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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DEVELOPMENT BANK OF SOUTHERN AFRICA

WATER RESEARCH COMMISSION

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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

A Report
to the Water Research Commission

by

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EXECUTIVE SUMMARY

BACKGROUND

South Africa is a water-stressed country facing increased dry spells and weather variability. From a climate change adaptation perspective, the country urgently needs to increase its resilience – specifically in terms of 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 globalisation. These pressures are presenting communities and regulators with an increasingly complex number of trade-offs and potential conflicts. While the demand for water is increasing, the global water cycle is changing (part of a wider phenomenon referred to as climate change), with the effects 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. Conduct a literature review to gather relevant information that would enable refinement of the project methodology document and updating of the respective models.
2. Upgrade the SA water social accounting matrix (SAM) for inclusion of alternative supply sources – specifically water reuse and desalination – to an alternative water SAM.
3. Develop an expanded computable general equilibrium (CGE) model that accommodates stochastic elements to enable evaluation of certainty of supply and supply elasticity.
4. Develop a dynamic version of the CGE model to reflect the dynamic nature of economy.
5. Demonstrate the model as an assessment framework, by conducting a scenario analysis for the Berg River WMA.
6. Undertake modelling of tariff structures with parallel evaluation of opportunity cost and cost of unserved water.
7. 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 that would allow evaluation of the 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 must 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 economic model with specific consideration of the competition between municipal, industrial and agricultural water use, water resource contributions, and considerations regarding supply certainty. The country-wide model was proposed to be demonstrated within the Berg River WMA (includes the City of Cape Town Metropolitan Municipality, and is currently one of South Africa's most stressed water management areas) 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

Several alternative water supply options were considered in this study, and a comprehensive analysis was undertaken on the options shown in the table below. Cost comparison 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^3/a)	Intervention/ Alternative Supply Cost (ZAR)
Alternative Supply Options			
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

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 analysis of farming under netting, 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 Agri-PV was similar to costs achieved for water reuse. The water savings and electricity generation potential results 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 cannot reasonably expect agricultural fields be covered by solar canopies anytime soon unless there is 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 Agri-PV, demonstrate the transferability to other regional areas, and also realise larger systems.

ECONOMIC ANALYSIS OF WATER SUPPLY OPTIONS

a. Development Of The 2016 water social accounting matrix (SAM)

The SAM is a disaggregated, consistent, and complete data system that captures the interdependence that exists within a socioeconomic system. It can be used as a conceptual framework to explore the impact of exogenous changes in such variables as exports, certain categories of government expenditure, and investment on the whole interdependent socioeconomic system, e.g., the resulting structure of production, factorial, and household income distributions. As such, it 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 SAM for South Africa that was developed in 2002 was used to underpin the development of a water SAM in 2016. The treatment of water within the supply and use tables published by Statistics South Africa (Stats SA) and the national water accounts published by the Water Research Commission (WRC) – which form the core data of a SAM – has changed since 2002, with the implication being 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 water SAM developed in 2016 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) sectors, 15 industrial sectors, and eight 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. Besides 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 was 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

A CGE model is useful whenever we wish to estimate the effect of changes in one part of the economy on the rest. CGE models fit economic data to a set of equations that aim to capture the structure of the economy and behavioural response of agents (industry, households, and 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 the base model and 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 that 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 is far more pronounced. For example, a 10% increase in the irrigation water tariff leads to 1 600 national job losses. The biggest negative impact of the irrigation water tariff increase is on the export 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 rate changes, there is little indirect effect on other water usage. In general, the production of horticulture increases when municipal water rates increase, whereas production of field crops decreases. 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 when compared to horticultural products – the demand for field crops is likely to decline. Changes in regional GDP resulting from 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 10 000 national job losses.

Transfer of water from use in irrigation to municipal use for industries: national level

The transfer of 50 million m^3 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 because of an expansion of industries and hence household income. There is also an increase in employment (5 800 jobs) 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%, and bulk and municipal water each by 40%. This led to a 37% decrease in households' use of municipal water, which is endogenously determined, and therefore also captures both some of the indirect impacts of the reduction in water as part of the imposed shock and 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 jobs, and on a national level by 26 800 jobs.

Water transfer between sectors in the Berg–Olifants/Doorn WMA

The transfer of 25 million m^3 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^3 of 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%. Results on a national level are small as they only reflect 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 an alternative water supply option in the Berg–Olifants/Doorn WMA: same volumes, different payment options

When an additional 50 million m^3 of 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. Taxation on users has a more positive outcome compared to when industries absorb the cost. All WMAs show an increase in employment, except for 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^3 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%. Household 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.

The GDP of industry in the directly affected WMA decreases by between 0.03% and 0.13%. This loss cannot be fully offset by the positive impact on agriculture, meaning that a net negative impact on GDP in the Berg–Olifants/Doorn WMA is experienced. Employment in the Berg–Olifants/Doorn WMA increases for additional desalination water volumes of up to 50 million m^3, but decreases for higher volumes because at lower volumes that positive impact on employment in the agricultural sector outweighs the negative impacts in industry. However, the GDP and employment impacts in the other WMAs are positive.

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

In this scenario, an additional 25 million m^3 reuse water is made available for industries and households, with the additional cost either covered by industries or all users of the water (including households). Economic benefits tend to be larger when all the users of water cover the additional cost. Also, since the cost is only carried 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^3 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 of 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 through paying a tax, their use of water increases by only 0.77%. This effect also drives the national results. The indirect effects of the additional reuse water on WMAs are small and positive.

Alien invasive plant removal for additional water in the Berg–Olifants/Doorn WMA

In this scenario, alien invasive plant removal provides an additional 25 million m^3 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 through taxation on water.

Summary

The total volume of water used within the Berg–Olifants/Doorn WMA increased by 2.29%, but the 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, creating a small positive impact on GDP in the Berg–Olifants/Doorn WMA. Employment in the WMA increases by 390 local and 3 170 national job opportunities. Impact 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 at the national level.

c. The dynamic computable general equilibrium (CGE) model and key results

To be able to assess the impact of water policies over time, a dynamic recursive model was configured alongside the static version. The dynamic version would provide the capability to evaluate policy options relating to water supply volume and tariff adjustments, but it requires calibration of economic variables and parameters that go beyond the static version’s requirements. The dynamic recursive model produces time series information that can be used in the techno-economical evaluation of proposed supply-side projects.

To demonstrate its capability, the recursive dynamic model was configured to simulate – building on the base year of 2016 – the following three scenarios over a nine-year period, :

- Determine the compound impact of annual increases in the price of irrigation water.
- Determine the compound impact of annual increases in municipal water tariffs.
- Estimate 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 by 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 household and industrial consumption rates, and the economic losses in industrial economic activity will more than offset the slight gains to be made in agriculture.

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^3 in the first year, and increasing by 50 million m^3 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, 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 WMAs only – the Breede–Gouritz WMA and the Berg–Olifants/Doorn – as they are 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 real-life recorded GDP and the employment impacts of the drought experienced in the WCWMAs.

It became evident that even though water volume changes and pricing can be substantial, they 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 from 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 was conducted; the SA Water SAM was updated and modified to allow for analysis of impacts of alternative supply sources – among 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; a scenario analysis for the Berg River WMA was conducted; the impact of different irrigation and municipal water tariffs was modelled (although different tariffs for household could not be modelled at a detailed level); and the impacts of different sets of policy interventions at national and regional/sectoral level were analysed and presented.

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

Cost comparisons and hydrological assessments of alternative water supply options were carried out for the following: desalination, water reuse, aquifer recharge, farming under netting, agrivoltaics, precipitation augmentation, and invasive alien 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 Agri-PV 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 the WMA level. The dynamic CGE model analysis focused on estimating the impacts of changes in municipal water tariffs and transfers of irrigation water to industry on the national level, as well as cyclical droughts due to climate change in the Western Cape over a 10-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 than industry. For the same reason, additional water (regardless of the source) directed to industry rather than irrigation agriculture, typically leads to a 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 regarding 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 that 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^3 and 75 million m^3, when the impact on employment numbers became negative due to the increasing costs of producing the additional water for industry – which started to outweigh the indirect benefits to the agricultural industry in the directly affected WMA. As such, care should be taken in the sizing of a desalination project.

The idea of providing additional water to agriculture by means of desalination and having other users paying for it would not be sound policy, and those costs would 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.

Regarding the water supply options, such as reuse of water and alien plant removal, the positive impact of the additional water availability is often dampened, due to the additional costs that need to be recovered. This means that 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 strongly diversified and although agriculture features highly in the economy, there is a level of resilience in the economy that means the dynamic CGE model may not always be the best model to model the economic impact of a longer, severe drought – where the drought is of such a dimension that it eclipses the inherent resolve 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 real-life historic macro-economic measures that, although water volume changes and pricing can be substantial, they have a rather subdued impact on the macro-economic measures of GDP, employment, and household income.

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ACRONYMS & ABBREVIATIONS

BAU	business as usual
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 plant
IB	irrigation board
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 litres per day
NWA	National Water Act 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
UV	ultraviolet
VMP	value of marginal product
WB	water board
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

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 urgently needs to increase its resilience – specifically in terms of 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 globalisation. These pressures are presenting communities and regulators with an increasingly complex number of trade-offs and potential conflicts. While the demand for water is increasing, the global water cycle is changing (part of a wider phenomenon referred to as climate change), with the effects 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.

Generally, water scarcity raises the following 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 this project was to develop an assessment framework that would allow evaluation of the 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 must be considered as supply options in the face of current constraints and variability in supply.

1.2 PROJECT AIMS

The aims of the project were as follows:

1. Conduct a literature review to gather relevant information that would enable refinement of the project methodology document and updating of the respective models.
2. Upgrade the SA water social accounting matrix (SAM) for inclusion of alternative supply sources – specifically water reuse and desalination – to an alternative water SAM.

3. Develop an expanded computable general equilibrium (CGE) model that accommodates stochastic elements to enable evaluation of certainty of supply and supply elasticity.
4. Develop a dynamic version of the CGE model to reflect the dynamic nature of economy.
5. Demonstrate the model as an assessment framework, by conducting a scenario analysis for the Berg River WMA.
6. Undertake modelling of tariff structures with parallel evaluation of opportunity cost and cost of unserved water.
7. 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 economic model with specific consideration of the competition between municipal, industrial and agricultural water use, water resource contributions, and considerations regarding supply certainty. The country-wide model was proposed to be demonstrated within the Berg River WMA (includes the City of Cape Town Metropolitan Municipality, and is currently one of South Africa's most stressed water management areas) 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. In this respect, it is worth noting that 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 their supply potential.

For this study, various interventions in groundwater utilisation, conventional run of river and dam infrastructure, water reuse, desalination, and 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 may also be standardly applied 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 the elasticity of supply.

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 urbanisation drive, increasing living standards, and industrialisation. 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).

To be able to assess the impact of water policies over time and 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.

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), the 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.

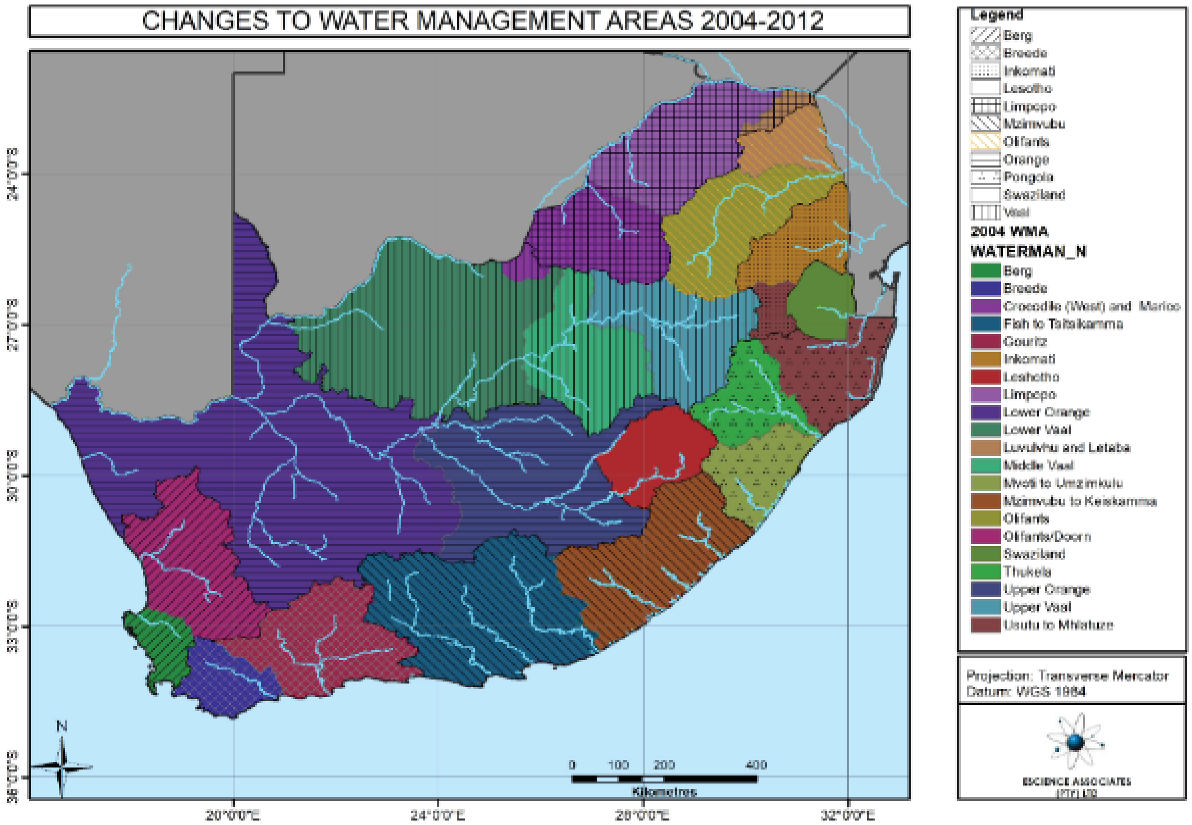


Figure 2-1: Changes to WMAs, 2004–2012

While irrigated agriculture is certainly the main use 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 was estimated to be between 51% and 63% of total water available (WRC, 2017). The study's 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 WMAs of 2004 to the current nine WMAs via their common elements.

Table 2-1: Area under irrigation – comparison between 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
Luvulvhu and Letaba	Area 2	54 829.6	90 735.6	Luvulvhu and Letaba	Area 2a	19 427.8					
Crocodile (West) and Maricc	Area 3	77 650.2	88 458.5	Crocodile (West) and Maricc	Area 3a	74 744.5					
Olifants	Area 4	91 121.5	124 603.7	Luvulvhu 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 Maricc	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-Tsitsikamı	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^3/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^3/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. 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.

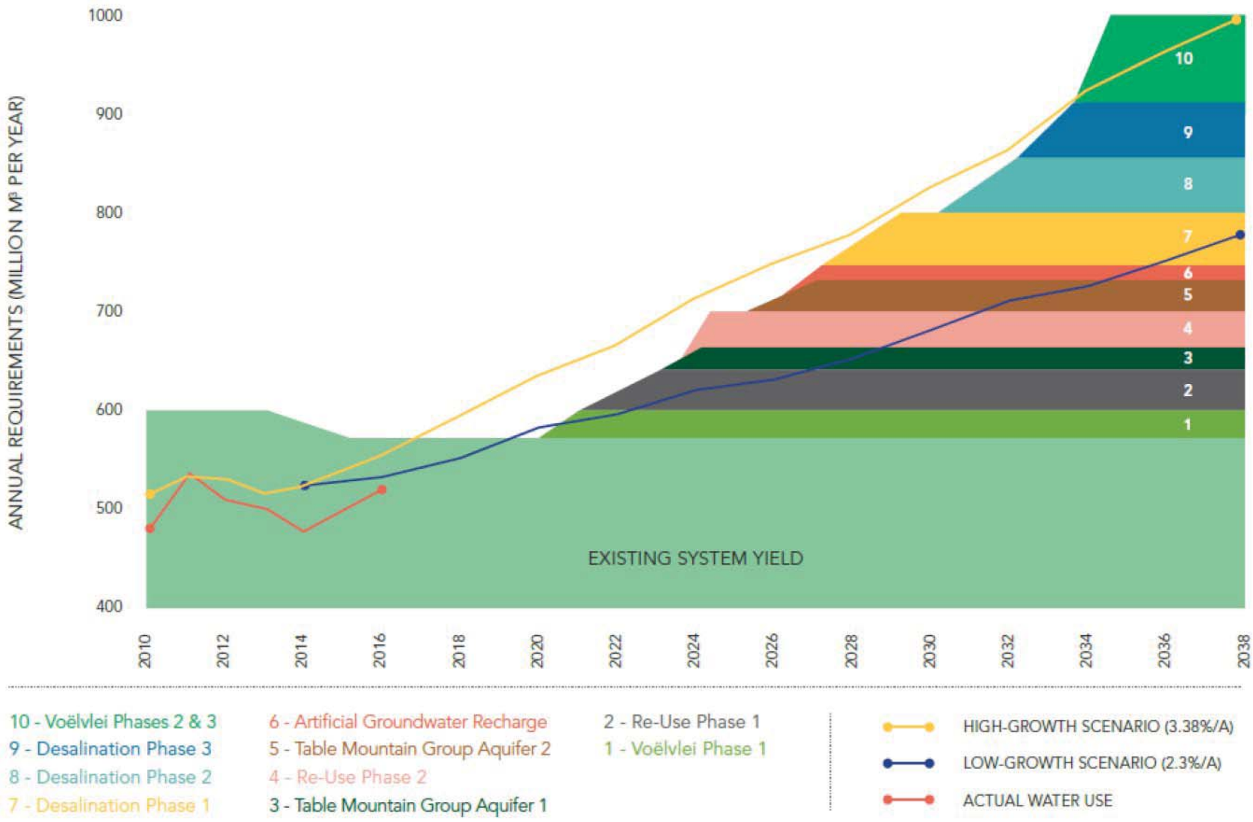
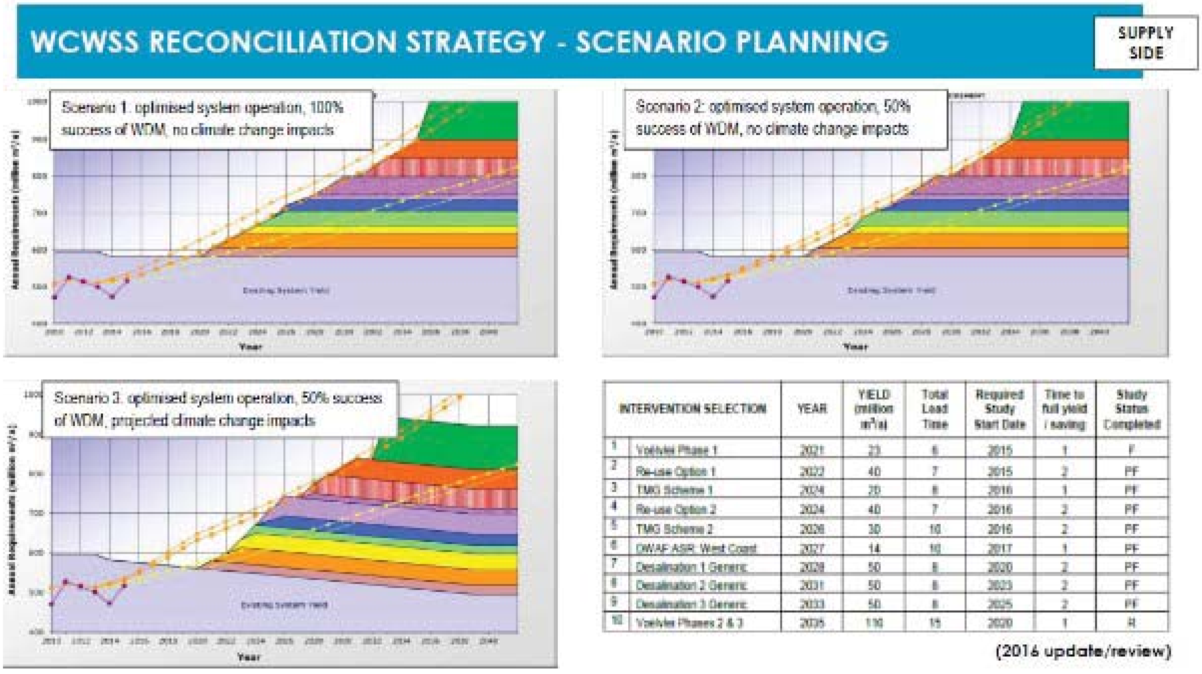


Figure 2-2: WCWSS reconciliation of supply and demand for the Planning Scenario (GreenCape, 2017)

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 CoCT that are effectively piloting the Table Mountain Aquifer Group and large-scale reuse schemes, yet also form part of CoCT's drought emergency supply schemes. (GreenCape, 2017).



	INTERVENTION SELECTION	YEAR	YIELD (million m³/a)	Total Lead Time	Required Study Start Date	Time to full yield / saving	Study Status Completed
1	Voëlvlei Phase 1	2021	23	6	2015	1	F
2	Re-use Option 1	2022	40	7	2015	2	PF
3	TMG Scheme 1	2024	20	8	2016	1	PF
4	Re-use Option 2	2024	40	7	2016	2	PF
5	TMG Scheme 2	2026	30	10	2016	2	PF
6	DWAF ASR: West Coast	2027	14	10	2017	1	PF
7	Desalination 1 Generic	2028	50	8	2020	2	PF
8	Desalination 2 Generic	2031	50	8	2023	2	PF
9	Desalination 3 Generic	2033	50	8	2025	2	PF
10	Voëlvlei Phases 2 & 3	2035	110	15	2020	1	R

Figure 2-3: WCWSS reconciliation strategy – scenario planning (GreenCape, 2017)

2.3 ALTERNATIVE WATER SUPPLY OPTIONS AND THEIR INVESTIGATION

In the past, the Western Cape Water Supply System (WCWSS) 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 (CoCT), 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) must now 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 CoCT 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 (CoCT, 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 (CoCT, 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	1 200	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	1 360	20	5
Desalination Phase 1	2026	50	18	1 650	33–40	9
Total, including WDM:		417	154	6 746		
Total new supply:		347	128	6 336		

Notes: +Timing, capital, and operating costs are the best available engineering estimates. All schemes are subject to the 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

Scheme	(Yield Ml/Day)	Detail	Cost	First Water Available
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 the following demand management measures: • Water restrictions • Pressure management • Water saving incentive schemes • Regulation of plumbing fittings and water using appliances • Informative water billing • Communication	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
- CoCT 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, 2016

The following three models were used as sources of data during this assessment: 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 and WRPM models were 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 – who made recent improvements to the model.

The WRYM model was improved as far as possible, to include variable demands instead of the typical fixed annual demands, and 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.

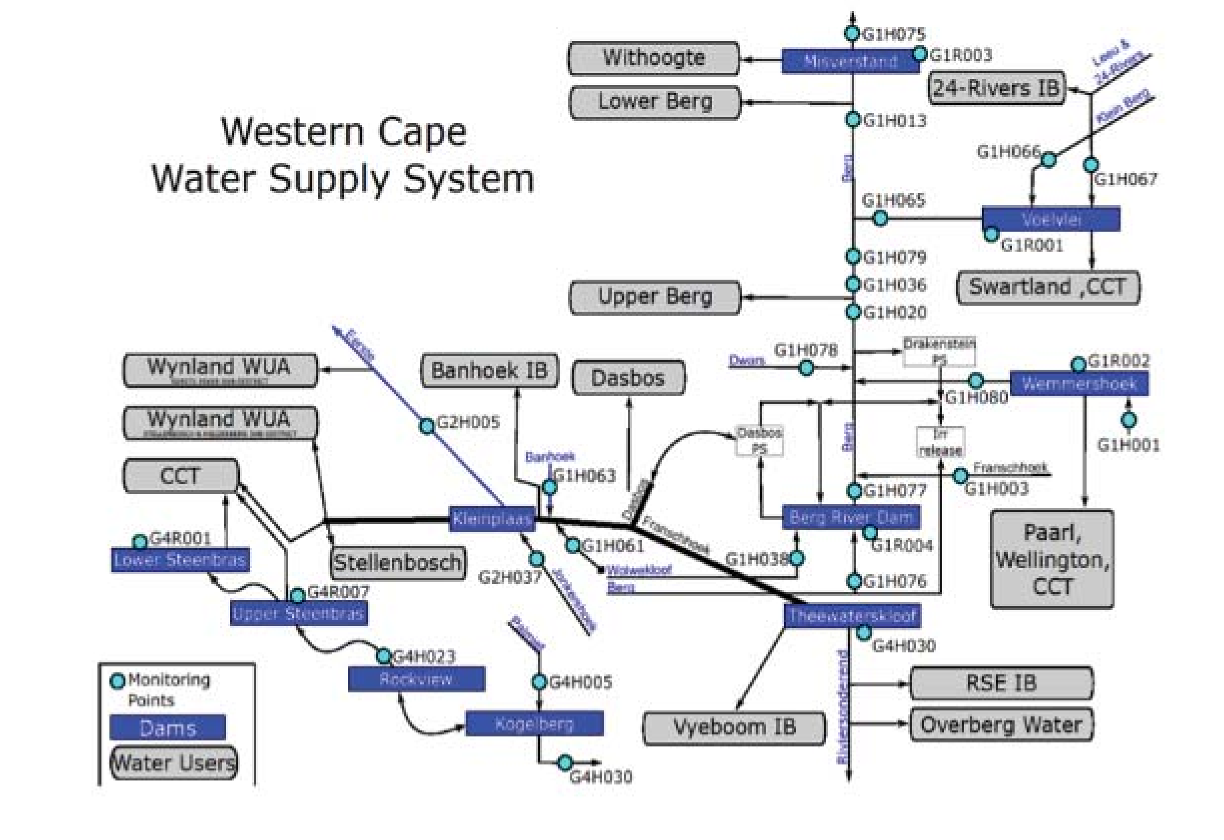


Figure 2-4: Western Cape Water Supply System (WCWSS; DWS, 2018)

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

3.1 DESALINATION

The main benefit of implementing desalination as an alternative source of bulk water or potable water supply is that it is independent of rainfall; it does not rely on rainfall for assured supply and can be used to supplement traditional water supplies that are rainfall dependent. 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 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 that is 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 CoCT. The following salient points are agreed upon in this regard:

- The need for construction of three separate seawater desalination plants, of capacities 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 the Cape Flats' aquifer's discharge into the bay), and on the Atlantic coast at or near the Koeberg nuclear power plant (to utilise existing infrastructure) or at another location in the vicinity of an existing large fresh-water delivery pipeline – in order to avoid construction of water supply infrastructure in a highly urbanised environment (Water Globe Consultants, 2017).

3.1.1 Desalination technology

The process of desalination can be broken down into the following two main types: thermal/multi-effect (MED) distillation and reverse osmosis (RO). There are variations of both, but the general principles 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 unwanted 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, with 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.

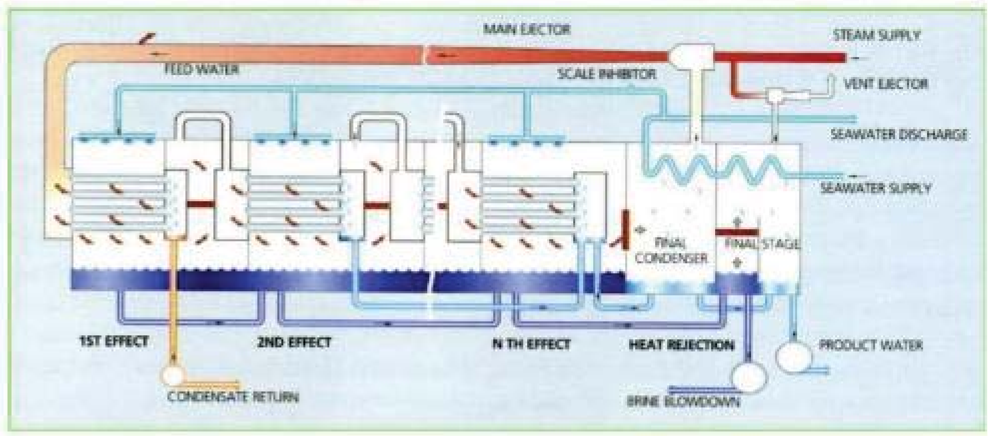


Figure 3-1: MED Schematic (Bushnak, n.d.)

3.1.1.2 Reverse osmosis (RO)

Reverse osmosis is a process where the input/feed water is forced through a semi-permeable membrane under high pressure, removing the unwanted salts and 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.

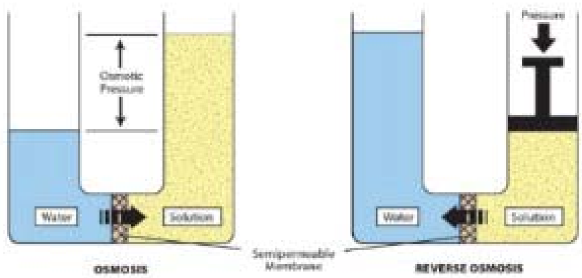


Figure 3-2: RO principle (Pacific Northwest Laboratory, 2013)

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).

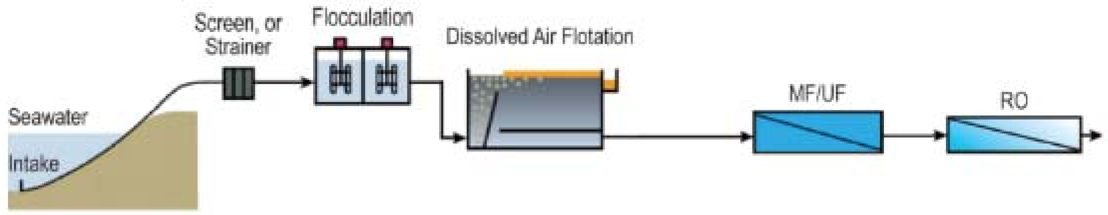


Figure 3-3: RO pre-treatment (Pacific Northwest Laboratory, 2013)

3.1.2 Desalination costing

The costing below (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.

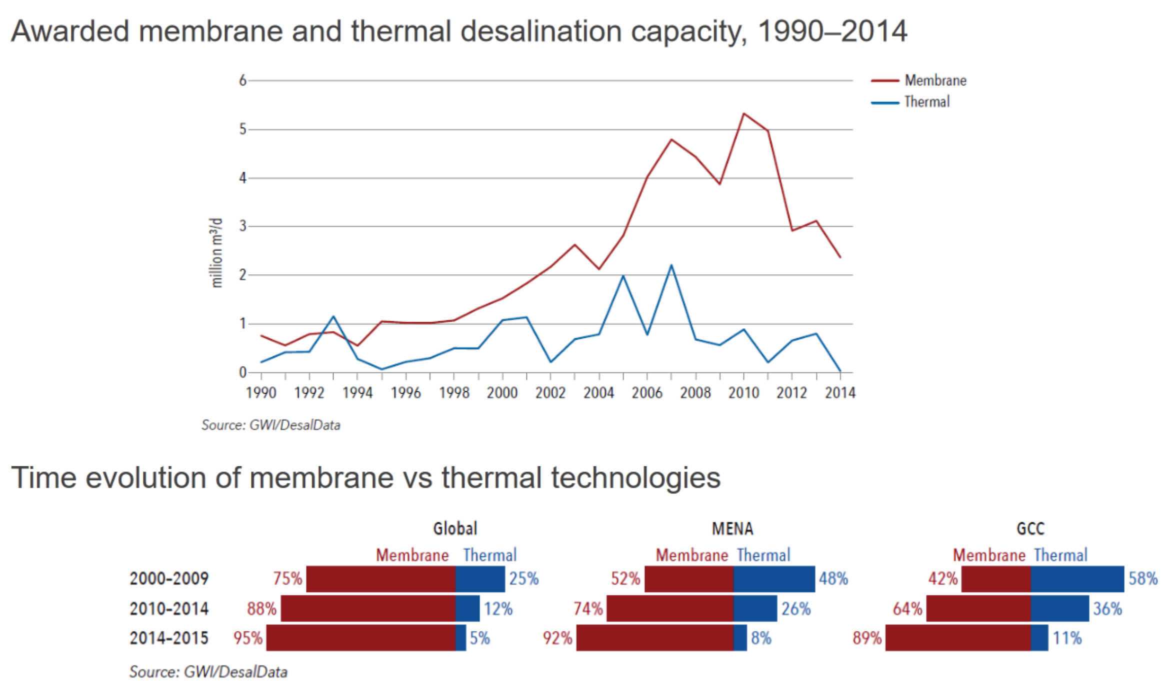


Figure 3-4: Desalination plant capital cost breakdown for reverse osmosis and multi-effect distillation

Capital costs were found to be insensitive to scale for plants larger than 50 Mℓ/day, except when diseconomy of scale occurs because of excessively large equipment and piping, and increased construction windows. This typically occurs with plants of a 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 Mℓl/day reference case facilities

Project type	SWRO, with energy recovery device	MED – free, waste heat	MED/MSF – heat from natural gas at 56 ZAR/GJ (4 USD/GJ and 14 ZAR/USD)
Capital costs, ZAR/m^3	7,97	8,96	8,96
Total operating costs, ZAR/m^3	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_{th}/m^3	0	45	45
Electrical energy consumption, kWh_e/m^3	2,7	1,75	1,75
Unitary charge, ZAR/m^3	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 the necessary low-cost natural gas, but MED may be an option for the country in future – if paired with low-grade waste heat from sources like 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.

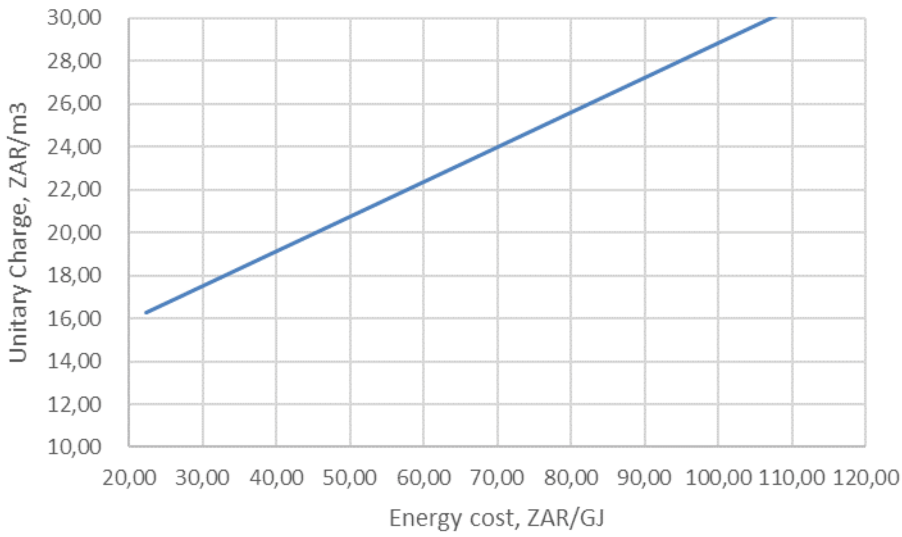


Figure 3-5: Influence of energy cost on desalinated water cost – multi-effect distillation

3.1.2.2 Benefits of colocation with existing seawater intakes and outfalls

Colocating 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 uses such as RO water preheating or hybrid MED-RO desalination, which can reduce energy consumption.

A qualitative analysis was conducted based on a colocational 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^3)
Reference case SWRO plant – standalone	12.82
Reference case SWRO plant – colocated intake and outfall	11.78

The analysis is hypothetical, based on a typical intake/outfall cost contribution and shared costs between colocated developments. Intake and outfall construction costs vary significantly and are highly site-specific and dependent on brine disposal and other environmental requirements. Colocation of desalination with, for example, 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 makes it possible in theory 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 must 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, desalination, 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 the indirect water reuse already prevalent in the agricultural sector. The use of this technology has been steadily increasing in recent years, almost doubling since 2010 (IDA, 2018-2019) – as shown in Figure 3-6.

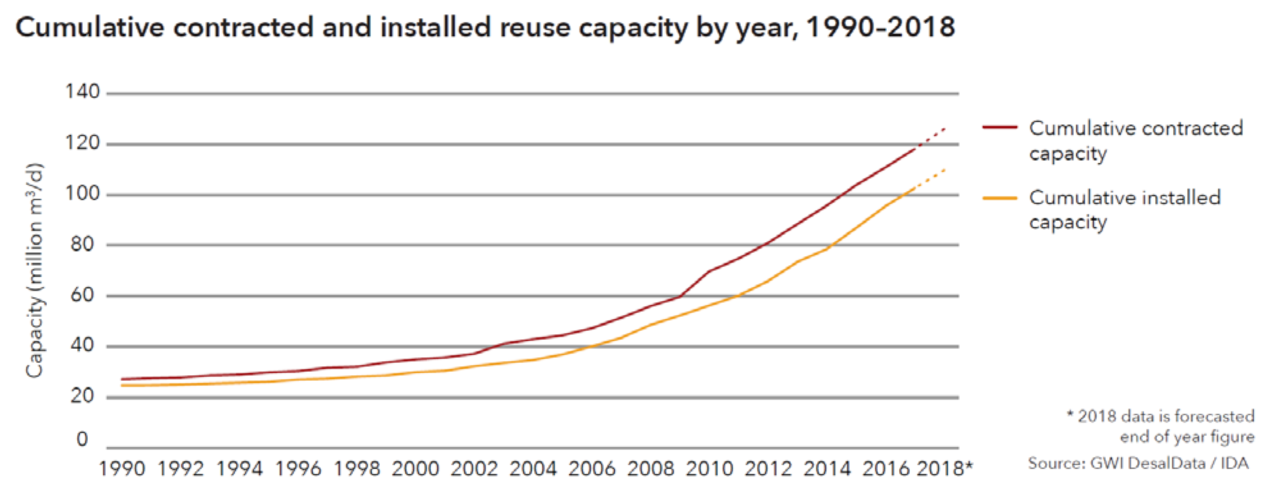


Figure 3-6: Cumulative contracted and installed reuse capacity world-wide, 1990–2018

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

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

In addition to this, the way the water is used can also be split 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 made available for consumption.

Typically, the input water intended to be reused has already undergone treatment at a WWTP or equivalent. CoCT has identified numerous WWTWs 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^3/a)

WWTW	Rated Hydraulic Capacity	Average Annual Flow[3]	Identified Potential Yield[4]					Total Identified Potential Yield	Existing Reuse
			Irrigation/ Industrial[5]	Local Agriculture[6]	Commercial Agriculture[7]	Aquifer Recharge[8]	Potable[9]		
Bellville	19.9	19.6	4.7	0.0	0.0	0.0	0.0	4.7	2.1 [10]
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 [11]
Zandvliet	22.6	17.5	0.8	0.0	3.3	0.0	16.3	20.4	0.0
Mitchells 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 [12]
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
Simon’s Town	1.8	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wildevoël Vlei	5.1	3.1	0.9	0.0	0.0	0.0	0.0	0.9	0.0
Total	**242.8**	**171.9**	**35.1**	**7.9**	**5.1**	**2.1**	**74.6**	**124.7**	**11.6**

[3] This represents the true potential yield, as opposed to the identified potential yield.
[4] This represents yields of schemes that have already been identified, and therefore does not equal the average annual flow.
[5] 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.
[6] The source of information for the potential for local agriculture is based on the Bvi study (small-scale agricultural demand).

[7] 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.
[8] The source of information for the potential for aquifer recharge is based on the Bvi Study.
[9] 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^3/a to 70 million m^3/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.
[10] 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.
[11] A project to convey treated effluent from the Macassar WWTW to a proposed housing development (old AECI property) has recently been initiated.
[12] 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: Ninham Shand Consulting Services, 2007; UWP Consulting, 2007

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 independent of rainfall but it 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 several revenue streams, including from treatment charges, the use of nutrients in fertilisers, the generation of biogas, and opportunities for water reuse. The challenge with addressing wastewater is therefore not largely a financing issue; 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 CoCT (Water Globe Consultants, 2017).

If reverse osmosis and advanced oxidation treatment of the effluent is necessary after UF 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 to produce 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 costing below is assumed for modelling of a reference case, with 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 yield options (Table 3-5) of direct reuse potable water have been considered for 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^3	3,58	4,60	2,51
Fixed O&M Cost, ZAR/m3	0,13	0,07	0,08
Variable O&M Cost, ZAR/m3	0,70	0,38	0,27
Electricity Cost, ZAR/m3	1,51	0,35	0,35
Unitary charge, ZAR/m3	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/m³	%
Plant M&E cost (amortised over 15 years)	R44 232 154	R1.76	20.60%
Plant civil cost (amortised over 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 and 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 and 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 and 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 costing shown below, 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, and 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, and UV polishing
Capital cost, ZAR/m^3	5,14
Fixed O&M cost, ZAR/m3	0,43
Variable O&M cost, ZAR/m3	0,86
Electricity cost, ZAR/m3	1,51
Unitary charge, ZAR/m3	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^3 increases with plant yield, likely due to a diseconomy of scale occurring because of excessively large equipment and piping, as well as increased construction windows. The Chapultepec unitised cost is greater than all the Faure costs at R7.94 /m^3. This is because of the polishing facility possessed by the plant as well as the input feed water having high total dissolved solids (TDS).

On comparison of the unitised costs of reuse as compared to SWRO and MED desalination, 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 the TDS of the input water and therefore these costs are significantly lower for effluent as opposed to sea water (Ninham Shand Consulting Services, 2007; UWP Consulting, 2007).

3.2.3 Hydrological modelling of water reuse

The interplay between treated wastewater, stormwater, desalination, and aquifer recharge was built into the WRYM model though different scenarios, to assess the impact on supply reliability. Implications such as reduced reuse in times of restrictions were 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 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 are required to ensure that these processes are efficient.

The technology is not solely dependent on surface water as desalination and reuse 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 of being rapidly deployable, 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 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 three to five 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. The water source 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, 2017).

Global international experience suggests that the recharge facilities located within five to 10 kilometres of the seacoast should be designed in such a way 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 priority of the water extraction projects is to establish their safe yield with standard pumping tests. Once the safe rate of groundwater extraction is known, the groundwater recharge fields as well as 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, 2017).

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 solution for CoCT is groundwater abstraction, and abstraction from the Atlantis and Cape Flats Aquifers (CFA) is being done at an unsustainable rate. As part of the water use licence 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, desalination, and aquifer recharge was built into the scoping level model though different scenarios, to assess the impact on supply. Implications such as reduced reuse in times of restrictions were considered.

3.4 FARMING UNDER NETTING – IMPROVED IRRIGATION EFFICIENCY

Improving irrigation efficiency aims to minimise 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 protect the fruit from adverse and extreme climatic events – such as high solar radiation, hailstorms, and high wind speeds – with the desired end objective being an increased return on investment, due to reduced irrigation costs, higher produce yields, and production of higher quality fruit (Prims, 2018).

Recent research has shown mixed results when it comes to reduced irrigation requirements and increased crop yields when crops are 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 Southern Cape, production has been seen to increase for citrus production (especially naartjies). Table grapes are very sensitive to the type of netting used and as such may not contribute towards water savings, but their crop yields seem to increase due to the protection of the netting against birds, insects, and the wind.

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

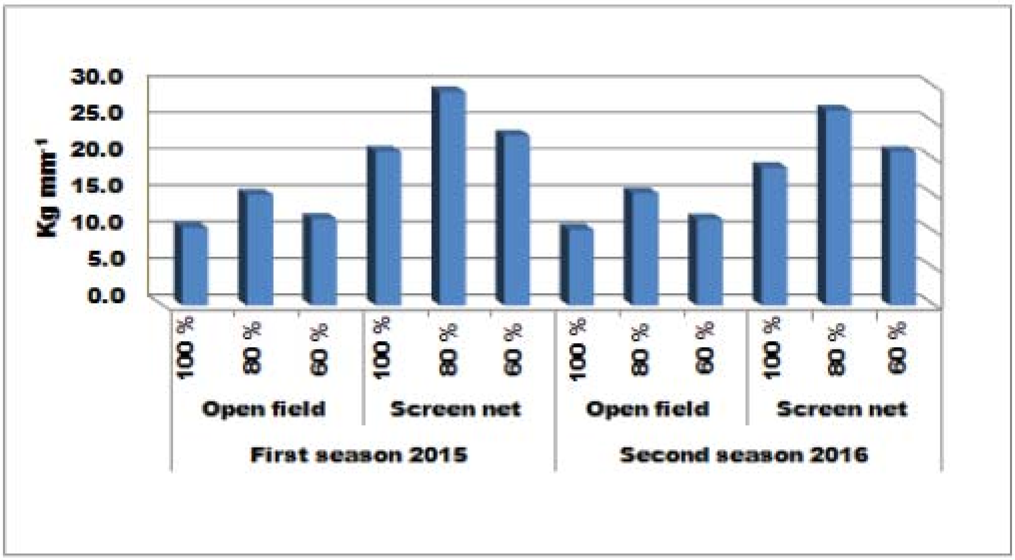


Figure 3-7: WUE at different irrigation levels (Mohamed, 2017)

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 the following main categories: 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). These costs need to be factored in for the erection of shade netting to be a viable water saving initiative, 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: a potential water saving of 20% to 30% for table grapes in the Berg River area (Ferreira, 2016); a fertiliser reduction of 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. Other effects 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% to 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 without netting, the time from establishment to harvest may be as much as four years – compared to 30 months for citrus crops under nets (Oosthuizen, 2019).

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, significantly affecting the viability of shade netting as a water saving intervention.

To combine all the above-mentioned potential effects of the erection of shade netting, it is necessary to perform a simulation, in which the base case of a farm without shade netting is compared to the case of a farm with shade netting – using 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 steps used in the method of this study are as follows:

1. Model the base case scenario of a farm without shade netting and with a fixed water tariff.
2. Model the case of a farm that erects shade netting.
3. Equate the value of the two different models above and solve for the water tariff that the farm with the shade netting can afford while still being on an equal footing with the base case farm.

What these three steps 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. It showed that farming under netting is only economically viable with 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 only 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.

With 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 farming under netting will be more economically viable for higher yielding and more valuable crops. This will need to be investigated further to assess whether that is the case, and if so, 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 of 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 like it is today.

A map of the irrigation areas to which the WCWSS WRYM is providing water is also not available, nor is the actual size of the 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 that the WRYM and WRPM account for losses in supplying the irrigation water requirements to the different irrigation boards (IBs).

For this analysis, the sizes of the IBs of the 1998-approved irrigation areas 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 as well as the integrated effect on the yield of the WCWSS.

The following two main sources of information were used to derive the crop requirements for irrigation subareas 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, which were verified during the recent validation and verification study conducted by the Breede-Gouritz Catchment Management Agency. A summary of the total field sizes under irrigation from the WCWSS subareas is provided in Table 3-11.
- A recent detailed aerial survey of irrigated fields in the Western Cape, carried out by the Western Cape Department of Agriculture provided per-field data on crops, field sizes, and irrigation methods, as well as other data collected during the winter of 2017.

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

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

Water User Association (WUA) or Irrigation Board (IB)	Verified Allocated Area (in ha)	Quota (in m^3/ha/a)	Maximum Allocated Water Use (in 10^6m^3/a)
Upper Berg River (G10A to G10D)			
Berg River Subdistrict 1	3 571	4 000	14.29
Berg River Subdistrict 2	4 227	5 000	21.13
Berg River Subdistrict 3	3 003	6 000	18.02
Groenberg Ward 2	119	5 000	0.60
Groenberg Ward 1	211	5 000	1.06
Noord-Agter Paarl	970	5 000	4.85
Perdeberg	1 324	5 000	6.62
Simondium	243	4 000	0.97
Simonsberg	125	4 000	0.50
Suid-Agter Paarl	867	4 000	3.47
Sub-Total	**14661**		**71.50**
Lower Berg River (G10E to G10K)			
Riebeeck Kasteel	224	6 000	1.34
Riebeek West Ward 2	135	6 000	0.81
Riebeek West Ward 1	115	6 000	0.69
Lower Berg River Summer	3 657	3 000	10.97
Lower Berg River	1 648	7 000	11.54
Sub-Total	**5779**		**25.35**
Jonkershoek River Transfer and Eerste River (G22E to H)			
Wynland WUA	6 531	4 000	26.12
Sub-Total	**6 531**		**26.12**
Upper Riviersonderend (H60A to H60C)			
Elandskloof	1 909	6 860	13.10
Upstream Elandskloof Dam	457	6 860	3.14
Vygeboom	1 863	7 100	13.23

Theewaterskloof Dam Direct	1 564	7 100	11.11
Sub-Total	**5 793**		**40.56**
Lower Riviersonderend (H60D to H60L)			
Zonderend	6 017	6 000	36.10
TOTAL WCWSS	**38 781**		**199.64**

The analysis shows that in the Berg and Winelands subareas, the total amount of fields under irrigation from the 2017 Survey was nearly four times as much as the verified allocated areas as seen in Table 3-11. This might be due to the following 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 incorrectly 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.

Nonetheless, the 2017 Survey's 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 subarea 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 the following five distinct irrigation subareas:

- 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 five irrigation subareas and Figure 3-9 shows the distribution in relation to the Köppen-Geiger climate classifications.

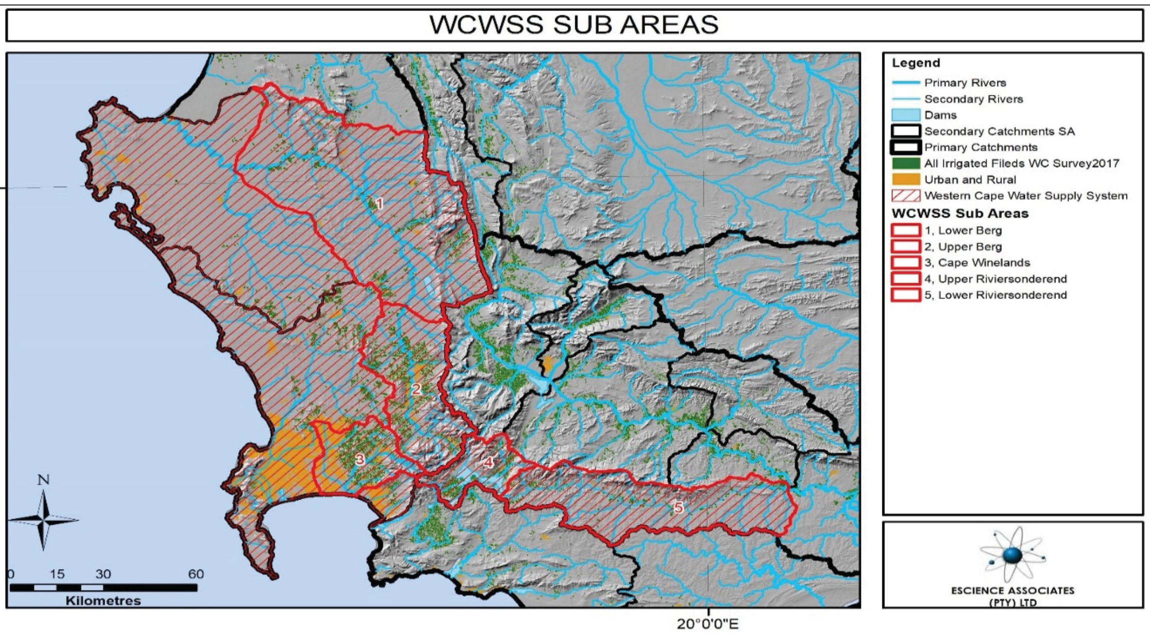


Figure 3-8: Distribution of irrigated agriculture in the three main subareas of the WCWSS, according to the 2017 survey (green = irrigated agriculture and red boundaries = WCWSS subareas)

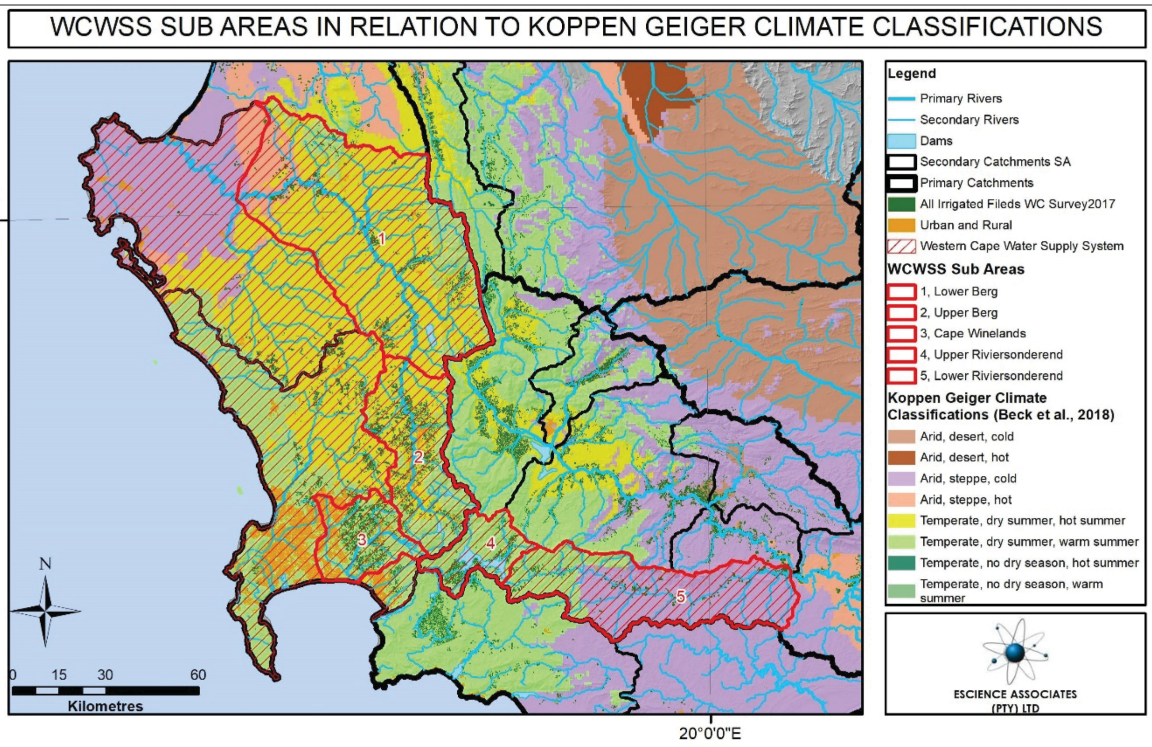


Figure 3-9: Distribution of irrigated agriculture in the three main subareas of the WCWSS, in relation to Köppen-Geiger climate classifications

The average monthly irrigation requirement for each of the five irrigation subareas were then calculated as follows:

- Determine an irrigation subarea representative crop requirement:
  - The unique crops' distributions from the 2017 Survey for each subarea were determined from the approximate quaternary catchment areas in which the IBs are situated. This had to be done

because no detailed map of the IB locations existed. Table 3-13 provides a breakdown of the crop groupings that make up the distribution in each of the main five irrigation subareas.

- To minimise the number of SAWPAT runs, the top seven WCWSS crop groupings were identified, to define a single representative crop requirement for each subarea. The top seven crop groupings represented 94.3% of all the crops that are irrigated in the WCWSS.
- For each irrigation subarea, 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 seven 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 to drip irrigation, and each quaternary's soil type was also considered in the calculation of the monthly crop irrigation water requirement.
- Average crop requirements were then determined for each irrigation subarea, with their individual hydro-climatic conditions. Using the 2017 Survey's crop area sizes per irrigation subarea, a single area weighted monthly, and annual crop requirement was determined for each irrigation subarea.

- Calculate the WCWSS subarea irrigation water requirement:
  - The single subarea specific crop requirement was then multiplied by the legal crop areas for all the IBs and WUAs per subarea.
  - The annual total volumetric crop requirement per subarea was then compared with the assigned irrigation quota.

Table 3-12 provides the subarea representative average annual crop requirement for the five subareas in the WCWSS, considering the rainfall provided in SAPWAT. Table 3-13 also provides a comparison between the total irrigation requirement per subarea 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 Winelands areas are still more than the surface water quotas for the IBs and WUAs. The irrigation requirement considered drip irrigation's 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 are substantially higher than the annual crop requirement – double that of the rest of the WCWSS – and the matter must be clarified as a matter of urgency.

Table 3-12: Crop requirements and total irrigation requirements per WCWSS subarea for the 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	Lucerne/medics	714	837		686	759
Planted pastures	Planted pastures (perennial)	844	1 000		862	995
Olives	Olives	388	459	278		
Representative area weighted gross crops requirement (mm/a)		**548**	**580**	**464**	**373**	**547**
IB and WUA legal area under irrigation (ha)		14 661	5 779	6 531	5 793	6 017
2017 Irrigation water requirement (million m^3/a) – drip irrigation with no distribution losses		80.4	33.5	30.3	21.6	32.9
Allocated SW Quota (million m3/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%

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

- Base scenario – this is the total irrigation demand for the 2017 crop distribution, as provided in Table 3-12.
- 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 subareas 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	32 291.0	55.2%	14 629.0	73.6%	5 756.9	39.6%	11 693.9	91.0%	115.4	2.1%	95.7	1.7%
Pome fruit	8 154.6	13.9%	167.7	0.8%	1 072.6	7.4%	51.2	0.4%	4 954.9	88.7%	1 908.3	33.4%
Grains	3 848.7	6.6%	77.9	0.4%	2 376.4	16.4%	0.0	0.0%	53.4	1.0%	1 341.0	23.5%
Stone fruit	3 721.7	6.4%	1 851.6	9.3%	1 292.5	8.9%	223.1	1.7%	307.8	5.5%	46.7	0.8%
Citrus fruits	2 687.5	4.6%	829.5	4.2%	1 404.2	9.7%	150.9	1.2%	29.6	0.5%	273.3	4.8%
Planted pastures	2 548.6	4.4%	223.0	1.1%	503.1	3.5%	65.9	0.5%	57.4	1.0%	1 699.2	29.7%
Olives	1 932.2	3.3%	1 170.1	5.9%	496.3	3.4%	226.3	1.8%	4.1	0.1%	35.3	0.6%
Vegetables	1 331.9	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%
Total	**58 547.9**		**19 880.5**		**14 525.4**		**12 844.7**		**5 584.7**		**5 712.6**	

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	Location	Relative evaporation or ET	Source
Bananas	20–30%	Jordan Valley, Israel	Very high (3 300 mm/a evaporation)	Institute of Soil, Water & Environmental Sciences, Agricultural Research Organization, The Volcani Center, Israel
Apples	15%			
Citrus	50%	Sous Massa, Morocco	High (1 800 mm/a ET and 2 600 mm/a evaporation)	Equipe de Génie de l'Environnement et Biotechnologie, ENSA, Université Ibn Zohr, BP1136 Agadir, Morocco.
Capsicum	33%	Rajasthan, India	Medium (800 mm/a ET)	Indian Institute of Technology Kharagpur, Kharagpur, 721302, West Bengal, India

It is expected that wetter areas will see less 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 are, however, some wet summer months and some overlap in transitional months – affecting 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 subarea's wetness index.

Table 3-15: Wetness index for subareas 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 subarea for each scenario.

Table 3-16: Total – as well as per WCWSS subarea – irrigation requirements (for three scenarios)

	Scenario	Upper Berg	Lower Berg	Winelands	Upper RSE	Lower RSE	WCWSS Total
Legal area under irrigation (ha)	Current	14 661	5 779	6 531	5 793	6 017	38 781
Allocated SW quota (million m3/a)	Current	71.5	25.4	26.1	40.6	36.1	199.6
Water requirement – no distribution losses and drip irrigation (million m^3/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^3/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^3/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 placed under shade netting. The biggest potential savings will be in the Berg and Winelands regions.

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

- A recent version of the WCWSS WRYM model was obtained from AURECON.
- The SAPWAT annual representative crop requirements as shown in Table 3-19 were regenerated, to exclude rainfall available in SAPWAT, and the average monthly representative crop requirements for each of the irrigation subareas 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 subarea representative rainfall distributions from the WRYM were used to calculate the monthly WRYM rainfall time series for each subarea.

- Time series of variable monthly irrigation water requirements for each subarea were then calculated using the WRSM2000/Pitman model's irrigation sub-model, with the following inputs per irrigation subarea:
    - SAPWAT average monthly representative crop requirements (excluding rainfall) based on the 2017 Survey's crop type distributions.
    - WRYM rainfall time series and the area weighted WR2012 MAP for the subarea.
    - Effective monthly rainfall estimates, as calculated from a FAO equation.
- Four scenarios of variable monthly irrigation water requirements for each subarea were generated as follows:
    - Scenario 1: monthly variable requirements (partly due to rainfall) without any quota considerations.
    - Scenario 2: monthly variable requirements were 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 but limiting each year to the maximum quota.
    - Scenario 4: same as Scenario 2 but limiting each year to the maximum quota.
- The irrigation water requirements in the WRYM were then compared with the annual and monthly distribution of the three scenarios of SAPWAT-based irrigation water requirements per subarea.
- 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 five irrigation subarea'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 subareas, 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 subarea.

Irrigation Subarea	Approximate Quaternaries	WRYM		WR2012	Legal Verified		
		Ran File	RAN MAP (mm/a)	Area-weighted MAP Applied (mm/a)	Irrigation Area (km^2)	Weighted Quota (m^3/ha/a)	Quota Volume (mn m^3/a)
Upper Berg	G10A-G10F	G1H20-S	799	916	146.6	4 877	71.5
Lower Berg	G10J & G10K	G1H35	407	488	57.8	4 386	25.4
Winelands	G22F-G22H	G2R01-S	1 613	941	65.3	3 999	26.1
Upper Riviersonderend	H60A&H60B	H6R02GW	1 037	831	34.3	7 100	24.3
Lower Riviersonderend	H60D-H60L	H6INCGW	532	489	60.2	6 000	36.1
				Total	364.2		183.4

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

Irrigation Subarea	Wetness Index (MAP/MAE)	Approximate Area of Netting (km^2)	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 three scenarios compared to the WRYM model's requirements.

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

Irrigation Subarea	Legal Verified Quota Volumes (mn m^3/a)	Annual Irrigation Water Requirements (mn m^3/a)				
			WRSM2000-SAPWAT (Using WRYM Rainfall Distribution)			
		WRYM 2019 WRYM Irrigation	Scenario 1: Present-Day and Variable Demand	Scenario 2: Present-Day, Variable Demand, and 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

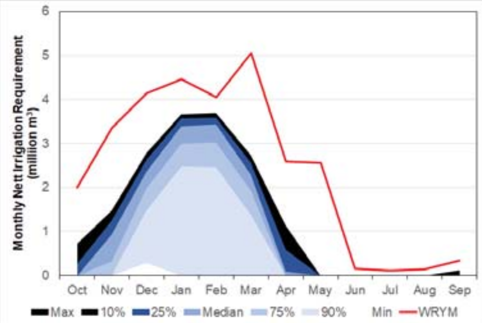
Please note the following regarding Table 3-19:

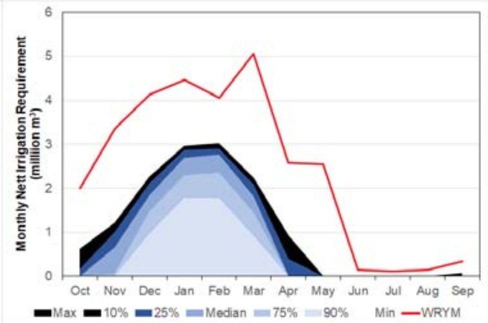
- The WRYM requirements are the end-of-pipe requirements after delivery losses have been accounted for.
- All WRYM irrigation requirements were provided as a fixed annual demand with a fixed monthly pattern.
- All the irrigation requirements were fully or 99% met in all the scenarios and in the original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

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

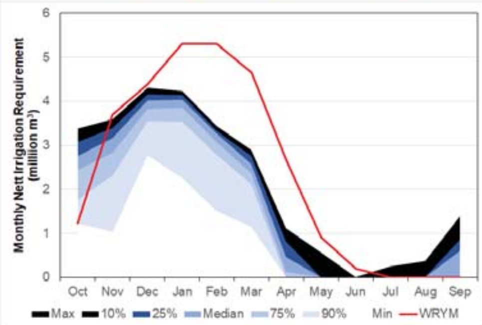
Scenario 4: Variable requirement from legal area using SAPWAT, with shaded netting, and quota limited

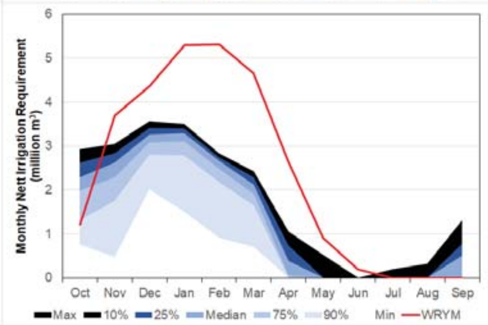
Upper Riviersonderend



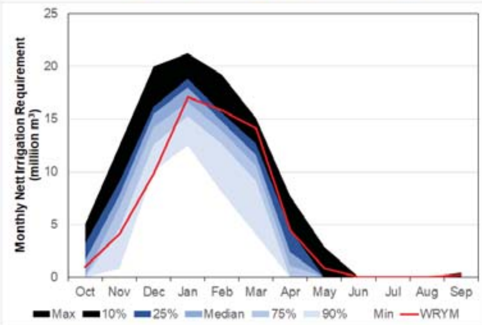


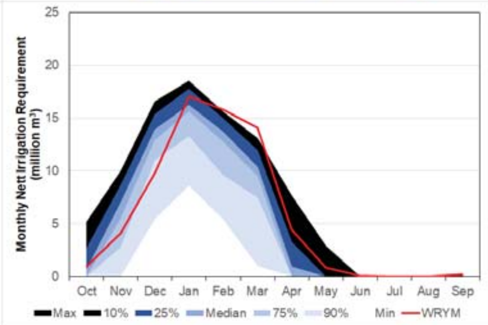
Lower Riviersonderend



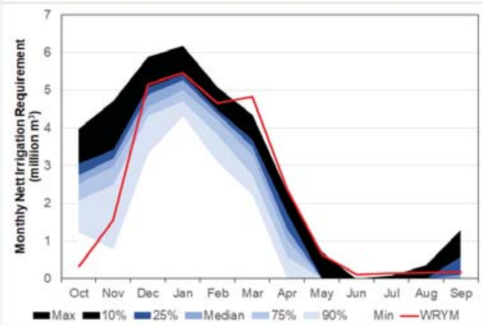


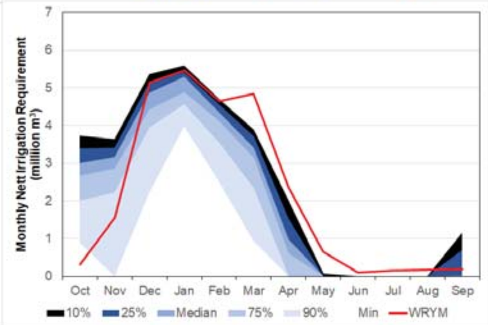
Upper Berg



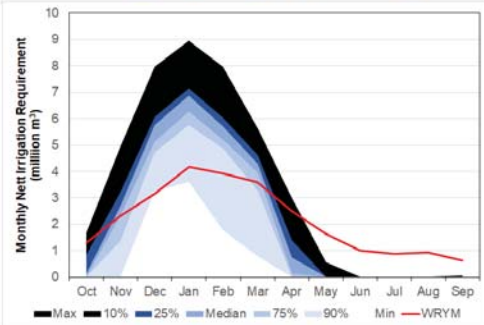


Lower Berg





Winelands



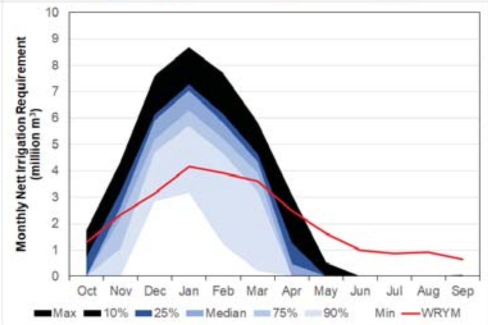


Figure 3-10: Exceedance probability of variable monthly irrigation requirements per subarea, as compared to fixed monthly irrigation requirements in the WRYM model

The following points are observed in Table 3-19 and Figure 3-10:

- Figure 3-10 shows that even though there is 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 irrigation requirements in the WRYM differs considerably given the SAPWAT distribution of irrigation requirements for the crop types in the subareas – especially in the winelands. The apparent overestimation of the irrigation requirements on the Riviersonderend end is also very evident. A reduction in irrigation requirements between scenarios 3 and 4 is not shown for the Winelands, 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 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 that their quota. The quota for these areas is nearly double the quotas in the Berg River and the Winelands. The SAPWAT requirement for 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^2, the total irrigation requirement from with 24%, or 45.5 million m^3/a. All the subareas then use less water than their quotas, except for the Winelands – which requires an additional 20% above its quota.
- In 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^3/a reduction in irrigation requirements, due to the inexplicably high Upper and Lower Riviersonderend requirements in the current WRYM model.
- In 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^3/a reduction in irrigation demand (37.1 million m^3/a against the current WRYM model irrigation requirement).

Incorporating the variable monthly irrigation requirements into the WRYM for scenarios 3 and 4 produced the results summarised in Table 3-20. Table 3-20 shows that there is a 25.4 to 40.3 million m^3/a difference in the irrigation water requirements 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 are 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 without being too conservative.

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

- R231 per m3 at a 10% interest rate

- R130 per m3 at a 7.5% interest rate

Table 3-20: WCWSS WRYM Results for scenarios 3 and 4, compared with baseline (all values in million m^3/a)

Component	WRYM Baseline		Scenario 3		Scenario 4		Saving (Scenario 3 & Baseline)	Saving (Scenario 4 & Baseline)	Saving (Scenario 4 & Scenario 3)
	Requirement	Supply	Requirement	Supply	Requirement	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 River 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, in which energy and food are harvested together on a given land area, that can maximise the land's productivity as well as bring additional potential benefits – such as reduced irrigation budget, improved crop yield, agricultural land preservation, and socioeconomic welfare of farmers. AV 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 minimise ecological changes to the land while favouring local communities.

In the AV approach, PV panel arrays are designed to partially cover the crops with optimal density, elevation, and tilt, manipulating 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 – such as minimising harmful thermal stress on plants in hot climates, and reducing leaching of soil due to excessive rain (through water management). Moreover, PV coverage has shown a lower water evaporation rate, 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 a socioeconomic perspective, AV farming could both make a significant improvement in the livelihood of farming communities and accelerate solar energy investments to enable more sustainable economies.

AV is the co-development 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. In AV systems, crops are grown in the intermittent shade cast by the PV panels. 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)

The shade does not necessarily diminish agricultural yield, and 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 AV experiments. When angled correctly, and when combined with shade tolerant crops, crops grown in AV settings have been shown to provide similar yields to those grown in traditional agricultural settings – while simultaneously providing added revenue through the electricity being generated (Dinesh and Pearce, 2016).

Advanced systems can determine the ideal tilt of the panels according to the sunshine, water requirements, and growth model of the crop – along with the 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 AV systems in North Italy reduced radiation, which affected mean soil temperature and reduced the 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 AV system than under full light. The maize yield under AV increased proportionally with low water availability, which indicates that AV systems could increase crop resilience to climate change.

3.5.2.2 Case study 2

Adeh et al. (2018) describe a 6 ha AV 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) – suggesting 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 and Nagashima, 2019) examined the yield, power output, and total revenue of an AV system with maize – a shade-intolerant crop. A 100m^2 area was divided into the following 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^2 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 AV system provided the highest yield (5% higher than the control).

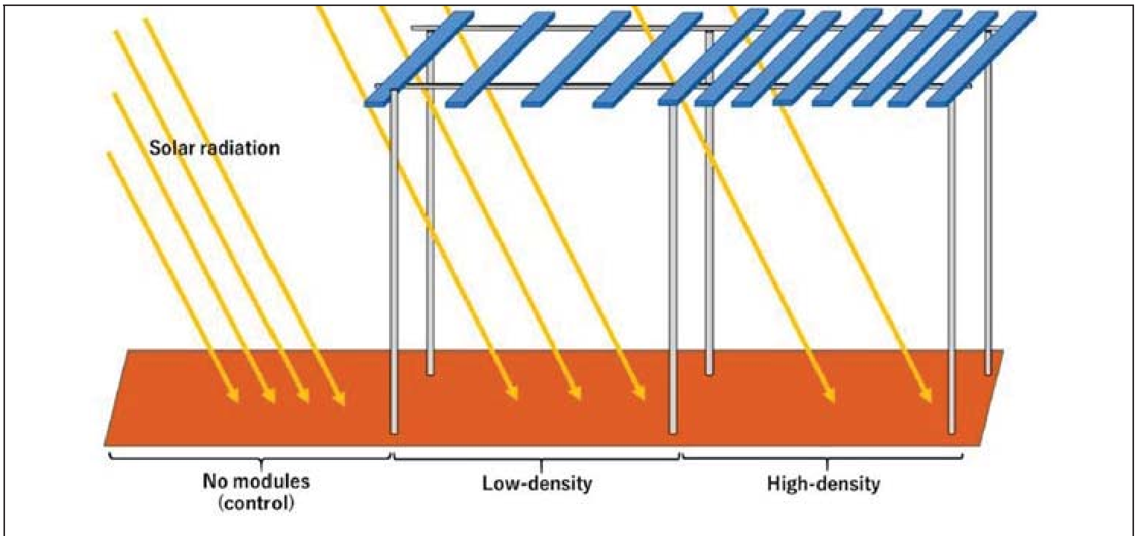


Figure 3-11: PV module configurations at the agrivoltaic experimental farm (Sekiyama and Nagashima, 2019)

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

	Configurations		
	Control	**Low-Density**	**High-Density**
Maize yield (kg/m2)	3.35	3.54	3.23

3.5.3 Potential of agrivoltaic systems 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 (AV) 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:

- Agri-PV PV support structure cost = conventional PV cost + cost of agricultural structure (no increase in greenfield)
- Agri-PV PV panels effectively shade netting as cover (shade net shading 30–50%)
- Agri-PV PV panels have 30% coverage, similar to conventional single-axis tracking PV
- Agri-PV PV panels use bifacial panels (panels for Agri-PV taken as 14% higher CapEx)
- Agri-PV PV panels at 4°C lower temperature (increased electrical yield at lower temperature)
- Agri-PV water saving is otherwise similar to that of 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 Agri-PV 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, improved learning rates, and economies of scale in the production of Agri-PV components.

The modelling indicated that the cost of water realised from Agri-PV was similar to costs achieved for water reuse. The water savings and electricity generation potential results are presented from Table 3-22 to Table 3-25.

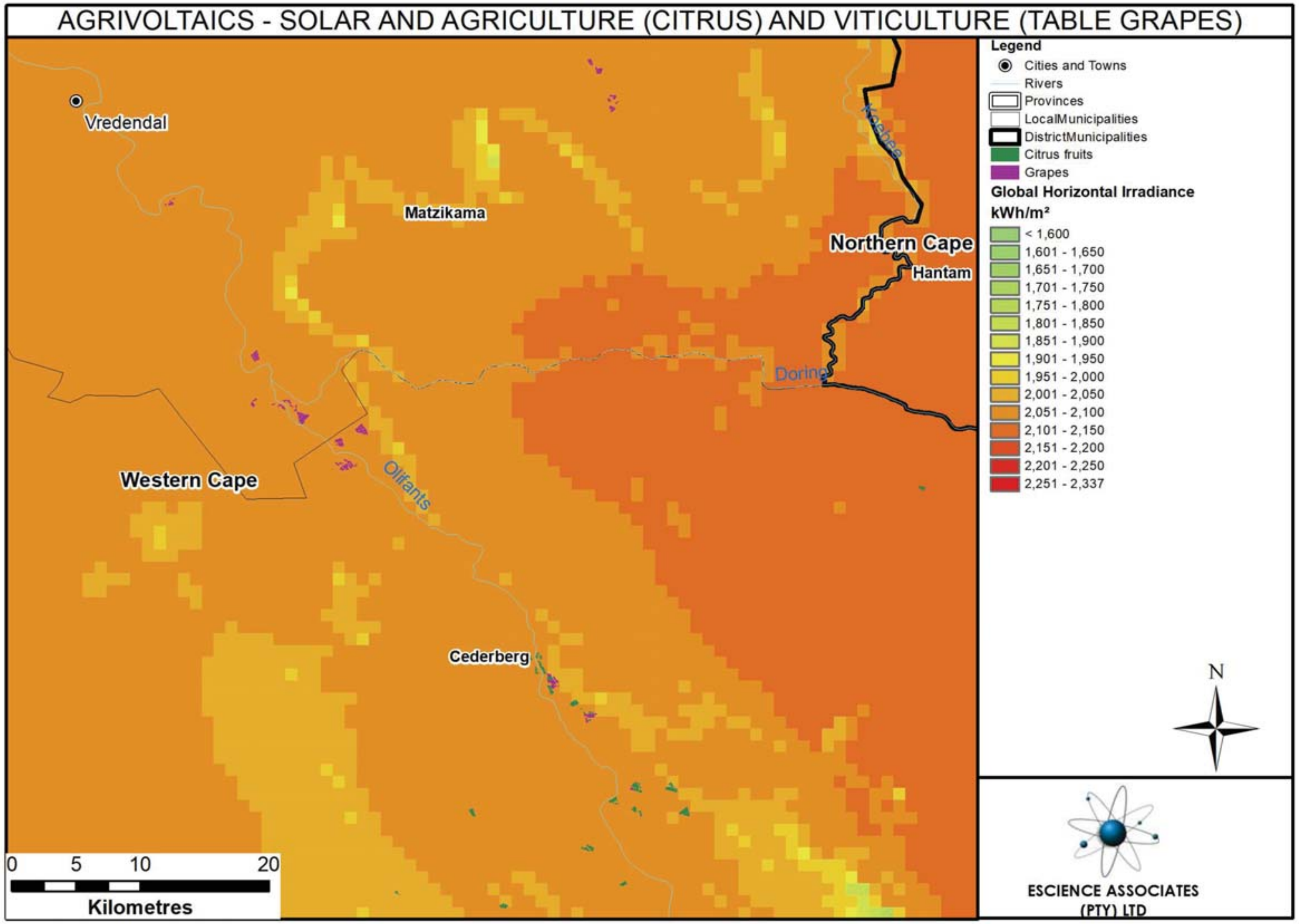


Figure 3-12: Solar PV potential (GHI) and compatible land uses (citrus and table grapes) – Olifants River

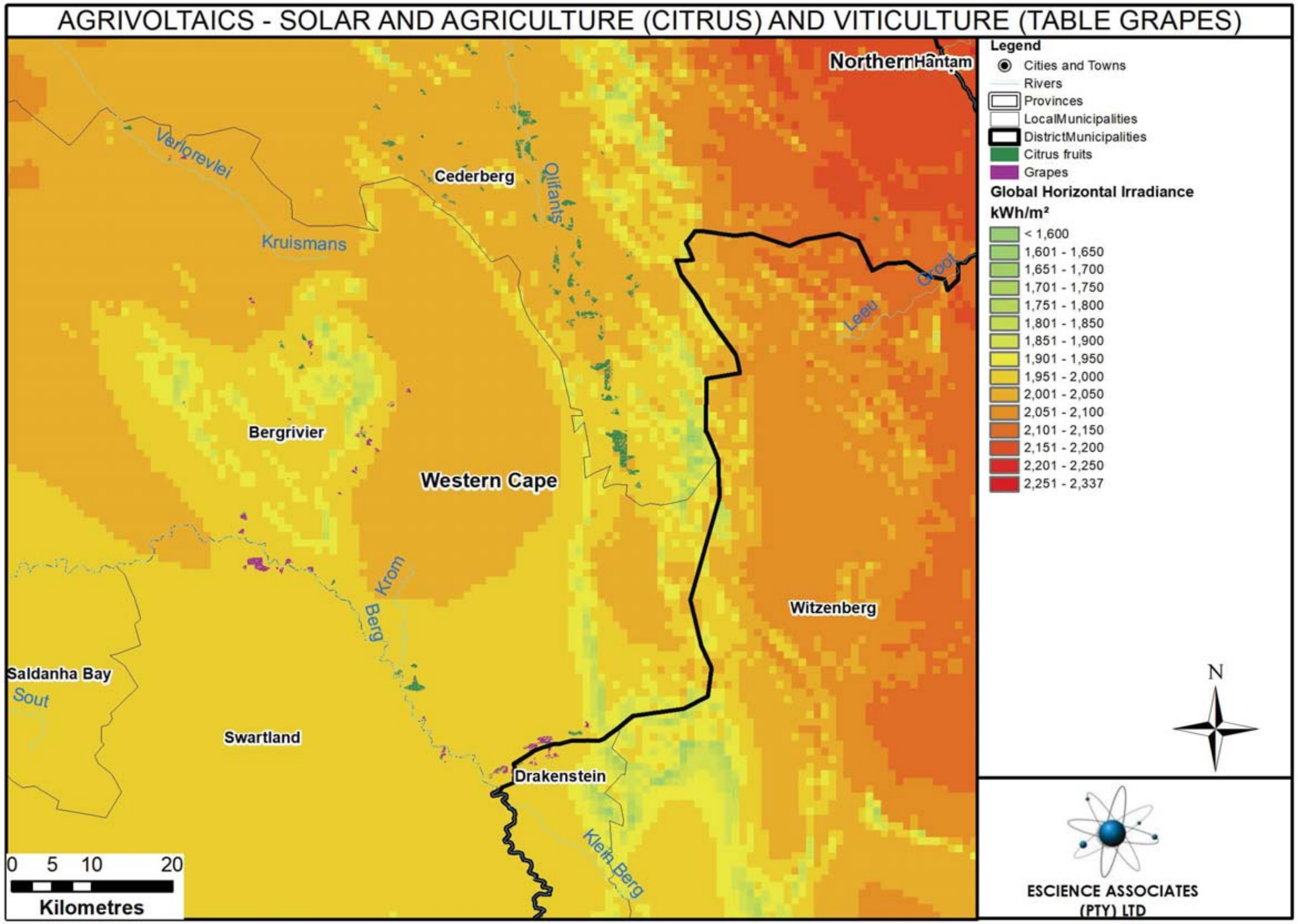


Figure 3-13: Solar PV potential (GHI) and compatible land uses (citrus and table grapes) – Upper Olifants

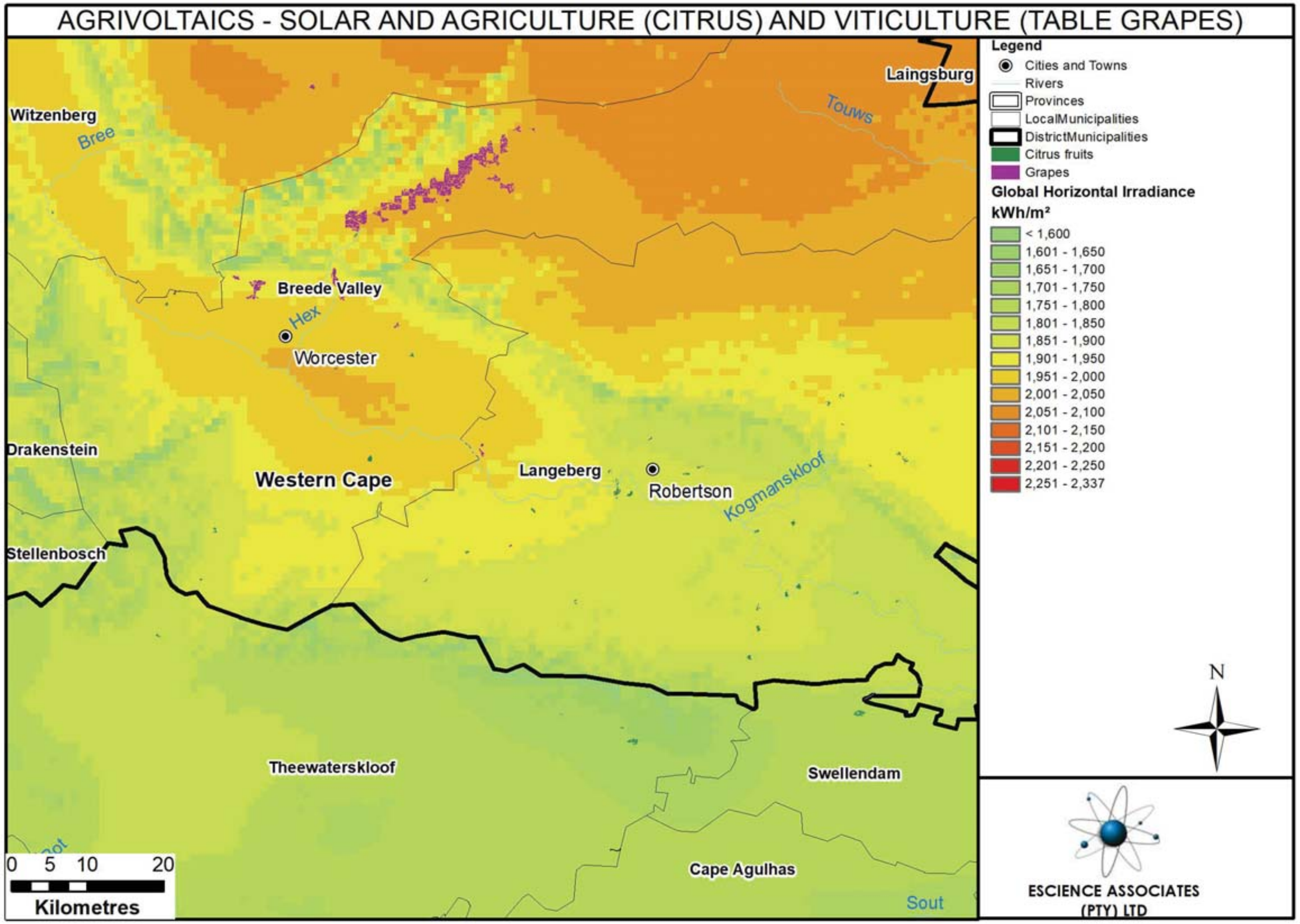


Figure 3-14: Solar PV potential (GHI) and compatible land uses (citrus and table grapes) – Breede River Valley

Table 3-22: Water saving and power generation potential (table grapes) – fixed-tilt agrivoltaic system

Table Grapes – Fixed-Tilt Agrivoltaic System					
	Average GHI (kWh/m²)	Area (ha)	Water Saving Potential (m3)	Energy Potential (GWh)	Power Generation Potential – Required Installed Capacity (GW)
Provincial					
Western Cape	1 962	1 379.3	3 273 048.7	27 060.0	13.729
District Municipality					
Cape Winelands	1 942	535.1	1 269 793.7	10 392.5	5.273
West Coast	1 977	844.2	2 003 255.1	16 689.1	8.467
Local Municipality					
Drakenstein	1 942	535.1	1 269 793.7	10 392.5	5.273
Bergrivier	1 980	397.5	943 216.3	7 871.1	3.993
Swartland	1 974	446.7	1 060 038.7	8 818.1	4.474
WCWSS					
Lower Berg	1 980	819.6	1 944 875.4	16 225.5	8.232
Upper Berg	1 940	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/m²)	Area (ha)	Water Saving (m3)	Energy Potential (GWh)	Power Generation Potential – Required Installed Capacity (GW)
Provincial					
Western Cape	1 962	1 379.3	3 273 048.7	27 060.0	10.366
District Municipality					
Cape Winelands	1 942	535.1	1 269 793.7	10 392.5	3.981
West Coast	1 977	844.2	2 003 255.1	16 689.1	6.393
Local Municipality					
Drakenstein	1 942	535.1	1 269 793.7	10 392.5	3.981
Bergrivier	1 980	397.5	943 216.3	7 871.1	3.015
Swartland	1 974	446.7	1 060 038.7	8 818.1	3.378
WCWSS					
Lower Berg	1 980	819.6	1 944 875.4	16 225.5	6.216
Upper Berg	1 940	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/m²)	Area (ha)	Water Saving (m3)	Energy Potential (GWh)	Power Generation Potential – Required Installed Capacity (GW)
Provincial					
Western Cape	1 930	726.5	3 360 092.6	14 018.2	7.112
Water Management Area					
Berg-Olifants	1 963	606.1	2 803 257.2	11 899.1	6.037
Breede-Gouritz	1 758	120.4	556 835.4	2 116.3	1.074
District Municipality					
Cape Winelands	1 937	199.7	923 741.8	3 869.6	1.963
West Coast	1 978	406.4	1 879 515.4	8 037.3	4.078
Overberg	1 758	120.4	556 835.4	2 116.3	1.074
Local Municipality					
Drakenstein	1 945	160.2	740 976.1	3 115.4	1.581
Stellenbosch	1 906	39.5	182 765.7	753.2	0.382
Bergrivier	1 983	314.8	1 455 754.3	6 242.9	3.167
Swartland	1 959	91.6	423 761.1	1 795.1	0.911
Swellendam	1 792	56.3	260 455.3	1 009.4	0.512
Theewaterskloof	1 727	64.1	296 380.1	1 106.5	0.561
WCWSS					
Cape Winelands	1 913	18.9	87 578.8	362.2	0.184
Lower Berg	1 981	400.1	1 850 597.4	7 928.4	4.023
Lower Riviersonderend	1 749	111.6	515 934.0	1 951.3	0.990
Upper Berg	1 932	187.0	865 081.1	3 614.4	1.834
Upper Riviersonderend	1 838	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/m²)	Area (ha)	Water Saving (m3)	Energy Potential (GWh)	Power Generation Potential – Required Installed Capacity (GW)
Provincial					
Western Cape	1 930	726.5	3 360 092.6	14 018.2	5.370
Water Management Area					
Berg-Olifants	1 963	606.1	2 803 257.2	11 899.1	4.558
Breede-Gouritz	1 758	120.4	556 835.4	2 116.3	0.811
District Municipality					
Cape Winelands	1 937	199.7	923 741.8	3 869.6	1.482
West Coast	1 978	406.4	1 879 515.4	8 037.3	3.079
Overberg	1 758	120.4	556 835.4	2 116.3	0.811
Local Municipality					
Drakenstein	1 945	160.2	740 976.1	3 115.4	1.193
Stellenbosch	1 906	39.5	182 765.7	753.2	0.289

Bergrivier	1 983	314.8	1 455 754.3	6 242.9	2.391
Swartland	1 959	91.6	423 761.1	1 795.1	0.688
Swellendam	1 792	56.3	260 455.3	1 009.4	0.387
Theewaterskloof	1 727	64.1	296 380.1	1 106.5	0.424
WCWSS					
Cape Winelands	1 913	18.9	87 578.8	362.2	0.139
Lower Berg	1 981	400.1	1 850 597.4	7 928.4	3.037
Lower Riviersonderend	1 749	111.6	515 934.0	1 951.3	0.747
Upper Berg	1 932	187.0	865 081.1	3 614.4	1.385
Upper Riviersonderend	1 838	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 Agri-PV projects, the sheer capital cost associated with energy development creates a demand for funding prerequisites that will require more than proof-of-concept, and that commercial demonstration projects of scale will be required before significant uptake in the market. Unlike the use of protective netting for farming, which has already proven to be commercially viable in the production of a number of crops, we cannot reasonably expect agricultural fields be covered by solar canopies in the near future unless there is 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 realise 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 are 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 that 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 in 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 and 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 and Tessendorf, 2018).

The difficulties in evaluating cloud-seeding effects are attributed to the following reasons:

1. The seeding signals are often very weak, making them 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.
4. The cost of programmes to evaluate the effects of cloud seeding – such as randomised seeding experiments – is very high (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 to 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; unintended effects may sometimes cross political boundaries. Weather modification programmes should be designed to minimise negative impacts, and 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: firstly, the downwind transport of ice nuclei and ice crystals from the seeding source; and secondly, the invigoration of clouds caused 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 at which downwind effects were experienced are presented in Table 3-26. Table 3-27 shows the level of enhancement of precipitation augmentation that was experienced downwind.

Table 3-26: Case studies of the distance downwind at which 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 that 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 and Heimbach, 2005). Furthermore, the main findings of one investigation into randomised cloud seeding were the following:

1. Seeding increased snowfall in the intended target and sometimes downwind, when the ridge top (~2595m) temperature was less than -9°C.
2. 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.
3. Positive seeding effects were suggested to occur in the target and in the valley downwind of the target, also (mainly for the colder cases).
4. A seeding effect of about +15% was also found just a few kilometres from the seeding site.
5. 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 Organization (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 labelled 'super cooled' (North American Weather Modification Council, n.d.; 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 and 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 and Solak, 2006). It is relatively rare for naturally occurring freezing nuclei to be active in the temperature range of approximately -5°C to -15°C (Griffith and 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°C 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 and Solak, 2006). The addition of silver iodide nuclei into these clouds can produce additional ice crystals, which – under the right conditions – grow through vapour deposition and possibly also aggregation to form snowflakes large enough to fall out of the cloud as either snow or rain and reach the ground (Griffith and 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°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°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°C (Griffith and Solak, 2006).

Both orographic and convective clouds have been studied in this regard, and research indicates that clouds whose tops are colder than -25°C already have sufficiently large concentrations of natural ice crystals, meaning 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 and Solak, 2006). Therefore, there appears to be an ideal 'temperature window' of between -5°C and 25°C where clouds react favourably to the use of silver iodide seeding. Airborne cloud seeding, using either frozen carbon dioxide (also known as dry ice) or the venting of liquid propane, can extend this temperature window to temperatures just between 0°C and -2°C (Griffith and Solak, 2006).

The dispersion of dry ice (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 and Solak, 2006). The advantage of dry ice over silver iodide is that dry ice is a natural substance. However, the only effective delivery mechanism for dry ice is an aircraft – which increases costs significantly. 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 and 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 but its costs are lower due to not requiring an aircraft for release. It is important to note that liquid propane cannot be dispensed from an aircraft because it is a flammable substance. Liquid propane can be dispensed from the ground if it is released in areas of elevation that are frequently within the supercooled clouds. The ground-based dispersion of liquid propane has been used by the United States Air Force for over 30 years to clear supercooled fog at military airports (Griffith and Solak, 2006).

Studies of orographic clouds within the mountainous western states of the United States of America indicate 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's 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 for wintertime cloud seeding: ground-based silver iodide (AgI) generators, and airborne cloud seeding.

Ground-based silver iodide is considered essential to the project, whereas airborne cloud seeding 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 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 meet the following requirements:

1. Have rainfall in excess of 800mm average /annum (Figure 3-15 and Figure 3-16).
2. Drain into major water supply systems.
3. Provide to agriculture but not major water supply systems.

Deviation from this was considered, based on first order cost-benefit analysis.

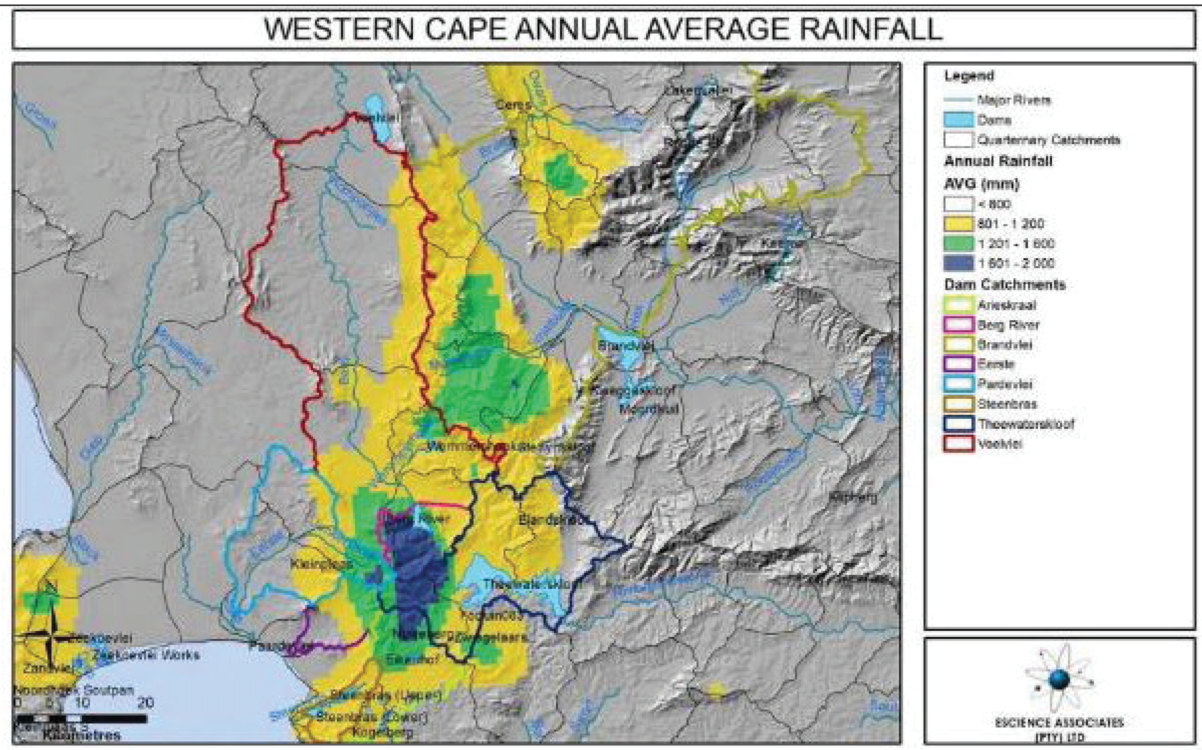


Figure 3-15: High-rainfall areas targeted for precipitation enhancement

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			
Labour	Rate	Hours	Amount
Programme Director	$181.68	1 320	$239 818
Project Meteorologist	$107.00	1 520	$162 640
Instrument Field Tech 1	$109.41	1 760	$192 562
Instrument Field Tech 2	$79.70	1 760	$140 272
Graduate Student	$45.86	1 200	$55 032
Subtotal: Labour			$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)			
Labour	Rate	Hours	Amount
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 Labour			$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 and Solak, 2006).

Certain cloud-seeding programmes have advantages and disadvantages in their usage, over other programmes, and these need to be considered 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 aircraft using either liquid-fuelled generators or pyrotechnics. 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 and 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 and Solak, 2006), while 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 (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 dams’ 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 between the natural runoff and yields between of the two versions of the WRYM, and the differences explained.

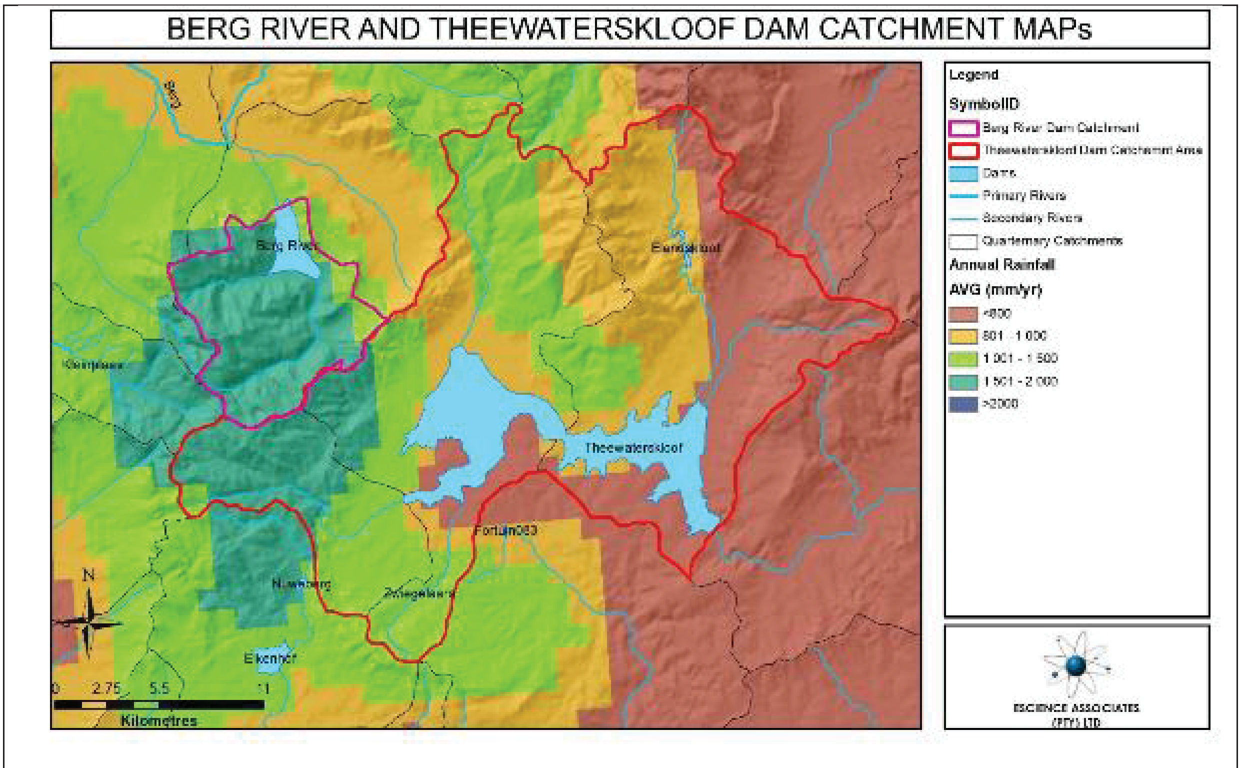


Figure 3-16: High rainfall areas in the Berg River and Theewaterskloof catchments

The following steps were taken during this analysis:

- The WRSM2000 rainfall-runoff model setups for the 2007 DWS study – *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 between 1927 and 2004. The hydrological data from this study is still 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.

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 then be 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 dam 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.

Berg River Dam	**Reference***	**Baseline**	**Scenario 1**
Area (km^2)		68.9	68.9
MAP (mm/a)		2 576	2 748
Natural MAR (mm/a)		2 067	2 203
% NMAR/MAP		80%	80%
Natural MAR ($10^6m^3/a$)	143.1	142.4	151.8
Forestry Reduction ($10^6m^3/a$)		1.6	1.6
Net MAR ($10^6m^3/a$)		**140.8**	**150.1**
Theewaterskloof Dam	**Reference***	**Baseline**	**Scenario 1**
Area (km^2)		441.2	441.2
MAP (mm/a)		1 238	1 292
Natural MAR (mm/a)		702	751
% NMAR/MAP		57%	58%
Natural MAR ($10^6m^3/a$)	317.1	309.9	331.5
Forestry Reduction ($10^6m^3/a$)		1.72	1.75
Net MAR ($10^6m^3/a$)		**308.1**	**329.8**

* - 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 used to generate the data. 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 time series – while this analysis made use of pure, natural simulated time series. This was due to the time-consuming nature of the naturalisation process, which is not conducive to conducting 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 – which range between 1% and 57%. Scenario 1 produces an average of 9.3 million m^3 per annum (6.6%) more net runoff over the period 1927–2004 (78-year monthly simulation).

Yield Analysis

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 had 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 for Theewaterskloof Dam it was 1961 to 1976. 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 report.

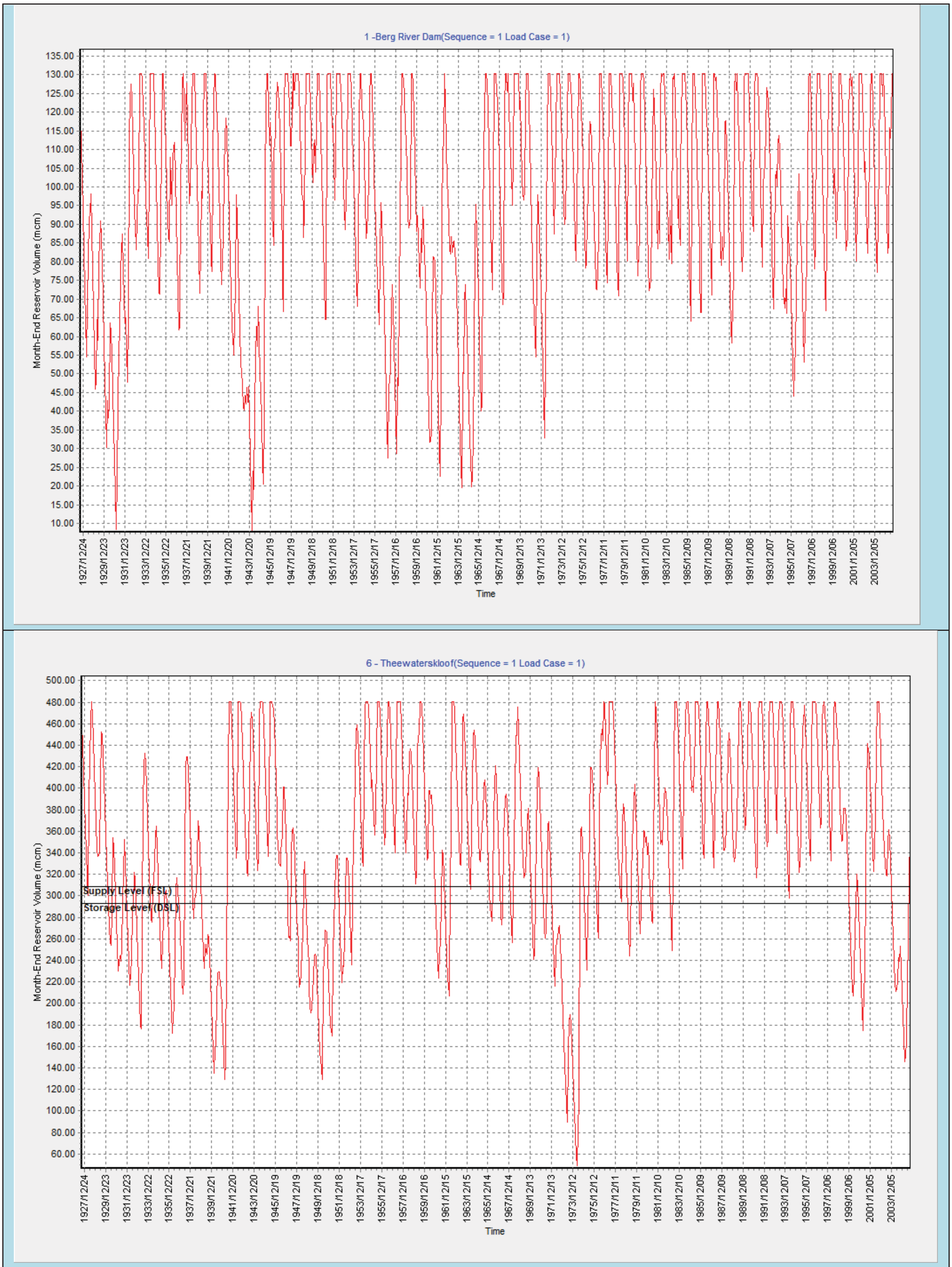


Figure 3-17:Simulated Berg River Dam (top) and Theewaterskloof Dam (bottom) volumes from 1927 to 2004 if the historical firm yield of the dam is constantly and abstracted

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

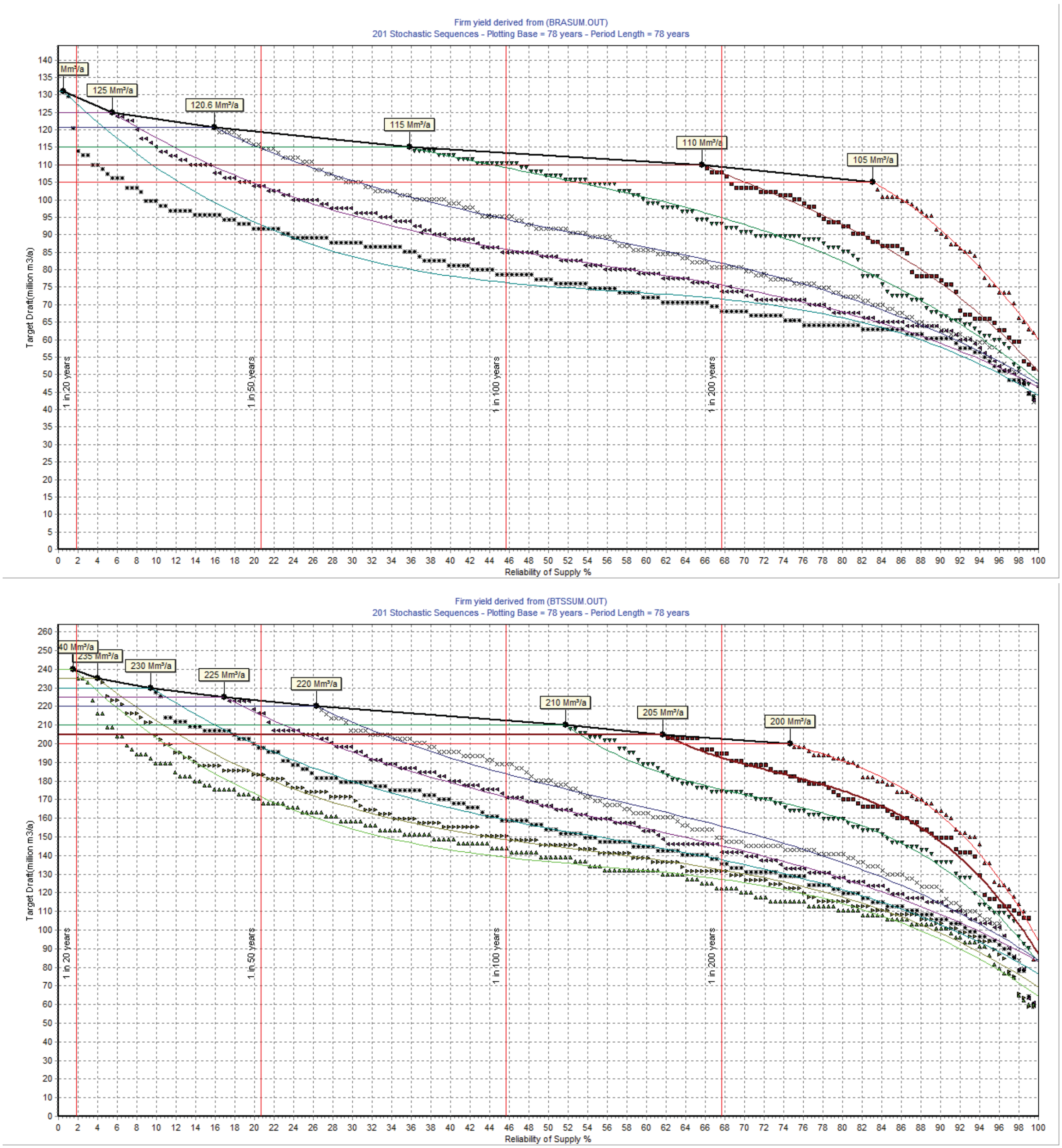


Figure 3-18: Scenario 1 stochastic yield reliability curves for the Berg River (top) and Theewaterskloof dams (bottom)

Table 3-31 provides a summary of the yield comparisons between the base scenario 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 ($10^6 m^3/a$)			Diff ($10^6 m^3/a$)	% 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 *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* (DWA, 2012).

There are significant differences between the historical firm yields from this analysis and the WCWSS analysis for both the Berg River and 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. In Table 3-31, with scenario 1, a gain of 4.6 million m^3 per annum is seen on average for a 1:50 assured supply, and 16.5 million m^3/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 likely prevent this situation occurring again.

3.7 INVASIVE ALIEN 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 rands annually in lost agricultural productivity and resources spent on management. Many IAPs are products of unwise and unintentional plant introductions. However, eradication is possible and management costs can be reduced if new invasions are discovered before they are well established. The economic benefits of clearing areas with high tourism, biodiversity, productivity, or water yield potential are necessary to maintain support for the continuation of the clearing project. In other words, the benefits of clearing – beyond 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, when 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 clusters of invasive plants – has confirmed the original findings, showing that plant invasions can have substantial impacts on streamflows (Le Maitre et al., 2019).

There is, however, still an ongoing debate about the impacts of flow reductions on the yields from large water supply schemes (WSS), despite there being 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 in relation to the mean annual run (Le Maitre and 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 it is 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 desalination. 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 lifespan of the infrastructure and relates it to the volume of water yielded, to derive a cost per m^3 of water (van Niekerk and 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 consider 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; however, if there really were no more land-based options for increasing yields, the only choice would be to clear the invasions. Although, by the time that time 'c' arrives, the costs of clearing the invasions would also have increased significantly – a factor that 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, as well as expensive safety equipment. It also incurs substantial additional costs through supporting workers who camp out for a week at a time in instances where daily access is not efficient. Additionally, the speed at which the invasive plants are cleared is low because the workers must use ropes when moving between plants – to safely secure themselves – which 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 the plants 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 the lowest density possible – and that the catchment is maintained in that state.

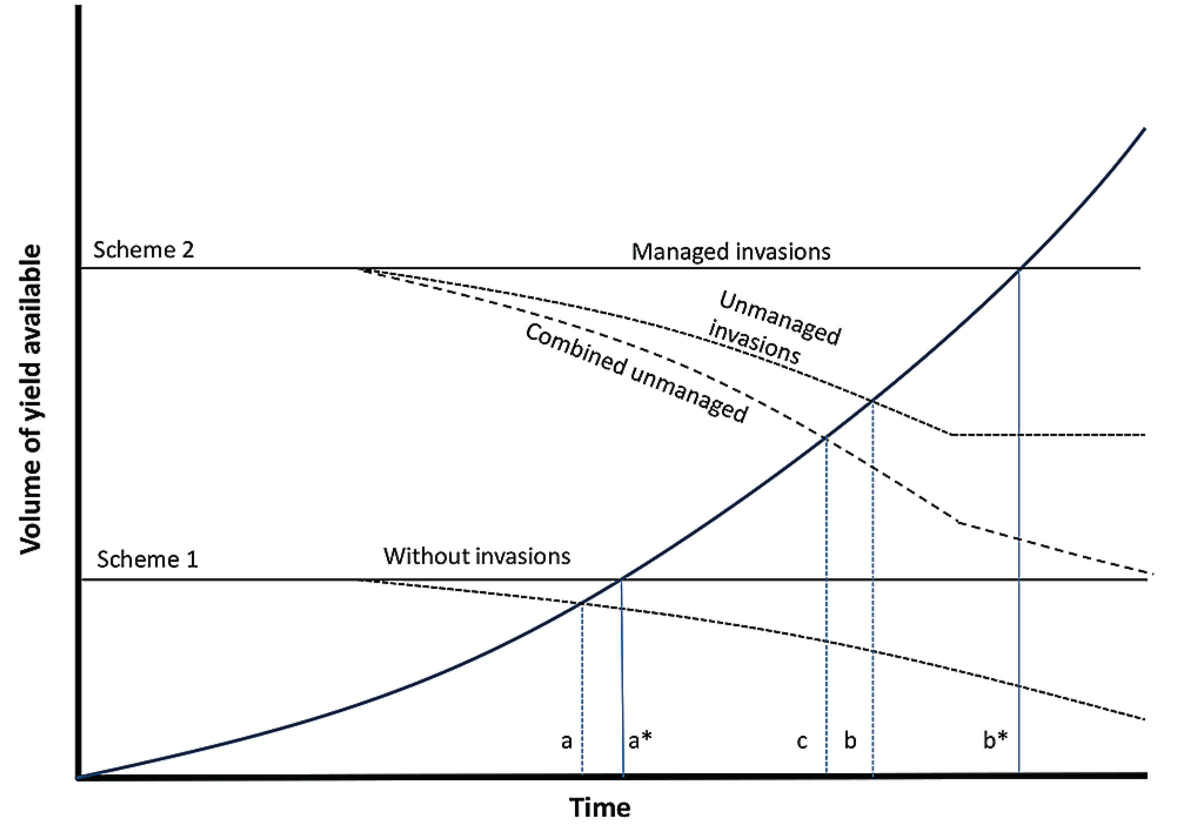


Figure 3-19: Typical relationships between increasing demand for water and the implementation of schemes to meet those needs, and the impacts of invasions in the scheme's catchments on the timing (adapted from van Wilgen et al., 1997). Scheme 1 needs to be implemented by time 'a*', without invasions, but by time 'a' if the invasions are not managed and, likewise, scheme 2 would shift from 'b*' to 'b'. The combined effects of invasions on both schemes necessitate moving scheme 2 forwards to time 'c'.

A key motivation for managing IAP species is their impacts on streamflows which – for the wetter half of South Africa – are about 970 m^3/ha/annum or 1 444 million m^3/a (2.9% of naturalised mean annual runoff), compared to forest plantations. However, the implications of these reductions for the 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 ±580 million m^3/annum under 'effective control', compared with ±542 million m^3/annum under 'baseline' invasions and ±450 million m^3/annum in 45 years' time with 'no management'. The 'baseline' invasions already reduce the yield by 38 million m^3/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 m^3/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 will also 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 Department of Environmental Affairs (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.
- 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 added. The improvements included correction of species for certain areas, consideration of clearing activities, correction of 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 fall 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 IAP for the WCWSS is summarised in Table 3-32 as for the baseline scenario from 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	1 182	1 182
Eucalypts	8 108	447	569	9 124
Longleaf Wattle	0	0	110	110
Pine	11 008	438	95	11 540
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	19 116	885	2 190	22 191

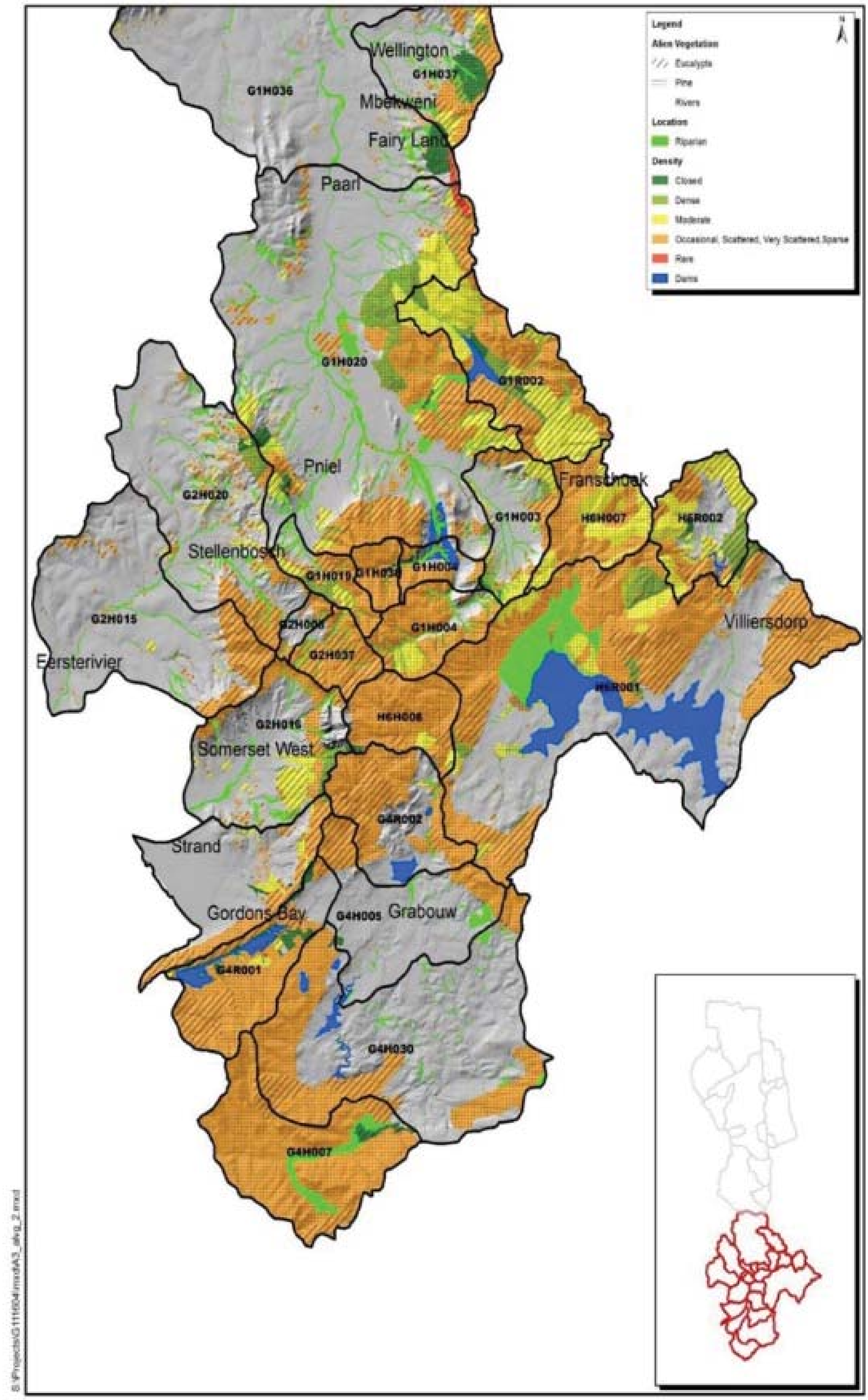


Figure 3-20: IAPs mapped in the southern reaches of the WCWSS

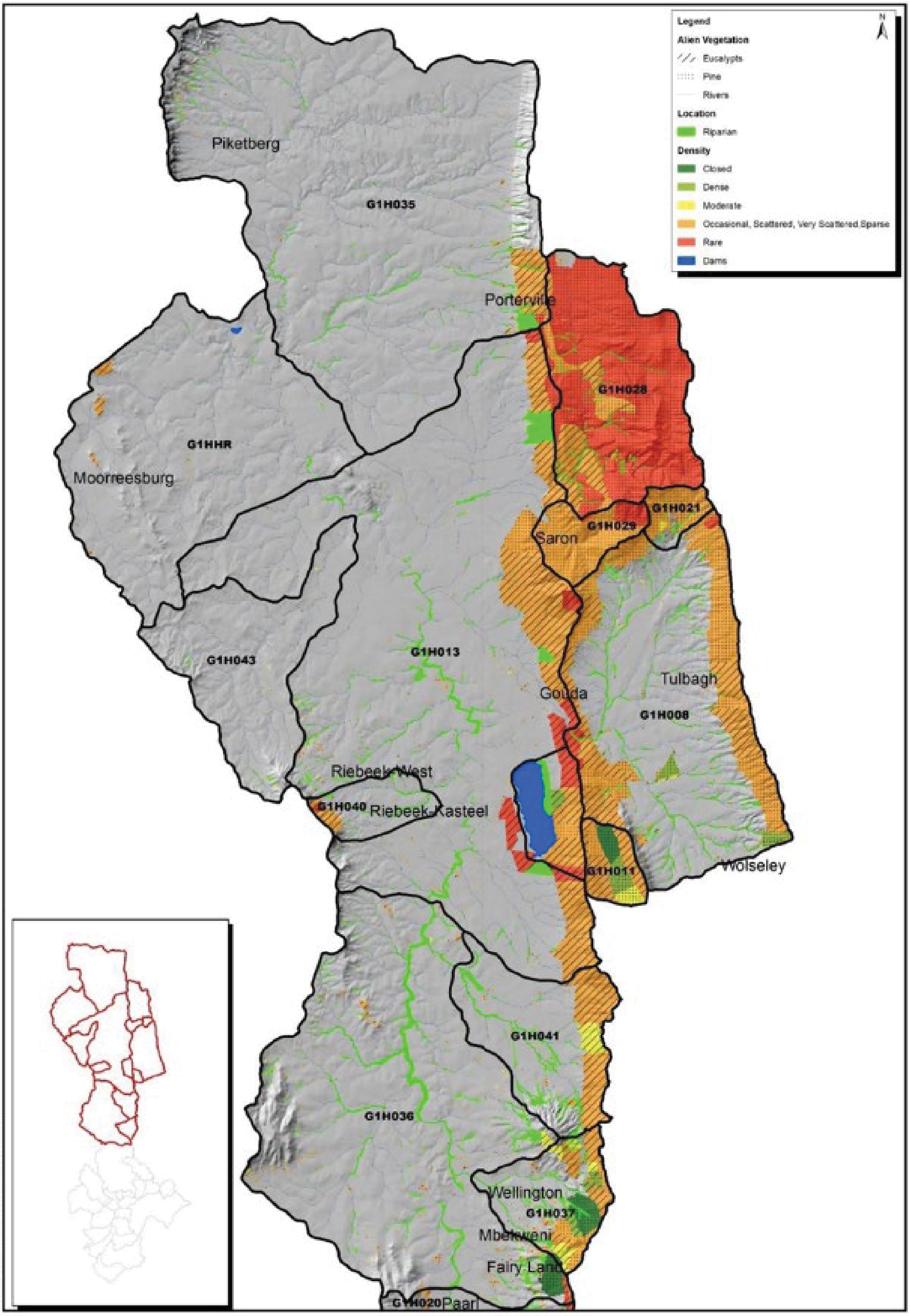


Figure 3-21: IAPs mapped in the northern reaches of the WCWSS

3.7.2 Hydrological modelling of invasive alien plant removal

The total streamflow reduction cause by IAPs was simulated using the WRSM2000 model and is summarised in Table 3-33

.

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

Area	Upland and Groundwater	Riparian	Total
	Reduced runoff ($10^6 m^3$ 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 the following three 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 conducted for the three scenarios and the 1:50 year assurance of supply (98% assured yield) was determined for each scenario, as 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 m^3/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 m^3/a at 98% assurance of supply for the WCWSS, if IAPs are cleared and properly managed in the future.

3.7.3 Invasive alien plant removal costs

The spread of IAPs is a dynamic phenomenon, requiring investment in controlling their spread as well as in managing the hectares they have already 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 and 2014 were determined. As Figure 3-22 indicates the investment in clearing IAPs has been fluctuating, affecting the hectares cleared.

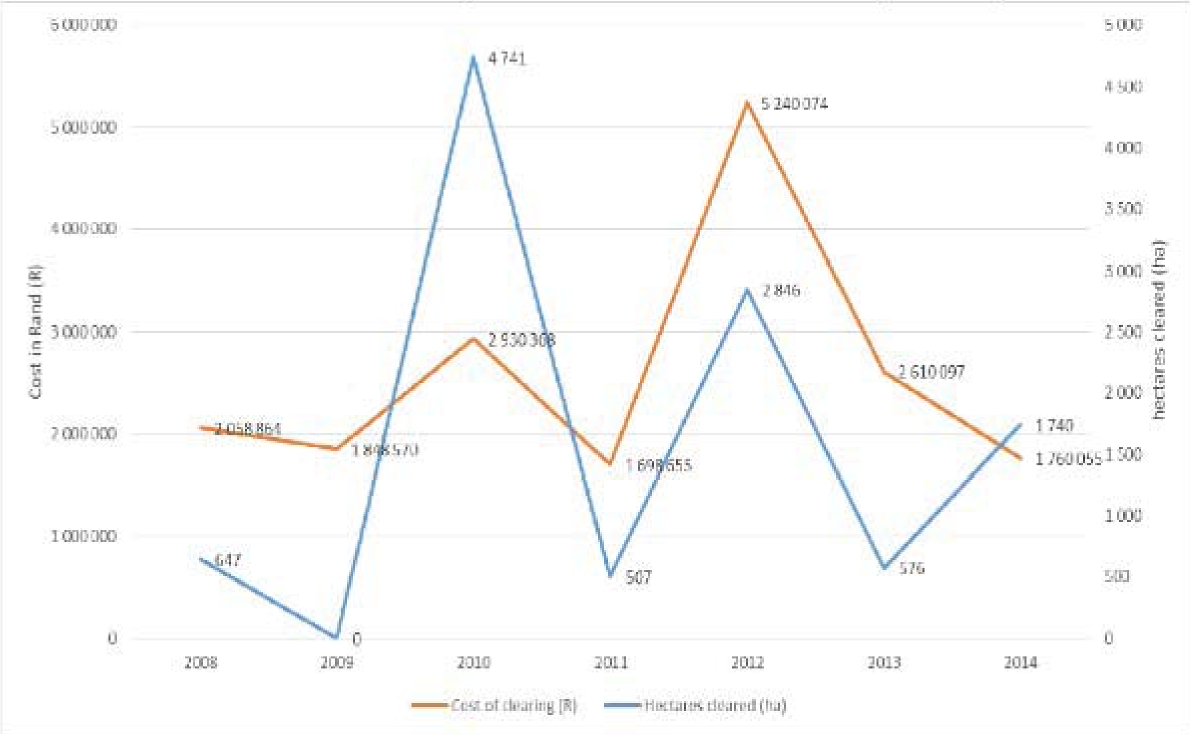


Figure 3-22: The investment in clearing IAPs at the Olifants River catchment, 2008–2014 (Morokong et al., 2016)

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 with the development of a new dam in the Olifants River catchment – in terms of securing water. Three sub-models were developed: a land-use model, a water-saved model, and an economic model, including the estimation of the URV.

The URV is calculated to analyse the cost effectiveness of water generation by clearing IAPs. It 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). The equation is presented as follows:

$$Unit\ Reference\ Value\ (R/\text{m}^3) = Net\ present\ value\ NPV\ of\ lifecycle\ cost / Discounted\ yield\ of\ the\ dam\ over\ its\ life\ span$$

$$Lifecycle\ cost = PV\ of\ capital\ costs + PV\ of\ operating\ and\ maintainance\ cost$$

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^3 as opposed to that of R2.93/m^3 for building the De Hoop Dam. Stated differently, the opportunity cost of not clearing the IAPs (R2.93/m^3) is higher than that of clearing (R1.44/m^3). This makes IAP clearance a socially desirable investment. Water consumed by IAPs is quite significant, meaning that clearing them is essential for ensuring 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.

3.8 SUMMARY

3.8.1 Technology comparison

To perform a high-level comparison of the technologies considered in this 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 – it the intervention dependent 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 is it to implement the intervention?
- Environmental – what environmental impacts/concerns are associated with the intervention?

It must be noted that the result of this study is the development of an assessment framework that would allow evaluation of the 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

	Desalination	Reuse	Aquifer Recharge	Improved Irrigation Efficiency	Precipitation Augmentation	Invasive Alien Plant Removal	Non-Revenue Water (Leaks & Unpaid Bills) Recovery
Demand or Supply Intervention	Supply	Supply	Supply	Demand	Supply	Supply	Demand
Quality of Water	Potable or raw	Potable or raw	Raw	Raw	Raw	Raw	Potable
Rainfall Dependence or Independence (Assurance of Supply)	Independent – seawater supply	Independent, but wastewater-output dependent	Independent – recharged using desalinated or reused water	Dependent	Dependent	Dependent	Independent
Barriers to Entry		Social perception – hesitance to consume water produced from wastewater		Access to funding – large capital costs required by farmers	Difficulty in evaluating efficacy		Social compliance regarding unpaid bills
Applicability of Intervention	Proximity to the coast is required for assured supply		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
Cost	High	Medium	Medium	High			Low
Environmental	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^3/a)	Intervention/ Alternative Supply Cost (ZAR)
Alternative Supply Options			
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; 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
Invasive Alien 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

Summary of findings:

- Desalination is 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 analysis of farming under netting, 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 invasive alien plants was found to be the most cost effective of the interventions.
- The cost of water realised from Agri-PV was similar to the 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 Agri-PV 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.

PART B:

ECONOMIC ANALYSIS OF WATER SUPPLY OPTIONS

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

4.1 INTRODUCTION

Hassan et al. (2008) constructed an agricultural and water-focused social accounting matrix (SAM) for South Africa in 2002, which 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 to reflect some of the key macro variable changes between 2002 and 2016. The 2016 version also had to consider the level of data granularity available for the 2002 SAM that was not available for the 2016 SAM. In this report, we followed – where possible – the basic structure from Hassan et al. (2008) to construct an agriculture- and water-focused 2016 SAM for South Africa. 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 report 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 social accounting matrix (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 – such as 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 SAM for South Africa that was developed in 2002 was used as foundation 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 being 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 sectors (including forestry and fishing), 15 industrial sectors, and eight 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 was not possible due to a lack of sufficiently detailed data. Irrigation water is incorporated in the model through the estimation of the shadow price of water per irrigated crop. 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

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 but not repeated in this report. It can be seen from Table 4-1 that agriculture, forestry, and fishery's contribution to GDP declined from 4.32% in 2002 (Hassan et al., 2008) to 2.55% in 2016. Although the employment share of agriculture remained stable between 7% and 8% from 2002 to 2016, employment has shifted 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 (%)					
	GDP	**Employment**	**Exports**	**Imports**	**Export Intensity**	**Import Intensity**
Total GDP	100.0	100.0	100.0	100.0	14.33	16.08
Agriculture, forestry, and fishery	**2.55**	**7.59**	**2.35**	**0.81**	**12.03**	**5.00**
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
Industry	**30.71**	**19.21**	**75.88**	**84.77**	**28.27**	**30.16**
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
Non-metallic 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	Employ ment	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
Services	**66.74**	**73.20**	**21.78**	**14.42**	**5.31**	**4.44**

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 compared to the 2016 SAM compiled as part of this study.

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

	2002	2016	% Change from 2002 Value
Supply			
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%
=Total supply at purchaser prices	**3 077**	**10 241**	**233%**
Demand			
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%
Total demand at purchaser prices	**3 077**	**10 241**	**233%**

Source: 2002 Water SAM (Hassan et al., 2008) 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 nine in 2012. Three of the previous 19 WMAs are split across more than one of the new nine 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 nine 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 nine 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, and 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 report follows the 11 WMAs as presented in Table 4-3.

Table 4-3: Former, new, and SAM WMAs

Nineteen former WMAs (2004)		Nine new WMAs (2012)		Eleven WMAs for SAM	
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) sectors, 15 industrial sectors, and eight service sectors, as summarised in Table 4-4.

Table 4-4: Sectors in the SAM

Agriculture		Non-Agriculture (per WMA)	
	Field crops (irrigated and dryland, per WMA)	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
	Horticultural crops (irrigated, per WMA)	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	**Bulk water distribution**
11	Other horticulture (tea, nuts)	31	**Municipal water distribution**
		32	Construction
	Livestock (per WMA)		

12	Livestock sales (cattle, sheep, pigs)		**Services (per WMA)**
13	Dairy	33	Retail & wholesale trade
14	Poultry (chickens, eggs)	34	Hotels & catering
15	Other livestock products (wool, game)	35	Transport
		36	Communication
	Other agriculture	37	Financial & insurance services
16	Fisheries *(per WMA)*	38	Business services & real estate
17	Forestry *(dryland, per WMA)*	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 Table 4-4 appearing 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 was a total of 477 production activities: 224 were agricultural, forestry and fishery activities (62 dryland, 107 irrigated, and 55 animal and animal product); 165 were industry activities (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 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. The other sources primarily include information published by the Department of Agriculture, Forestry and Fisheries (DAFF) in assorted reports, as well as publications and data supplied by multiple 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, meaning it and could be mapped to the WMAs. Intermediate demands for non-agricultural production were taken from the national SU tables (Stats SA, 2017), and data for the production technologies across WMAs were based on data from the SASID for 2016.

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 those decreased between 2002 and 2016 from 32.7% to 19.9% and from 36.2% to 2.4%, respectively.

Table 4-5: Summary characteristics of WMAs (2016)

	Population (1 000)	GDP per Capita (ZAR)	Share of National GDP (%)			Share of Regional 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, and one 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 WMAs (2016)

	Agricultural Land Allocated to Crops (%)							
	All Crops (1 000 ha)	Summer Cereals	Winter Cereal s	Oilseeds & Legumes	Fodder Crops	Sugarc ane	Cotton & Tobacco	Horticu lture
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%

	Agricultural Land Allocated to Crops (%)							
	All Crops (1 000 ha)	Summer Cereals	Winter Cereal s	Oilseeds & Legumes	Fodder Crops	Sugarc ane	Cotton & Tobacco	Horticu lture
Orange	753	47%	10%	24%	11%	0%	0.1%	7%
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 WMAs. The data were then 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 that also collects the savings from households and the rest of the world (foreign savings). These savings are 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 are 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. To calculate the shadow price of water, it is necessary to take the productivity effects of water on crop yields into account – in other words 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 was 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 retain 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 $1000m^3$/ha, which is slightly greater compared to that which was reported in the report by Hassan et al. (2008). The volume of irrigation water used increased from 7.3 to 8.5 billion m^3 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 (1 000 mt)	Land Area Total (1 000 ha)	Land Area Irrigated (%)	Yields Rainfed (mt/ha)	Yields Irrigated (mt/ha)	Irrigation Water Use Volume (mn m^3)	Irrigation Water Use (1 000 m^3/ ha irrig.)
Total	**-**	**6 778**	**20.85**	**-**	**-**	**8 483**	**6.00**
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: agricultural water, bulk water, and 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 both in some cases). 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. 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 in 2016 (mn m^3)				
	Irrigation	**Bulk Water (Industries)**	**Municipal Water (Industries)**	**Municipal Water (Households)**	**Total Water Use**
National	**8 483**	**3 923**	**1 079**	**3 741**	**17 226**
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/Doorn	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 WMAs; (iii) estimating the shadow value of irrigation water for different crops; and (iv) distinguishing between the bulk and municipal water distribution systems.

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

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 the base model, and 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 must 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 versus 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% are presented here. The static model results were tested 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 (mn 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 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 with a 50% increase in irrigation water tariff

	Production Quantity		Agricultural Irrigated Area		Agricultural Dryland Area		Water Use	
	Base (1 000 mt)	Change from Base (%)	Base (1 000 ha)	Change from Base (%)	Base (1 000 ha)	Change from Base (%)	Base (mn m^3)	Change from Base (%)
All crops	**51 316**	**-0.7**	**1 413**	**-2.8**	**5 365**	**0.7**	**8 483**	**-13.2**
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 indicates that agriculture accounts for 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 and therefore much less pronounced.

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

	Base Contribution to GDP at Factor Cost (%)	Change in Contribution Based on Values in Real Terms (%)
GDP factor cost	100.00	-0.03
Agriculture	**2.55**	**-0.44**
Field crops	0.71	-0.46
Horticulture	0.62	-1.18
Livestock	0.87	-0.05
Other	0.34	-0.05
Non-agriculture	**97.45**	**-0.02**
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% and +20%, with 10% increments.
- Changes in the municipal water rate used by industries ranging between -20% and +20%, with 10% increments.
- A transfer of 50 million m^3 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% and +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

	Base	Scenario: Changes in Irrigation Water Tariff			
	Quantity Used	-20%	-10%	+10%	+20%
	(mn m^3)	% Change (from Base) in Quantity of Water Used			
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 (households)	3 741	0.017	0.008	-0.008	-0.016
Total	17 226	3.24	1.56	-1.45	-2.81

Table 5-4 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.

Table 5-5: Change in volume of irrigation water used in different WMAs, with changes in irrigation water tariff

	Base	Scenario: Changes in Irrigation Water Tariff			
	Quantity Used	-20%	-10%	+10%	+20%
	(mn m^3)	% Change (from Base) in Quantity of Water Used			
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 that would be moved out of irrigation more readily than horticultural products.

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

			Scenario: Changes in Irrigation Water Tariff			
		Base	**-20%**	**-10%**	**+10%**	**+20%**
		Quantities	**% Change from Base**			
Production (1 000 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 (1 000 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 (mn m^3)						
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 indicates selected macroeconomic impacts on a regional level, with 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, with changes in irrigation water tariff

			Scenario: Changes in Irrigation Water Tariff			
		BASE GDP	**-20%**	**-10%**	**+10%**	**+20%**
WMA/Region	**Sectors**	**Value (ZAR bn)**	**% 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 is far more pronounced.

5.3.2 Scenario 2: change in municipal water rate

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

Table 5-8: Change in volume of different types of water used, with changes in the municipal water rate

	Base	**Scenario: Changes in Municipal Water Rate**			
	Quantity Used	**-20%**	**-10%**	**+10%**	**+20%**
	(mn m^3)	**% Change (from Base) in Quantity of Water Used**			
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 (households)	3 741	2.17	1.03	-0.94	-1.81
Total	17 226	1.48	0.69	-0.61	-1.15

Table 5-8 indicates that although municipal water use decreases by up to 9.4% when the municipal water rates change, 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, with changes in the municipal water rate

	Base	Scenario: Changes in Municipal Water Rate			
	Quantity Used	-20%	-10%	+10%	+20%
	(mn m^3)	% Change (from Base) in Quantity of Water Used			
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 shows that, in general, the production of horticulture increases when municipal water rates increase, whereas production of field crops decreases. 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, and volume of irrigation water used in different WMAs, with changes in the municipal water rate

			Scenario: Changes in Municipal Water Rate			
		Base	**-20%**	**-10%**	**+10%**	**+20%**
		Quantities	**% Change (from Base) in Quantities**			
Production (1 000 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
RSA	**Irrigated production**	**22 625**	**0.016**	**0.008**	**-0.007**	**-0.015**
Area (1 000 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
RSA	**Irrigated area**	**1 413**	**0.019**	**0.009**	**-0.009**	**-0.017**
Irrigated water (mn m^3)						
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
RSA	**Irrigated water use**	**8 483**	**0.070**	**0.034**	**-0.032**	**-0.063**

Table 5-11 indicates selected macroeconomic impacts on a regional level with changes in the 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, with changes in the municipal water rate

			Scenario: Changes in Municipal Water Rate			
		Base GDP	-20%	-10%	+10%	+20%
WMA/Region	Sectors	Value (ZAR bn)	% Change (from Base)			
WMAs 1–7	**Region total**	**3 253**	**0.179**	**0.087**	**-0.083**	**-0.163**
	Agriculture	75	0.125	0.061	-0.058	-0.114
	Non-agric.	3 178	0.180	0.088	-0.084	-0.164
Breede–Gouritz	**Region total**	**90**	**0.180**	**0.088**	**-0.084**	**-0.164**
	Agriculture	7	0.107	0.052	-0.050	-0.098
	Non-agric.	82	0.187	0.091	-0.087	-0.170
Berg–Olifants/Doorn	**Region total**	**472**	**0.179**	**0.087**	**-0.083**	**-0.163**
	Agriculture	14	0.102	0.049	-0.047	-0.092
	Non-agric.	458	0.181	0.088	-0.084	-0.165
RSA	**Total**	**3 814**	**0.179**	**0.087**	**-0.083**	**-0.163**
	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^3 of 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 shows that a 50 million m^3 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 because of an expansion of industries and hence household income.

Table 5-12: Change in volume of water used for a 50 mil m^3 water transfer from irrigation to municipal use

	Base (mn m^3)	Change (from Base) (%)
Irrigation water	8 483	-0.59
Bulk water	3 923	0.00
Municipal (industry)	1 079	4.63
Municipal (households)	3 741	0.76
Total	17 226	0.17

Table 5-13 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 area is relatively smaller than the reduction in production.

Table 5-13: Change in production, area, and water use, with a 50 million m^3 water transfer from irrigation to municipal use

		Base	Scenario: 50 mn m^3 Water Transferred
		Quantities	% Change (from Base) in quantities
Production (1 000 tons)			
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
RSA	**Irrigated production**	**22 625**	**-0.158**
Area (1 000 ha)			
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
RSA	**Irrigated area**	**1 413**	**-0.087**
Irrigated water (mn m^3)			
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
RSA	**Irrigated water use**	**8 483**	**-0.589**

Table 5-14 indicates selected macroeconomic 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, with a 50 mil m^3 water transfer from irrigation to municipal use

		Base GDP	Scenario: 50 mn m^3 Water Transferred
WMA/Region	**Sectors**	**Value (ZAR bn)**	**% Change (from Base)**
WMAs 1–7	**Region total**	**3 253**	**0.049**
	Agriculture	75	0.040
	Non-agric.	3 178	0.049
Breede–Gouritz	**Region total**	**90**	**0.062**
	Agriculture	7	0.031
	Non-agric.	82	0.065

WMA/Region	Sectors	Base GDP Value (ZAR bn)	Scenario: 50 mn m^3 Water Transferred % Change (from Base)
Berg–Olifants/Doorn	**Region total**	**472**	**0.049**
	Agriculture	14	0.026
	Non-agric.	458	0.050
RSA	**Total**	**3 814**	**0.049**
	Agriculture	96	0.038
	Non-agric.	3 718	0.050

5.3.4 Macro results for the three scenarios

Table 5-15 compares the macroeconomic effects at a national level of the three scenarios that were discussed and indicates that agriculture accounts for 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 export 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: Macroeconomic effects (in real terms) – comparison of three scenarios

		Scenario: 10% Increase in Irrigation Water Tariff	**Scenario: 10% Increase in Municipal Water Rate**	**Scenario: 50 m m^3 Transfer from Irrigation to Municipal**
	Base Contribution to GDP at Factor Cost (%)	**Change in Contribution Based on Values in Real Terms (%)**		
GDP factor cost	100.00	-0.01	-0.03	0.02
Agriculture	**2.55**	**-0.10**	**0.01**	**-0.04**
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
Non-agriculture	**97.45**	**0.00**	**-0.03**	**0.02**
Consumption	59.29	-0.01	-0.03	0.02
Investment	19.40	-0.01	-0.08	0.05

		Scenario: 10% Increase in Irrigation Water Tariff	Scenario: 10% Increase in Municipal Water Rate	Scenario: 50 m m^3 Transfer from Irrigation to Municipal
	Base Contribution to GDP at Factor Cost (%)	Change in Contribution Based on Values in Real Terms (%)		
Government	20.79	0.00	0.00	0.00
Exports	30.58	-0.01	-0.05	0.03
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 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: 50 mn m^3 Transfer from Irrigation to Municipal
	Base Employment ('000)	Change in Employment ('000)		
WMAs 1–7	**13 173**	**-1.3**	**-8.6**	**5.0**
Agriculture	921	0.1	-0.4	0.1
Non-agric.	12 252	-1.4	-8.2	4.9
Breede–Gouritz	**533**	**-0.1**	**-0.3**	**0.2**
Agriculture	104	0.0	0.0	0.0
Non-agric.	429	-0.1	-0.3	0.2
Berg–Olifants/Doorn	**1 926**	**-0.3**	**-1.1**	**0.6**
Agriculture	162	-0.1	0.0	0.0
Non-agric.	1 764	-0.2	-1.1	0.6
RSA	**15 632**	**-1.6**	**-10.0**	**5.8**
Agriculture	1 186	0.1	-0.5	0.1
Non-agric.	14 446	-1.7	-9.6	5.7

Table 5-17 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: 50 mn m³ Transfer from Irrigation to Municipal
	Base Household Income ('000)	Change in Income (%)		
WMAs 1–7	2 632	-0.01	-0.07	0.04
Breede–Gouritz	74	-0.02	-0.07	0.05
Berg–Olifants/Doorn	366	-0.02	-0.07	0.04
RSA	**3 072**	**-0.01**	**-0.07**	**0.04**

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, 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.

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

	Base (mn m³)	Decrease (mn m³)
Irrigation	1 027	513.5
Bulk	275	110
Municipal (industry)	73	29.2
Municipal (households)	438	0
Total (Berg–Olifants/Doorn)	1 813	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
	Water Volumes (mn m^3) for Berg–Olifants/Doorn WMA		
Irrigation	1 027	-25	+25
Bulk	275	+20	-20
Municipal (industry)	73	+5	-5
Municipal (households)	438	0	0
Total (Berg–Olifants/Doorn)	1 813	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^3) 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

	Base	Sim1	Sim2	Sim3	Sim4
	Water Volumes (mn m^3) for Berg–Olifants/Doorn WMA				
Irrigation	1 027	+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)	1 813	+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: Additional desalination water to industry of 25 mil m^3.

Sim2: Additional desalination water to industry of 50 mil m^3.

Sim3: Additional desalination water to industry of 75 mil m^3.

Sim4: Additional desalination water to industry of 100 mil m^3.

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
	Water Volumes (mn m^3) for Berg–Olifants/Doorn WMA				
Irrigation	1 027	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)	1 813	+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
	Water Volumes (mn m^3) for Berg–Olifants/Doorn WMA		
Irrigation	1 027	0	0
Bulk	275	+20	+20
Municipal (industry)	73	+5	+5
Municipal (households)	438	0	0
Total (Berg–Olifants/Doorn)	1 813	+25	+25
Cost borne by:		Water industry	Users of municipal water
Tariff increase		5.4 R/kl	5.4 R/kl

Scenario 5: Invasive alien plant (IAP) removal for additional water in the Berg–Olifants/Doorn WMA

Sim1: IAP 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
	Water Volumes (mn m^3) for Berg–Olifants/Doorn WMA	
Irrigation	1 027	0
Bulk	275	+20
Municipal (industry)	73	+5
Municipal (households)	438	0
Total (Berg–Olifants/Doorn)	1 813	+25
Cost borne by:		Water industry
Tariff increase		2.1 R/kl

The 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 indicates that on a national level the total volume of water used decreased by only 4.8%, but that within the Berg–Olifants/Doorn WMA it decreased on average by 45%. The decrease in households' 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 (mn m^3)	Change (%)	Base (mn m^3)	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 (households)	3 741	-4.7%	438	-37%
Total	17 226	-4.8%	1 813	-45%

Table 5-25 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 Reduction
		Quantities	Change (%)
Production (1 000 tons)			
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
	Horticulture	2 166	-7.8
RSA	**Irrigated production**	**22 625**	**-0.5**
Area (1 000 ha)			
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
RSA	**Irrigated area**	**1 413**	**-0.9**
Irrigated water (mn m^3)			
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
RSA	**Irrigated water use**	**8 483**	**-6.1**

Table 5-26 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

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

Table 5-27 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 (ZAR m)	Change in Income (%)
WMAs 1–7	**13 173**	**-19.6**	**2 632**	**-0.18**
Agriculture	921	-0.6		
Non-agric.	12 252	-19.0		
Breede–Gouritz	**533**	**-0.3**	**74**	**-0.16**
Agriculture	104	0.4		
Non-agric.	429	-0.7		
Berg–Olifants/Doorn	**1 926**	**-6.9**	**366**	**-0.31**
Agriculture	162	-3.5		
Non-agric.	1 764	-3.4		
RSA	**15 632**	**-26.8**	**3 072**	**-0.19**
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 Sim1 there is a transfer of water from irrigation to bulk and municipal use and in Sim2 the transfer of water is from bulk and municipal use to irrigation in the Berg–Olifants/Doorn WMA. A total of 25 million m^3 is transferred. Table 5-28 indicates that the indirect effects of the water transfers on areas not directly affected by the water transfers are negligible. When 25 million m^3 of irrigation water is transferred away from agriculture towards industries (Sim1), then the total volume of water used within the Berg–Olifants/Doorn WMA increased by 1.36%. When 25 million m^3 of industry water (20 million m^3 bulk and 5m m^3 municipal) is transferred away from industries towards agriculture (Sim2), 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	Sim1: Irrigation to Industry	Sim2: Industry to Irrigation
	Volume (mn m^3)	Change (%)	
WMAs 1–7	**14 298**	**0.01**	**-0.01**
Irrigation	6 502	0.00	0.00
Bulk	3 593	0.00	0.00
Municipal (industries)	991	0.00	0.00
Municipal (households)	3 212	0.05	-0.05

	Base	Sim1: Irrigation to Industry	Sim2: Industry to Irrigation
	Volume (mn m^3)	Change (%)	
Breede–Gouritz	**1 116**	**0.00**	**0.00**
Irrigation	955	0.00	0.00
Bulk	56	0.00	0.00
Municipal (industries)	14	0.00	0.00
Municipal (households)	91	0.05	-0.05
Berg–Olifants/Doorn	**1 813**	**1.36**	**-1.40**
Irrigation	1 027	-2.43	2.43
Bulk	275	7.28	-7.28
Municipal (industries)	74	6.79	-6.79
Municipal (households)	438	5.63	-5.82
RSA	**17 226**	**0.15**	**-0.16**
Irrigation	8 483	-0.29	0.29
Bulk	3 923	0.51	-0.51
Municipal (industries)	1 079	0.46	-0.46
Municipal (households)	3 741	0.70	-0.73

Table 5-29 shows the impacts of water transfers on the irrigation sector in the directly affected Berg–Olifants/Doorn WMA area, as well as on the national level. When 25 million m^3 of irrigation water is transferred to industries (Sim1), 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%. Results are small on a national level, as they reflect only the indirect effects of the changes in the Berg–Olifants/Doorn WMA.

When 25 million m^3 water is transferred from industries to irrigation in Sim2, the results are almost a mirror image of those for Sim1, 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	Sim1: Irrigation to Industry	Sim2: Industry to Irrigation
		Quantities	Change (%)	
Production (1 000 tons)				
Berg–Olifants/Doorn	Field crops	122	-1.14	1.11
	Horticulture	2 166	-0.25	0.24
RSA	**Irrigated production**	**22 625**	**-0.01**	**0.01**
Area (1 000 ha)				
Berg–Olifants/Doorn	Field crops	19	-0.18	0.17
	Horticulture	167	-0.29	0.29
RSA	**Irrigated area**	**1 413**	**-0.04**	**0.04**
Irrigated water (mn m^3)				
Berg–Olifants/Doorn	Field crops	94	-1.99	1.96
	Horticulture	933	-2.48	2.48
RSA	**Irrigated water use**	**8 483**	**-0.29**	**0.29**

Results in Table 5-30 show that when 25 million m^3 of irrigation water is transferred to industries (Sim1), 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^3 water is transferred from industries to irrigation (Sim2), 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

		Base GDP	Sim1: Irrigation to Industry	Sim2: Industry to Irrigation
WMA / Region	**Sectors**	**Value (ZAR bn)**	**Change (%)**	
WMAs 1–7	**Region total**	**3 253**	**0.020**	**-0.021**
	Agriculture	75	0.027	-0.029
	Non-agric.	3 178	0.020	-0.021
Breede–Gouritz	**Region total**	**90**	**0.022**	**-0.024**
	Agriculture	7	0.042	-0.043
	Non-agric.	82	0.021	-0.022
Berg–Olifants/Doorn	**Region total**	**472**	**0.036**	**-0.038**
	Agriculture	14	-0.004	0.001
	Non-agric.	458	0.037	-0.040
RSA	**Total**	**3 814**	**0.022**	**-0.024**
	Agriculture	96	0.024	-0.026
	Non-agric.	3 718	0.022	-0.024

Table 5-31 indicates the impact of water transfers on employment. The changes in employment in the directly affected WMA are less pronounced than in the rest of South Africa, reflecting that the impact on industries has greater national linkages through price changes when compared to the agricultural sector. Although employment in agriculture is negatively impacted when 25 million m^3 of irrigation water is transferred to industries (Sim1), 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^3 water is transferred from industries to irrigation (Sim2), 2 610 job opportunities are lost on a national level.

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

	Base Employment	Sim1: Irrigation to Industry	Sim2: Industry to Irrigation
	Quantity ('000)	**Change ('000)**	
WMAs 1–7	**13 173**	**2.04**	**-2.18**
Agriculture	921	0.21	-0.23
Non-agric.	12 252	1.82	-1.95
Breede–Gouritz	**533**	**0.10**	**-0.11**
Agriculture	104	0.04	-0.04
Non-agric.	429	0.07	-0.07
Berg–Olifants/Doorn	**1 926**	**0.30**	**-0.33**
Agriculture	162	-0.09	0.08
Non-agric.	1 764	0.38	-0.41
RSA	**15 632**	**2.44**	**-2.61**
Agriculture	1 186	0.17	-0.18

	Base Employment	Sim1: Irrigation to Industry	Sim2: Industry to Irrigation
	Quantity ('000)	Change ('000)	
Non-agric.	14 446	2.27	-2.43

When 25 million m^3 of irrigation water is transferred to industries (Sim1), household income increases by 0.034% in the Berg–Olifants/Doorn WMA and by 0.02% on a national level. When 25 million m^3 water is transferred from industries to irrigation (Sim2), 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	Sim1: Irrigation to Industry	Sim2: Industry to Irrigation
	Value (ZAR m)	Change (%)	
WMAs 1–7	2 632	0.018	-0.020
Breede–Gouritz	74	0.021	-0.022
Berg–Olifants/Doorn	366	0.034	-0.037
RSA	3 072	0.020	-0.022

5.4.3 Scenario 3: Desalination as an 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^3. 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 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 following tables: 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.

From Sims 1 and 2 in Table 5-33, 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 (Sims 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 (Sim 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 (mn m^3)	Change (%)			
WMAs 1–7	**14 298**	**0.47**	**0.03**	**0.04**	**0.07**
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 (households)	3 212	0.00	-0.07	0.10	0.12
Breede–Gouritz	**1 116**	**0.11**	**0.01**	**0.04**	**0.09**
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 (households)	91	0.04	-0.04	0.12	0.15
Berg–Olifants/Doorn	**1 813**	**-15.98**	**-13.08**	**5.07**	**-0.49**
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 (households)	438	-40.50	-46.33	9.44	-13.76
RSA	**17 226**	**-1.28**	**-1.35**	**0.57**	**0.02**
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 (households)	3 741	-4.74	-5.49	1.20	-1.50

Table 5-34 shows the impact on agricultural production under irrigation due to additional desalination water available for irrigation (Sims 1 and 2) and industry (Sims 3 and 4). 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 (Sims 1 and 2), for both field crops (2.21% and 2.24%, respectively) and horticulture (0.66% and 0.71%, respectively), with resultant increases in area and irrigation water used. On aggregate, production of horticulture in WMAs 1 to 7 decreases, but area and volume of irrigation water used increase – which appears to be a contradiction. It should be noted, however, that on a more disaggregated commodity level (not presented here), there is a consistent increase or decrease in production, area, and volume of irrigation water used per commodity. When additional desalination water is allocated to industry (Sims 3 and 4), the indirect effects on agricultural production, area, and irrigation water use are positive, even if small, throughout.

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

		Base	Sim1: Irrigation Water & Industry Pays	Sim2: Irrigation Water & Municipal Users Pay	Sim3: Industry Water & Industry Pays	Sim4: Industry Water & Municipal Users Pay
		Quantities	Change (%)			
Production (1 000 tons)						
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
RSA	**Irrigated production**	**22 625**	**0.01**	**0.05**	**0.02**	**0.06**
Area (1 000 ha)						
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
RSA	**Irrigated area**	**1 413**	**0.08**	**0.16**	**0.04**	**0.10**
Irrigated water (mn m^3)						
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
RSA	**Irrigated water use**	**8 483**	**0.59**	**0.59**	**0.04**	**0.10**

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 (Sim1), 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 Sim2).

When industries receive the additional desalination water (Sims 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. Taxation on users has 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 (ZAR bn)**	**Change (%)**			
WMAs 1–7	**Region total**	**3 253**	**-0.08**	**0.00**	**0.05**	**0.09**
	Agriculture	75	-0.10	0.00	0.04	0.10
	Non-agric.	3 178	-0.08	0.00	0.05	0.09
Breede–Gouritz	**Region total**	**90**	**-0.09**	**0.00**	**0.05**	**0.10**
	Agriculture	7	-0.15	-0.06	0.04	0.09
	Non-agric.	82	-0.08	0.00	0.05	0.10
Berg–Olifants/Doorn	**Region total**	**472**	**-0.29**	**-0.23**	**-0.08**	**-0.05**
	Agriculture	14	-0.01	0.08	0.04	0.10
	Non-agric.	458	-0.30	-0.24	-0.08	-0.05
RSA	**Total**	**3 814**	**-0.11**	**-0.03**	**0.03**	**0.07**
	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 indicates the impact of different desalination options on employment. Employment for the agricultural sector in the Berg–Olifants/Doorn WMA increases between 190 (Sim1) and 320 (Sim2) 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. The impact is less negative, with a net national job loss of 1 290, when costs are recovered via a tax, .

When desalination water is available to industry, all WMAs show an increase in employment, except for non-agricultural industry in the directly affected WMA. With this availability, net national job opportunities increase between 6 440 (Sim3) and 10 290 (Sim4).

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

	Base Employment	Sim1: Irrigation Water & Industry Pays	Sim2: Irrigation Water & Municipal Users Pay	Sim3: Industry Water & Industry Pays	Sim4: Industry Water & Municipal Users Pay
	Quantity ('000)	Change ('000)			
WMAs 1–7	**13 173**	**-7.73**	**0.84**	**5.23**	**9.79**
Agriculture	921	-0.75	-0.03	0.28	0.75
Non-agric.	12 252	-6.99	0.87	4.95	9.04
Breede–Gouritz	**533**	**-0.39**	**-0.01**	**0.21**	**0.42**
Agriculture	104	-0.13	-0.06	0.03	0.08
Non-agric.	429	-0.25	0.04	0.18	0.34
Berg–Olifants/Doorn	**1 926**	**-2.22**	**-2.12**	**1.00**	**0.08**
Agriculture	162	0.19	0.32	0.04	0.14
Non-agric.	1 764	-2.41	-2.44	0.95	-0.06
RSA	**15 632**	**-10.34**	**-1.29**	**6.44**	**10.29**
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 are quite mixed because households are the owners of all factors and receive incomes from these factors in different proportions. In all four simulations, the 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	Sim1: Irrigation Water & Industry Pays	Sim2: Irrigation Water & Municipal Users Pay	Sim3: Industry Water & Industry Pays	Sim4: Industry Water & Municipal Users Pay
	Value (ZAR m)	Change (%)			
WMAs 1–7	2 632	-0.07	0.00	0.05	0.08
Breede–Gouritz	74	-0.08	-0.01	0.05	0.09
Berg–Olifants/Doorn	366	-0.28	-0.20	-0.13	-0.05
RSA	3 072	-0.10	-0.03	0.02	0.07

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:

1. Sim1: 25 million m^3
2. Sim2: 50 million m^3

3. Sim3: 75 million m^3
4. Sim4: 100 million m^3

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 that this is recovered as a tax on water. Table 5-38 indicates the impacts on use of different types of water in the different WMAs, for different volumes of additional desalination water allocated 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% (Sim1) and 37.4% (Sim4). 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 (Sim1) and R1.28 billion (Sim4).

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

	Base	Sim1: 25 mn m3	Sim2: 50 mn m^3	Sim3: 75 mn m^3	Sim4: 100 mn m^3
		Industry Water and Municipal Water Users Pay			
	Volume (mn m^3)	**Change (%)**			
WMAs 1–7	**14 298**	**0.04**	**0.07**	**0.11**	**0.14**
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 (households)	3 212	0.06	0.12	0.18	0.22
Breede–Gouritz	**1 116**	**0.05**	**0.09**	**0.14**	**0.19**
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 (households)	91	0.08	0.15	0.23	0.29
Berg–Olifants/Doorn	**1 813**	**-0.14**	**-0.49**	**-1.77**	**-3.36**
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 (households)	438	-6.45	-13.76	-24.95	-37.42
RSA	**17 226**	**0.02**	**0.02**	**-0.09**	**-0.22**
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 (households)	3 741	-0.78	-1.68	-3.08	-4.63

Table 5-39 shows the impact on agricultural production of irrigation due to additional desalination water allocated to 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% (Sim1) and 0.13% (Sim4). Irrigated area and water use both increase by between 0.05% (Sim1) and 0.21% (Sim4).

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

		Base	Sim1: 25 mn m3	Sim2: 50 mn m^3	Sim3: 75 mn m^3	Sim4: 100 mn m^3
		Quantities	Change (%)			
Production (1 000 tons)						
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
RSA	**Irrigated production**	**22 625**	**0.03**	**0.06**	**0.10**	**0.13**
Area (1 000 ha)						
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
RSA	**Irrigated area**	**1 413**	**0.05**	**0.10**	**0.16**	**0.21**
Irrigated water (mn m^3)						
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
RSA	**Irrigated water use**	**8 483**	**0.05**	**0.10**	**0.16**	**0.21**

In Table 5-40 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. The GDP of industry in the directly affected WMA decreases by between 0.03% (Sim1) and 0.13% (Sim4), and the positive impacts on agriculture are 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 positive, however, hence the national GDP increases of between 0.04% (Sim1) and 0.13% (Sim4).

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

		Base	Sim1: 25 mn m3	Sim2: 50 mn m^3	Sim3: 75 mn m^3	Sim4: 100 mn m^3
			Industry Water and Municipal Water Users Pay			
WMA/Region	**Sectors**	**Value (ZAR bn)**	**Change (%)**			
WMAs 1–7	**Region total**	**3 253**	**0.05**	**0.09**	**0.13**	**0.17**
	Agriculture	75	0.05	0.10	0.15	0.19
	Non-agric.	3 178	0.05	0.09	0.13	0.17
Breede–Gouritz	**Region total**	**90**	**0.05**	**0.10**	**0.14**	**0.19**
	Agriculture	7	0.05	0.09	0.14	0.19
	Non-agric.	82	0.05	0.10	0.14	0.19
Berg–Olifants/Doorn	**Region total**	**472**	**-0.03**	**-0.05**	**-0.08**	**-0.12**
	Agriculture	14	0.05	0.10	0.15	0.20
	Non-agric.	458	-0.03	-0.05	-0.09	-0.13
RSA	**Total**	**3 814**	**0.04**	**0.07**	**0.11**	**0.14**
	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 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	Sim1: 25 mn m^3	Sim2: 50 mn m^3	Sim3: 75 mn m^3	Sim4: 100 mn m^3
		Industry Water and Municipal Water Users Pay			
	Quantity ('000)	**Change ('000)**			
WMAs 1–7	**13 173**	**5.09**	**9.79**	**14.70**	**19.28**
Agriculture	921	0.39	0.75	1.15	1.53
Non-agric.	12 252	4.70	9.04	13.56	17.75
Breede–Gouritz	**533**	**0.22**	**0.42**	**0.64**	**0.84**
Agriculture	104	0.04	0.08	0.13	0.17
Non-agric.	429	0.18	0.34	0.51	0.67
Berg–Olifants/Doorn	**1 926**	**0.07**	**0.08**	**-0.10**	**-0.40**

	Base	Sim1: 25 mn m^3	Sim2: 50 mn m^3	Sim3: 75 mn m^3	Sim4: 100 mn m^3
		Industry Water and Municipal Water Users Pay			
	Quantity ('000)	**Change ('000)**			
Agriculture	162	0.07	0.14	0.21	0.29
Non-agric.	1 764	-0.003	-0.06	-0.32	-0.69
RSA	**15 632**	**5.37**	**10.29**	**15.24**	**19.72**
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 the household incomes increase, as these households do not pay for the desalination, but rather 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	Sim1: 25 mn m^3	Sim2: 50 mn m^3	Sim3: 75 mn m^3	Sim4: 100 mn m^3
		Industry Water and Municipal Water Users Pay			
	Value (ZAR m)	**Change (%)**			
WMAs 1–7	2 632	0.04	0.08	0.12	0.16
Breede–Gouritz	74	0.04	0.09	0.13	0.17
Berg–Olifants/Doorn	366	-0.03	-0.05	-0.08	-0.10
RSA	3 072	0.03	0.07	0.10	0.13

5.4.4 Scenario 4: Reuse as an 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^3. 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 indicates the direct impact of the additional 25 million m^3 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 (Sims 1 and 2). Household use increases by 5.54% when households are not responsible for the cost of the treatment of water (Sim1), but when households cover the cost of water treatment via a tax (Sim2), their use of water increases by only 0.77%. This effect also drives the national results. The indirect effects of the additional reuse water on WMAs are small and positive.

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

	Base	Sim1: Industry Water & Industry Pays	Sim2: Industry Water & Municipal Users Pay
	Volume (mn m^3)	Change (%)	Change (%)
WMAs 1–7	**14 298**	**0.02**	**0.03**
Irrigation	6 502	0.02	0.04
Bulk	3 593	0.00	0.00
Municipal (industries)	991	0.00	0.00
Municipal (households)	3 212	0.06	0.06
Breede–Gouritz	**1 116**	**0.02**	**0.04**
Irrigation	955	0.02	0.04
Bulk	56	0.00	0.00
Municipal (industries)	14	0.00	0.00
Municipal (households)	91	0.06	0.07
Berg–Olifants/Doorn	**1 813**	**2.73**	**1.59**
Irrigation	1 027	0.03	0.04
Bulk	275	7.28	7.28
Municipal (industries)	74	6.79	6.79
Municipal (households)	438	5.54	0.77
RSA	**17 226**	**0.31**	**0.19**
Irrigation	8 483	0.02	0.04
Bulk	3 923	0.51	0.51
Municipal (industries)	1 079	0.46	0.46
Municipal (households)	3 741	0.70	0.14

When industries receive an additional 25 million m^3 of treated water but pay the additional cost themselves (Sim1), the GDP increase in the Berg–Olifants/Doorn WMA is almost negligible (0.008%), but it is slightly higher (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 the GDP in the Berg–Olifants/Doorn WMA – as well as on a national level – are slightly greater than that of simulation 1. This is because the cost in simulation 2 is more concentrated on the households than on 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	Sim1: Industry Water & Industry Pays	Sim2: Industry Water & Municipal Users Pay
WMA/Region	**Sectors**	**Value (ZAR bn)**	**Change (%)**	**Change (%)**
WMAs 1–7	**Region total**	**3 253**	**0.023**	**0.032**
	Agriculture	75	0.023	0.037

WMA/Region	Sectors	Base GDP Value (ZAR bn)	Sim1: Industry Water & Industry Pays Change (%)	Sim2: Industry Water & Municipal Users Pay Change (%)
	Non-agric.	3 178	0.023	0.031
Breede–Gouritz	**Region total**	**90**	**0.024**	**0.034**
	Agriculture	7	0.023	0.037
	Non-agric.	82	0.024	0.034
Berg–Olifants/Doorn	**Region total**	**472**	**0.008**	**0.012**
	Agriculture	14	0.022	0.036
	Non-agric.	458	0.008	0.012
RSA	**Total**	**3 814**	**0.021**	**0.029**
	Agriculture	96	0.023	0.037
	Non-agric.	3 718	0.021	0.029

Table 5-45 indicates the impact of additional reused water on employment. When industries receive an additional 25 million m^3 of treated water (in both Sims 1 and 2), there is expansion of non-agricultural industries in the Berg–Olifants/Doorn WMA, which 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 (Sim1), 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 (Sim2). In contrast, the indirect impacts in other WMAs are slightly smaller for simulation 1 compared to simulation 2. On a national level, more jobs (3 450) are created in non-agriculture when consumers carry the cost of the water treatment (Sim2) compared to the jobs created (2 650) when industries cover the cost (Sim1). As mentioned, this is because in simulation 2 the cost of water treatment is more concentrated on the households than on industries – while the industries have the benefit of the additional water.

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

	Base Employment Quantity ('000)	Sim1: Industry Water & Industry Pays Change ('000)	Sim2: Industry Water & Municipal Users Pay Change ('000)
WMAs 1–7	**13 173**	**2.32**	**3.35**
Agriculture	921	0.17	0.28
Non-agric.	12 252	2.15	3.07
Breede–Gouritz	**533**	**0.10**	**0.15**
Agriculture	104	0.02	0.03
Non-agric.	429	0.08	0.11
Berg–Olifants/Doorn	**1 926**	**0.45**	**0.31**
Agriculture	162	0.03	0.05
Non-agric.	1 764	0.42	0.26
RSA	**15 632**	**2.87**	**3.81**
Agriculture	1 186	0.22	0.36
Non-agric.	14 446	2.65	3.45

Table 5-46 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 (Sim2) compared to when industry pays

(Sim2) – 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	Sim1: Industry Water & Industry Pays	Sim2: Industry Water & Municipal Users Pay
	Value (ZAR m)	Change (%)	Change (%)
WMAs 1–7	2 632	0.02	0.03
Breede–Gouritz	74	0.02	0.03
Berg–Olifants/Doorn	366	0.00	0.01
RSA	3 072	0.02	0.03

5.4.5 Scenario 5: Invasive alien plant removal for additional water in the Berg–Olifants/Doorn WMA

There is additional water for industries that use bulk and municipal water in the Berg–Olifants/Doorn WMA in this scenario, due to alien invasive plant removal. This provides an additional 25 million m^3 of water. It is assumed that the users of municipal water (including households) cover the increased cost of the invasive alien plant removal, and that 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 indicates that the total volume of water used increased by only 0.27% on a national level, but that it increased by 2.29% on average within the Berg–Olifants/Doorn WMA. A negligible increase in water use in WMAs 1 to 7 and in the Breede–Gouritz WMA is shown, due to indirect effects.

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

	Base	Scenario: Invasive Alien Plant Removal
	Volume (mn m^3)	Change (%)
WMAs 1–7	**14 298**	**0.03**
Irrigation	6 502	0.03
Bulk	3 593	0.00
Municipal (industries)	991	0.00
Municipal (households)	3 212	0.06
Breede–Gouritz	**1 116**	**0.03**
Irrigation	955	0.03
Bulk	56	0.00
Municipal (industries)	14	0.00
Municipal (households)	91	0.06
Berg–Olifants/Doorn	**1 813**	**2.29**
Irrigation	1 027	0.04
Bulk	275	7.28
Municipal (industries)	74	6.79
Municipal (households)	438	3.70

	Base	Scenario: Invasive Alien Plant Removal
	Volume (mn m^3)	Change (%)
RSA	**17 226**	**0.27**
Irrigation	8 483	0.03
Bulk	3 923	0.51
Municipal (industries)	1 079	0.46
Municipal (households)	3 741	0.48

Changes in regional GDP for agricultural and non-agricultural industries are presented in Table 5-48. When invasive alien 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 invasive alien plant removal scenario

		Base GDP	Scenario: Alien Invasive Plant Removal
WMA/Region	**Sectors**	**Value (ZAR bn)**	**Change (%)**
WMAs 1–7	**Region total**	**3 253**	**0.026**
	Agriculture	75	0.031
	Non-agric.	3 178	0.026
Breede–Gouritz	**Region total**	**90**	**0.027**
	Agriculture	7	0.031
	Non-agric.	82	0.027
Berg–Olifants/Doorn	**Region total**	**472**	**0.028**
	Agriculture	14	0.030
	Non-agric.	458	0.028
RSA	**Total**	**3 814**	**0.026**
	Agriculture	96	0.030
	Non-agric.	3 718	0.026

Table 5-49 indicates the impact of invasive alien plant removal on employment and income. Impacts on the directly affected Berg–Olifants/Doorn WMA are 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 by 3170 on a national level. 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 invasive alien plant removal scenario

	Base Employment (‘000)	Change In Employment (‘000)	Base Income (ZAR m)	Change In Income (%)
WMAs 1–7	**13 173**	**2.66**	**2 632**	**0.02**
Agriculture	921	0.23		
Non-agric.	12 252	2.43		
Breede–Gouritz	**533**	**0.12**	**74**	**0.03**
Agriculture	104	0.03		
Non-agric.	429	0.09		
Berg–Olifants/Doorn	**1 926**	**0.39**	**366**	**0.03**

	Base Employment ('000)	Change In Employment ('000)	Base Income (ZAR m)	Change In Income (%)
Agriculture	162	0.04		
Non-agric.	1 764	0.35		
RSA	**15 632**	**3.17**	**3 072**	**0.02**
Agriculture	1 186	0.30		
Non-agric.	14 446	2.87		

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

6.1 INTRODUCTION

The 2016 Water SAM discussed in Chapter 4 contains significant updates to agricultural production and yields. Changes to SAMs often lead to instabilities when applied 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 that are driven by policy.

A dynamic recursive model was configured alongside 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 nine consecutive years.
- **Scenario 2:** Project an annual increase of 10% on the municipal water tariffs for the same nine-year period.
- **Scenario 3:** Allow an incremental water volume of 50 million m^3 to be transferred from agriculture use to municipal consumption each year for the said nine-year period, each year transferring 50 million m^3 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 nine 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 business as usual (BAU) case (without tariff increase) increases over the period from 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

	Case: Without tariff increase			Case: With annual tariff increase		
	Water consumption (Mm3/a)			Water consumption (Mm3/a)		
Year	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 nine-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. 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

	Case: Without tariff increase			Case: With annual tariff increase		
	Water consumption (Mm3/a)			Water consumption (Mm3/a)		
Year	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^3 to be transferred from agriculture use to municipal consumption each year for the said nine-year period, each year transferring 50 million m^3 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^3 of water from irrigation use to municipal consumers

	Case: Without tariff increase			Case: With annual tariff increase		
	Water consumption (Mm3/a)			Water consumption (Mm3/a)		
Year	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^3 from irrigation to municipal consumers results 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

	Crop Production (kton/a)			
		With Tariff Increase		Adjusted
Year	BAU	Irrigation	Municipal	Volumes
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 are shown in table 6-5.

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

	Crop production deviation from BAU			
		With Tariff Increase		Adjusted
Year	BAU	Irrigation	Municipal	Volumes
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.

Table 6-6: Expected scenario impacts – on real GDP

	GDP deviation from BAU			
		With Tariff Increase		Adjusted
Year	BAU	Irrigation	Municipal	Volumes
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.

Table 6-7 illustrates the changes in the macroeconomic profile of GDP for the BAU case. Since the expected adjustments in GDP would be marginal 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, macroeconomic 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, namely irrigation, bulk, and municipal water were assumed to be subject to varying availability factors over the period between 2016 and 2026 – with the variations driven by experienced and projected rainfall as a proxy for water availability.

The rainfall statistics provided by Wolski (2018), as shown in Figure 6-1, 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.

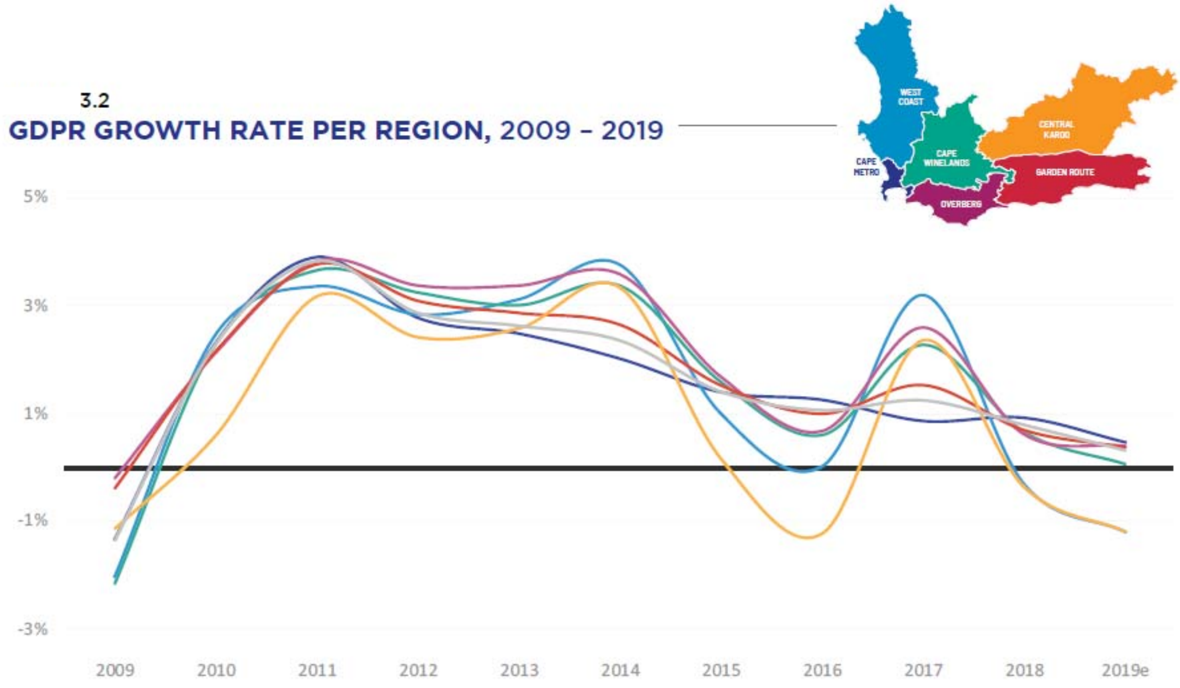
Table 6-8: Assumed water availability, relative to 2016 as the base year

	Water availability index		
Year	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 rather to be indicative of what was experienced. Water levels were assumed sufficient to meet manifested demand at the time.

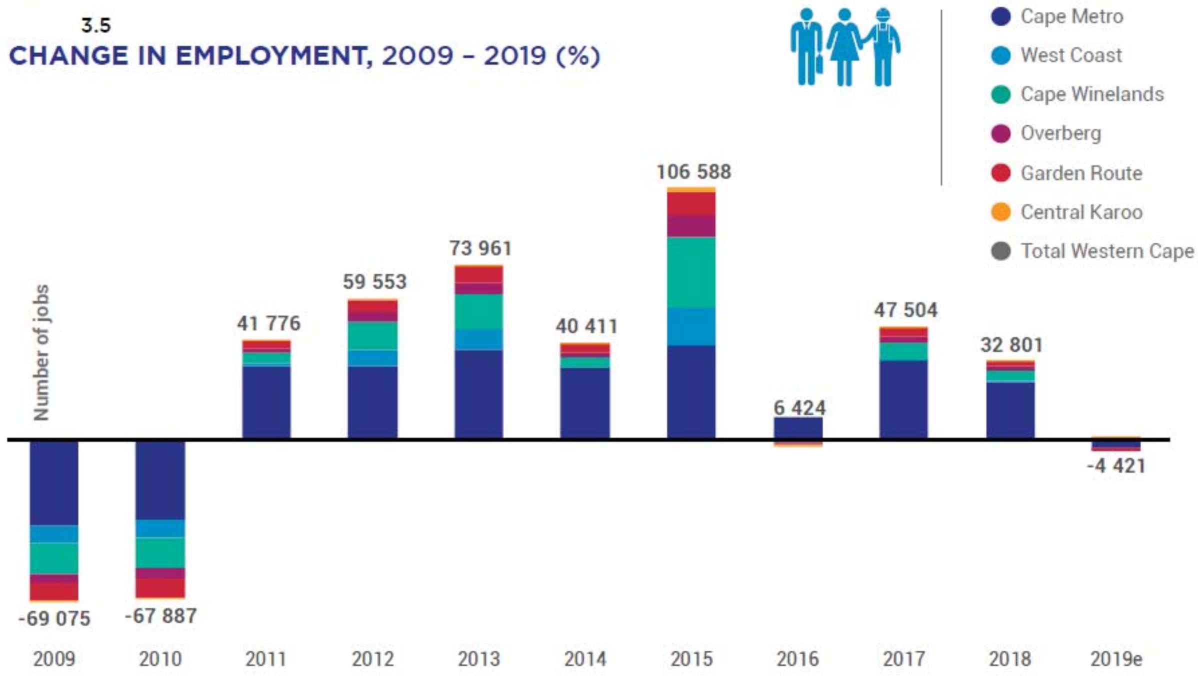
The drought cycle was introduced to only two WMAS only: the Breede–Gouritz and Berg—Olifants/Doorn; these being representative of the WCWMAs. No water availability impingement in any of the other WMAs was allowed. This presents an extreme scenario, where only two WMAs in the Western Cape are subjected to drought, while the rest of South Africa experiences normal climate conditions. The dynamic general equilibrium model was allowed to generate economic balances subject to these constrained water availabilities, and the outcomes were expected to indicate the lasting effects of such drought conditions on the economy – both regionally and nationally.

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.



	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 GDPR growth



	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, per region

GDPR		Ref (Rm)	GDPR				
		2018	2014	2015	2016	2017	2018
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, per 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 macroeconomic 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, namely (i) the Breede–Gouritz, (ii) the Berg–Olifants/Doorn, and (iii) all the other WMAs, are depicted in tables below; the 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 WMAs, while it is not as pronounced with the other WMAs. 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 WMA

	Breede-Gouritz					
	BAU case (Mm3/a)			Drought simulation impact (%)		
Year	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 WMA

	Breede-Gouritz					
	BAU case (R/m3)			Drought simulation impact (%)		
Year	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

	Berg-Olifants/Doorn					
	BAU case (Mm3/a)			Drought simulation impact (%)		
Year	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

	Berg-Olifants/Doorn					
	BAU case (R/m3)			Drought simulation impact (%)		
Year	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 WMAs are reflected Table 6-15 and Table 6-16.

Table 6-15: Assumed water availability for the other WMAs

	Other WMA's					
	BAU case (Mm3/a)			Drought simulation impact (%)		
Year	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

	Other WMA's					
	BAU case (R/m3)			Drought simulation impact (%)		
Year	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 of the overall national effects is given:

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

	Total Water					
	BAU case (Mm3/a)			Drought simulation impact (%)		
Year	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

	Total Water					
	BAU case (R/m3)			Drought simulation impact (%)		
Year	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

	Total GDP (Rm)							
	Breede-Gouritz		Berg-Olifants/Doorn		Other WMA's		Total	
Year	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

	WCWMAs GDPR (Rm)				
		Agri curtailment 50%		Agri curtailment 70%	
Year	Realised	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 to those seen above are observed in the case of employment; Table 6-21 depicts the impacts on regional aggregate employment at factor costs.

Table 6-21: The regional aggregate employment impacts

	Total Employment							
	Breede-Gouritz		Berg-Olifants/Doorn		Other WMA's		Total	
Year	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

	WCWMAs Employment				
		Agri curtailment 50%		Agri curtailment 70%	
Year	Realised	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 figures deviate 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

Table 6-23 depicts the impacts on regional aggregate household income, at factor costs.

Table 6-23: The regional aggregate household income impact

	Total Household Income (Rm)							
	Breede-Gouritz		Berg-Olifants/Doorn		Other WMA's		Total	
Year	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 – only a rather subdued impact is felt on the macroeconomic 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%.

CHAPTER 7: SUMMARY, CONCLUSION, AND RECOMMENDATIONS

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 that outcome is dependent on many crucial assumptions. Although the model can generate reasonable results, the value and desired accuracy of the outcomes will require further refinement and optimisation of control parameters in the model – such as elasticities and economic growth factors. 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 conducted 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 invasive alien 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^3/a)	Intervention/ Alternative Supply Cost (ZAR)
Alternative Supply Options			
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
Invasive Alien 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

Summary of findings:

- Desalination was found to be 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 analysis of farming under netting, 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 invasive alien plants was found to be the most cost effective of the interventions.

The modelling indicated that the cost of water realised from Agri-PV was similar to costs achieved for water reuse. The water savings and electricity generation potential results 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 in the near future without a concerted effort to establish commercial test utilities at scale and as integral to the production of specific crops. To provide the necessary proof-of-concept before market entry, we need to compare further techno-economical applications of Agri-PV, demonstrate the transferability to other regional areas, and also realise 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 – such as 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 SAM for South Africa that was developed in 2002 was used as foundation 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 being 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) sectors, 15 industrial sectors, and eight 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 was 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.

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. Such models fit economic data to a set of equations that aim to capture the structure of the economy and behavioural response of agents (industry, households, and 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 the base model and adjusted, for the 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 is far more pronounced. A 10% increase in the irrigation water tariff leads to national job losses of 1 600. 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 change, there is little indirect effect on other water usage. In general, the production of horticulture increases when municipal water rates increase, whereas production of field crops decreases. This could be because an increase in municipal water rates has a dampening effect on industry and that 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^3 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 because of an expansion of industries and hence household income. There is also an increase in employment on a national level (5 800).

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%, and bulk and municipal water each by 40%. This led to a decrease in households' use of municipal water (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 26 800 job opportunities are lost on the national level.

7.4.1.5 *Water transfer between sectors in the Berg–Olifants/Doorn WMA*

The transfer of 25 million m^3 of 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^3 of 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 they only reflect 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^3 of 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 positive, even if small, throughout – and likewise for the net national effect. 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. Taxation on users has a more positive outcome compared to when industries absorb the cost. All WMAs show an increase in employment, except for 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.

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^3 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 that 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 (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 are 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 m3 yet decreases for higher volumes because at lower volumes that positive impact on employment in the agricultural sector outweighs the negative impacts on industry. The impacts on GDP and employment in the other WMAs are positive, however.

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^3 of 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^3 of 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 of 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 indirect effects of the additional reuse water on WMAs are small and positive.

7.4.1.9 Invasive alien plant removal for additional water in the Berg–Olifants/Doorn WMA

In this scenario, there invasive alien plant removal provides an additional 25 million m^3 of water 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 invasive alien plant removal, and that this is recovered as a tax on water.

7.4.1.10 Summary

Total volume of water used increased by 2.29% within the Berg–Olifants/Doorn WMA, 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 by on 3 170 on the national level. Impacts on the directly affected Berg–Olifants/Doorn WMA are relatively small because the cost of the plant removal is covered, 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 alongside 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.
To demonstrate its capability, the recursive dynamic model was configured to simulate the following three scenarios over a nine-year period starting at 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.
- Estimate 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 household and industrial consumption rates, and the economic losses in industrial economic activity will more than offset the slight gains to be made in agriculture.

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^3 in the first year, and increasing by 50 million m^3 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, to observe changes in water availability and costing, macroeconomic 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 only two WMAs: the 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 real 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 macroeconomic 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

This project developed an assessment framework to allow for the evaluation of bulk water supply investments and regulatory options required for demand-side management from 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 (water reuse and desalination, among others); 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; a 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); and the impacts of different sets of policy interventions at national and regional/sectoral level were analysed and presented.

The greatest challenge regarding SAM development is the availability of the required up-to-date and detailed data at the level of disaggregation. For the 2016 water SAM, this was no exception, since very little data in the public domain is published on a WMA level. Detailed agricultural and household data proved particularly difficult to find and time consuming to construct. In the case of households, 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 invasive alien 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 considered 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 10-year period.

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 than industry. For the same reason, additional water (regardless of the source) allocated to industry rather than irrigation agriculture, typically leads 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 regarding 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 in the increased water use of all water categories in all WMAs. The exception to this 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 that 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^3 and 75 million m^3 when the impact on employment numbers became negative due to the increasing costs of producing 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 of providing additional water to agriculture by means of desalination and having other users pay for it would not be sound policy, and those costs would 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 than when only industry absorbs the cost.

Regarding the water supply options, such as reuse of water and invasive alien plant removal, the positive impacts of the additional water availability are often subdued, due to the additional costs that need to be recovered – hence the macroeconomic impacts in terms of GDP, employment, and household incomes being generally small (yet still 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 distinct level of resilience in the economy – meaning that the dynamic CGE model may not always be the best model to measure the economic impact of a longer and more severe drought, where the drought is of such a dimension that it eclipses the inherent resolve of the communities in surviving with the bare minimum of water.

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

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