.029

Table 5-45 below indicates the impact of additional reused water on employment. When industries receive an additional 25 million m<sup>3</sup> of treated water (in both simulations 1 and 2), there is expansion of non-agricultural industries in the Berg - Olifants/Doorn WMA and this has further positive indirect effects on employment in other WMAs. When industries in the Berg - Olifants/Doorn WMA pay for the additional cost of water treatment (sim 1) 450 employment opportunities are created in the Berg - Olifants/Doorn WMA, compared to 310 when consumers in the Berg - Olifants/Doorn WMA pay for the water treatment via a tax (sim 2). In contrast, the indirect impacts in other WMAs are slightly smaller for simulation 1 compared to simulation 2. On a national level relatively more jobs (3 450) are created in non-agriculture when consumers carry the cost of the water treatment (sim 2) compared to the jobs created (2 650) when industries cover the cost (sim 1). As mentioned, this is because in simulation 2 the cost of water treatment is more concentrated on the households rather than industries, while the industries have the benefit of the additional water.

**Table 5-45: Employment effects for the water reuse scenario**

	<b>Base employment</b>	<b>Sim 1: Industry water &amp; industry pays</b>	<b>Sim 2: Industry water &amp; municipal users pay</b>
	<b>Quantity ('000)</b>	<b>Change ('000)</b>	<b>Change ('000)</b>
<b>WMAs 1 – 7</b>	<b>13 173</b>	<b>2.32</b>	<b>3.35</b>
Agriculture	921	0.17	0.28
Non-agric	12 252	2.15	3.07
<b>Breede – Gouritz</b>	<b>533</b>	<b>0.10</b>	<b>0.15</b>
Agriculture	104	0.02	0.03
Non-agric	429	0.08	0.11
<b>Berg - Olifants/Doorn</b>	<b>1 926</b>	<b>0.45</b>	<b>0.31</b>
Agriculture	162	0.03	0.05
Non-agric	1 764	0.42	0.26
<b>RSA</b>	<b>15 632</b>	<b>2.87</b>	<b>3.81</b>
Agriculture	1 186	0.22	0.36
Non-agric	14 446	2.65	3.45

Table 5-46 below indicates that the impact on household incomes for the water reuse scenario is almost negligible, but positive, and slightly larger when consumers pay for the treatment (sim 2) compared to when industry pays (sim 2), with national income increases of 0.02% and 0.03% for the two respective simulations.

In the directly affected WMA there is no net benefit because, although the Berg - Olifants/Doorn WMA receives the benefit of additional water, the WMA is also directly responsible for the cost of the water treatment.

**Table 5-46: Household income effects for the water reuse scenario**

	Base income	Sim 1: Industry water & industry pays	Sim 2: Industry water & municipal users pay
	Value (Rmillion)	Change (%)	Change (%)
<b>WMAs 1 – 7</b>	2 632	0.02	0.03
<b>Breede - Gouritz</b>	74	0.02	0.03
<b>Berg - Olifants/Doorn</b>	366	0.00	0.01
<b>RSA</b>	3 072	0.02	0.03

#### 5.4.5 Scenario 5: Alien invasive plant removal for additional water in the Berg - Olifants/Doorn WMA

In this scenario there is additional water for industries that use bulk and municipal water in the Berg - Olifants/Doorn WMA due to alien invasive plant removal. This provides an additional 25 million m<sup>3</sup>. It is assumed that the users of municipal water (including households) cover the increased cost of the alien invasive plant removal and this is recovered as a tax on water. Detailed changes for the agricultural sector in terms of production of field crops and horticulture and respective areas irrigated are negligible and are not presented for this scenario.

Table 5-47 below indicates that on a national level the total volume of water used increased by only 0.27% but within the Berg - Olifants/Doorn WMA it increased on average by 2.29%. There is a negligible increase in water use in WMAs 1 to 7 and in the Breede - Gouritz WMA due to indirect effects.

**Table 5-47: Model changes in volumes of water used for the alien invasive plant removal scenario**

	Base	Scenario: alien invasive plant removal
	Volume (mil m <sup>3</sup> )	Change (%)
<b>WMAs 1 – 7</b>	<b>14 298</b>	<b>0.03</b>
Irrigation	6 502	0.03
Bulk	3 593	0.00
Municipal (industries)	991	0.00
Municipal (hholds)	3 212	0.06
<b>Breede - Gouritz</b>	<b>1 116</b>	<b>0.03</b>
Irrigation	955	0.03
Bulk	56	0.00
Municipal (industries)	14	0.00
Municipal (hholds)	91	0.06
<b>Berg - Olifants/Doorn</b>	<b>1 813</b>	<b>2.29</b>
Irrigation	1 027	0.04
Bulk	275	7.28
Municipal (industries)	74	6.79
Municipal (hholds)	438	3.70
<b>RSA</b>	<b>17 226</b>	<b>0.27</b>
Irrigation	8 483	0.03

	<b>Base</b>	<b>Scenario: alien invasive plant removal</b>
	<b>Volume (mil m<sup>3</sup>)</b>	<b>Change (%)</b>
Bulk	3 923	0.51
Municipal (industries)	1 079	0.46
Municipal (hholds)	3 741	0.48

Changes in regional GDP for agricultural and non-agricultural industries are presented in Table 5-48 below. When alien invasive plants are removed the GDP in the Berg –Olifants/Doorn WMA increases by 0.028% and by 0.026% on a national level. The positive impact of additional water available to industry outweighs the negative impact of the regional tax to cover the cost.

**Table 5-48: Change in GDP in different WMAs for the alien invasive plant removal scenario**

		<b>Base GDP</b>	<b>Scenario: alien invasive plant removal</b>
<b>WMA / Region</b>	<b>Sectors</b>	<b>Value (Rbn)</b>	<b>Change (%)</b>
<b>WMAs 1 – 7</b>	<b>Region total</b>	<b>3 253</b>	<b>0.026</b>
	Agriculture	75	0.031
	Non-agric	3 178	0.026
<b>Breede - Gouritz</b>	<b>Region total</b>	<b>90</b>	<b>0.027</b>
	Agriculture	7	0.031
	Non-agric	82	0.027
<b>Berg - Olifants/Doorn</b>	<b>Region total</b>	<b>472</b>	<b>0.028</b>
	Agriculture	14	0.030
	Non-agric	458	0.028
<b>RSA</b>	<b>Total</b>	<b>3 814</b>	<b>0.026</b>
	Agriculture	96	0.030
	Non-agric	3 718	0.026

Table 5-49 below indicates the impact of alien invasive plant removal on employment and income. Impacts on the directly affected Berg - Olifants/Doorn WMA is relatively small because it is only this area that covers the cost of the plant removal, whereas the expansionary effects of the increase in water availability to industries has a positive indirect effect on a national level. Employment in the directly affected WMA increases by 390 job opportunities and on a national level by 3 170. Household income increases by 0.03% in the Berg - Olifants/Doorn WMA and by 0.02% on a national level.

**Table 5-49: Employment and household income effects for the alien invasive plant removal scenario**

	<b>Base employment ('000)</b>	<b>Change in employment ('000)</b>	<b>Base income (Rmillion)</b>	<b>Change in income (%)</b>
<b>WMAs 1 – 7</b>	<b>13 173</b>	<b>2.66</b>	<b>2 632</b>	<b>0.02</b>
Agriculture	921	0.23		
Non-agric	12 252	2.43		
<b>Breede - Gouritz</b>	<b>533</b>	<b>0.12</b>	<b>74</b>	<b>0.03</b>
Agriculture	104	0.03		
Non-agric	429	0.09		
<b>Berg - Olifants/Doorn</b>	<b>1 926</b>	<b>0.39</b>	<b>366</b>	<b>0.03</b>
Agriculture	162	0.04		
Non-agric	1 764	0.35		

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	<b>Base employment (‘000)</b>	<b>Change in employment (‘000)</b>	<b>Base income (Rmillion)</b>	<b>Change in income (%)</b>
<b>RSA</b>	<b>15 632</b>	<b>3.17</b>	<b>3 072</b>	<b>0.02</b>
Agriculture	1 186	0.30		
Non-agric	14 446	2.87		

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## CHAPTER 6: PREDICTING THE LONG TERM IMPACT OF TARIFF CHANGES, TRANSFERS AND CLIMATE CHANGE USING THE DYNAMIC COMPUTABLE GENERAL EQUILIBRIUM MODEL

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### 6.1 INTRODUCTION

The 2016 Water SAM discussed in CHAPTER 4: contains significant updates to agricultural production and yields. Changes to SAM's often lead to instabilities when applying it to CGE models. However, in this case it has been successfully applied in the static CGE model, which allows for one-time testing of scenarios affecting water tariffs and volumes. The challenge was to transfer this capability to the dynamic CGE model to investigate long-term impacts of water tariff and volume adjustments, driven by policy.

A dynamic recursive model was configured along-side the static version. The dynamic recursive model also provides the capability to evaluate policy options relating to water supply volume and tariff adjustments but requires calibration of economic variables and parameters that go beyond the static version's requirements. The dynamic recursive model provides sufficient time series information to be fed into the techno-economical evaluation of proposed supply-side projects.

### 6.2 PRELIMINARY RESULTS

The following hypothetical scenarios were constructed to demonstrate typical outcomes from the dynamic recursive model:

- **Scenario 1** - Introduce tariff increases on irrigation water, such that it is increased by 5% annually for a period of 9 consecutive years.
- **Scenario 2** - Project an annual increase of 10% on the municipal water tariffs for the same 9-year period.
- **Scenario 3** - Allow an incremental water volume of 50 million m<sup>3</sup> to be transferred from agriculture use to municipal consumption each year for the said 9-year period, each year transferring 50 million m<sup>3</sup> more than the previous year.

#### 6.2.1 Scenario 1: Impact of introducing tariff increases on irrigation water, such that it is increased by 5% annually for a period of 9 consecutive years.

Table 6-1 depicts the impact of scenario 1 on the demand for water in all sectors of the economy. It is evident that a 5% annual increase in the irrigation water tariff will eventually lead to a 14.8% reduction in irrigation water consumption by 2025, with minimal indirect impact on the use of bulk (~ 0.09%) and municipal water (~ 0.005%). In this scenario irrigation water is assumed to become more expensive, but the water is not necessarily transferred to other water users. It is important to note that the volume of water consumed for the



BAU case (without tariff increase) increases over the period 2016 to 2025, signifying a growth in demand, while assuming that there will always be sufficient supply to satisfy the demand. The water demand growth follows the growth in economic activity.

**Table 6-1: Change in volume of water consumed due to a 5% annual increase in irrigation water tariff**

Year	Case: Without tariff increase			Case: With annual tariff increase		
	Water consumption (Mm3/a)			Water consumption (Mm3/a)		
	Irrigation	Bulk	Municipal	Irrigation	Bulk	Municipal
2016	8 483	3 923	1 079	8 483	3 923	1 079
2017	8 729	3 995	1 074	8 596	3 995	1 074
2018	8 956	4 071	1 078	8 678	4 070	1 078
2019	9 171	4 151	1 087	8 738	4 150	1 087
2020	9 379	4 235	1 100	8 783	4 233	1 100
2021	9 584	4 322	1 115	8 815	4 320	1 115
2022	9 788	4 412	1 133	8 838	4 409	1 133
2023	9 992	4 505	1 152	8 854	4 502	1 152
2024	10 198	4 600	1 172	8 864	4 597	1 172
2025	10 406	4 698	1 193	8 868	4 694	1 193

## 6.2.2 Scenario 2 - Projecting an annual increase of 10% on the municipal water tariffs for the same 9-year period.

The impact of an annual increase of 10% on the municipal water tariffs (scenario 2) on water consumption is shown in a similar configuration in Table 6-2. It is evident that tariff increases for municipal water would result in a 39.4% reduction in expected consumption, with a slight increase in irrigation water consumption (~0.34%), supplied from a transfer from the municipal sector. The bulk water consumption is expected to be reduced indirectly by ~2.1%.

**Table 6-2: Change in volume of water consumed due to a 10% annual increase in municipal water tariff**

Year	Case: Without tariff increase			Case: With annual tariff increase		
	Water consumption (Mm3/a)			Water consumption (Mm3/a)		
	Irrigation	Bulk	Municipal	Irrigation	Bulk	Municipal
2016	8 483	3 923	1 079	8 483	3 923	1 079
2017	8 729	3 995	1 074	8 732	3 981	1 021
2018	8 956	4 071	1 078	8 962	4 043	971
2019	9 171	4 151	1 087	9 181	4 109	927
2020	9 379	4 235	1 100	9 392	4 179	887
2021	9 584	4 322	1 115	9 601	4 252	850
2022	9 788	4 412	1 133	9 809	4 329	816
2023	9 992	4 505	1 152	10 018	4 411	784
2024	10 198	4 600	1 172	10 229	4 499	753
2025	10 406	4 698	1 193	10 441	4 598	723

**6.2.3 Scenario 3 - Allow an incremental water volume of 50 million m<sup>3</sup> to be transferred from agriculture use to municipal consumption each year for the said 9-year period, each year transferring 50 million m<sup>3</sup> more than the previous year.**

Scenario 3 illustrates the volume transfer of water between the application sectors indicated by “irrigation”, “bulk” and “municipal”. Table 6-3 summarises the impact of the potential transfer of water from agriculture (irrigation) to municipal consumption.

**Table 6-3: Change in volume of water consumed due to a transfer of 50 million m<sup>3</sup> of water from irrigation use to municipal consumers**

Year	Case: Without tariff increase			Case: With annual tariff increase		
	Water consumption (Mm3/a)			Water consumption (Mm3/a)		
	Irrigation	Bulk	Municipal	Irrigation	Bulk	Municipal
2016	8 483	3 923	1 079	8 483	3 923	1 079
2017	8 729	3 995	1 074	8 527	4 014	1 257
2018	8 956	4 071	1 078	8 559	4 103	1 442
2019	9 171	4 151	1 087	8 584	4 192	1 634
2020	9 379	4 235	1 100	8 602	4 280	1 832
2021	9 584	4 322	1 115	8 614	4 370	2 037
2022	9 788	4 412	1 133	8 622	4 460	2 250
2023	9 992	4 505	1 152	8 626	4 552	2 470
2024	10 198	4 600	1 172	8 625	4 646	2 699
2025	10 406	4 698	1 193	8 621	4 741	2 935

The increased annual transfer of the incremental volume of 50 million m<sup>3</sup> from irrigation to municipal consumers result in a significant reduction (~17.2%) in irrigation consumption (against the BAU case) while municipal consumption increases by 146% from the expected BAU case. A slight indirect increase (~0.9%) can also be expected for the bulk water consumption.

The impact of the three scenarios on crop production is summarised in Table 6-4. Note that scenario 1 is depicted as “With tariff increase” for “Irrigation”, while the impact of scenario.2 is recorded as “With tariff increase” for “Municipal”. The “adjusted volumes” column indicates the impact of scenario 3.

**Table 6-4: Change in crop production due to the three hypothetical scenarios**

Year	Crop Production (kton/a)			
	BAU	With Tariff Increase		Adjusted Volumes
		Irrigation	Municipal	
2016	51 788	51 788	51 788	51 788
2017	52 809	52 785	52 813	52 612
2018	53 911	53 864	53 921	53 553
2019	55 078	55 006	55 093	54 580
2020	56 295	56 199	56 316	55 670
2021	57 555	57 433	57 582	56 808
2022	58 852	58 702	58 886	57 983
2023	60 181	60 002	60 223	59 188
2024	61 542	61 331	61 591	60 418
2025	62 932	62 688	62 989	61 668

The differences against the BAU case can be shown as follows (Table 6-5):

**Table 6-5: Percentage change in crop production due to the three scenarios**

Year	Crop production deviation from BAU			
	BAU	With Tariff Increase		Adjusted Volumes
		Irrigation	Municipal	
2016	51 788	0.000%	0.000%	0.00%
2017	52 809	-0.046%	0.009%	-0.37%
2018	53 911	-0.088%	0.018%	-0.67%
2019	55 078	-0.130%	0.027%	-0.90%
2020	56 295	-0.171%	0.037%	-1.11%
2021	57 555	-0.212%	0.047%	-1.30%
2022	58 852	-0.255%	0.058%	-1.48%
2023	60 181	-0.298%	0.069%	-1.65%
2024	61 542	-0.342%	0.080%	-1.83%
2025	62 932	-0.388%	0.091%	-2.01%

It is evident that crop production can only increase where more irrigation water is supplied, as indicated in scenario 2.

The macroeconomic GDP impact of the three hypothetical scenarios is illustrated in Table 6-6 below.

**Table 6-6: Expected scenario Impacts on real GDP**

Year	GDP deviation from BAU			
	BAU	With Tariff Increase		Adjusted Volumes
		Irrigation	Municipal	
2016	4 323 028	0.000%	0.000%	0.000%
2017	4 416 283	-0.003%	-0.007%	-0.004%
2018	4 512 270	-0.007%	-0.015%	-0.009%
2019	4 610 913	-0.010%	-0.022%	-0.012%
2020	4 712 137	-0.013%	-0.031%	-0.015%
2021	4 815 877	-0.016%	-0.040%	-0.018%
2022	4 922 083	-0.019%	-0.049%	-0.021%
2023	5 030 718	-0.023%	-0.059%	-0.025%
2024	5 141 753	-0.026%	-0.069%	-0.031%
2025	5 255 166	-0.030%	-0.080%	-0.037%

All three scenarios will have a negative impact on GDP in the long term. Although crop production is expected to increase somewhat in scenario 2 (municipal water tariff increases), it is clear that a reduction in municipal water consumption will affect both households and industrial consumption rates, and that the economic losses in industrial economic activity will more than offset the slight gains to be made in agriculture.

The following table illustrates the changes in the macroeconomic profile of GDP for the BAU case. Since the expected adjustments in GDP would be marginal, as indicated in Table 6, the expected adjustments in

macroeconomic shares due to the scenarios are found to disappear in the rounding of the values stated in Table 6-7.

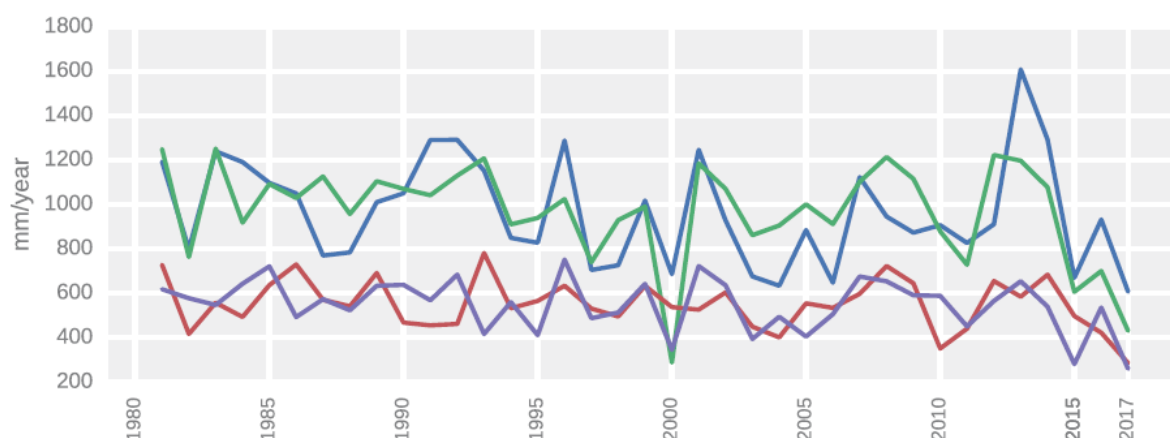
**Table 6-7: Macroeconomic shares of contributing sectors for real GDP**

Year	GDP	Private consumption	Government consumption	Fixed investment	Exports	Imports	Stock adjustment
2016	100.0%	57.5%	21.0%	21.6%	30.3%	-29.8%	-0.6%
2017	100.0%	57.5%	20.8%	21.8%	30.4%	-29.9%	-0.6%
2018	100.0%	57.4%	20.6%	22.0%	30.4%	-29.9%	-0.5%
2019	100.0%	57.4%	20.4%	22.2%	30.5%	-30.0%	-0.5%
2020	100.0%	57.4%	20.3%	22.4%	30.5%	-30.0%	-0.5%
2021	100.0%	57.3%	20.1%	22.6%	30.6%	-30.1%	-0.5%
2022	100.0%	57.3%	19.9%	22.8%	30.6%	-30.1%	-0.5%
2023	100.0%	57.2%	19.7%	23.1%	30.6%	-30.2%	-0.5%
2024	100.0%	57.2%	19.6%	23.3%	30.7%	-30.2%	-0.5%
2025	100.0%	57.2%	19.4%	23.5%	30.7%	-30.3%	-0.5%

## 6.3 CLIMATE CHANGE SIMULATION

### 6.3.1 Drought cycle induction

An attempt to simulate water availability subject to drought cycles proved to be a significant challenge. However, it was thought to be a useful test to illustrate the dynamic model capabilities. The model was forced to accept a hypothetical “drought-normal-drought” cycle spanning over 10 years, in order to observe changes in water availability and costing, macro-economic conditions, employment and household income. The drought cycle imposed is built on the recent dry spell of 2015 to 2017 experienced in the Western Cape Water Management Areas (WCWMAs). The hypothetical test scenario commences in 2016, which was right in the middle of the Western Cape drought period. The three water classes, i.e., irrigation, bulk and municipal water were assumed to be subject to varying availability factors over the period 2016 till 2026, the variations driven by experienced and projected rainfall as proxy for water availability. The following rainfall statistics provided by Wolski (2018) shown in Figure 2-2 guided the availability factor specification:



**Figure 6-1: WCWSS: Rainfall recorded at four Department of Water and Sanitation stations – Vogel Vallij, Zacharashoek, Theewaterskloof and Kogelbaai.**

The derived historic and expected future availability factors are depicted in Table 3-8 below.

**Table 6-8: Assumed water availability relative to 2016 as base year**

Year	Water availability index		
	Irrigation	Bulk	Municipal
2016	1.0	1.0	1.0
2017	0.5	0.6	0.6
2018	0.7	0.8	0.8
2019	1.0	1.0	1.0
2020	1.1	1.1	1.1
2021	1.2	1.2	1.2
2022	1.2	1.2	1.2
2023	1.2	1.2	1.2
2024	1.0	1.0	1.0
2025	0.7	0.8	0.8
2026	0.5	0.6	0.6

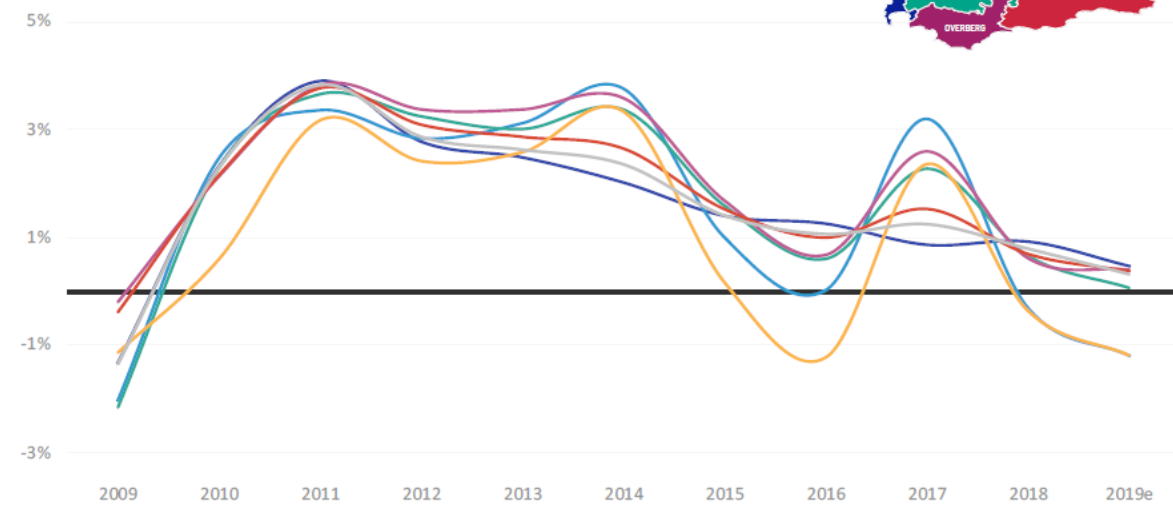
The availability index is indicated relative to the amounts of water per class available in 2016. The historic availability is not meant to reflect reality perfectly but to be indicative of what was experienced. Water levels were assumed sufficient to meet manifested demand at the time.

The drought cycle was introduced to two water management areas (WMAs) only, i.e., Breede–Gouritz and Berg–Olifants/Doorn; these being representative of the WCWMAs. No water availability impingement in any of the other WMAs was allowed. This presents an extreme scenario where only two WMAs in the Western Cape are subjected to droughts, while the rest of South Africa experiences normal climate conditions.

The dynamic general equilibrium model was allowed to generate economic balances subject to the above constrained water availabilities. The outcomes were expected to indicate the lasting effects of such drought conditions on the economy, both regional and on a national scale.

In order to appreciate a comparison between the model outcomes and reality in the WCWMAs, one needs to consider the following evidence of the economic impact of the 2015-2017 drought, obtained from the Municipal Economic Review and Outlook (2020) and depicted in Figure 6-2 and Figure 6-3.

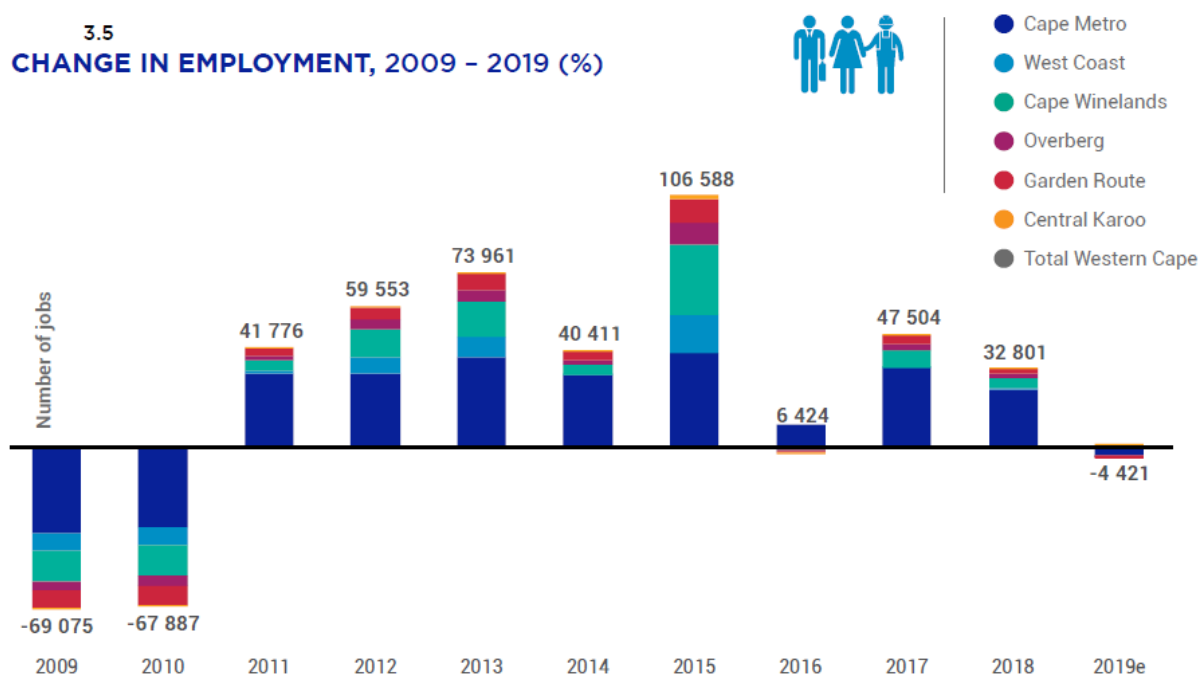
### 3.2 GDPR GROWTH RATE PER REGION, 2009 – 2019



	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019e
Western Cape	-1.3%	2.3%	3.8%	2.9%	2.6%	2.4%	1.4%	1.1%	1.2%	0.8%	0.3%
Cape Metro	-1.3%	2.3%	3.9%	2.8%	2.5%	2.0%	1.4%	1.2%	0.9%	0.9%	0.5%
West Coast	-2.0%	2.5%	3.4%	2.9%	3.1%	3.8%	1.0%	0.0%	3.2%	-0.3%	-1.2%
Cape Winelands	-2.1%	2.3%	3.7%	3.3%	3.0%	3.4%	1.6%	0.6%	2.3%	0.7%	0.1%
Overberg	-0.2%	2.2%	3.8%	3.4%	3.4%	3.6%	1.7%	0.7%	2.6%	0.6%	0.4%
Garden Route	-0.4%	2.2%	3.8%	3.1%	2.9%	2.6%	1.5%	1.0%	1.5%	0.7%	0.4%
Central Karoo	-1.1%	0.6%	3.2%	2.4%	2.6%	3.4%	0.2%	-1.2%	2.4%	-0.4%	-1.2%

**Figure 6-2:: Western Cape GDP growth**

### 3.5 CHANGE IN EMPLOYMENT, 2009 – 2019 (%)



	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019e
Western Cape	-69 075	-67 887	41 776	59 553	73 961	40 411	106 588	6 424	47 504	32 801	-4 421
Cape Metro	-36 610	-34 028	31 207	31 143	38 071	30 138	39 833	9 132	33 229	24 035	-3 564
West Coast	-7 840	-7 380	786	6 901	8 525	483	16 290	-686	605	707	-389
Cape Winelands	-12 523	-13 218	4 767	11 630	14 925	4 389	29 419	-518	6 926	4 407	751
Overberg	-4 287	-4 592	1 740	4 084	5 016	1 657	9 318	-483	2 477	1 591	-90
Garden Route	-7 049	-7 904	3 142	5 373	6 900	3 672	10 373	-885	4 166	1 990	-1 163
Central Karoo	-766	-765	134	422	524	72	1 355	-136	101	71	34

**Figure 6-3: Western Cape employment**

The net level impact of the regional GDP and employment on the WCWMAs are summarised in Table 6-9 and Table 6-10.

**Table 6-9: GDPR for WCWMAs region**

GDPR	Ref (Rm)	GDPR				
		2018	2014	2015	2016	2017
DC01 West Coast District	30 500	29 350	29 643	29 643	30 592	30 500
DC02 Cape Winelands District	67 500	64 107	65 133	65 524	67 031	67 500
DC03 Overberg District	20 500	19 394	19 723	19 861	20 378	20 500
Cape Metro	423 200	405 084	410 755	415 684	419 425	423 200
Total WCWSS	541 700	517 934	525 254	530 712	537 425	541 700

**Table 6-10: Employment in WCWMAs region**

Employment		Ref	Number				
		2018	2014	2015	2016	2017	2018
DC01	West Coast District	183 969	167 083	183 343	182 657	183 262	183 969
DC02	Cape Winelands District	396 426	356 192	385 611	385 093	392 019	396 426
DC03	Overberg District	133 362	120 459	129 777	129 294	131 771	133 362
	Cape Metro	1 622 989	1 516 760	1 556 593	1 565 725	1 598 954	1 622 989
	Total WCWSS	2 336 746	2 160 494	2 255 324	2 262 769	2 306 006	2 336 746

### 6.3.2 Dynamic simulation results

The output from the dynamic general equilibrium model is exhaustive and covers most economic factors of relevance. However, for the purpose of this exercise, only the water supply quantities and prices will be discussed, together with macro-economic conditions relating to GDP, employment and household income.

#### 6.3.2.1 Water supply quantities and associated water cost impacts

A summary of the available water quantities and cost impacts for the three WMA's, i.e., (i) Breede – Gouritz, (ii) Berg – Olifants/Doorn, and (iii) all the other WMA's, are depicted in tables below. The business as usual (BAU) cases are presented against that of the drought cycle simulation.

It is evident that the pricing impacts are significant in the cases of the Breede-Gouritz and the Berg-Olifants/Doorn WMA's, while it is not so pronounced in the case of the other WMA's. The induced droughts have a significant impact on water pricing, even on a national scale.

All prices quoted below refer to factor costs, excluding taxes.



**Table 6-11 : Assumed water availability for the Breede-Gouritz water management area**

Year	Breede-Gouritz					
	BAU case (Mm3/a)			Drought simulation impact (%)		
	Irrigation	Bulk	Municipal	Irrigation	Bulk	Municipal
2016	955	56	108	0%	0%	0%
2017	955	56	108	-50%	-40%	-40%
2018	955	56	108	-30%	-20%	-20%
2019	955	56	108	0%	0%	0%
2020	955	56	108	10%	10%	10%
2021	955	56	108	20%	20%	20%
2022	955	56	108	20%	20%	20%
2023	955	56	108	20%	20%	20%
2024	955	56	108	0%	0%	0%
2025	955	56	108	-30%	-20%	-20%
2026	955	56	108	-50%	-40%	-40%

The associated water price impact for the Breede-Gouritz WMA is shown in Table 6-12.

**Table 6-12:: Associated water price impacts for the Breede-Gouritz water management area**

Year	Breede-Gouritz					
	BAU case (R/m3)			Drought simulation impact (%)		
	Irrigation	Bulk	Municipal	Irrigation	Bulk	Municipal
2016	0.163	2.162	3.721	0.0%	0.0%	0.0%
2017	0.168	2.181	3.729	176.0%	44.7%	53.7%
2018	0.174	2.204	3.747	73.8%	17.0%	20.9%
2019	0.179	2.233	3.773	-0.4%	-0.9%	-0.1%
2020	0.185	2.268	3.807	-15.5%	-7.7%	-8.1%
2021	0.191	2.308	3.849	-27.7%	-13.4%	-14.8%
2022	0.196	2.354	3.898	-27.4%	-13.1%	-14.8%
2023	0.202	2.406	3.953	-27.0%	-12.8%	-14.7%
2024	0.208	2.464	4.016	0.0%	0.4%	0.0%
2025	0.215	2.529	4.085	68.9%	18.4%	21.1%
2026	0.221	2.602	4.161	159.2%	44.9%	53.9%

Similar results for the Berg-Olifants/Doorn WMA are reflected in Table 6-13 and Table 6-14.

**Table 6-13: Assumed water availability for the Berg-Olifants/Doorn water management area**

Year	Berg-Olifants/Doorn					
	BAU case (Mm3/a)			Drought simulation impact (%)		
	Irrigation	Bulk	Municipal	Irrigation	Bulk	Municipal
2016	1 027	275	510	0%	0%	0%
2017	1 027	275	510	-50%	-40%	-40%
2018	1 027	275	510	-30%	-20%	-20%
2019	1 027	275	510	0%	0%	0%
2020	1 027	275	510	10%	10%	10%
2021	1 027	275	510	20%	20%	20%
2022	1 027	275	510	20%	20%	20%
2023	1 027	275	510	20%	20%	20%
2024	1 027	275	510	0%	0%	0%
2025	1 027	275	510	-30%	-20%	-20%
2026	1 027	275	510	-50%	-40%	-40%

Its associated water price impact is:

**Table 6-14: Associated water pricing impacts for the Berg-Olifants/Doorn WMA**

Year	Berg-Olifants/Doorn					
	BAU case (R/m3)			Drought simulation impact (%)		
	Irrigation	Bulk	Municipal	Irrigation	Bulk	Municipal
2016	0.439	2.164	3.857	0.0%	0.0%	0.0%
2017	0.458	2.183	3.866	92.6%	46.1%	53.3%
2018	0.475	2.207	3.884	39.1%	17.4%	20.7%
2019	0.491	2.236	3.911	-2.3%	-1.0%	-0.2%
2020	0.506	2.271	3.947	-10.9%	-7.9%	-8.0%
2021	0.521	2.311	3.989	-18.0%	-13.7%	-14.7%
2022	0.536	2.358	4.039	-17.3%	-13.4%	-14.7%
2023	0.550	2.410	4.096	-16.7%	-13.1%	-14.6%
2024	0.563	2.469	4.160	0.0%	0.4%	0.0%
2025	0.577	2.534	4.231	38.0%	18.9%	20.9%
2026	0.590	2.607	4.309	82.3%	46.3%	53.4%

Similar results for the other WMA's are reflected Table 6-15 and Table 6-16.

**Table 6-15: Assumed water availability for the other water management areas**

Year	Other WMA's					
	BAU case (Mm3/a)			Drought simulation impact (%)		
	Irrigation	Bulk	Municipal	Irrigation	Bulk	Municipal
2016	6 502	3 593	4 202	0%	0%	0%
2017	6 502	3 593	4 202	0%	0%	0%
2018	6 502	3 593	4 202	0%	0%	0%
2019	6 502	3 593	4 202	0%	0%	0%
2020	6 502	3 593	4 202	0%	0%	0%
2021	6 502	3 593	4 202	0%	0%	0%
2022	6 502	3 593	4 202	0%	0%	0%
2023	6 502	3 593	4 202	0%	0%	0%
2024	6 502	3 593	4 202	0%	0%	0%
2025	6 502	3 593	4 202	0%	0%	0%
2026	6 502	3 593	4 202	0%	0%	0%

Its associated water price impact is:

**Table 6-16: The associated water pricing impacts for the other WMAs**

Year	Other WMA's					
	BAU case (R/m3)			Drought simulation impact (%)		
	Irrigation	Bulk	Municipal	Irrigation	Bulk	Municipal
2016	0.088	2.010	3.601	0.0%	0.0%	0.0%
2017	0.095	2.029	3.607	-8.3%	9.6%	1.8%
2018	0.102	2.053	3.623	-5.2%	3.7%	0.9%
2019	0.108	2.082	3.647	-1.2%	-0.6%	0.0%
2020	0.114	2.115	3.679	0.2%	-2.3%	-0.3%
2021	0.119	2.153	3.718	1.6%	-3.8%	-0.7%
2022	0.125	2.197	3.763	1.9%	-3.6%	-0.7%
2023	0.130	2.246	3.815	2.1%	-3.4%	-0.7%
2024	0.136	2.301	3.874	-0.1%	0.3%	0.0%
2025	0.141	2.362	3.939	-4.2%	4.5%	0.8%
2026	0.147	2.431	4.011	-7.9%	9.7%	1.7%

Finally, a view the overall national effects:

**Table 6-17: Assumed water availability on a national scale**

Year	Total Water					
	BAU case (Mm3/a)			Drought simulation impact (%)		
	Irrigation	Bulk	Municipal	Irrigation	Bulk	Municipal
2016	8 483	3 923	4 820	0.00%	0.00%	0.00%
2017	8 483	3 923	4 820	-11.68%	-3.37%	-5.13%
2018	8 483	3 923	4 820	-7.01%	-1.69%	-2.56%
2019	8 483	3 923	4 820	0.00%	0.00%	0.00%
2020	8 483	3 923	4 820	2.34%	0.84%	1.28%
2021	8 483	3 923	4 820	4.67%	1.69%	2.56%
2022	8 483	3 923	4 820	4.67%	1.69%	2.56%
2023	8 483	3 923	4 820	4.67%	1.69%	2.56%
2024	8 483	3 923	4 820	0.00%	0.00%	0.00%
2025	8 483	3 923	4 820	-7.01%	-1.69%	-2.56%
2026	8 483	3 923	4 820	-11.68%	-3.37%	-5.13%

Its associated water price impact is:

**Table 6-18: The associated water pricing impacts on the national account**

Year	Total Water					
	BAU case (R/m3)			Drought simulation impact (%)		
	Irrigation	Bulk	Municipal	Irrigation	Bulk	Municipal
2016	0.139	2.023	3.631	0.00%	0.0%	0.0%
2017	0.147	2.042	3.637	53.4%	12.9%	8.8%
2018	0.155	2.066	3.654	21.3%	4.9%	3.6%
2019	0.162	2.095	3.678	-1.5%	-0.7%	0.0%
2020	0.169	2.128	3.710	-5.8%	-2.8%	-1.4%
2021	0.176	2.167	3.749	-9.0%	-4.7%	-2.6%
2022	0.183	2.210	3.796	-8.5%	-4.5%	-2.6%
2023	0.189	2.260	3.848	-8.0%	-4.3%	-2.6%
2024	0.196	2.315	3.908	0.0%	0.3%	0.0%
2025	0.202	2.377	3.974	19.1%	5.8%	3.5%
2026	0.209	2.446	4.046	42.9%	13.0%	8.7%

### 6.3.2.2 Regional GDP impact

It is evident from the above analyses that the induced drought cycle has a significant impact on water availability and pricing. It transpires into regional GDP as follows:

**Table 6-19: The regional GDP impact at factor cost**

Year	Total GDP (Rm)							
	Breede-Gouritz		Berg-Olifants/Doorn		Other WMA's		Total	
	BAU	Sim chg	BAU	Sim chg	BAU	Sim chg	BAU	Sim chg
2016	86 148	0	454 912	0	3 135 850	0	3 676 910	0
2017	87 206	-164	460 313	-795	3 173 512	-2 085	3 721 031	-3 044
2018	88 318	-70	466 026	-358	3 213 311	-864	3 767 655	-1 293
2019	89 489	-7	472 078	-10	3 255 434	23	3 817 001	6
2020	90 726	17	478 491	131	3 300 059	386	3 869 276	534
2021	92 034	40	485 289	265	3 347 360	726	3 924 683	1 031
2022	93 419	43	492 496	272	3 397 517	715	3 983 432	1 030
2023	94 888	46	500 137	280	3 450 721	717	4 045 745	1 043
2024	96 446	-3	508 238	-13	3 507 177	-90	4 111 862	-106
2025	98 101	-88	516 831	-425	3 567 108	-1 085	4 182 039	-1 598
2026	99 859	-220	525 947	-961	3 630 753	-2 460	4 256 559	-3 641

Similar layouts can be produced to indicate the split between agricultural and non-agricultural activities.

The following comparison of expected and realised GDP for the WCWMAs is possible:

**Table 6-20: Comparison of realised regional GDP for the WCWMAs against model results**

Year	WCWMAs GDPR (Rm)				
	Realised	Agri curtailment 50%		Agri curtailment 70%	
		Simulation	Difference	Simulation	Difference
2016	530 712	541 060	1.95%	541 060	1.95%
2017	537 425	546 560	1.70%	546 404	1.67%
2018	541 700	553 915	2.26%	553 873	2.25%

The estimated GDPR deviates from the realised magnitudes by less than 3%. The sensitivity of the assumption of water use curtailment on agriculture is also illustrated in **Table 6-20**.

### 6.3.2.3 Employment impacts

Similar results are observed in the case of employment.

The following Table 6-21 depicts the impacts on regional aggregate employment at factor costs:

**Table 6-21: The regional aggregate employment impact**

Year	Total Employment							
	Breede-Gouritz		Berg-Olifants/Doorn		Other WMA's		Total	
	BAU	Sim chg	BAU	Sim chg	BAU	Sim chg	BAU	Sim chg
2016	547 414	0	1 826 708	0	12 369 512	0	14 743 633	0
2017	554 480	-2 545	1 845 055	-5 307	12 512 180	-12 000	14 911 715	-19 851
2018	561 636	-1 363	1 864 064	-2 998	12 657 970	-5 530	15 083 670	-9 892
2019	568 934	-206	1 883 849	-351	12 807 846	-170	15 260 629	-727
2020	576 428	179	1 904 517	623	12 962 768	2 172	15 443 713	2 974
2021	584 174	562	1 926 173	1 621	13 123 684	4 441	15 634 031	6 625
2022	592 226	630	1 948 919	1 759	13 291 533	4 492	15 832 679	6 881
2023	600 638	696	1 972 861	1 890	13 467 240	4 584	16 040 739	7 170
2024	609 463	-38	1 998 104	-63	13 651 727	-518	16 259 294	-618
2025	618 750	-1 542	2 024 758	-3 410	13 845 922	-7 027	16 489 429	-11 979
2026	628 551	-3 368	2 052 938	-6 726	14 050 763	-15 019	16 732 252	-25 113

The following comparison of expected and realised employment for the WCWMAs is possible:

**Table 6-22: Comparison of realised aggregate employment for WCWMAs, against model results**

Year	WCWMAs Employment				
	Realised	Agri curtailment 50%		Agri curtailment 70%	
		Simulation	Difference	Simulation	Difference
2016	2 262 769	2 374 122	4.92%	2 374 122	4.92%
2017	2 306 006	2 391 684	3.72%	2 387 905	3.55%
2018	2 336 746	2 421 339	3.62%	2 419 845	3.56%

The estimated employment deviates from the realised magnitudes by less than 5%. The sensitivity of the assumption of water use curtailment on agriculture is also illustrated in Table 6-22.

#### 6.3.2.4 Household income impacts

The following Table 6-23 depicts the impacts on regional aggregate household income at factor costs:

**Table 6-23: The regional aggregate household income impact**

Year	Total Household Income (Rm)							
	Breede-Gouritz		Berg-Olifants/Doorn		Other WMA's		Total	
	BAU	Sim chg	BAU	Sim chg	BAU	Sim chg	BAU	Sim chg
2016	42 197	0	228 025	0	1 476 816	0	1 747 038	0
2017	42 688	-92	230 640	-369	1 494 345	-1 339	1 767 674	-1 800
2018	43 209	-43	233 426	-164	1 512 907	-543	1 789 542	-751
2019	43 762	-2	236 392	1	1 532 587	36	1 812 741	34
2020	44 350	13	239 551	66	1 553 463	271	1 837 364	350
2021	44 976	27	242 910	128	1 575 615	489	1 863 501	645
2022	45 642	28	246 482	129	1 599 122	478	1 891 246	635
2023	46 349	29	250 278	131	1 624 070	474	1 920 697	634
2024	47 103	-2	254 309	-7	1 650 552	-52	1 951 963	-61
2025	47 904	-50	258 590	-196	1 678 668	-696	1 985 162	-943
2026	48 756	-113	263 137	-436	1 708 530	-1 574	2 020 423	-2 124

#### 6.3.3 Concluding remarks

It is evident from the climate change simulation that, although water volume changes and pricing can be substantial, it does have a rather subdued impact on the macro-economic measures of GDP, employment and household income. This is manifestly due to the overwhelming role of non-agricultural activity in the South African economy – considering that in the case of WCWMAs the agriculture, forestry and fishing industries contribute only 3.8% towards the regional GDP, while the tertiary sector's contribution is 72.3%.

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## CHAPTER 7: SUMMARY, CONCLUSION AND RECOMMENDATIONS

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### 7.1 INTRODUCTION

It is noteworthy that the results depicted in this report are indicative of reasonable expectations but should never be viewed as reflective of the final outcome, as it is dependent on many crucial assumptions. Although the model is capable of generating reasonable results, the value and desired accuracy of the outcomes will require further refinement and optimisation of control parameters, such as elasticities and economic growth factors, in the model. Specific option combinations, such as those introduced in the above drought cycle simulation, may also affect the scenario-testing capability. However, despite the associated levels of uncertainty, this recursive dynamic general equilibrium model does provide useful information regarding the outcomes of policy options affecting water regulation as it has proven to be able to adequately simulate equilibria over time.

### 7.2 TECHNO-FINANCIAL EVALUATION OF ALTERNATIVE WATER SUPPLY OPTIONS

In this study, a number of alternative water supply options were considered, and a comprehensive analysis was undertaken on the options shown in the table below. Cost comparisons and hydrological assessment of alternative water supply options were carried out for the following: desalination, water reuse, aquifer recharge, farming under netting, agrivoltaics, precipitation augmentation, and alien invasive plant removal. A cost of supply was determined for each of the supply interventions for input into the economic analysis.

Modelling Scenarios	Description	Intervention volume WCWSS Total Mm <sup>3</sup> /a	Intervention/ alternative supply cost (R)
<b>Alternative Supply Options</b>			
Desalination			
a) Municipal	Desalination to supply municipal use	50	12.82
b) Agricultural	Desalination to supply agricultural use	50	12.82
Water Reuse	Water reuse for municipal supply (WCWSS discharges most suitable to recovery of potable water due to geographic location of discharge)	25	5.39
Farming under netting	Different irrigation crops respond differently under netting and not all crops can be cost effectively provided with netting (different water use reduction and different yield improvements)		



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	Citrus	6	6.49
	Table Grapes	9	12.64
	Pome	2	24.15
Alien Invasive Plant Removal	Removal of alien vegetation through labour intensive processes - increased availability to municipal users	25	2.13
Agri PV	Different irrigation crops respond differently under PV and not all crops can be cost effectively provided with PV (different water use reduction and different yield improvements)	9.45	5.11

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#### Summary of findings:

- Desalination was, one of the more expensive water supply alternatives. This expense may be justified where the cost of unserved water is greater than the cost of water produced through desalination.
- In the farming under netting analysis, different irrigation crops responded differently under netting and not all crops could be cost effectively provided with netting due to different water use reduction and different yield improvements. Farming under netting was shown to be most cost effective for citrus crops and least cost effective for pome.
- Removal of alien invasive plants was found to be the most cost-effective of the interventions.

The modelling indicated that the cost of water realised from AgriPV was similar to costs achieved for water reuse. The water savings and electricity generation potential results potential are also significant enough to warrant further exploration of the technology. Unlike the use of netting to protect farming under cover which has already proven to be commercially viable in the production of a number of crops, we reasonably cannot expect agricultural fields be covered by solar canopies anytime soon without a concerted effort to establish commercial test utilities at scale and as integral to the production of specific crops. In order to provide the necessary proof-of-concept before market entry, we need to compare further techno-economical applications of AgriPV, demonstrate the transferability to other regional areas, and also realize larger systems.

### **7.3 DEVELOPMENT OF THE 2016 WATER SOCIAL ACCOUNTING MATRIX (SAM)**

The SAM is a comprehensive, disaggregated, consistent and complete data system that captures the interdependence that exists within a socioeconomic system. The SAM can be used as a conceptual framework to explore the impact of exogenous changes in such variables as exports, certain categories of government expenditures, and investment on the whole interdependent socioeconomic system, e.g. the resulting structure of production, factorial and household income distributions. As such the SAM becomes the basis for simple multiplier analysis and the building and calibration of a variety of applied general equilibrium models.

The basic structure of an agricultural and water-focused social accounting matrix (SAM) for South Africa that was developed in 2002 was used as base to develop a Water SAM for 2016. The treatment of water within the supply and use tables published by Statistics South Africa, as well as the national water accounts published by the Water Research Commission, which forms the core data of a SAM, has changed since 2002, with the implication that structural changes to the SAM were required. The 2016 SAM represents the nine 2012 water management areas while retaining the more detailed former WMAs for the Western Cape, resulting in 11 WMAs in total. The developed 2016 water SAM was used to calibrate a static and a recursive dynamic computable general equilibrium (CGE) model.

The SAM contains 40 sectors/commodities assumed to be at national market level, including 17 agricultural (including forestry and fishing), 15 industrial and 8 service sectors. Field crop production activities are further disaggregated in the SAM into irrigated and rainfed production per crop, while all horticultural production activities are assumed to be irrigated. All sectors are further disaggregated to capture production within each of the 11 water management areas. Beside capital, labour, and land, the SAM also includes three types of water (irrigation, bulk and municipal) per WMA as production factors. The institutions included in the 2016 SAM are enterprises, one representative household per WMA and the government. Further disaggregation of households were not possible due to lack of sufficiently detailed data. Irrigation water is incorporated in the model through the estimation of the shadow price of water per crop irrigated. Non-agricultural water use, in the form of bulk water and municipal water, is captured via the water distribution system. Irrigation and non-

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agricultural water used by industries is treated as a factor of production and water used by households is treated as a commodity.

## **7.4 PREDICTING THE IMPACT OF CHANGES IN WATER TARIFFS AND TRANSFERS ON THE NATIONAL AND WESTERN CAPE ECONOMY USING THE STATIC COMPUTABLE GENERAL EQUILIBRIUM MODEL**

### **7.4.1 The Static Computable General Equilibrium (CGE) Model And Key Results**

CGE models are useful whenever we wish to estimate the effect of changes in one part of the economy upon the rest. CGE models fit economic data to a set of equations which aim to capture the structure of the economy and behavioural response of agents (industry, households, government). This provides a framework to simulate policy changes and trace the impact on key economic variables, including income and expenditure flows. The static dynamic computable general equilibrium model as developed by the International Food Policy Research Institute (IFPRI) was used as base model and was adjusted for purposes of this project to allow for policy options related to a water focus, notably the inclusion of water tariffs

#### *7.4.1.1 Change in irrigation water tariff – national level*

Modelling of changes in irrigation water tariffs where water is not transferred to other users indicated minimal indirect impact on the use of bulk water, municipal water used by industry and water used by households. Irrigated field crops are most affected by a change in water tariffs since these crops can be more easily switched to dryland conditions than horticultural products and field crops are often lower value crops and would be moved out of irrigation more readily than horticultural products. In general the impacts of the irrigation water tariff changes are small on a regional GDP level, but one can expect that the impact on individual irrigation farms are much more pronounced. A 10% increase in the irrigation water tariff leads to national job losses of 1600. The biggest negative impact of the irrigation water tariff increase is on the exports of horticultural products.

#### *7.4.1.2 Change in municipal water rate – national level*

The modelling of changes to the municipal water tariff rate showed that although municipal water use decreases by up to 9.4% when the municipal water rates changes, there is little indirect effect on other water usage. In general that the production of horticulture increases when municipal water rates increase, whereas production of field crops decrease. This could be because an increase in municipal water rates has a dampening effect on industry and since a larger share of field crops is used as intermediate product compared to horticultural products, the demand for field crops is likely to decline. Changes in regional GDP for agriculture and non-agriculture impacts are more pronounced compared to that of the changes in irrigation water tariff rates. A 10% increase in the municipal water tariff leads to national job losses of 10 000.

#### *7.4.1.3 Transfer of water from use in irrigation to municipal use for industries – national level*

The transfer of 50 million m<sup>3</sup> from irrigation to municipal use resulted in a 0.6% decrease in irrigation water used and a 4.6% increase in the use of municipal water, while household use increased by 0.8%. The 0.8% increase in water used by households for domestic purposes reflects a positive impact on the economy as a

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result of an expansion of industries and hence household income. There is also an increase in employment of 5 800 on a national level.

#### *7.4.1.4 Reduction in water supply in the Berg - Olifants/Doorn WMA*

The volume of water available in the Berg - Olifants/Doorn WMA was assumed to decrease as follows: irrigation water by 50%; bulk and municipal water each by 40%. This led to a decrease in household's use of municipal water of 37%, which is endogenously determined, and therefore also captures some of the indirect impacts of the reduction in water as part of the imposed shock; it also captures some of the effects of the general contraction of the economy. In the Berg - Olifants/Doorn WMA the reduction in the volume of water available for irrigation is reflected by a reduction in production output under irrigation that is more pronounced for field crops (31.3%) than for horticulture (7.8%). GDP in the Berg - Olifants/Doorn WMA decreases by 0.35% and the decrease in GDP at a national level is 0.22%, with similar but slightly smaller impacts on households. Employment in the directly affected WMA decreases by 6 900 and on a national level 26 800 job opportunities are lost.

#### *7.4.1.5 Water transfer between sectors in the Berg - Olifants/Doorn WMA*

The transfer of 25 million m<sup>3</sup> water from irrigation to bulk and municipal use and the transfer of a similar volume of water from bulk and municipal use to irrigation in the Berg - Olifants/Doorn WMA was investigated. The results of the two simulations are almost mirror images, but the magnitudes of the changes are slightly smaller when the water is transferred from industry to irrigation.

When 25 million m<sup>3</sup> irrigation water is transferred to industries, field crop production in the Berg - Olifants/Doorn WMA decreases by 1.14%, while the use of irrigation water for field crops decreases by 2%. On a national level results are small as it reflects only the indirect effects of the changes in the Berg - Olifants/Doorn WMA. GDP increases by 0.036% in the Berg - Olifants/Doorn WMA and by 0.022% on a national level. Although employment in agriculture is negatively impacted, the net effect is that 300 job opportunities are created in the Berg - Olifants/Doorn WMA; and 2 440 job opportunities are created on a national level. Household income increases by 0.034% in the Berg - Olifants/Doorn WMA and by 0.02% on a national level.

#### *7.4.1.6 Desalination as alternative water supply option in the Berg - Olifants/Doorn WMA - same volumes, different payment options*

When an additional 50 million m<sup>3</sup> water is allocated to industry, the expansion in the economy is sufficiently large to stimulate further use of water, as observed by the increased water use of all water categories in all WMAs. It is only in the case where costs are recovered by users in the Berg - Olifants/Doorn WMA that there is a reduction in the use of water by households of 13.8%, with a net negative effect of 0.49% on the WMA level. Indirect effects on agricultural production, area and irrigation water use are small but positive throughout. The net national impact is small but positive. It is only the Berg - Olifants/Doorn WMA that shows a decrease in GDP because the cost of desalination is covered by either industries or users in this WMA. Tax on users have a more positive outcome compared to when industries absorb the cost. All WMAs show an increase in employment, with the exception of non-agricultural industry in the directly affected WMA. Households in the Berg - Olifants/Doorn WMA are worse off, indicating that the benefit of the additional water is outweighed by the cost thereof. Households are better off when the cost of desalination is recovered via a tax paid by users of the water rather than by the industries.

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#### *7.4.1.7 Desalination as alternative water supply option in the Berg - Olifants/Doorn WMA - different volumes, same payment option*

Simulations were run in which additional desalination water of 25, 50, 75 and 100 million m<sup>3</sup> was made available to industries that use bulk and municipal water in the Berg - Olifants/Doorn WMA. In all four simulations it was assumed that the users of municipal water (including households) cover the increased cost of the more expensive desalination water and this is recovered as a tax on water.

When additional water is allocated to industry the expansion in the economy is sufficiently large to stimulate further use of water. The exception is the reduction in the use of water by households in the Berg - Olifants/Doorn WMA, which declines by between 6.5% and 37.4%. Households water use is endogenously determined and it declines substantially because of the substantial cost increase. The cost that needs to be recovered from water consumers (industries and households) for the additional desalination water at R12.8/kl, amounts to between R320 million and R1.28 billion depending on the additional amount of water.

GDP of industry in the directly affected WMA decreases by between 0.03% and 0.13% and the positive impacts on agriculture is not sufficient to offset it, giving a net negative impact on GDP in the Berg - Olifants/Doorn WMA. Employment in the Berg - Olifants/Doorn WMA increases for additional desalination water volumes of up to 50 million m<sup>3</sup> but decreases for higher volumes, because at lower volumes that positive impact on employment in the agricultural sector outweighs the negative impacts in industry. The GDP and employment impacts in the other WMAs are however positive.

#### *7.4.1.8 Water reuse as alternative water supply option in the Berg - Olifants/Doorn WMA*

In this scenario an additional 25 million m<sup>3</sup> reuse water is made available for industries and households, with either industries paying, or all users of the water (including households) covering the additional cost. Economic benefits tend to be larger when all the users of water cover the additional cost. Also, since the cost is borne only by users in the directly affected Berg - Olifants/Doorn WMA, the net positive impact on GDP in this WMA is smaller compared to the positive indirect impact on GDP in the other WMAs.

When an additional 25 million m<sup>3</sup> reuse water is made available for industries, the bulk and municipal water use within the Berg - Olifants/Doorn WMA increases by 7.28% and 6.79% respectively regardless who covers the cost. Household use increases by 5.54% when households are not responsible for the cost of the treatment of water, but when households cover the cost of water treatment via a tax, their use of water increases by only 0.77%. This effect also drives the national results. The effects of the additional reuse water on WMAs not directly affected are small positive indirect effects.

#### *7.4.1.9 Alien invasive plant removal for additional water in the Berg - Olifants/Doorn WMA*

In this scenario there alien invasive plant removal provides an additional 25 million m<sup>3</sup> for industries that use bulk and municipal water in the Berg - Olifants/Doorn WMA. It is assumed that the users of municipal water (including households) cover the increased cost of the alien invasive plant removal and this is recovered as a tax on water.

#### *7.4.1.10 Summary*

Within the Berg - Olifants/Doorn WMA total volume of water used increased by 2.29%, but indirect effects in the other WMAs are minimal. The positive impact of additional water available to industry outweighs the negative impact of the regional tax to cover the cost, leading a small positive impact on GDP in the Berg - Olifants/Doorn WMA. Employment in the directly affected WMA increases by 390 job opportunities and on a national level by 3 170. Impacts on the directly affected Berg - Olifants/Doorn WMA is relatively small because

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it covers the cost of the plant removal, whereas the expansionary effects of the increase in water availability to industries has a positive indirect effect on a national level.

#### **7.4.2 The Dynamic Computable General Equilibrium (CGE) Model And Key Results**

In order to be able to assess the impact of water policies over time a dynamic recursive model was configured along-side the static version. The dynamic version would provide the capability to evaluate policy options relating to water supply volume and tariff adjustments. However, it requires calibration of economic variables and parameters that go beyond the static version's requirements. The dynamic recursive model produces time series information which can be used in the techno-economical evaluation of proposed supply-side projects. In order to demonstrate its capability, the recursive dynamic model was configured to simulate three scenarios over a 9-year period following on the base year of 2016:

- Determine the compound impact of annual increases in the price of irrigation water,
- Determine the compound impact of annual increases in municipal water tariffs, and
- Estimation of the compound impact of annual increases in the transfer of water between application sectors.

##### **7.4.2.1 Irrigation Water Tariff Increase**

A 5% annual increase in the irrigation water tariff will eventually lead to a 15% reduction in irrigation water consumption by 2025, with minimal indirect impact on the use of bulk (~ 0,09%) and municipal water (~ 0,005%). There is a negative impact on GDP in the long term.

##### **7.4.2.2 Municipal Water Tariff Increase**

An annual increase of 10% in municipal water tariffs would result in a 39% reduction in expected consumption, with a slight increase in irrigation water consumption (~0,34%), supplied from a transfer from the municipal sector. The bulk water consumption is expected to be reduced indirectly by ~2,1%. There is a negative impact on GDP in the long term. Although crop production is expected to increase, a reduction in municipal water consumption affects both households and industrial consumption rates, and the economic losses in industrial economic activity will more than offset the slight gains to be made in agriculture.

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#### 7.4.2.3 *Volume transfer of water between the application sectors*

The annual transfer of water from irrigation to municipal consumers, beginning with a volume of 50 million m<sup>3</sup> in the first year, and increasing by 50 million m<sup>3</sup> in every subsequent year, results in a significant reduction (~17%) in irrigation consumption (against the BAU case) while municipal consumption increases by 146% from the expected BAU case. A slight indirect increase (~0,9%) can also be expected for the bulk water consumption. There is a negative impact on GDP in the long term.

#### 7.4.2.4 *Climate Change Simulation*

An attempt to simulate water availability subject to drought cycles was thought to be a useful test to further demonstrate the dynamic model capabilities. The model was forced to accept a hypothetical “drought-normal-drought” cycle spanning a 10-year period, in order to observe changes in water availability and costing, macro-economic conditions, employment and household income. The imposed drought cycle was built on the recent dry spell of 2015 to 2017 experienced in the Western Cape Water Management Areas (WCWMAs). The hypothetical test scenario commences in 2016, which was right in the middle of the Western Cape drought period.

The drought cycle was introduced to two water management areas (WMAs) only, i.e., Breede–Gouritz and Berg–Olifants/Doorn; these being representative of the WCWMAs. No water availability impingement in any of the other WMAs was allowed. The dynamic general equilibrium model was allowed to generate economic balances subject to constrained water availabilities. The outcomes correlated well with the actually recorded GDP and employment impacts of the drought experienced in the WCWMAs.

It became evident that, although water volume changes and pricing can be substantial, it does have a rather subdued impact on the macro-economic measures of GDP, employment and household income. This is manifested due to the overwhelming role of non-agricultural activity in the South African economy.

### 7.5 CONCLUSIONS AND RECOMMENDATIONS

The project developed an assessment framework to allow for the evaluation of bulk water supply investments and regulatory options required for demand-side management in a socioeconomic perspective. The majority of the project aims were achieved. Notably a literature review related to project methodology and updating of the respective models were conducted; the SA Water SAM was updated and modified to allow for analysis of impacts of alternative supply sources, amongst other water reuse and desalination; a computable general equilibrium (CGE) model was expanded to accommodate different supply options; a dynamic version of the CGE model was developed to reflect the dynamic nature of economy; scenario analysis for the Berg River WMA was conducted; the impact of different irrigation and municipal water tariff were modelled, although different tariffs for household could not be modelled at a detailed level; the impacts of different sets of policy interventions at national and regional/sectoral level were analysed and presented.

The greatest challenge with regard to SAM development is the availability of up to date and detailed data at the level of disaggregation that is required. For the 2016 water SAM this was no exception since very little data in the public domain is published on a water management area level. Detailed agricultural and household data proved particularly difficult to find and time consuming to construct. In the case of household the level of detail in the data that would have allowed for more interesting institutional results was simply not available.

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Cost comparisons and hydrological assessment of alternative water supply options were carried out for the following: desalination, water reuse, aquifer recharge, farming under netting, agrivoltaics, precipitation augmentation, and alien invasive plant removal. The estimated costs of some of these augmentation strategies were subsequently used in the analysis of policy interventions using the CGE static model to ensure that the cost recovery of additional water supply is taken into account in the analysis. The dynamic CGE model analysis focused on estimating the impacts of changes in municipal water tariffs and transfers of irrigation water to industry on a national level, as well as cyclical droughts due to climate change in the Western Cape over a ten year period.

Some key results from national policy interventions using the static CGE model are mentioned here. The biggest negative impact of the irrigation water tariff increase is on the exports of horticultural products. When municipal tariffs increase changes in regional GDP for agriculture and non-agriculture impacts and job losses are more pronounced compared to that of the changes in irrigation water tariff rates because the agricultural sector is substantially smaller and less integrated with the rest of the economy compared to industry. For the same reason, additional water (regardless the source) to industry rather than irrigation agriculture, typically lead to greater economic benefit in terms of GDP.

Different alternative water supply options with different cost recovery options were also simulated using the static CGE model. The CGE modelling provided valuable insight that can be used to inform policy with regard to who is best placed to pay for desalinated water. When additional water is allocated to industry the expansion in the economy is sufficiently large to stimulate further use of water, as observed by the increased water use of all water categories in all WMAs. The exception is the reduction in the use of water by households in the Berg - Olifants/Doorn WMA.

Modelling of desalination as an alternative supply option in the Berg - Olifants/Doorn WMA by varying the supply volumes with the cost of the water borne by the municipal users (including households) and the additional water made available to industry indicated negative impacts on GDP and these negative impacts became more pronounced as the desalination supply volumes increased. A positive effect was observed for employment numbers at lower supply volumes coming from the industries that benefit from the additional water. However, there was a tipping point between 50 million m<sup>3</sup> and 75 million m<sup>3</sup> when the impact to employment numbers became negative due to the increasing costs to produce the additional water for industry, which started to outweigh the indirect benefits to the agricultural industry in the directly affected WMA. Therefore, care should be taken in the sizing of a desalination project.

The idea to provide additional water to agriculture by means of desalination and having other users paying for it would not be sound policy and those costs will not be recovered from the rest of the economy as the agricultural sector is somewhat insular. In terms of payment options impacts on the economy tend to be more positive when the consumers of municipal water (industry and households) pay for the desalinated water compared to when only industry absorbs the cost.

With regard to the water supply options such as reuse of water and alien plant removal, the positive impacts of the additional water availability is often subdued due to the additional costs that need to be recovered, hence the macro-economic impacts in terms of GDP, employment and household incomes are generally small but positive.

The recursive dynamic model enables the testing of the impact of policy options affecting water regulation over time. Despite this, the Western Cape economy is quite diversified and although agriculture features highly in the economy, there is a level of resilience in the economy and the dynamic CGE model may not always be the best model to model the economic impact of a longer and severe drought, where the drought is of such a dimension that it eclipses the inherent resilience of the communities in making do with the bare minimum of water.



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It is evident from the climate change simulation, as well as from the actually recorded historic macro-economic measures, that although water volume changes and pricing can be substantial, it does have a rather subdued impact on the macro-economic measures of GDP, employment and household income.

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## REFERENCES

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1. Adeh, E., Good, S., Calaf, M. & Higgins, C., 2019. Solar PV power potential is greatest over croplands. *Scientific Reports*, pp. <https://doi.org/10.1038/s41598-019-47803-3>.
2. Adeh, E., Selker, J. & Higgins, C., 2018. Remarkable agrivoltaic influence on soil moisture, micrometeorology and water-use efficiency. *PLoS One* 13, p. e0203256.
3. Albrecht, T. R., Crootof, A. & Scott, C. A., 2018. The water-energy-food nexus: A comprehensive review of nexus-specific methods. *Environmental Research Letters*, 13(4), pp. 1-26.
4. Amaducci, S., Yin, X. & Colauzzi, M., 2018. Agrivoltaic systems to optimise land use for electric energy production.. *Applied Energy* 220, pp. 545-561.
5. Anon., 2020. *AgriVoltaics* 2020. [Online] Available at: <http://www.agrivoltaics-conference.org/home.html>
6. Ascough, J. C. et al., 2018. *Agriculture Models, in: Reference Module in Earth Systems and Environmental Sciences*. s.l.:Elsevier.
7. Barnard, S. A. & Cloete, R., 2018. *Economic Study of Assurance of Supply Requirements for water Resource Management with reference to Irrigation Agriculture*, WRC Report K5/2517, Pretoria: WRC.
8. Basson, M., Combrink, A., Schroder, J. & Rossouw, J., 2010. *Assessment of the ultimate potential and future marginal cost of water resources in South Africa*, Pretoria: Department of Water affairs.
9. Blanco, M. et al., 2015. *Extension of the CAPRI model with an irrigation sub-module*, Luxembourg: Publications office of the European Union.
10. Boccanfusso, D., Estache, A. & Savard, L., 2005. *A Poverty and Inequality Assessment of Liberalization of Water Utility in Senegal: A Macro-Micro Analysis*, Universite de Sherbrooke: Groupe de Recherche en Economie et Developpement International.
11. Brisson, N. et al., 2014. How do various maize crop models vary in their responses to climate change factors?. *Global Change Biology*, Volume 20, pp. 2301-2320.
12. Brocklehurst, C., 2002. *New designs for water and sanitation transactions: making private sector participation work for the poor*, s.l.: PPIAF.
13. Bundschuh, J. & Chen, G., 2014. *Sustainable Energy Solutions in Agriculture*. Leiden: CRC Press.
14. Burek, P. A., Van der Knijff, J. & De Roo, A., 2013. *LISFLOOD - Distributed Water Balance and Flood Simulation Model - Revised User Manual*. Luxembourg: Joint Research Centre, EU Science Hub, European Commission..
15. Bushnak, D. A., n.d. *Assessment of Best Available Technologies for Desalination in Rural/Local Areas*, s.l.: s.n.
16. Cervigni, R., Liden, R., Neumann, J. E. & Strzepek, K. M., 2015. *Enhancing the climate resilience of Africa's infrastructure: the power and water sectors*, s.l.: World Bank.
17. Chen, Y. et al., 2018. Mapping croplands, cropping patterns, and crop types using MODIS time-series data. *International Journal of Applied Earth Observation and Geoinformation*, Volume 69, pp. 133-147.
18. City of Cape Town, Department of Water and Sanitation, 2018b. *Water Outlook 2018 Report*, City of Cape Town: Department of Water and Sanitation.
19. City of Cape Town, Dept of Water and Sanitation, 2018a. *Water Outlook 2018: Summary Report*, Cape Town: s.n.
20. City of Cape Town, 2020. *Cape Town's Water Strategy*, Cape Town: s.n.
21. Cole, M. J., Bailey, R. M., Cullis, J. D. & New, M. G., 2018. Water for sustainable development in the Berg Water Management Area, South Africa. *South African Journal of Science*, Volume 114.
22. Cossu, M., 2014. Solar radiation distribution inside a greenhouse with south-oriented photovoltaic roofs and effects on crop productivity. *Applied Energy* 133, pp. 89-100.

23. Cullis, J. D. S., Gorgens, A. H. M. & Marais, C., 2007. A strategic study of the impact of invasive alien plants in the high rainfall catchments and riparian zones of South Africa on total surface water yield. *Water SA*, Volume 33, pp. 35-42.
24. DAFF, 2017. *Trends in the Agricultural Sector*. s.l.:s.n.
25. De Roo, A. D. et al., 2016. *Modelling water demand and availability scenarios for current and future land use and climate in the Sava River Basin*, Luxembourg: Publications Office of the European Union.
26. DEA, 2015. *Natural resources management database on invasive alien plants in South Africa*, Pretoria: Department of Environmental Affairs.
27. Department of Agriculture, Forestry, and Fisheries, 2017. *Trends in the Agricultural Sector*, Pretoria: Department of Agriculture, Forestry, and Fisheries.
28. Department of Water Affairs South Africa, 2013. *National Water Resource Strategy (NWRS2)*, s.l.: Department of Water Affairs .
29. Desert Research Institute, 2014. *Proposal and Scope of Work: Cloud Seeding Project for the State of Nevada for WY2016*, Reno, Nevada: Division of Atmospheric Sciences: Desert Research Institute.
30. Desert Research Institute, 2016. *Preliminary Proposal and Scope of Work for a Cloud Seeding Project for the State of Nevada for WY2017 – WY2018*, Reno, Nevada: Division of Atmospheric Sciences, Desert Research Institute.
31. Dinesh, H. & Pearce, J., 2016. The Potential of Agrivoltaic Systems. *Renewable and Sustainable Energy Reviews*, 54, pp. 299-308.
32. DWA, 2013. *National Water Resource Strategy (NWRS2)*, s.l.: Department of Water Affairs.
33. DWA, 2013. *Strategic Overview of the Water Sector in South Africa*, Pretoria: DWA.
34. DWAF, 1998. *The National Water Act, Act No. 36 of 1998*, Pretoria.: DWAF.
35. DWAF, 2004. *National Water Resources Strategy*, Pretoria: DWAF.
36. DWS, 2015. *Support to the Continuation of the Water Reconciliation Strategy for the Western Cape Water Supply System: Status Report October 2015*, s.l.: National Water Resource Planning..
37. DWS, 2018. *Cape Town Water Outlook 2018*, Cape Town: City of Cape Town.
38. Dwyer, G. et al., 2005. *Integrating Rural and Urban Water Markets in South East Australia: Preliminary Analysis, Paper presented to the OECD Workshop on Agriculture and Water*. Adelaide, OECD.
39. Elliott, J. et al., 2014. The parallel system for integrating impact models and sectors (pSIMS). *Environmental Modelling Software*, Volume 62, pp. 509-516.
40. Evans, A. E. et al., 2018. Agricultural water pollution: key knowledge gaps and research needs.. *Current Opinion in Environmental Sustainability*, Volume 36, pp. 20-27.
41. FAO, 2011. *Energy-Smart Food For People And Climate*, Rome: FAO.
42. FAO, 2015. *The impact of disasters on agriculture and food security*. Rome: FAO.
43. Ferreira, J., 2016. *Farmers Weekly*. [Online] Available at: <https://www.farmersweekly.co.za/crops/field-crops/the-value-of-nets-in-citrus-and-table-grape-production/> [Accessed 27 3 2019].
44. Finnoff, D. & Caplan, A. J., 2004. *A Bioeconomic Model of the Great Salt Lake Watershed*, Utah : Utah State University.
45. Fiorese, G. & Guariso, G., 2010. A GIS-based approach to evaluate biomass potential from energy crops at regional scale. *Environmental Modelling Software*, Volume 25, pp. 702-711.
46. French, J. & Tessendorf, S., 2018. *Green Technology: Strategy and Leadership for Clean and Sustainable Communities*. [Online] Available at: <https://green-technology.org/magazinews/cloud-seeding-work/> [Accessed 11 04 2019].
47. FruitSA, 2018. *Drought challenges fruit industry*. [Online] Available at: <https://www.fruitsa.co.za/drought-challenges-fruit-industry/> [Accessed 18 April 2019].
48. Fuso Nerini, F., Andreoni, A., Bauner, D. & Howells, M., 2016. Powering production. The case of the sisal fibre production in the Tanga region, Tanzania. *Energy Policy*, Volume 98, pp. 544-556.

- 
49. Ganoulis, J. J. et al., 2017. *Scientific Inventory Of The Nexus*, s.l.: s.n.
  50. Goodman, D. J., 2000. More reservoirs or transfers - A Computable General Equilibrium Analysis of Projected Water Shortages in the Arkansas River Basin. *Journal of Agricultural and Resource Economics*, 25(2), pp. 698-713.
  51. GreenCape, 2017. *Managing Water as a Constraint to Development with Decision-Support Tools That Promote Integrated Planning: The Case of the Berg Water Management Area*, Pretoria: WRC.
  52. GreenCape, 2018. *Market Intelligence Report*, s.l.: s.n.
  53. GreenCape, 2019. *Market Intelligence Report*, s.l.: s.n.
  54. Griffith, D. A., Beall, S. D. & Yorty, D. P., 2016. *Feasibility/Design Study for a Winter Cloud Seeding Program in the Upper Cuyama River Drainage, California*, Utah: North American Weather Consultants, Incorporated.
  55. Griffith, D. A. & Solak, M. E., 2006. *The Potential Use of Winter Cloud Sedding Programs to Augment the Flow of the Colorado River*, Utah: North American Weather Consultants, Incorporated.
  56. Gustafsson, J., Cederberg, C., Sonesson, U. & Emanuelsson, A., 2013. *The methodology of the FAO study: Global Food Losses and Food Waste-extent, causes and prevention*, Rome: FAO.
  57. Hasan, R. J. T., 2011. Macro-micro feedback links of water management in South Africa. *Agricultural Economics*, 42(2), pp. 235-247.
  58. Hassan, R., 2003. *Total economic benefits from water-intensive agricultural activities: A Partial I- O approach*, s.l.: Development Southern Africa.
  59. Hassan, R. M. & Crafford, J., 2006. *Environmental and economic accounts for water resources in South Africa*, London: s.n.
  60. Hassan, R. & Thurlow, J., 2010. Macro-micro feedback links of water management in South Africa: CGE. *Agricultural Economics*, Volume 00, pp. 1-13.
  61. Hassan, R. et al., 2008. *Macro-micro feedback links of water management in South Africa : CGE analyses of selected policy regimes*, Washington, DC: World Bank.
  62. Havlík, P. et al., 2014. Climate change mitigation through livestock system transitions. *Proceedings of the National Academy of Sciences of the United States of America*, Volume 111, pp. 3709-3714.
  63. Hoffman, T. & Ashwell, A., 2001. *Nature divided: land degradation in South Africa*, Cape Town: University of Cape Town Press.
  64. Huggins, A. W., 2009. Summary of Studies that Document the Effectiveness of Cloud Seeding for Snowfall Augmentation. *Journal of Weather Modification*, Volume 41, pp. 127-134.
  65. IDA, 2018-2019. *Water Security Handbook*. s.l.:s.n.
  66. Jauna, J., 2008. *iciency and equity considerations in modeling sectoral water use in South Africa*. University of Pretoria, Pretoria.: Unpublished PhD thesis, .
  67. Johnston, P., 2018. How Western Cape farmers are being hit by the drought. *The Conversation*.
  68. Jordan , T. E., Whigham, D. F., Hofmockel, K. H. & Pittek, M. A., 2003. Nutrient and Sediment Removal by a Restored Wetland Receiving Agricultural Runoff. *Journal of Environmental Quality*, Volume 32, pp. 1534-1547.
  69. Karow, M., 2020. *Agrivoltaics: Agriculture of the Future*. [Online] Available at: <https://weatherology.com/trending/articles/Agrivoltaics-Agriculture-Future.html>
  70. Keith, B., Ford, D. N. & Horton, R., 2017. Considerations in managing the fill rate of the Grand Ethiopian Renaissance Dam Reservoir using a system dynamics approach. *Journal of defense modelling and simulation*, Volume 14, pp. 33-43.
  71. Kohn, R. E., 2003. Israel's Need to Import Freshwater. *Water Air and Soil Pollution*, Volume 143, pp. 257-270.
  72. Le Maitre, D. C., 2004. Predicting invasive species impacts on hydrological processes: the consequences of plant physiology for landscape processes. *Weed Technology*, Volume 18, pp. 1408-1410.
  73. Le Maitre, D. C. & Gorgens, A. H. M., 2001. *Potential impacts of invasive alien plants on reservoir yields in South Africa*. Pietermaritzburg, s.n.

74. Le Maitre, D. C., van Wilgen, B. W., Chapman, R. A. & McKelly, D., 1996. Invasive plants and water resources in the Western Cape Province, South Africa: modelling the consequences of a lack of management. *Journal of Applied Ecology*, 33(1), pp. 161-172.
75. Le Maitre, D., Görgens, A., Howard, G. & Walker, N., 2019. Impacts of alien plant invasions on water resources and yields from the Western Cape Water Supply System (WCWSS). *Water SA*, 45(4).
76. Lesk, C., Rowhani, P. & Ramankutty, N., 2016. Influence of extreme weather disasters on global crop production. *Nature*, Volume 529, pp. 84-87.
77. Letsoalo, A. et al., 2005. *Triple Dividends of Water Consumption Charges in South Africa*, s.l.: Water Resources Research..
78. Li, S. & Yang, X., 2016. Biofuel production from food wastes. In: *Handbook of Biofuels Production*. s.l.:Elsevier, pp. 617-653.
79. Li, T. et al., 2015. Uncertainties in predicting rice yield by current crop models under a wide range of climatic conditions. *Global Change Biology*, Volume 21, pp. 1328-1341.
80. Long, A., 2001. Review of downwind extra-area effects of precipitation enhancement. *Journal of Weather Modification* , Volume 33, pp. 24-45.
81. Maila, D. C. J. M. V. N. N. V. W., 2018. *National water accounts for South Africa systems, methods, and initial results*, Pretoria: Prime Africa Consultants.
82. Maila, D., Crafford, J., Visser, W. & Mathebula, V., 2018. *National Water Accounts for South Africa: Systems, Methods and Initial Results*, s.l.: s.n.
83. Maila, D. et al., 2018. *National water accounts for South Africa systems, methods, and initial results*, Pretoria: Prime Africa Consultants.
84. Marmulla, G., 2001. *Dams, fish and fisheries. Opportunities, challenges and conflict resolution*.. Rome, FAO Fisheries Technical Paper.
85. Marrou, H., Wery, J., Dufour, L. & Dupraz, C., 2013. Productivity and Radiation Use Efficiency of Lettuces Grown in the Partial Shade of Photovoltaic Panels. *European Journal of Agronomy* 44, pp. 54-66.
86. Mateo-Sagasta, J., Marhjeni Zadeh, S. & Turrall, H., 2017. *Water pollution from agriculture: a global review. Executive summary*.. s.l., International Water Management Institute (IWMI) and Food and Agriculture Organisation of the United Nations (FAO)..
87. Matete, M. & Hassan, R., 2007. Integrated ecological economics accounting approach to evaluation of inter basin water transfers: An application to the Lesotho Highlands Water project. *Ecological Economics*, Volume 60, pp. 246-259.
88. Mathys, A., 2008. *Appropriateness of tariff structure: lessons from experience. Working paper for: Managing and planning water services*. Vienna, IWA World Water Conference.
89. México, N. C., 2008. *Impacto del huracán Félix en la región autónoma del Atlántico Norte y de las lluvias torrenciales en el noroeste de Nicaragua*. , s.l.: s.n.
90. Mohamed, A. A. A., 2017. *Water Budget Economy of Navel Oranges Production under Screen Net*, s.l.: s.n.
91. Morokong, T. et al., 2016. *Clearing Invasive Alien Plants as a cost-effective strategy for Water Catchment Management: the Case of the Olifants River Catchment, South Africa*, s.l.: SAJEMS Asset research.
92. Ninham Shand Consulting Services; UWP Consulting, 2007. *Treatment of Effluent to Potable Standards for Supply from the Faure Water Treatment Plant*, s.l.: s.n.
93. Ninsham Sahnd Consulting Services; UWP Consulting, 2007. *Overview of Water Re-use potential from Wastewater Treatment plants*, s.l.: s.n.
94. North American Weather Modification Council, unknown. *Understanding Warm Season Cloud Seeding*. [Online] Available at: [http://www.nawmc.org/publications/summer%20r18%20press\\_final.pdf](http://www.nawmc.org/publications/summer%20r18%20press_final.pdf) [Accessed 11 04 2019].
95. O'Neill, B. C. et al., 2014. A new cenario framework for climate change research: the concept of shared socioeconomic pathways. *Cliamte Change*, Volume 122, pp. 387-400.
96. Oosthuizen, F., 2019. *Farm Manager, Kruisriver Farm* [Interview] (27 March 2019).
97. Otto, F. E. L. et al., 2018. Anthropogenic influence on the drivers of the Western Cape drought 2015–2017. *Environmental Research Letters*, 13(12).
98. Pacific Northwest Laboratory, 2013. *Reverse Osmosis Optimization*, s.l.: s.n.

99. Peterson, D., Dwyer, G., Appels, D. & Fry, J. M., 2004. *Modeling Water Trade in the Southern Murray- Darling Basin. Staff Working Paper*, Melbourne: Melbourne Productivity Commission.
100. Planning, Western Cape Department of Agriculture and Western Cape Department of Environmental Affairs and Development, 2016. *A Status Quo Review of Climate Change and the Agriculture Sector of the Western Cape Province*, s.l.: Smart Agri.
101. Preston, I. R., 2015. *Water supply development decision-making in South Africa. Masters' Thesis*, s.l.: Rhodes University.
102. Prime Africa, 2018. *National Water Accounts for South Africa - Systems, Methods and Initial Results*, Pretoria: WRC.
103. Prims, M. D. T., 2018. *The impact of shade netting on the microclimate of a citrus orchard and the tree's physiology*, Stellenbosch: s.n.
104. Ravi, S., 2016. Colocation opportunities for large solar infrastructures and agriculture in drylands. *Applied Energy* 165, pp. 383-392.
105. Reinders, F., 2019. *Personal Communication, Argicultural Research Council [Interview]* 2019.
106. Roe, T. L., Dinar, A., Tsur, Y. & Diao, X., 2005. Feedback Links Between Economy-Wide And Farm- Level Policies: With Application to Irrigation Water Management in Morocco. *Journal of Policy Modeling*, 27(8), pp. 905-928.
107. Rogers, P., De Silva, R. & Bhatia, R., 2002. "Water is an economic good: How to use prices to promote equity, efficiency, and sustainability." Water policy 4.1 (2002): 1-17.. *Water Policy*, 4(1), pp. 1-17.
108. Rosenzweig, C. et al., 2014. Assessing agricultural risks of climate change in the 21st century in a global gridded crop model intercomparison. *Proceedings of the National Academy of Sciences of the United States of America*, Volume 111, pp. 3268-3273.
109. SARS, 2018. SARS. [Online] Available at: <https://www.sars.gov.za/About/TaxSystem/Pages/Tax-Statistics.aspx>
110. Sekiyama, T. & Nagashima, A., 2019. Solar Sharing for Both Food and Clean Energy Production: Performance of Agrivoltaic Systems for Corn, A Typical Shade-Intolerant Crop. *Environments* , p. doi:10.3390/environments6060065.
111. Seung, C. K., Harris, T. R., Englin, J. E. & Noelwa, R. N., 2000. Impacts of Water Reallocation: A Combined Computable General Equilibrium And Recreation Demand Model Approach. *The Annals of Regional Science*, Volume 34, pp. 473-487.
112. Sixt, G. N., Klerkx, L. & Griffin, T. S., 2018. Transitions in water harvesting practices in Jordan's rainfed agricultural systems: Systemic problems and blocking mechanisms in an emerging technological innovation system.. *Environmental Science and Policy*, Volume 84, pp. 235-249.
113. Smajgl, A., Morris, S. & Heckbert, S., 2005. Water Policy Impact Assessment - Combining Modeling Techniques in the Great Barrier Reef Region. *International Congress on Modeling and Simulation*, Issue December, pp. 1985-1991.
114. South African Reserve Bank, 09/2018. *Quarterly Bulletin*, Pretoria: SARS.
115. South African Reserve Bank, 2018. *Quarterly Bulletin: September*, s.l.: South African Reserve Bank.
116. Sridharan, V., Howells, M., Ramos, E. P. & Sundin, C., 2018. *The climate-land-energy and water nexus: implications for agricultural research..* Stellenbosch, Science Forum.
117. Statistics South Africa, 2017. *Supply-Use Tables for South Africa: 2016*, Pretoria: Stats SA.
118. StatsSA, 2017. *Statistical release P0441, Gross domestic product, Third quarter 2017*, Pretoria: StatsSA.
119. StatsSa, 2017. *Supply-Use Tables for South Africa*, Pretoria: StatsSA.
120. StatsSA, 2017. *Supply-Use Tables for South Africa*, Pretoria: StatsSA.
121. StatsSA, 2020. *Census of Commercial Agriculture. Financial and production statistics*, Pretoria: StatsSA.
122. Stehfest, E. et al., 2014. *Integrated Assessment of Global Enviromental Change with Image 3.0 Model Description and policy application*. s.l.:s.n.

123. St-Pierre , N. R., Cobanov, B. & Schnitkey, G., 2003. Economic Losses from Heat Stress by US Livestock Industries. *International Journal of Dairy Science*, pp. 52-77.
124. Super, A. B. & Heimbach, J. A., 2005. Randomized propane seeding experiment: Wasatch. *Journal of Weather Modification*, Volume 37, pp. 35-66.
125. Tian, Y. et al., 2015. Modeling surface water-groundwater interaction in arid and semi-arid regions with intensive agriculture. *Environmental Modelling Software*, Volume 63, pp. 170-184.
126. Tirado, D., Gomez, C. M. & Lozano, J., 2006. Efficiency Improvements and Water Policy in The Balearic Islands: A General Equilibrium Approach. *Investigaciones Economicas*, XXX(3), pp. 441-463.
127. UCAR, 2019. *NCAR/UCAR Research Application Laboratory*. [Online] Available at: <https://ral.ucar.edu/projects/wyo2008/seedfaq.php> [Accessed 11 04 2019].
128. Uçkun Kiran, E., Trzcinski, A. P., Ng, W. J. & Liu, Y., 2014. Bioconversion of food waste to energy: A review. *Fuel*, Volume 134, pp. 389-399.
129. USDA, 2018. *Commodity Intelligence Report*, s.l.: s.n.
130. Van Niekerk, A. et al., 2018. *An earth observation approach towards mapping irrigated areads and quantifying water use by irrigated crops in South Africa-Report to the WRC*, Pretoria: WRC .
131. van Niekerk, J., 2012. *Technological innovation in the design and construction of De Hoop dam*, s.l.: s.n.
132. van Niekerk, P. H., 2013. *Hydrologic-economic appraisal of inter-basin water transfer projects.Phd Thesis*, Stellenbosch: Stellenbosch University.
133. van Niekerk, P. H. & du Plessis, J. A., 2013. Unit reference value: Application in appraising inter-basin water transfer projects. *Water SA*, 39(4), pp. 549-554.
134. van Wilgen, B. W. et al., 1997. The sustainable development of water resources: History, financial costs, and benefits of alien plant control programmes. *South African Journal of Science*, 93(9), pp. 404-411.
135. Velqzquez, E., Cardenete, M. A. & Hewings, G. J., 2007. *Water Price and Water Reallocation in Andalusia: A Computable General Equilibrium Approach, Working Paper ECON 07.04*, s.l.: Universidad Pablo de Olavide.
136. Vogel, J. C., Fuls, A. & Visser, E., 2001. Radiocarbon adjustments to the dendrochronology of a yellowwood tree. *South African Journal of Science*, 97(3-4), pp. 164-166.
137. Vuuren, D. P. et al., 2014. A new scenario framework for Climate Change Research: scenario matrix architecture. *Climate Change*, Volume 122, pp. 373-386.
138. Water Consultants International, 2018. *Seawater Desalination Cape Town, South Africa*, s.l.: s.n.
139. Water Globe Consultants, 2017. *Critical Review of the Desalination Component of the WRP*, s.l.: s.n.
140. Weselek, A., Ehmann, A. & Zikeli, S., 2019. Agrophotovoltaic systems: applications, challenges, and opportunities. A review. *Agronomy for Sustainable Development* 39, pp. <https://doi.org/10.1007/s13593-019-0581-3>.
141. Western Cape Government, B., 2018. *Drought Policy Brief, Western Cape Agriculture*, s.l.: s.n.
142. World Bank, 2016. *High and Dry: Climate Change, Water and the Economy.*, Washington DC: World Bank.
143. World Meteorological Organization, 2010. *WMO Documents on Weather Modification*. Phitsanulok, Thailand, Updated in the meeting of the Expert Team on Weather Modification Research.
144. World Water Commission, 2000. *A Water Secure World: Vision for Water, Life, and the Environment: World Water Vision Commission Report*, s.l.: Thanet Press.
145. WRC, 2017. *Wide-scale modelling of water use and water availability with Earth observation/satellite imagery (WRC Project No. K5/2401)*, Pretoria: WRC.
146. WWAP, 2015. *The United Nations World Water Development Report 2015: Water for a Sustainable World..* s.l.:s.n.

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147. Wyoming State Climate Office, 2004. *Wyoming State Climate Office*. [Online] Available at: <http://www.wrds.uwyo.edu/sco/climateatlas/drought.html> [Accessed 15 7 2019].
  148. Xie, J. et al., 2009. *Addressing China's Water Scarcity: Recommendations for Selected Water Resource Management Issues*, Washington DC: The World Bank.
  149. Xue, L. et al., 2013. Implementation of a Silver Iodide Cloud-Seeding Parameterization in WRF. Part I: Model Description and Idealized 2D Sensitivity Tests. *Journal of Applied Meteorology and Climatology*, 52(6), pp. 1433-1457.
  150. Zhao, C. et al., 2017. Temperature increase reduces global yields of major crops in four independent estimates. *Proceedings of the National Academy of Sciences of the United States of America*, Volume 114, pp. 9326-9331.



