

**A WATER FOOTPRINT ASSESSMENT OF PRIMARY CITRUS  
PRODUCTION IN THE LOWER SUNDAYS RIVER VALLEY CITRUS  
FARMS, EASTERN CAPE, SOUTH AFRICA**

A thesis submitted in fulfilment of the requirements for the degree of  
MASTER OF SCIENCE  
of  
RHODES UNIVERSITY

BY:  
**SAMANTHA ALANNA MUNRO**

SUPERVISED BY:  
PROFESSOR G.C.G. FRASER  
PROFESSOR J.D. SNOWBALL  
DR. M. PAHLOW

Department of Economics and Economic History  
Rhodes University  
Grahamstown  
South Africa  
February 2015

## **ABSTRACT**

With the current implementation of the South African National Water Act (NWA) underway, comprehensive tools to assist in the efficient, fair and sustainable management of water resources are needed. Water footprints (WFs) are increasingly being recognised as a meaningful way to represent human appropriation of water resources and provide a framework for assessing the sustainability of water use.

The study calculated blue, green and grey WF for the lower Sundays River Valley (LSRV) citrus sector across dry, humid and long-term average climates for a number of cultivars. The sustainability of both the LSRV and the production process of citrus were examined through the adoption of a number of environmental, social and economic indicators. The study revealed that there was no water scarcity in the area because of an inter-basin transfer and that water pollution levels attributed to citrus production required a more comprehensive indicator than the grey WF.

Results showed that navels, despite being the dominant cultivar, had the highest WF and the lowest water productivity and technical efficiency. It also provided lower benefits of income and employment in terms of water use in comparison to other cultivars. Conversely, cultivars such as lemons, which required a greater amount of water and fertiliser, were the most productive cultivar with the lowest blue, green and grey WF. The study demonstrated the complexity of decisions regarding water management and the need to assess accurately the environmental, social and economic implications of strategies to increase efficiency of water. The importance of incorporating local data and verifying WFs was also illustrated.

The analysis highlighted that WF assessments could be useful for the South African government and agricultural sectors to assist in future water management decisions and promote increased collaboration between stakeholders. The study found that the adoption of local benchmarks could be useful in aiding the promotion of more efficient water use and could factor in sensitive economic and social attributes. WFs in conjunction with other economic and social indicators could also be used to evaluate the sustainability of current and future allocations pertaining to

the implementation of the NWA. It was however noted that this requires vast amounts of accurate data.

**Keywords:** water footprint assessment, sustainability, water allocations, economic indicators, citrus, policy.

## DECLARATION

This thesis has not been submitted to a university other than Rhodes University, Grahamstown, South Africa. The work presented here is that of the author, unless otherwise stated.

Signed \_\_\_\_\_ Date \_\_\_\_\_

## TABLE OF CONTENTS

<i>Abstract</i>	ii
<i>Declaration</i>	iv
<i>Table of Contents</i>	v
<i>List of Tables</i>	ix
<i>List of Boxes</i>	ix
<i>List of Figures</i>	x
<i>List of Abbreviations</i>	xii
<i>Acknowledgments</i>	xiv
<b>CHAPTER ONE: INTRODUCTION</b>	
<b>1.1 Water scarcity and security in South Africa</b>	<b>2</b>
<b>1.2 South African policy reforms</b>	<b>3</b>
1.2.1 Policy limitations and future initiatives for water management	5
<b>1.3 Water footprint assessments</b>	<b>6</b>
1.3.1 Water footprint assessments in South Africa	7
1.3.2 The lower Sundays River Valley citrus industry	8
<b>1.4 Problem statement</b>	<b>8</b>
<b>1.5 Aims and Objectives</b>	<b>9</b>
1.5.1 Aim	9
1.5.2 Objectives	9
<b>1.6 Structure of thesis</b>	<b>10</b>
<b>CHAPTER TWO: THE WATERFOOTPRINT ASSESSMENT: CONCEPTS, APPLICATIONS AND RELEVANCE FOR SOUTH AFRICAN POLICY</b>	
<b>2.1 Introduction</b>	<b>13</b>
<b>2.2 The water footprint framework: key concepts and definitions</b>	<b>14</b>
2.2.1 Green, blue and grey water footprints	15
2.2.2 Virtual water and the water footprint	20
2.2.3 Footprint Family	21
2.2.4 Life cycle assessments and water footprint assessments	22
<b>2.3 Scope and application of water footprint accounting studies</b>	<b>23</b>
2.3.1 Global and national studies	23
2.3.2 Products and corporate water footprints	26
	v

2.3.3 Criticisms surrounding water footprint accounting studies	27
<b>2.4 The water footprint sustainability assessment: theoretical concepts and applications</b>	<b>29</b>
2.4.1 Sustainability and the water footprint sustainability assessment framework	29
2.4.2 Applications of the WF sustainability assessment	33
2.4.3 Limitations of the water footprint assessment and potential economic considerations	38
2.4.4 Life Cycle Assessment and the aggregation and weighting of impacts versus water footprint assessment	40
<b>2.5 The relevance of water footprint assessments for policy and the private sector</b>	<b>42</b>
2.5.1 Water neutrality and reduction of WFs	43
2.5.2 Benchmarks, caps and WF allocations	44
2.5.3 Shared risk and responsibility	45
<b>2.6 Water footprint assessments and its relevance to South African water policy</b>	<b>45</b>
<b>CHAPTER THREE: SOUTH AFRICAN AGRICULTURAL CONTEXT AND STUDY AREA</b>	
<b>3.1 The South African agricultural sector</b>	<b>48</b>
3.1.1 Fruit crops	49
<b>3.2 Rationale for study site selection</b>	<b>50</b>
<b>3.3. General attributes of the study site</b>	<b>51</b>
3.3.1 Location	51
3.3.2 Biophysical context	52
3.3.3 Historical and current water use	54
<b>3.4 The lower Sundays River Valley citrus industry</b>	<b>58</b>
3.4.1 The scope for a water footprint assessment in the lower Sundays River Valley	61
<b>CHAPTER FOUR: METHODOLOGICAL APPROACH, STUDY DESIGN AND RESEARCH METHODS</b>	
<b>4.1 Methods and study design</b>	<b>64</b>
4.1.1 Study design	64
<b>4.2. Goals and scope</b>	<b>65</b>
4.2.1 Scope of water footprint accounting	65
4.2.2 Scope of water footprint sustainability assessment	67
<b>4.3 Data collection and sources</b>	<b>68</b>
4.3.1 Secondary data collection	69
4.3.2 Primary data collection	69
<b>4.4 Water footprint accounting</b>	<b>71</b>
4.4.1 Blue and green water footprints: calculating crop water use	73
4.4.2 Models for calculating crop water use: SAPWAT 3.0 versus CROPWAT 8.0	74
4.4.3 Modelling crop water use: SAPWAT 3.0 input and output data	75
4.4.4 Grey water footprints	81

<b>4.5 Water footprint sustainability assessment</b>	<b>84</b>
4.5.1 The sustainability of the LSRV basin	85
4.5.2 The sustainability of citrus production in the LSRV	86
<b>4.6 Policy Responses</b>	<b>88</b>
<b>4.7 Limitations</b>	<b>88</b>
<b>4.8 Ethical considerations</b>	<b>90</b>

## **CHAPTER FIVE: IRRIGATION PRACTICES AND WATER FOOTPRINTS OF CITRUS CULTIVARS IN THE LOWER SUNDAYS RIVER VALLEY**

<b>5.1 Introduction</b>	<b>92</b>
<b>5.2 Farm profiles and farming practices</b>	<b>92</b>
<b>5.3 Theoretical crop water use, irrigation requirements and yield</b>	<b>96</b>
5.3.1 Green and blue water use	96
5.3.2 Verifying data through comparative studies and irrigation records	99
5.3.3 Monthly green and blue water use and demand	103
<b>5.4 Grey water and water quality</b>	<b>105</b>
5.4.1 Application rates and grey water	105
5.4.2 Water quality data	107
<b>5.5 Yield data</b>	<b>111</b>
<b>5.6 The water footprint and water productivity of the lower Sunday River Valley citrus sector</b>	<b>113</b>
5.6.1 Total green, blue and grey water footprints	114
<b>5.7 Farmer's perception on future risks, price increases in water and a decrease in allocation</b>	<b>118</b>
<b>5.8 The importance of identifying virtual water and water footprints and potential risk prevention and reduction strategies</b>	<b>120</b>

## **CHAPTER SIX: SUSTAINABILITY ASSESSMENT AND POLICY RESPONSES**

<b>6.1 Introduction</b>	<b>123</b>
<b>6.2 Measuring the sustainability of the LSRV river basin</b>	<b>123</b>
6.2.1 Water availability and scarcity	123
6.2.2 Water pollution level	129
6.2.3 Evapotranspiration and land use change	131
6.2.4 Social and economic sustainability	132
6.2.5 Efficiency of allocations	134
<b>6.3 Sustainability of the citrus production process</b>	<b>135</b>
6.3.1 Economic water productivity	135
6.3.2 Economic land productivity	138
6.3.3 Labour water productivity	140

6.3.4 Total factor productivity	142
<b>6. 4 Policy responses and usefulness of WF assessments in decision making</b>	<b>146</b>
6.4.1 Determining and assessing current and future status of water resources	147
6.4.2 Addressing issues of equity and efficiency	148
<b>6.5 Summary</b>	<b>151</b>
<b>CHAPTER SEVEN: CONCLUSIONS AND RECOMMENDATIONS</b>	
<b>7.1 Overview</b>	<b>154</b>
7.1.1 Scope	154
7.1.2 Water footprint accounting	155
7.1.3 Water footprint sustainability assessment	157
7.1.4 Water footprint response formulations and policy implications	158
<b>7.2. The need for future research</b>	<b>160</b>
<b>7.3 Concluding remarks</b>	<b>162</b>
<b>APPENDIX</b>	
1. Examples of Data inputs for Sapwat 3.0	199
2. Examples of Data outputs from Sapwat 3.0	204
3. Yield	206
4. Grey water data	207
5. Crop budgets	215
6. Questionnaire	216
7. Farm interview data	229

## LIST OF TABLES

<b>Table 3.1</b>	Raw water user charges (R/ha/yr) for the lower Sundays River Valley	59
<b>Table 4.1</b>	Data inputs and sources	68
<b>Table 4.2</b>	Derived crop-growth stages for navel, valencia, lemon and soft citrus cultivars	79
<b>Table 4.3</b>	Mean percentage of soils across farms (n=12)	80
<b>Table 5.1</b>	Summary of farmers irrigation schedules according to farm type	95
<b>Table 5.2</b>	Crop water use (m <sup>3</sup> ) and yield (tons) for each citrus cultivar per hectare	97
<b>Table 5.3</b>	Application rate (tons/ha/yr) and grey water (m <sup>3</sup> /ha/yr) for citrus cultivars.	107
<b>Table 5.4</b>	Citrus fruit yields for navel, Valencia and lemon varieties	113
<b>Table 6.1</b>	Natural MAR and estimate EFR for Sunday River (million m <sup>3</sup> /yr) at a 1:50 year assurance	124
<b>Table 6.2</b>	Tributary flows and transfer volumes (Mm <sup>3</sup> /yr) for the Fish-Sundays scheme	124
<b>Table 6.3</b>	Water requirements and availability for the year 2000 at 1:50 year assurance (Mm <sup>3</sup> /yr)	126

## LIST OF BOXES

<b>Box 2.1</b>	Sustainability assessments versus impact assessments	31
----------------	--	----

## LIST OF FIGURES

<b>Figure 2.1</b>	Water footprint sustainability assessment for a geographic context e.g. a river basin or catchment	32
<b>Figure 3.1</b>	Map of Sundays River Valley, Eastern Cape, South Africa	52
<b>Figure 3.2</b>	Forty-three year average monthly rainfall (mm) for Kirkwood, Dunbrody, Sunland and Hermitage	53
<b>Figure 3.3</b>	Seasonal rainfall (mm), maximum and minimum temperatures (°C) over the last five years for the Lower Sundays River Valley.	54
<b>Figure 3.4.</b>	Schematic diagram of the Orange-Fish transfer scheme	56
<b>Figure 3.5</b>	Sundays River Valley citrus exports by selected variety for 2005-2013	60
<b>Figure 3.6</b>	Sundays River Valley citrus plantings by selected variety based on a voluntary survey 1982-2012	60
<b>Figure 3.7</b>	Sundays River Valley 2012 citrus tree census data showing age distribution by selected variety, based on a voluntary survey	61
<b>Figure 4.1</b>	Blue, green and grey water footprint calculations	71
<b>Figure 4.2</b>	Citrus growth curves and average start and end of harvest dates for lemons, navel, valencia and clementine cultivars	78
<b>Figure 4.3</b>	Questions relating to the sustainability of water use by the LSRV citrus sector	84
<b>Figure 5.1</b>	Size of farm (ha) and proportion of each cultivar within each sampled farm	93
<b>Figure 5.2</b>	Age distribution of tree data from sampled farms	93
<b>Figure 5.3</b>	Average monthly $ET_0$ (mm/month) for the 2009-2013 seasons	98
<b>Figure 5.4</b>	Average water use ( $m^3/ha/an$ ) for five farms in the LSRV for the 2013 season	100
<b>Figure 5.5</b>	Annual water use ( $m^3$ ) per hectare in irrigated areas and mean annual rainfall (mm) in the lower Sundays River Valley basin	101
<b>Figure 5.6</b>	Effective rainfall and irrigation requirements ( $m^3$ ) per hectare per season for citrus in the Addo region for different irrigation applications (5mm to 100 mm)	102
<b>Figure 5.7</b>	Monthly blue water use ( $m^3/ha$ ) in the lower Sundays River Valley based on farm data and modelled data using SAPWAT 3.0	104
<b>Figure 5.8</b>	Average monthly water consumption for different size citrus trees	105
<b>Figure 5.9a</b>	Mean ( $\pm$ s.d) nitrite ( $NO_2$ ) and nitrate ( $NO_3$ ) at monitoring points within the lower Sundays River Valley	108
<b>Figure 5.9b</b>	Mean ( $\pm$ s.d) for ammonium ( $NH_4$ ) (mg/L) at monitoring points within the lower Sundays River Valley	109

<b>Figure 5.9c</b>	Total dissolved salts (TDS) at monitoring points within the lower Sundays River Valley	110
<b>Figure 5.10</b>	Rainfall (mm) and yield data (tons/ha) for the seasons 2009-2013	112
<b>Figure 5.11</b>	Average green, blue and grey WF ( $\text{m}^3/\text{ton}$ ) and WP ( $\text{ton}/\text{m}^3$ ) per hectare for citrus cultivars in wet, dry and average rainfall years under micro and drip irrigation	115
<b>Figure 6.1</b>	Total seasonal blue water usage and quotas in the lower Sundays River Valley from 2004-2013	127
<b>Figure 6.2</b>	Current water use abstractions based on data from the LSRV WUA and estimated LTA grey and blue water use per month.	128
<b>Figure 6.3</b>	Mean ( $\pm$ s.d) monthly TDS (mg/L) for monitoring points in the LSRV taken by DWS from 1999-1998	130
<b>Figure 6.4</b>	Addo Elephant National Park accumulated ET and rainfall from the 10 June 2008- 8 June 2009	132
<b>Figure 6.5</b>	Total economic water productivity and blue economic water productivity ( $\text{R}/\text{m}^3$ ) for citrus cultivars across different climatic years based on farm gate export prices	136
<b>Figure 6.6</b>	Total economic water productivity and blue economic water productivity ( $\text{R}/\text{m}^3$ ) for citrus cultivars across different climatic years based on net revenue	137
<b>Figure 6.7</b>	ELP ( $\text{R}/\text{ha}$ ) of cultivars in the LSRV for the 2009-2013 season using net revenue	138
<b>Figure 6.8</b>	Average net Rand per ton and pack-out percentage for all cultivars for the seasons 2008-2013 in the LSRV	139
<b>Figure 6.9</b>	LWP ( $\text{hrs}/\text{m}^3$ ) for citrus cultivars in the LSRV for the 2009-2013 seasons	141
<b>Figure 6.10</b>	TFP showing ratio of outputs to inputs in Rands for citrus cultivars in the LSRV for the 2009-2013 seasons	143
<b>Figure 6.11</b>	Comparison of the LTA orange, lemons and soft citrus water footprints in SRV and green-blue and grey water footprints ( $\text{m}^3/\text{ton}$ ) at different production percentiles and global averages	144
<b>Figure: 6.12</b>	Comparison between WFs of LSRV citrus cultivars and WFs derived by Mekonnen & Hoekstra (2010b) for EC and SA	145

## LIST OF ABBREVIATIONS

AR	application rate
ARS	Addo Research Station
AS	ammonium sulphate
BOCMA	Breede Overberg Catchment Management Agency
CF	carbon footprint
CGASA	Citrus Growers Association of Southern Africa
CHDM	Chris Hani District Municipality
CMA	catchment management agency
CWR	crop water requirements
CWU	crop water use
DAFF	Department of Agriculture, Forestry and Fishing
DAEAT	Department Economic Affairs, Environmental and Tourism
DEAT	Department of Environmental Affairs and Tourism
DOA	Department of Agriculture
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
EC	Eastern Cape
EF	ecological footprint
EFR	ecological flow requirements
ELP	economic land Productivity
EOH	end of harvest
ET	evapotranspiration
EWP	economic water productivity
FAO	Food and Agricultural Organization
GDP	gross domestic product
IBT	inter-basin transfer
IFC	International Finance Corporation
ISO	International Standardisation Organisation
IWRM	Integrated Water Resource Management
LCA	life cycle assessment
LSRV	lower Sundays River Valley
LTA	long-term average
LWP	labour water productivity
MAP	mean annual precipitation
MPV	marginal product value
NMBM	Nelson Mandela Bay Municipality

NWA	National Water Act
NWRS	National Water Resource Strategy
OPEN	One Planet Economy Network
PFP	partial factor productivities
SA	South Africa
SABC	South African Broadcasting Commission
SENET	South East Region North East Thames Area
SOH	start of harvest
SP	Superphosphate
SRCC	Sundays River Citrus Company
SRV	Sundays River Valley
SRVM	Sundays River Valley Municipality
TDS	Total Dissolved Solids
TFP	Total Factor Productivity
UAN	Urea Ammonium Nitrate
UE	European Union
UK	United Kingdom
WF	water footprint
WP	water productivity
WPL	water pollution level
WUA	water user association

## ACKNOWLEDGMENTS

I would firstly like to thank Rhodes University, the Department of Economics and Economic History staff, specifically the Environmental Natural Resource Economic Focus Area foremost for generously funding this project and secondly for the continued support provided through the programme particularly from my peers Juniors, Nqobizitha, Patricia and Malone.

To my supervisors, Prof Gavin Fraser, Prof Jen Snowball and Dr Markus Pahlow, your contributions and inputs to this project is unfathomable. Thank you for all the feedback, encouragement, criticism, support and patience throughout the duration of this project. I have learnt and grasped so much that would have not been possible without your efforts.

To all the farmers who gave up their time to meet with me and provided me with data, that without, this project would not have been possible. Particular thanks go to Eldon Whittle, Zelda van Tonder and Andre Combrink for going above and beyond in helping me gain the necessary information I needed.

To all the people who helped or contributed in some way by providing me with information or assisting with data collection and dissemination: Prof Tally Palmer; Jai-Clifford- Holmes, Juan Antonio, Prof Jack Houston, Suritha Kampman, Kobus Steenkamp, Peter Van Heerden, Nikki Combrink, Lucio Zuma, Dr Tony Palmer, Marco Brutsch, Pieter Swanepoel and Deon Joubert.

Finally, I would like to thank my family and friends who have supported and encouraged me, not only for the duration of this thesis, but throughout my years attending Rhodes University.



# CHAPTER ONE:

## INTRODUCTION

*"Only when the crops dry out, the rivers stop flowing and the wells run dry, will we know the worth of water"*

*-Benjamin Franklin*

Nova in September

Photo: S.A Munro

## **1.1 Water scarcity and security in South Africa**

Water is one of the most fundamental and indispensable natural resources. It is vital to the maintenance and functioning of ecological systems, crucial to human life and underpins socio-economic development (Costanza and Daly, 1992; Gleick, 1993; Falkenmark, 2003). Many South African macro-strategies including the National Development Plan and the New Growth Path rely on sufficient quantities of water in order to create economic growth and job opportunities (Department of Water Affairs (DWA), 2012). Water is vital for food production, hygiene, industries and power generation.

South Africa, like most other semi-arid countries, face a number of resource challenges related to water including increasing scarcity and competition of water as a result of population expansion, economic growth and climate change (Falkenmark, 2003; Gush & Taylor, 2014). Furthermore, water quality has been compromised because of industrial, household and agricultural pollutants (DWA, 2012). This further reduces the supply of safe drinking water and increases treatment costs (Backeberg, 2005; Lange & Hassan, 2006).

The South African water scarcity situation is exacerbated further by the fact that rainfall is not only distributed unevenly, but is also extremely variable geographically, seasonally and socio-politically, thus limiting options for water management (Muller, 2000; DWA, 2012). The mean annual rainfall in South Africa is 450 mm/year, which is significantly lower than the global average of 860 mm/year (Department of Water Affairs and Forestry (DWAF), 2004). In fact, 21% of the country receives less than 200mm/year (Perret, 2002). Furthermore, in the wake of climate change South Africa is expected to suffer from decreased rainfall and experience more severe droughts (DWAF, 2004). According to Schulze & Perks (2000), unpredictability, secondary affects and consequences related to climate change will require substantial capacity from the water sector.

Water demands have previously been met through supply side initiatives however, due to increasing costs associated with some of these measures, not to mention scarcity of water, these initiatives have become less viable (Muller, 2000; Lange & Hassan 2006; Turpie *et al.*, 2008). It is

well established that South Africa is very near reaching its limits to make water available through traditional methods and policy needs to be directed towards more efficient water use and conservation (Muller, 2000; Backeberg, 2005; DWAF, 2005). Given limited resources available, it is unlikely that increasing demands can be met unless new approaches are adopted to balance demand and supply.

Despite water being one of the most urgent developmental constraints facing South Africa, it has been argued that there is enough fresh water for current and future generations (Rijsberman, 2006; Molden, 2007). An increasing number of researchers have acknowledged that water security is largely attributed to poor water management and not water scarcity (Rosegrant *et al.*, 2002; Saleth & Dinar, 2004; Benoit and Comeau 2005; Aldaya & Llamas, 2008; Garrido *et al.*, 2010). A new global paradigm for Integrated Water Resource Management (IWRM) has emerged placing emphasis on demand-side strategies whereby institutional reforms have been deemed key to the efficient governing of limited environmental resources (Challen, 2000; Paavola & Adger, 2002; Saleth & Dinar, 2004).

## 1.2 South African policy reforms

South Africa has taken cognisance of this global paradigm and recognises the need to manage its resources sustainably and optimally to meet its developmental and socio-economic goals (DWAF, 2005). The National Water Act (NWA) (Act 36 of 1998) is the principal legal instrument governing water resource management and is supported by a number of Acts including The National Environmental Act (Act 107 of 1998) and The Water Services Act (Act 108 of 1997). The NWA is currently being incrementally implemented and sets out a number of objectives, which include:

1. "To achieve **equitable** access to water. That is access to water services, to the use of water resources and to the benefits from the use of water resources"
2. "To achieve **sustainable** use of water, by making progressive adjustments to water use, to achieve a balance between water availability and legitimate water requirements, and by implementing measures to protect water resources and the natural environment"

3. “To achieve *efficient* and *effective* water use for optimum social and economic benefit”  
(DWAF, 2005:2)

The NWA aims to achieve the above objects through institutional reforms and changes within the water sector in the form of policy and organisational dimensions in water allocation. The legislation provides a means for change in management through decentralisation, establishing new local and regional institutions, introducing water user registration and licensing and the potential emergence of water rights markets (DWAF, 1998). South Africa was one of the first countries in the world to recognise and legalise the inclusion of the environment as a priority water user with the NWA, reserving an unspecified portion of in-stream flow to ensure sustained ecological services (Conradie, 2002; Tewari, 2009).

The National Water Resource Strategy (NWRS) provides the implementation strategy and framework for implementing the NWA (DWAF, 2005). The strategy sets out policies, objectives, institutional arrangements, plans, procedures and guidelines by which the NWA legislation should be carried out. According to the new draft NWRS, South African businesses and industries could expect increased regulation of water quality, escalating costs of usage and constraints on availability, not only in the form of water licence allocations, but also as a result of increasing demand and water scarcity (DWA, 2012). It is therefore imperative that industries that rely heavily on water, consider the potential impacts of a reduction in water use through licensing allocations and the effect of increasing marginal water use costs. This is highlighted particularly for the South African irrigated agriculture sector (DWA, 2012; Taylor & Gush, 2014).

South Africa has approximately 16.7 million hectares of arable land (Department of Agriculture, Fisheries and Forestry (DAFF), 2013), most of which is dry land cultivated, with only 1.5 million hectares irrigated. However, irrigated agriculture accounts for 62.7% of South Africa’s total water use (DWA, 2012). The share of water to this sector has been previously justified through job creation and food security however, as the economy develops and populations expand this water needs to be shared with a greater number of users (Muller, 2000; Backeberg, 2005). The DWA

(2012:54) emphasise that “future demands for agriculture will to a large extent depend on crop selection and financially attractive opportunities of increasing water efficiencies.”

### **1.2.1 Policy limitations and future initiatives for water management**

Despite the South African NWA and its reforms regarded as progressive, implementation has been slow. Numerous challenges have arisen and remain, particularly those inherited because of the previous apartheid system (Funke *et al.*, 2007; Tewari, 2009). Water security is a major issue in many poor, marginalised communities with current patterns of water use in South Africa characterised by inequality, inefficiency, and inadequacy (Mokgope *et al.*, 2001). Poor rural communities and emerging farmers have limited access to water resources while water continues to be used inefficiently by irrigation sectors with very few incentives to improve water use efficiency (Mokgope *et al.*, 2001; King, 2004; Nieuwoudt *et al.*, 2008). A fundamental constraint is trying to achieve the potentially contradicting objectives of resource protection, social and economic equity and efficiency within a context of resource scarcity, budget constraints, competing users and social backlogs while maintaining production capacity and creating jobs and economic growth (Backeberg & Odendaal, 1998; Perret, 2002; Hassan & Crafford, 2006). These challenges have placed mounting pressure on South Africa’s water management institutions.

Dealing with these challenging tasks requires improved knowledge by policy makers and water managers of the economic contribution and value of water for various uses, the effectiveness and potential of water conservation through demand management and pricing for financial sustainability, economic efficiency and social justice (Hassan & Crafford 2006; Nieuwoudt *et al.*, 2008). Such broad based knowledge requires powerful information systems that integrate a wide range of hydrological, economic and social dimensions for water supply and use (Hassan & Crafford, 2006). Although the DWA have used information regarding the hydrological and physical data on water sources, according to Hassan & Crafford, (2006), they have neglected to interlink any economic components. Current efforts have been described as uncoordinated, resulting in the use of inconsistent information, which lack components of critical relevance (Funke *et al.*, 2007; Tewari, 2009).

The transition from the old to the new Water Act in South Africa has started the development path to not only implement policies to achieve more fair, efficient and sustainable allocation of water, but to provide insights into the institutional frameworks and economic approaches that can be adopted in achieving its objectives. The continual development of new tools to facilitate the implementation of the NWA are emphasised by authors (Conradie, 2002; Funke *et al.*, 2007) as well as in the new draft NWRS (DWA, 2012). Of particular importance are tools to assist decision makers in understanding the social and economic value of water, aiding the effectiveness of institutions. The NWRS illustrates the need to use innovative approaches and “smart” management concepts. Particular emphasis is placed on the introduction and application of new concepts such as the water footprint (WF) (DWA, 2012).

### **1.3 Water footprint assessments**

The concept of ‘footprints’ has emerged, to indicate the pressures that humans exert on the environment (Hoekstra, 2009). Footprints provide a basis for understanding environmental changes arising from pressures and resultant impacts (Hoekstra & Wiedman, 2014). Hoekstra first suggested the term WF in 2002 at the International Expert Meeting on Virtual Water Trade, held in Delft, the Netherlands (Hoekstra, 2003). A WF is regarded as a comprehensive indicator of the appropriation of freshwater resources, and is comprised of the direct and indirect volumes of water appropriated to produce a product over a full supply chain (Hoekstra *et al.*, 2009a; Hoekstra *et al.*, 2011). The WF differs from previous water accounting tools in that it does not include return flows and relates water appropriation to consumption as well as production (Hoekstra, 2007; Hoekstra *et al.*, 2011; Chapagain & Tickner, 2012). A WF also considers the origin of the water used, as well as both water quantity and water quality impacts by differentiating between types of water use; namely blue, green and grey water (Hoekstra *et al.*, 2009a; Hoekstra *et al.*, 2011).

Although the WF itself is not a measure of environmental, economic and social impacts of water consumption and pollution (Hoekstra *et al.*, 2011), efforts to incorporate impacts and response strategies have been partly tackled through the establishment of a WF assessment. The WF assessment, as per Hoekstra *et al.* (2011) is a four-step process classified into: setting goals and

scope, WF accounting, sustainability assessment and response formulation (Hoekstra *et al.*, 2009a; Hoekstra *et al.*, 2011). By considering the origin of water use, the WF provides a spatio-temporal explicit account of water use, specifying all types of water use geographically and temporally through a WF assessment (Hoekstra *et al.*, 2011).

As a newly established concept, the aim is to continuously update, revise and incorporate various recommendations and through feedback to increasingly refine WF methodology (Hoekstra *et al.*, 2011). This is particularly prevalent for the last two steps of the WF assessment where authors acknowledge the need for further development and refinement through applications of studies (Hoekstra *et al.*, 2011).

### **1.3.1 Water footprint assessments in South Africa**

The WF concept has been said to have the ability to provide insights into the potential water risks that businesses and products may have along their supply chain (Aldaya & Hoekstra, 2010; Ercin *et al.*, 2011; Ercin *et al.*, 2013). It also is said to be able to assist government institutions in reallocating water within catchments with regard to licence allocations by examining the efficiency and sustainability of sectors water use (Aldaya *et al.*, 2010b; Hoekstra *et al.*, 2011; Vanham & Bodiglio, 2013; Zhang *et al.*, 2014). The WF can therefore potentially not only assist industries, but also give support to implementing South African water policies by providing various hierarchies of government institutions with information to make informed decisions within the context of water management. A recent WF assessment, conducted within the Breede-Overberg catchment, has already demonstrated that having an understanding of how the use and allocation of water can contribute to economic growth could aid in long-term development, recommendations regarding crop types, location, distribution of water and allocation between economic sectors within South Africa (Breede-Overberg Catchment Management Agency (BOCMA), 2011).

### **1.3.2 The lower Sundays River Valley citrus industry**

The citrus industry within the lower Sundays River Valley (LSRV) in the Eastern Cape of South Africa is just one of many agricultural sectors that rely significantly on irrigation schemes. The LSRV is regarded as one of the key production areas for citrus farming in South Africa (DAFF, 2011). The industry is primarily export orientated and is one of the largest foreign exchange earners in the Eastern Cape (DAFF, 2011). This is particularly relevant given the large number of agricultural industries in South Africa that do rely on inter-basin transfers (IBT) and are still receiving inefficiently cheap water (DWA, 2012). This area is therefore a potentially useful area in which to conduct a WFA.

### **1.4 Problem statement**

It is important that both government and sectors have a good understanding of water use activities and allocations. WF assessments provide a framework in which to identify and understand current and future water use related risks. This is particularly relevant for agricultural production, which rely heavily on a consistent supply of water. The LSRV citrus industry is no exception and relies entirely on fresh water resources supplied by an IBT scheme. Water scarcity coupled with climate change and new demand strategies to reduce water use could have adverse impacts on the industry. Simultaneously, it is the responsibility of government custodians of water use to make informed decisions about water allocation taking into account sustainability, efficiency and equity of water use. WF assessments provide a framework that can assist in making such decisions and help identify risks for industries. A practical application of the full water footprint assessment will not only be potentially useful for South Africa and its industries but also add to the limited literature base that conduct full WF assessments at a local scale.

## **1.5 Aims and Objectives**

### **1.5.1 Aim**

The aim of this study was to conduct a WF assessment of the citrus farms in the LSRV. This included all four stages of the WF assessment, namely setting goals and scope, WF accounting, WF sustainability assessment and a WF response formulation.

### **1.5.2 Objectives**

By conducting a water footprint assessment a number of goals emerged and included:

- To calculate the volumetric blue, green and grey WF indicators of the different citrus cultivars using high-resolution spatial and geographical data to achieve accurate estimates of the WF of different citrus cultivars in the LSRV
- To assess the environmental, social and economic sustainability of blue, green and grey WFs.
- To identify potential future water risks relating to climate change and a reduction of water to the area by examining changes in WFs across different climatic years.

A final and overarching research question is:

- How WF assessments are applicable and relevant with regard to the implementation of the South African Water Legislation, and what other potential considerations can be made regarding assessing the economic sustainability within the WF assessment framework.

## **1.6 Structure of thesis**

The basis of the information for this thesis was formed from both primary and secondary data that aimed to examine current farming practices within the area as well obtain baseline data by which to measure water use for the different citrus crops. The research focused on identifying indicators in the context of achieving a full water footprint assessment to examining the sustainability of current water use, and formulating appropriate response strategies.

Chapter one (this chapter) provides an introduction summarising the rationale for this research and presenting the studies aim and objectives. This is followed by a detailed discussion of the theoretical framework of a WF assessment, including a literature review of current applications and its relevance to South African policy. Chapter two also discusses some of the potential ways by which to assess the sustainability of WFs. Chapter three contextualises the study by highlighting the importance of understanding water use specifically in citrus crops, giving a rationale for the study area and detailed descriptions of the socio-economic and biophysical context of study site. Chapter four is the final background chapter and describes the research design and methodological approaches used in this study.

The next set of chapters (Chapter five to seven) present the findings of the study. Chapter five provides a summary profile of the farmers interviewed and their irrigation and farming practices as well as their perceptions on water and risks to the industry. Chapter five also presents the estimated crop water use (CWU), yields and blue, green and grey WF and water productivities of navel, valencias, lemon and soft citrus cultivars. Local data and literary sources are discussed and examined to verify findings. Climatic variations of WFs across wet and dry years are used to assess potential future climate change implications of water use.

Chapter six attempts to examine the sustainability of the LSRV basin by examining the water pollution level, blue water scarcity, impacts of land use changes on evapotranspiration, social conflicts and the efficiency of allocations. Furthermore, the WF of all the citrus cultivars is examined in terms of employment and net revenue. Economic land productivity and total factor productivities are measured across five seasons of data. WFs are compared to available

benchmarks. Chapter six also discusses some of policy responses related to the thesis findings. How these findings relate to other literature and what they mean in terms of policy initiatives related to water use in South Africa are discussed. Finally, chapter seven provides an overall synthesis of the thesis. It discusses the key messages that emerged from the results presented, followed by potential suggestions for possible future research.

# CHAPTER TWO:

## THE WATER FOOTPRINT ASSESSMENT: CONCEPTS, APPLICATIONS AND RELEVANCE FOR SOUTH AFRICAN WATER POLICY

*“Prudent environmental management, namely environmental management that takes into consideration ecological and social realities has become a prerequisite for sustaining economic development, i.e. the creation of welfare”*

*-Blignaut & de Wit, (2004:5).*

Irrigation canals, Sunland

Photo: S.A Munro

## 2.1 Introduction

The concepts of virtual water, green, blue and grey WFs have dominated recent discussions on water management, particularly in food production (Hoekstra, 2008; Chapagain & Tickner, 2012; Chenoweth *et al.*, 2013). A number of WF studies have been conducted for a wide variety of livestock (Ercin *et al.*, 2012; Hoekstra, 2012; Mekonnen & Hoekstra, 2012a; Gerben-Leenes *et al.*, 2013) and crop products (Chapagain & Hoekstra, 2011; Mekonnen & Hoekstra, 2011a; Gerbens-Leenes & Hoekstra, 2012) and applied to nations (Van Oel *et al.*, 2009; Mekonnen & Hoekstra, 2011b; Ercin *et al.*, 2013), river basins (Zeng *et al.*, 2012; Dumont *et al.*, 2013; Vanham & Bidoglio, 2014), businesses (The Coca-Cola Company and The Nature Conservancy (TCCC& TNC), 2010; Chapagain & Orr, 2010; SABMiller *et al.*, 2010; Ruini *et al.*, 2013), sectors (Aldaya *et al.*, 2010b; Feng *et al.*, 2011), groups of consumers and individuals (Vanham *et al.*, 2013b; Cazcarro *et al.*, 2014), from both consumption and production perspectives. The WF has been shown to be useful at a number of different scales and demonstrates the importance of examining water issues from a variety of perspectives.

WF studies thus far have extended the scope of water management from a predominantly water-user perspective, focusing on industries, municipalities and farmers, to considering consumer and trade perspectives (Chapagain & Hoekstra, 2008; Bulsink *et al.*, 2010). Quantifying the effects of consumption and trade on water resources throughout the supply chain has aided in understanding and highlighting impacts, as well as uncovering the hidden links between water use and final consumers (Hoekstra *et al.*, 2011).

This chapter aims to examine the theoretical framework that is the WF assessment, firstly by clarifying and discussing definitions and concepts and secondly, by examining the progression and applicability of the WF as an accounting or pressure indicator and as a sustainability assessment. Some of the contributions that have currently been made to the sustainability and response formulation of the WF assessment will be critiqued and discussed. Finally, the applicability of WF assessment concerning South Africa and its policy initiatives will be examined.

## 2.2 The water footprint framework: key concepts and definitions

Although a new concept, the WF as an indicator of water consumption has evolved tremendously. Usually expressed as a water volume per product, such as m<sup>3</sup> per kg, it has also been expressed as m<sup>3</sup>/year and as m<sup>3</sup>/capita/year or per capita in order to make cross comparisons between countries of different population sizes and resources (Yang *et al.*, 2003; Hoekstra & Chapagain, 2007b). It has been calculated as m<sup>3</sup> per caloric value (kcal) (Liu & Savenjie, 2008; Mekonnen & Hoekstra, 2011b; Vanham *et al.*, 2013b) and per unit of bioenergy (GJ) (Gerben-Leenes *et al.*, 2008; 2009b; Gerbens-Leenes & Hoekstra, 2010; Mekonnen & Hoekstra, 2012b).

By providing a measure of water use, the WF can be classified as a 'water-inventory tool' or framework by which calculations of water use can be made (Berger & Finkbeiner, 2013). Actual volumes of water provide a means for decision makers to understand how water is allocated among users, if water is allocated equitably, whether basic human and environmental needs are being met (Morrison *et al.*, 2010; Hastings & Pegram, 2012) and to work out which users are providing the most economic value per unit of volume (Aldaya *et al.*, 2010b). Therefore, in terms of water resource management, the WF assessment ensures that policymakers and water managers are better equipped to make decisions regarding water allocation (Aldaya *et al.*, 2010b; Morrison *et al.*, 2010; Hastings & Pegram, 2012).

All water inventories differ in terms of scope, data requirements, water outputs, global water balances, objectives and level of detail. Therefore, depending on the database and method required by the specified tool or framework, the information content and freshwater balances can vary considerably (Berger & Finkbeiner, 2010; Kounina *et al.*, 2012; Mekonnen & Hoekstra, 2011a). Other water inventory tools include the World Business Council for Sustainable Development (WBCSD) Global Water Tool (WBCSD, 2010) and the corporate water gauge (Centre for Sustainable Organisations, 2011). Other tools or frameworks for water accounting include United Nations Environmental Programme (UNEP)/Society of Environmental Toxicology and Chemistry (SETAC) life cycle initiative provide a method for assessing inflows and outflows termed 'water-footprinting' (International Standardisation Organisation (ISO) 14046, 2014).

Most water inventories classify input and output fluxes according to the type of blue water withdrawn and released, WFs also take into account green and grey water. Hence, water footprints are regarded as advanced water inventories (Berger & Finkbeiner 2010). The database established by the WF Network<sup>1</sup> has also provided data relating to water use for numerous products produced and consumed at a broad spatial scale (Chapagain & Hoekstra, 2004; Van Oel *et al.*, 2008; Hoekstra & Mekonnen, 2012b; Vanham *et al.*, 2013).

### **2.2.1 Green, blue and grey water footprints**

#### ***a) Green and blue water footprints***

The separation of water into blue, green and grey has been said to provide more detail and relevant information than other aggregated estimations of water, such as those found in LCA (Chapagain & Orr, 2009). This is particularly the case for the inclusion of green water (Chapagain & Tickner, 2012). Although the first WF studies did not include green water, as data was not available (Hoekstra & Hung, 2002), the recognition of green water, which is colloquially referred to as rain or soil water, was an important revolution in water resource management. Green water was first introduced by Falkenmark (1995) as the total crop evaporation during crop growth, but has subsequently been revised as water derived from precipitation, stored in soil and evaporated into the atmosphere through crop evapotranspiration (Savenije, 2000; Döll, 2002; Falkenmark & Rockström, 2004). Döll (2002) classified green water into productive (if transpired by crops or vegetation), and non-productive (if evaporated from soil or open water). It is also (alternatively) the water supply of non-irrigated vegetation. The green WF, therefore, refers to the human use of evaporative flow or rainwater insofar as it does not become runoff, it is mostly used for crop and forest production (Hoekstra *et al.*, 2011).

---

<sup>1</sup> The WF Network is a collation of various organisations and institutes, formed to exchange ideas regarding the WF have also established a database of green, blue and grey WF's at a global scale for a number of crop and animal products (Hoekstra *et al.*, 2011).

It has been established that green water dominates global virtual water trade (Renault, 2003; Hoekstra & Chapagain, 2007a; Liu *et al.*, 2009; Aldaya *et al.*, 2010a). Rockström (2001) argued that strengthening rainwater management and the effective use of green rainfall could potentially quadruple maize yields in sub-Saharan Africa. Some authors even view the use of green water as a potential source of water to meet the demands for increasing food production without harming blue water resources further (Obuobie *et al.*, 2005; Liu *et al.*, 2009). Although in rain-fed systems, apparent water productivities are lower and more sensitive to variations in comparison to irrigated systems, water assessments (especially of crop water use) are deemed incomplete without the use of green water considerations (Falkenmark & Rockström, 2006; Aldaya *et al.*, 2010a; Salmoral *et al.*, 2010).

Previous research focused exclusively on the role of 'blue water' or irrigated water in agricultural production (Rockström, 2001). Green water was marginalised as unproductive, unreliable and inefficient (particularly in developing countries) (Falkenmark, 2003; Rockström, 2001). Blue water refers to surface and groundwater resources such as recharging rivers, lakes, ponds, reservoirs and aquifers (Rockström, 1999). The blue WF is the direct and indirect water use minus return flows, or the 'consumptive' use of these ground and surface water bodies (Hoekstra *et al.*, 2011). It is 'consumptive' in that it does not take into account water that is returned to where it was originally abstracted (Hoekstra *et al.*, 2011). In this regard, both green and blue WFs account only for losses in water whereby water is evaporated, returned to another catchment or sea, or incorporated into a product (Hoekstra *et al.*, 2011).

The WF has also been argued to be 'conservative' in that the majority of studies assess blue and green water requirements of crops but fail to include the losses due to infiltration and evaporation during transport and application (Chapagain *et al.*, 2006a). Calculating evaporative losses during transport and application is however difficult and time and data intensive. Recent studies have also questioned the assumptions of whether evaporated water is actually lost from the original shed, although more research is required on this subject before it can be incorporated (Van der Ent *et al.*, 2010; Van der Ent & Savenjie, 2011; Berger & Finkbeiner, 2012). What is important is that the WF is an indicator of water use and not water withdrawal like other water indicators (Hoekstra *et al.*, 2011).

## ***b) Grey water footprints***

More recently, the grey WF was subsequently added as the third component or type of WF by which to classify consumptive water use. The grey WF is defined as “the volume of freshwater that is required to assimilate the load of pollutant given natural background concentrations and existing ambient water quality standards” (Hoekstra *et al.*, 2011:24). The concept of grey water (originally referred to as ‘dilution water’) was first suggested by Chapagain *et al.* (2006a), in recognition that water does not only function as a resource base but also as a system for waste assimilation (Chapagain *et al.* 2006a). The concept of expressing polluted water as a volume also allowed for comparisons between consumption volumes to be made (Chapagain *et al.* 2006a; Hoekstra & Chapagain, 2008; Hoekstra *et al.*, 2011).

The grey WF reflects the notion that water pollution can be expressed as a volume of water required to dilute pollutants so that the quality of water remains above ambient water quality standards (Falkenmark and Lindh, 1974; Postel *et al.*, 1996; Chapagain *et al.*, 2006a; Hoekstra & Chapagain, 2008; Hoekstra *et al.*, 2009a; 2011; Franke *et al.*, 2013). The grey WF takes into account both point and diffuse source pollutants and only accounts for the most critical pollutant. It is assumed if the most critical pollutant is sufficiently diluted all others will be as well (Hoekstra *et al.*, 2009a; Hoekstra *et al.*, 2011). The overall grey WF is therefore equal to the largest grey WF and ignores the possible cumulative effects of pollutants (Hoekstra, 2007; Franke *et al.*, 2013). Treatment of wastewater can reduce the grey WF and in the instance that returned water is of better quality than that of abstracted water, the grey WF can be nullified (Hoekstra *et al.*, 2011).

While the green and blue WF are direct consumptive measures the grey WF is considered indirect (SAB & World Wildlife Fund (WWF) - United Kingdom (UK), 2009). The grey WF assessment manual recommends a three-tier approach for estimating the pollutant load entering a water body (Franke *et al.*, 2013). Although the accuracy increases from tier one to three, feasibility decreases due to laborious data demands. All grey WF studies have been tier one studies and this is expected to continue (Franke *et al.*, 2013).

The grey WF is the most underdeveloped WF component and as a result has been described as difficult and controversial (Chapagain & James, 2011). It has been criticized for not clearly defining 'common standards' for water quality (Aldaya & Hoekstra, 2010; Chapagain & Tinker, 2012). It has also been illustrated that grey WF's vary substantially according to the standards and data that are used (TCCC & TNC, 2010; Berger & Finkbeiner, 2010). Application rates per crop, pre-existing water quality standards, leaching fractions and runoff estimates are not always available and broadly agreed water quality standards for all substances do not exist. As a result, grey WFs have often been omitted from WF studies (Chapagain & Tickner, 2012; SAB & WWF-UK, 2009). Furthermore, most studies estimating grey WFs for diffuse pollution have focused only on using nitrates from fertilisers (Chapagain *et al.*, 2006a; Chapagain & Orr, 2009; Bulsink *et al.*, 2010; Aldaya & Hoekstra, 2010; Hoekstra & Mekonnen, 2012b), with the exception of a few studies who also included phosphorus (Liu *et al.*, 2012; Ercin *et al.*, 2012; Zhang *et al.*, 2014). Salmoral *et al.* (2010; 2011) examined nitrogen surplus as oppose to the chemical application rate per hectare multiplied by the leaching fraction. Other chemicals found in pesticides, herbicides and other nutrients have generally not been included.

The recently published grey WF accounting guidelines (Franke *et al.*, 2013) also acknowledged that previous grey WF calculations have been hampered by lack of guidance and reference, and have therefore been based on limited information and assumptions. Subsequently, the recently published grey WF manual provides guidelines to determine leaching-run off fractions for diffuse point sources, maximum allowable concentrations and natural background concentrations for tier-one level calculations (Franke *et al.*, 2013). These guidelines were first applied by Franke & Mathews (2013b) to quantify and compare the impacts of organic and conventional cotton farming in India on freshwater pollution. The use of the new grey WF guidelines was said to provide more robust comparisons than the previous study that was based on limited information and assumptions (Zarate, 2010; Zarate *et al.*, 2011; Franke & Mathews, 2013b). A wide scope for research regarding the grey WF exists.

### ***c) Criticisms and methodological problems of the blue, green and grey water footprints***

Despite advancements, there are still methodological problems that remain. Regarding the grey WF, it cannot only be derived from blue water but also from green water due to soil leaching (Chapagain & Tinker, 2012). Concerns regarding the meaningfulness of grey WF representing water quality as a volume have also been raised since it cannot be something that can be measured directly or validated (Liu *et al.*, 2012). Many companies have revealed that the grey WF needs to be developed further to be considered useful (SAB & WWF-UK, 2009; Hastings & Pegram, 2012). Grey water also remains within the hydrological system, whether to treat such water as lost from the system in the same way as blue and green water is evapotranspired is considered to be theoretically difficult (Chapagain & Tickner, 2012). Moreover, information deemed necessary for appropriate responses toward water quality impacts is lost (Hastings & Pegram, 2012). There is still a large amount of uncertainty and scepticism regarding the grey WF.

As natural vegetation also leads to evaporation, some studies have explored the concept of a 'net green WF', which calculates the difference between agricultural and natural evapotranspiration (SAB & WWF-UK, 2009). Studies have suggested that agricultural vegetation consumes less evapotranspiration than natural vegetation, resulting in a negative green WF (Nunez *et al.*, 2010; SAB & WWF-UK, 2009). Authors have also shown that land use change will generally result in a negative blue WF due to increases in runoff (Rost *et al.*, 2008; Ridoutt & Pfister, 2010; Berger & Finkbeiner, 2012). Berger & Finkbeiner (2012) argue that negative WFs imply that compensation of WF's can be achieved through changes in land use.

Studies have also claimed that green water use is more 'sustainable' than blue water, as the impacts of irrigation can cause salinisation, water logging and soil degradation. Rain-fed systems are also less costly in terms of labour and capital (Aldaya *et al.*, 2008). Authors therefore, deem green water to be more efficient overall (holding other factors constant) (Obunobie *et al.*, 2005; Yang *et al.*, 2006; Yang & Zehner, 2007). In terms of the WF, the opportunity cost of green water is said to be lower than that of blue water, as blue water has many potential uses other than irrigation (Obuobie *et al.*, 2005; Chapagain *et al.*, 2006b; Aldaya *et al.*, 2008). The green WF would have been evaporated through natural vegetation if it were not used for crop growth (Chapagain

*et al.*, 2006b). Studies have therefore been generally concerned with blue water impacts as these are viewed as having greater environmental implications (Chapagain *et al.*, 2006b; Yang & Zehnder, 2007). The impacts of land use changes on green water cannot however be ignored. A number of factors effect evaporation losses and run-off because of land use changes. These include loss of precipitation, flooding and salinisation and therefore need to also be considered (Rost *et al.*, 2008; Berger & Finkbeiner, 2012).

There has also been contention surrounding the aggregation of green, blue and grey WFs. It was argued firstly, that the aggregation of green, blue and grey 'without any weighting' and combining green, blue and grey water implies equal weighting and compensation between the water sources (Berger & Finkbeiner, 2012). Each water component has different characteristics and opportunity costs; therefore, they should not be weighted equally. Witmer & Cleij (2012) argue they are incomparable each with their own impacts. Important and valuable information is lost through aggregation and aggregated WFs are not appropriate to reflect any potential impacts. In fact, it has since been recognized that the green, blue and grey WF are all individual indicators and it has been recommended that each component be analysed separately (Boulay *et al.*, 2013).

### **2.2.2 Virtual water and the water footprint**

The origin of the term water footprint stems from the concept of virtual water. The concept of 'virtual water' proposed by Allan (1998a; 1998b, 2001a; 2001b), is defined as the total volume of water, or 'embedded water' (Fishelson, 1994) used in the production of a product. It includes all direct and indirect water use throughout a products entire value chain (Allan, 1998a; 1998b; Hoekstra *et al.*, 2011). The WF expanded on the virtual water concept by distinguishing types of water use, namely green, blue and grey, and specifying components geographically and temporally (Hoekstra *et al.*, 2011). The virtual water content of a product is essentially the same as the WF of a product, except that the former refers to a volume alone and the latter is a multidimensional indicator (Hoekstra *et al.*, 2011). The WF of a product is also referred to as the 'virtual water of a product' if water for product use is excluded (Zhang *et al.*, 2012; Chenoweth *et al.*, 2013). What distinguishes water footprints from virtual water is that it is also applied at a consumer level and is therefore a consumption-based indicator (Velasquez, *et al.*, 2011).

Applications of examining virtual water have been used in conjunction with WF studies and will be further discussed in section 2.3.

### **2.2.3 Footprint Family**

Apart from being an accounting tool, the WF is also part of a family of footprints (Galli *et al.*, 2012; Cucek *et al.*, 2012). These include the Ecological Footprint (EF) and Carbon Footprint (CF) as well as numerous others (see Fang *et al.*, 2014). The development of the WF has been described as analogous to the EF and independent of the CF. However, there are evident similarities and differences between both indicators (Hoekstra, 2007; Ercin & Hoekstra, 2012). Despite being referred to as tools, all have been identified as pressure indicators (Rotmans & De Vries, 1997; Cucek *et al.*, 2012). Pressure indicators measure and show the appropriation and contamination of resources, but do not illustrate the resulting change or impacts to the environment (Ercin & Hoekstra, 2012).

Each indicator has its roots, intended purposes, metric units, calculation methodology and accounting frameworks (Hoekstra, 2007; Ercin & Hoekstra, 2012; Fang *et al.*, 2014). All have both top down and bottom up approaches, as they can be applied to a wide spatial coverage and scale including single products, cities, regions, nations and a global scale (Ewing *et al.*, 2012; Galli *et al.*, 2012). By drawing on concepts from more developed indicators such as the EF and CF, the WF is able to employ lessons from their progress, and the mechanisms that make the EF and CF robust and successful. Understanding their similarities and differences has enabled the success of the WF but is also important in terms of illustrating the broader context in which the WF has developed within (Hoekstra, 2007).

Despite differences between the CF, WF and EF, most authors refer to the concepts as complementary indicators of natural capital within the sustainability debate (Galli *et al.*, 2012; Hoekstra, 2007; Ercin & Hoekstra, 2012). Recently studies have started to examine footprints simultaneously. It has been argued that bringing footprints into a single conceptual framework will provide a robust set of multidisciplinary indicators that will be more informative for

policymaking (Best *et al.*, 2008; Galli *et al.*, 2012). It also stems from the idea that no single indicator will be able to monitor comprehensively all human impacts (Galli *et al.*, 2012).

Studies that have specifically looked at carbon and water footprints have emphasised the integration of the two indicators (Mordini *et al.*, 2009; Chapagain & James, 2011; Steen-Olsen *et al.*, 2012; Franke & Castro, 2013). For example, Steen-Olsen *et al.*, (2012) examined carbon, blue water and land (the equivalent of EF excluding land to assimilate carbon) for the EU from both a consumption and production perspective. All studies have highlighted how efforts to alleviate one footprint may imply hidden trade-offs with others. For example, hydroelectricity was shown to have a high WF but a low CF and fossil fuels were shown to have a low WF but a high CF (Franke & Castro, 2013). Conversely, footprints can also complement each other. For example, use of fertilizers or alternative techniques can reduce both CF and WF (Franke & Castro, 2013).

Research efforts to integrate “the footprint family” are currently underway with breakthrough research being undertaken by the European One Planet Economy Network (OPEN:EU) (Galli *et al.*, 2012; Steen-Olsen *et al.*, 2012; Fang *et al.*, 2014). Studies emphasise that integration would enable more effective inter-industry analysis of the linkages across multiple economies, providing a better assessment of trade-offs among the three indicators and avoid problem shifting (Galli *et al.*, 2012; Rushforth *et al.*, 2013; Fang *et al.*, 2014). Combining the related concepts and methods of footprints into one consistent analytical framework are still in its initial stages and will be a challenge for future researchers. What is important though is to recognise that the WF cannot be looked in isolation from policymaking.

#### **2.2.4 Life cycle assessments and water footprint assessments**

LCA is a structured, comprehensive, internationally standardised environmental management tool that is used to measure various environmental interventions caused by products from the extraction process (‘cradle’) to disposal (‘grave’) (Schnoor, 2009; Berger & Finkbeiner, 2010). It is widely applied and accepted within industries and by academics, with its international standards having even been embedded within the laws of countries such as the EU, Japan, Malaysia and Australia (Morrison *et al.*, 2010; Cucek *et al.*, 2012). LCA has predominantly focused its attention

on environmental impacts, particularly on measuring greenhouse gases by means of the carbon footprint. In the past, very little attention has been given to water use and its subsequent impacts (Foster *et al.*, 2006; Chapagain & Orr, 2009). ISO have very recently just published a standard for waterfootprinting (ISO 14046, 2014). Preceding the ISO 14046 standard, the LCA community had developed and explored numerous methods for water accounting and assessing the environmental impacts related to water (Berger & Finkbeiner, 2010; Kounina *et al.*, 2012). Many studies have been developed as deliverables for ISO 14046 to include water use on both an inventory and impact assessment level (Berger & Finkbiner, 2010).

### **2.3 Scope and application of water footprint accounting studies**

As already highlighted WF studies have broadened the scope of water accounts, and have proven to be useful at a number of spatial scales.

#### **2.3.1 Global and national studies**

The WF has been used to map water use of various crops, livestock and industrial products of individual nations across the globe. These studies have demonstrated countries dependency and reliance on other countries water resources, predominantly for food consumption (Hoekstra & Hung, 2002; Hoekstra & Hung, 2005; Chapagain & Hoekstra, 2007; Hoekstra & Chapagain, 2007a; Chapagain & Hoekstra, 2008; Hoekstra & Mekonnen, 2012b). These studies have also highlighted the average amount of virtual water within a number of crop, livestock and industrial products, and demonstrated the substantial amount of virtual water that is exported across the globe (Allan, 2002; Turton *et al.*, 2000; Hoekstra & Hung, 2002; Chapagain & Hoekstra, 2003; Zimmerman & Renault, 2003; Oki *et al.*, 2003; Oki & Kanae, 2004; de Fraiture *et al.*, 2004). It was estimated that 92% of global water is consumed through agricultural production and approximately one fifth of global WF's relate to production for export (Hoekstra & Mekonnen, 2012b).

Virtual water has been deemed an alternative source of water as well as a mechanism by which to improve national water scarcity (Allan, 1998b; Allan, 2003; Oki & Kanae, 2004; Chapagain *et al.*, 2006b; Chapagain & Hoekstra, 2008; Garrido *et al.*, 2010; Aldaya & Llamas, 2008). Studies

demonstrated that virtual water provides a more environmentally friendly alternative to inter-basin transfers (Earle & Turton, 2003; Meissner, 2003; Nakayama, 2003; Allan, 2003; Ma *et al.*, 2006) and a means to store water during droughts (through imports of water-intensive goods) (Renault, 2003; Verma *et al.*, 2009). Early studies particularly focused on the concepts of 'water losses' and 'savings' (Hoekstra & Chapagain, 2007b; Galloway, 2007; Verma *et al.*, 2009). Fader *et al.* (2011) even examined 'land savings' through virtual water trade. Studies suggested that global water 'savings' could be achieved by importing water through products, from areas of high water productivity to areas of low productivity (Chapagain *et al.*, 2006b; Chapagain & Hoekstra, 2008).

WF studies have also been conducted for a number of countries including China (Ma *et al.*, 2006), India (Kampman *et al.*, 2008; Verma *et al.*, 2009), Indonesia (Bulsink, *et al.*, 2010), Morocco (Hoekstra & Chapagain, 2007b), the Netherlands (Hoekstra & Chapagain, 2007b; van Oel *et al.*, 2009), Spain (Aldaya *et al.*, 2010b; Garrido *et al.*, 2010) and the UK (Chapagain & Orr, 2008). These studies all highlighted the volume of net virtual water imports and exports between specific countries or regions, demonstrating the dependencies on certain products, revealing the displacement of environmental pressures and highlighting the hidden links between consumption and production sites.

Studies have also used the WF to examine relationships and patterns in trade and water use (Yang *et al.*, 2003; Feng *et al.*, 2011; Vanham, 2013; Erzin *et al.*, 2013). For example, Feng *et al.* (2011) found a strong relationship between WFs and per capita income, highlighting relationship between lifestyles and water consumption and Vanham (2013) showed that river basin's within the EU that were net virtual water importers were attributed with densely populated and industrialised regions.

Global WF calculations have been continuously revised for a crops and crop derived products (Chapagain *et al.*, 2006a; Gerbens-Leenes *et al.*, 2009a; 2009b; Mekonnen & Hoekstra, 2010a; 2010b; 2011a; Chapagain & Hoekstra, 2011; Fader *et al.*, 2011), as well as livestock and livestock products (Galloway *et al.*, 2007; Mekonnen & Hoekstra, 2010c; 2012a; Hoekstra, 2012). New estimates of nations' WFs included higher spatial resolutions, green, grey and blue components

analysed separately, climatic data from local producing regions, considerations for optimal and non-optimal conditions for growth and more detailed data including different animal feed composition and production systems (Hoekstra & Mekonnen, 2012b; Mekonnen & Hoekstra, 2012a). Longer periods of data have also been used, diminishing the influence of inter-annual trade delays specifically for livestock products. These estimates (although still rough) have proven to be useful in providing a global database for in-depth analyses of water use.

A number of studies carried out at national and sub-national scales have used the WF database derived from the abovementioned studies. For example, data has been used to: examine food consumption and production patterns and scenarios for China (Liu & Savenije, 2008), the European Union (EU) (Vanham *et al.*, 2013a; 2013b; Vanham, 2013; Vanham & Bidgolio, 2014) and at a global scale (Ercin & Hoekstra, 2014; Orłowsky *et al.*, 2014). These and other studies have highlighted which sectors, diets and lifestyles use the most amount of water per output (Zhao *et al.*, 2009; Garrido *et al.*, 2010; Dumont *et al.*, 2013). Gerbens-Leenes *et al.* (2012) estimated that transition to energy sources such as biofuels could increase water use tenfold by 2030.

Studies have also investigated the effects of reduced water availability on consumption (Orłowsky *et al.*, 2014). In this regard, studies have emphasized the role of consumers and the impacts of their choices. For example, examination of food consumption patterns illustrated that animal products need substantially more water than plant-based food products to supply the same amount of energy (Liu & Savenije, 2008; Mekonnen & Hoekstra, 2012a). By shifting consumption from food groups such as sugar, oil, meat, animal fats and dairy products to cereals, fruit and vegetables could potentially reduce consumers WF by 36% (Hoekstra, 2012; Ercin & Hoekstra, 2014). Furthermore, avoidable food waste was calculated to be 6% of an average UK citizens WF (Chapagain & James, 2011) and Van Oel *et al.* (2012) demonstrated that recycling paper reduces the global average water footprint of paper by 60%. Data has also been used to highlight how water resources are allocated across sectors such as agriculture, domestic and industrial in countries such as France (Ercin *et al.*, 2013) and river basins such as the Heihe (Zeng *et al.*, 2012). The WF has thus raised awareness of the links between lifestyles and consumption patterns on the impacts of water resources.

Comparisons from a consumption perspective are seen as more valuable in the context of sustainability and equitability than that of a production perspective (Chapagain *et al.*, 2006a). For example, comparisons of different regions, populations, countries, sectors and local authorities can provide a better understanding on the efficiency of water use by highlighting production sites where water use is particularly high in comparison to others.

### **2.3.2 Products and corporate water footprints**

Another accolade in terms of awareness is the amount of water embedded with commodities throughout their supply chain. This was shown through the calculation of commodities in earlier studies where specific average quantities of water for numerous products were calculated for example one kg of beef, one cup of tea, rice, a cotton shirt and even a computer microchip (Chapagain & Hoekstra, 2003; 2004; 2007). These values were criticised as WF's have been shown to vary significantly according to location because of climate (growth conditions) and agricultural practices (water use efficiency) (Hoekstra & Chapagain, 2007; Ercin *et al.*, 2011). A revised study done by Coca-Cola using industry data instead of public data reduced WF calculations by 9% (TCCC & TNC, 2010). Local studies have allowed for; more accurate comparisons between different production systems such as organic and conventional (Franke & Mathews, 2013b), grazing, mixed and industrial production systems (Hoekstra & Mekonnen, 2012b; Gerben-Leenes *et al.*, 2013), irrigation systems such as flood and drip (International Finance Corporation (IFC) *et al.*, 2010) and open air and green house (Chico *et al.*, 2010). Furthermore, yields vary from year to year and are affected by diseases and pests in certain areas (SABMiller & WWF-UK, 2010; Aldaya *et al.*, 2010b).

Studies of products (specifically agricultural) demonstrated the importance in assessing the water use of the whole supply-chain. Companies such as SABMiller (SABMiller & WWF-UK, 2010), Coca-Cola (TCCC & TNC, 2010; Coca-Cola Europe, 2011), Nestlé (Chapagain & Orr, 2010), Barilla (Ruini *et al.*, 2013) and Dole Food Company (Sikirica, 2011) have been pioneers in implementing the WF at corporate and local levels. These and other studies have demonstrated that operational and overhead WF's are negligible in comparison to crop production (TCCC & TNC, 2010; Ercin *et al.*, 2009; Ercin *et al.*, 2012). Most studies demonstrate that approximately 95-99% of supply-chain

water use can be attributed to crop production (Salmoral *et al.*, 2011; Ercin *et al.*, 2011; Ercin *et al.*, 2012). Business water-accounting measures often only consider operational water use (Ercin *et al.*, 2009; 2011). Results have demonstrated the need for companies that specifically produce agricultural derived products to understand water use in supply chains.

An increasing number of businesses are consequently recognizing the need to manage and account for all water uses throughout the supply chain, specifically beyond operational stages. Managing fresh water issues is no longer only a threat to companies' reputations but to the functioning of their operations (Hoekstra, 2008; Chapagain & Tickner, 2012). Companies need sufficient freshwater and are faced with threats of increased regulatory control and financial risks caused by pollution and water scarcity (Morrison *et al.*, 2010; Hoekstra, 2014b). It is therefore imperative for companies to understand potential water related risks and support sustainable practices to sustain their profitability and competitiveness (Morrison *et al.*, 2010). Sustainable sourcing and transparency to consumers is also becoming a precondition for corporate survival (Hoekstra, 2014b). WFs have shown to help inform better decision-making in companies regarding water management and increasing stakeholder collaboration through increased interactions between suppliers, government, communities and business activities (SABMiller, 2011; Hastings & Pegram, 2012; Ruini *et al.*, 2013).

### **2.3.3 Criticisms surrounding water footprint accounting studies**

Many authors have however disputed the concept of virtual water 'savings' arguing that water scarcity cannot alone provide a criterion for policy-making decisions regarding trade (Ansink, 2010; Turton, 2000; Warner, 2003; El-Fadel & Maroun, 2003; Meissner, 2003; Mori, 2003; Renault, 2003; Wilhelms, 2004; 2010a; Gawel & Bernsen, 2011). Wilhelms (2010a) argues water 'savings' and 'losses' categorized as good or bad without considering local opportunity costs, livelihoods and production conditions are meaningless. The assumption that virtual water flows from high to low productive sites is not always true (Wichelns, 2010a). Some countries face limitations in factors such as arable land and labour and choose to import water intensive products. These and other factors such as income, population, irrigated area, soil profiles, climate change, energy prices and other inputs influencing agricultural productivity are all deemed more useful in

explaining trade patterns (Kumar & Singh, 2005; Guan & Hubacek, 2007; Dabrowski *et al.*, 2008; Lopez-Gunn & Llamas, 2008; Wichelns, 2010a). Farmers will choose to use more water intensive, low valued crops if macroeconomic policies encourage it through subsidized water or other complementary inputs (El Fadel & Maroun, 2003; Wichelns, 2010a). It is also unlikely that countries or regions will stop irrigating and farming water-intensive crops and substitute for less water-intensive imports. Millions of farmers and labourers depend on agricultural activities for income and food security, and choose to use water more carefully rather than stop farming completely (Yang *et al.*, 2006; Wichelns, 2010b).

Most countries also cannot absorb a large number of unemployed farm workers in other economic sectors, and in some countries, livestock are also indicators of wealth or status and have underlying cultural implications (Gawel & Bernsen, 2011). Increasing globalisation and interdependency on other countries for food imports could also be threatening due to increased exposure and sensitivity to price shocks (Warner, 2003; Horlemann & Neubert, 2007; Wichelns, 2010b; Gawel & Bernsen, 2011). Developing countries, despite having a comparative advantage in water resources, may not have the ability to compete with highly subsidized OECD countries or have limited foreign currency reserves (Meissner, 2003; Turton *et al.*, 2000; Horlemann & Neubert, 2007). There are also tariffs and quotas that will potentially be a major constraint to the development of a virtual water market (World Water Council, 2004; Reimer & Li, 2010; Gawel & Bernsen, 2011).

Another concern is that virtual water imports give countries a false sense of security offering a short-term solution that has slowed the pace of policy reform and water management initiatives that require long-term investments (Allan, 2003; Warner, 2003). It also allows countries to divert more water than what may be deemed fair, allowing unsustainable water use to continue (Hoff, 2009; Gawel & Bernsen, 2011). In order for virtual water trade strategies to be successful, consideration needs to be given to other political, social and economic factors that vary across time and space. Therefore only under a number of assumptions, including that export commodities reflect opportunity costs and externalities, will water savings occur if water intensive commodities are imported from areas of low water scarcity to high water scarcity.

While water inventories can be useful, volumetric accounts need to be interpreted carefully as they omit important information, including benefits and costs of water use (Hastings & Pegram, 2012; Hoekstra & Tickner, 2012; Wichelns, 2014). It is generally agreed that WFs need to be impact-orientated, as volumetric water footprints can be misleading when they are not considered in the context of their withdrawal (Berger & Finkneiner, 2012; Hastings & Pegram, 2012). Even large amounts of water use can be sustainable in locations where water is sufficient (Coca-Cola Europe, 2011; Hastings & Pegram, 2012). Interpretations of WF's therefore need to account for local conditions including; efficiency of water use, competition for water resources and local issues including access to water (Chapagain & James, 2011). It is broadly acknowledged that the WF accounting is merely a starting point to address the sustainability of a resource (TCCC & TNC, 2010).

## **2.4 The water footprint sustainability assessment: theoretical concepts and applications**

The broader WF assessment, recently developed, attempts to examine the sustainability of the water appropriation and formulate a response strategy (Hoekstra *et al.*, 2009a; Hoekstra *et al.*, 2011). However, assessing the sustainability of a WF has only recently gained attention, and only a limited number of studies have conducted a full water footprint assessment many of which focus on identifying 'water scarcity hotspots,' as stated in chapter one.

### **2.4.1 Sustainability and the water footprint sustainability assessment framework**

First defined in 1987 (WCED, 1987) the concept of sustainability has evolved to encapsulate all three pillars of economic, social and environmental wellbeing (Franklin & Blyton, 2011; Moldan *et al.*, 2012). Although 'sustainable initiatives' are prevalent concepts of numerous governmental and political agendas, 'sustainability' is a concept that has proven difficult to define. Despite the general view that 'sustainability is a good thing' (Scrase & Sheate, 2003; Allen & Hoekstra, 1992; Pope *et al.*, 2004), the concept has also been criticised for being too broad, empty, elusive, controversial and subject to a wide variety of meanings, generalisations and interpretations (Fortune & Hughes, 1997; Bossel, 1999). However, it has also been praised for being a concept of which the value and strength lies in its vagueness (Hopwood *et al.*, 2005; Bell & Morse, 2008).

Franklin & Blyton, (2011:5) note, “the term is now so broad as to be meaningless”. Some authors recognise that its ability to be defined by its context and purpose is what has made sustainability initiatives so accessible and popular (Schaller, 1993; Bell & Morse, 2008).

As an integrative concept, sustainability requires the integration of multidisciplinary approaches, expertise, research, and literature (Ginson, 2006; Pinter *et al.*, 2012). With sustainability methods depending largely on the context of the research, an extensive literature base exploring numerous frameworks and criteria for defining and assessing sustainability, selecting indicators and determining impacts, as well their consequent discussions has developed over the years.

Due to the inability to define sustainability in one concise definition, as well as the lack of a preferred methodology, most studies adopt the authors preferred definition. The WF sustainability assessment is no exception, and researchers in this field have developed their own definitions of environmental, economic and social sustainability for different geographic perspectives, products, consumers and producers as well as for each classification of water (Hoekstra *et al.*, 2009a; 2011).

“When the WF of a process, product, producer or consumer contributes to the unsustainable situation observed within a certain geographic context, one can say the WF is unsustainable”

(Hoekstra *et al.*, 2011:75)

Hoekstra *et al.*, (2011) also note that sustainability of a process, product or consumer cannot be assessed without knowing the total WF of a catchment or geographic context in which the process is located. Assessing the WF of a process therefore depends on the sustainability of the catchment whereby the process occurs in and whether it contributes to an observed unsustainable situation (Hoekstra *et al.*, 2011). The four-step sustainability assessment guideline recommended by the WF assessment manual is summarised in Figure 2.1 for a geographic context. When the green, blue or grey WF does not fulfil the criteria in step one, the WF is considered unsustainable. The first two steps can be classified as a sustainability assessment (sustainability criteria and hot spot identification) whereas the latter steps are more reminiscent of an impact assessment (Identifying primary and secondary impacts) (See Box 2.1).

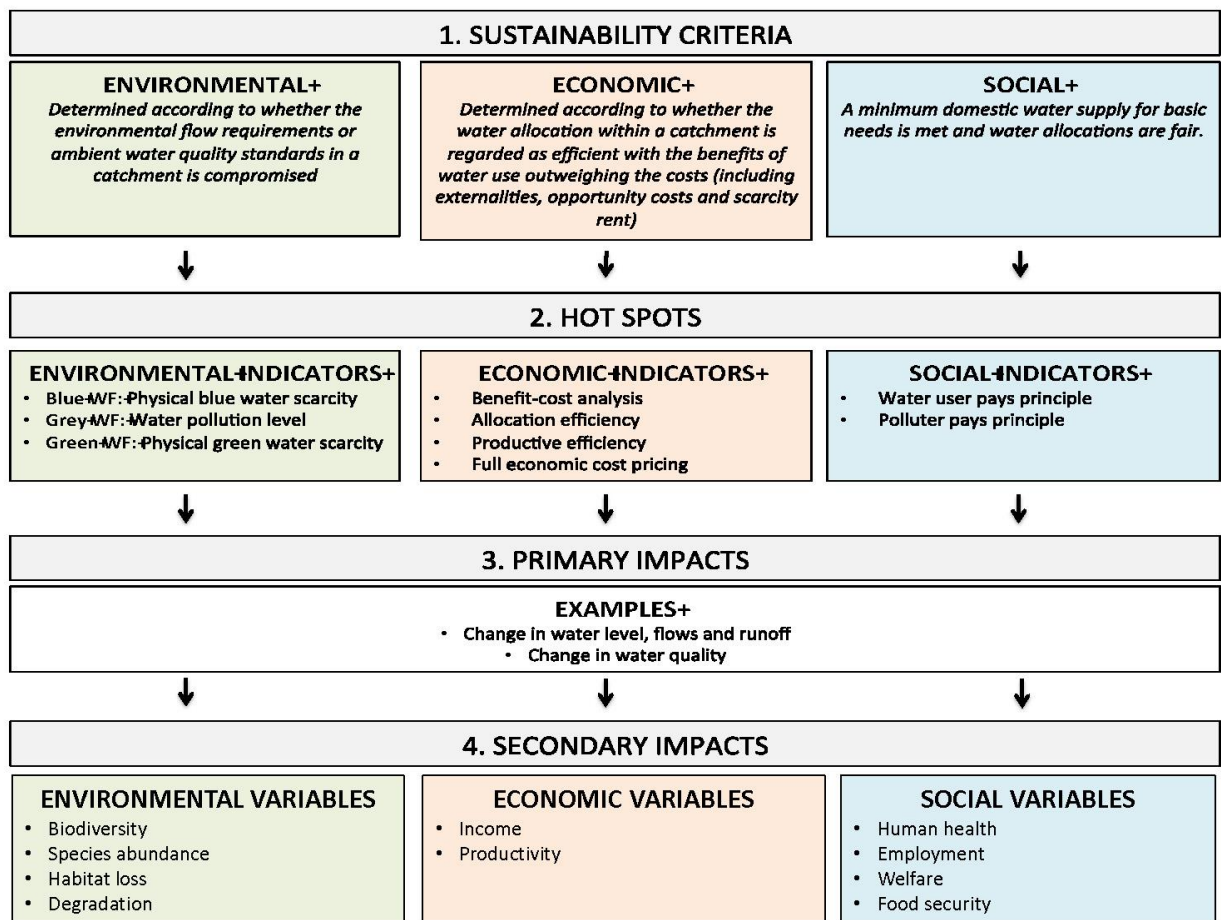
## **BOX 2.1 SUSTAINABILITY ASSESSMENTS VS IMPACT ASSESSMENTS**

The terms 'integrated assessment,' 'triple bottom-line assessment', 'environment, economic or equity impact assessments' and 'extended impact assessment' are all variations of 'sustainability assessments.' All these terms commonly aim to evaluate impacts of plans and activities to direct planning and decision making towards SD (Devuyst, 2001; Verheem, 2002; Hackin & Guthrie, 2008;). Devuyst (2001) acknowledges sustainability assessment as a tool in a 'family' of impact assessment processes. In fact, Hoekstra *et al.*, (2009a) originally used the term 'impact assessment', until the term 'sustainability assessment' was adopted to reflect the broader scope which the water footprint assessment encompasses. Assessing the sustainability of WFs is more than looking at whether a WF has immediate local impacts (Hoekstra *et al.*, 2011)

Although ultimately impacts can be assessed over as broader spatial range as one chooses, impact assessments are widely associated with 'sustainable development tools' such as Environmental Impact Assessments and Strategic Environmental Assessments (Devuyst, 2000; Sheate *et al.*, 2001; 2003; Hackin & Guthrie, 2008). These established techniques have been predominately associated and conducted at a project level (Hackin & Guthrie, 2008; Dalal-Clayton & Sadler, 2005; Gibson *et al.*, 2005; Grace & Pope, 2005).

Other common analytical assessment techniques include LCA, Multi-Criteria Analysis, Cost–Benefit Analysis, and Risk Assessment. Multi-Criteria Analysis, Cost–Benefit Analysis and 'political' decision making are the three main approaches used to compare impacts, usually through using 'scoring' tools (Hackin & Guthrie, 2008). Generally, hierarchical scores for criteria such as magnitude and duration are utilised. Like aggregated indicators, weighting is often applied to identify the relative importance of an impact, and an overall significance score is calculated, with results of presented using Tables or matrices (Glasson *et al.*, 1999).

Generally, these impact assessments are described as 'direction to target' approaches that aim to compare current conditions with a set of reference or desired conditions or targets (Pope *et al.*, 2004; Moldan *et al.*, 2012). The target however is generally unknown or a broadly defined so that net assets are not degraded and impacts are positive overall (Neumayer, 2003) and consequently to identify mitigation measures to avoid adverse impacts (George, 2001). Outcomes can often be controversial when variables are difficult to measure or there are trade-offs (Brookes *et al.*, 2001; Pearce & Hett, 1999). This leads to some targets either being promoted or discounted against others (Sadler, 1999; George, 2001).



**Figure 2.1 Water footprint sustainability assessment for a geographic context e.g. a river basin or catchment**

Source: adapted from Hoekstra *et al.* (2011)

According to the WF assessment manual, no clear criteria exist to determine whether a process in itself is sustainable, but recommend comparisons between benchmark WFs (Hoekstra *et al.*, 2011). Benchmark WFs along with caps have been suggested as a way to set limits on the maximum water volume that can be consumed or polluted by specific activities, aiding in fairer WF consumption (Hoekstra, 2013; Hoekstra, 2014a; 2014b). Mekonnen & Hoekstra (2013; 2014a) have already started research within this area providing benchmark values for 124 crops. It is also suggested that if the WF of a process independent of its geographic context could be reduced or avoided at an acceptable social cost it should be considered unsustainable even if there are no immediate water scarcity or pollution concerns within their geographic context (Hoekstra *et al.*, 2011). However, Hastings & Pegram (2012) describe the WF assessment’s definition of sustainability as too broad, vague and does not clearly define what an “acceptable societal cost”

is. This demonstrates that there is still contention regarding the methodology, particularly in trying to incorporate social and economic aspects.

## **2.4.2 Applications of the WF sustainability assessment**

### ***a) Environmental sustainability assessments of water footprints***

Generally, studies to date have focused on examining the environmental hotspots for blue WFs (Mekonnen *et al.*, 2012; Hoekstra *et al.*, 2012; Zeng *et al.*, 2012; Erkin *et al.*, 2013; Schyns & Hoekstra, 2014; Zhang *et al.*, 2014). The indicator developed and accepted by the WF Network is a consumption-to-availability indicator. This blue WF water scarcity indicator measures consumptive use of ground and surface water flows, rather than withdrawals, and makes comparisons of water use on a monthly basis (Hoekstra *et al.*, 2012). Blue water scarcity values have been categorized according to low, moderate, significant and severe blue water scarcity (Hoekstra *et al.*, 2012; Chouchane *et al.*, 2013; Zhang *et al.*, 2014). Since its conception, the blue WF scarcity indicator has subsequently been applied within a number of WF studies to identify monthly blue water scarcity hotspots of river basins across the globe (Hoekstra *et al.*, 2012; Mekonnen *et al.*, 2012; Liu *et al.*, 2012; Zeng *et al.*, 2012; Erkin *et al.*, 2013; Schyns & Hoekstra, 2014; Zhang *et al.*, 2014).

Previous studies used a number of water scarcity indicators to assess environmental impacts such as withdrawal-to-availability indicators including the water exploitation index (Chapagain & Orr, 2010) and water stress indicators (Kampman 2008; Chapagain & Orr, 2008; Van Oel *et al.*, 2009; Aldaya & Hoekstra, 2010b; Garrido *et al.*, 2010). However, Hoekstra *et al.* (2012) deem their indicator to be a more reliable and accurate estimate of physical water scarcity than other water scarcity metrics as it captures the seasonal nature of water scarcity, incorporates environmental flow requirements and excludes return flows. Kounina *et al.* (2012) described the WF assessment blue water scarcity indicator as offering increased temporal precision for impact evaluation. Lautze & Hanjra (2014) also argue that water stress and subsequent water stress indicators are conceptually distinct from water scarcity. Therefore, although water stress indicators (Alcamo *et al.*, 2000; Alcamo & Henrichs, 2002) is said to provide potentially more useful information than

indicators, such as the Falkenmark indicator (Falkenmark, 1989; Falkenmark *et al.*, 1989), it is deemed a questionable water scarcity measure (Lautze & Hanjra, 2014).

Measuring physical blue water has allowed countries thus far to identify potential hotspots where environmental flow requirements are not met (Hoekstra *et al.*, 2012; Schyns & Hoekstra, 2014; Zhang *et al.*, 2014). This has allowed for the identification of supply chain risks as well as highlighting which products are responsible (Chapagain & Orr, 2010; Erwin *et al.*, 2013).

As illustrated in Figure 4.1, other environmental indicators to assess hotspots include water pollution level (WPL) and physical green water scarcity for grey and green WFs respectively. WPL is defined as the fraction of the waste assimilation capacity consumed. A recent study by Zhang *et al.* (2014) measured WPL for sub catchments within the South East Region North East Thames Area (SENET) in the United Kingdom. Where the grey WF of the sub catchment exceeded the assimilation capacity for water pollution, the grey WF was considered unsustainable (Zhang *et al.*, 2014). Liu *et al.* (2012) also mapped global pollution for over 1000 river basins demonstrating that the pollution assimilation capacity has been consumed for two thirds of global river basins in the year 2000.

In terms of assessing the environmental sustainability of the green WF, the manual also provides criteria for defining a green water scarcity indicator, which denotes the appropriation fraction of green water resources. Green water availability can be defined as the total evapotranspiration of rainwater from land ( $ET_{green}$ ) minus the evapotranspiration from land that cannot be made productive (Hoekstra *et al.*, 2011). No studies could be found that have assessed green WF sustainability according to this criteria so far. The manual does however acknowledge assessment for green water scarcity requires further research particularly since estimating green water availability is difficult due to lack of data (Hoekstra *et al.*, 2011). Despite some of the concerns discussed in section 2.2.1c, authors have justified that in certain cases, such as WF assessments of hydropower or biofuels, that a net approach, as oppose to the recommended gross or total approach, would be more appropriate in reflecting impacts (Hastings & Pegram, 2012).

In terms of assessing primary and secondary impacts, studies have generally only examined potential changes that would occur in water use and quality of water by examining different

scenarios. For example, Multsch *et al.* (2011) examined potential scenarios relating to changes in cropping scenarios by modifying certain parameters (Multsch *et al.*, 2011) and Chico *et al.* (2010) examine changes due to seasonal differences and production systems. Garrido *et al.* (2010) also estimated potential changes in irrigation demand, available water resources and reservoir inflows for potential climate change scenarios and Dumont *et al.* (2013) examined the impacts on the blue WF when drought restrictions were imposed. Liu *et al.* (2012) also examined the implications of future millennium ecosystem assessment scenarios for WPLs. No studies could be found that have examined the indirect effects that occur when WPL or water availability exceeds the appropriate threshold. Witmer & Cleij (2012) claim that one of the shortfalls of WF assessments is that they do not cover all water related issues related to production processes such as impacts on river discharge patterns, flooding and morphological changes resulting from dams and canalisation, and that it simply addresses water use in volumes and water pollution. Coca-Cola Europe (2014) has however recently discussed but did not quantify primary impacts of water use on blue and grey water. There is a huge scope for combing WFs with local data to determine the secondary impacts listed in Figure 2.1.

### ***b) Economic and social sustainability assessments of water footprints***

Studies have been limited in terms of economic and social sustainability assessments. In fact, the framework provided by the WF assessment manual is considerably underdeveloped in comparison to the environmental assessment criteria. They do however provide some basic criteria by which assessments can be made. This includes benefit-cost analyses, allocation efficiency, productive efficiency and full economic pricing (see Figure 4.1). Primary and secondary impacts would include the impacts of changes in water availability and quality on variables such as income, employment and productivity (Hoekstra *et al.*, 2011).

Studies thus far have generally examined efficiency and productivity of water use through measures of partial factor productivities (PFP) (Aldaya *et al.*, 2010b; Chico *et al.*, 2010; Garrido *et al.*, 2010; Chouchane *et al.*, 2013; Schyns & Hoekstra, 2014; Mekonnen & Hoekstra, 2014b). Efficiency in this regard refers to concepts such as irrigation efficiency, which is defined as “the relationship between the amount of water required for a particular purpose and the amount of

water applied for that purpose” (Lautze *et al.*, 2014: 88). Measuring partial factor productivity is when one evaluates the relationship of one factor of production with total agricultural output (Lautze *et al.*, 2014). Agricultural outputs generally refer to yield, but in some cases, outputs can refer to income and employment.

Physical water productivity (WP) (ton/m<sup>3</sup>) is one of the PFP that has been examined and is defined and expressed as the total agricultural benefit per unit of water used, or in simple terms ‘crop per drop’ (Cook *et al.*, 2004; Lautze *et al.*, 2014). WP has been described as a more comprehensive indicator in comparison to other efficiency measures such as irrigation efficiency, as it provides an indication of the net benefits produced or the output derived from water use (Molden, 2007; Lautze *et al.*, 2014). WP has been measured along with the WF in a number of studies (Liu *et al.*, 2007; Aldaya & Llamas, 2010; Schyns & Hoekstra, 2014). WP is essentially the inverse of the WF.

Similar to WP, agricultural productivity is defined as the ratio of agricultural output to agricultural inputs (Zepeda, 2001). The most common way to measure agricultural productivity is through agricultural production per unit of land (land productivity) or labour (labour productivity). To assess production practices policy makers often use land productivity (Wiebe *et al.*, 2001). Partial productivity measures such as land productivity do however fail to reveal whether variations occur due to fertiliser, water use or other factors. Total factor productivity (TFP) is therefore a more holistic measure and includes all the factors of production. TFP is measured by monetising and aggregating the value of all outputs and dividing by the monetary and aggregated value of inputs (Lautze *et al.*, 2014). However, since it is often difficult to place a monetary value on water, it is often excluded. Therefore, authors suggest and have advocated that TFP and WP should be used as complementary indicators as WP captures the water use that TFP omits and together provide an advantageous combination of production per hectare and water use (Bessembinder *et al.*, 2005). Conversely, it has also been argued that WP does not provide and value over and above joint use of agricultural productivity and water efficiency (Zoebel, 2006; Lautze *et al.*, 2014). WF assessments thus far have begun to adopt some PFP indicators in order to express outputs such as the monetary value of production and employment per input of water (Chico *et al.*, 2010; Aldaya *et al.*, 2010b; Chouchane *et al.*, 2013; Schyns & Hoekstra, 2014). One increasingly applied

indicator is economic water productivity (EWP)<sup>2</sup> which aims to examine the economic efficiency, expressed in market price, of water use consumed per ton of product produced (Aldaya & Llamas, 2010b; Chico *et al.*, 2010; Dumont *et al.*, 2013; Schyns & Hoekstra, 2014). For example, Salmoral *et al.* (2010; 2011) illustrated that EWP was lower and more sensitive in rain-fed production of olives in comparison to irrigated production using provincial market prices. Garrido *et al.*, (2010) measured EWP using gross value added as well as crop economic value.

Presenting the WF in terms of EWP has been described as providing a means to economically value irrigation water (Dumont *et al.*, 2013). BOCMA (2012) also expressed water use in relation to income as well as employment. Pegram (2010) also used a number of indicators including GDP, exports, income and employment to demonstrate the economic contributions that water use provides in Lake Naivasha in Kenya. Although these contributions were merely described, the study demonstrated the importance combining WF analysis with economic data (Chapagain & Tickner, 2012).

EWP along with WP has been described within WF studies as a means to assist towards the reallocation of water resources by presenting water use in terms of their highest economic productivity and physical productivity. Aldaya *et al.* (2010b) state that the previous paradigm of “more crops and jobs per drop” is shifting towards “more cash and nature per drop.” They argue that knowing the EWP and irrigation sources are becoming increasingly important in water management decisions. The intention of BOCMA (2012) connecting water use metrics with economic indicators, was also to provide insights to inform strategy and planning by demonstrating which crops have a higher economic return per unit of water. Economic land productivity (ELP)<sup>3</sup> has also been examined to represent the economic value of farm output per hectare calculated (Aldaya *et al.*, 2010b; Chouchane *et al.*, 2013; Schyns & Hoekstra, 2014). Chouchane *et al.*, (2013) state that generally irrigation water is applied to increase land productivity not WP therefore it would be the most beneficial to increase irrigated area for crops which exhibit a greater ELP.

---

<sup>2</sup> Also been referred to as apparent water productivity (Garrido *et al.*, 2010; Salmoral *et al.*, 2010).

<sup>3</sup> Also referred to as apparent land productivity (Chico *et al.*, 2010; Salmoral *et al.*, 2010).

It is important to also remember that a number of factors affect agricultural production do not necessarily pertain to water (Conradie, 2002; Zoebel, 2006; Lautze *et al.*, 2014). Using indicators in isolation, particularly partial factor productivities, will fail to reflect variation and mask numerous important variables that often explain variation (Lautze *et al.*, 2014). In fact, BOCMA (2012) despite measuring EWP and employment created per m<sup>3</sup> still concluded that the WF was not sufficiently connected to environmental, social and economic status indicators to inform strategic planning or policy. However, BOCMA (2012) used WFs and EWP without assessing water scarcity or pollution, therefore their conclusion is based on an incomplete WF assessment.

### **2.4.3 Limitations of the water footprint assessment and potential economic considerations**

It is important to note that water scarcity has three dimensions:

1. Physical water scarcity: when demand of water is greater than the supply of available water. Available water resources are insufficient to meet all the demands.
2. Infrastructural water scarcity: when demand cannot be met as a result of insufficient or ineffective structures
3. Institutional scarcity: when a secure and equitable supply of water is not ensured by public authorities (Food and Agriculture Organisation (FAO), 2013).

Infrastructural and institutional scarcity combined has also been referred to as economic water scarcity (Rijsberman, 2006; Molden, 2007). Economic water scarcity looks beyond physical water availability and incorporates financial, human and institutional capacity constraints as well as the notion of access (Rijsberman, 2006; Molden, 2007; Lautze & Hanjra, 2014). The WF assessment framework provides only clear measures for examining physical water scarcity and not economic scarcity. From an economic perspective, it is also difficult to attach an opportunity cost and subsequently put a value on green water (Garrido *et al.*, 2010). Therefore, there are issues in assessing both physical and economic scarcity of green water. However, efforts to include economic blue water scarcity have been made by Garrido *et al.*, (2010).

Garrido *et al.* (2010) was one of the first WF studies to deal with the economic valuation of virtual water. They defined the economic value of blue water in terms of shadow prices and scarcity

values. A shadow price refers to the economic value or opportunity cost and is equivalent to the marginal value of water endowments (Young, 1996). Shadow prices represent true economic scarcities more correctly than market prices as they reflect the true undistorted price (Beli *et al.*, 2001; Blignaut & Lumby, 2004). Differences between observed market price and shadow price is the result of market failure (Blignaut & Lumby, 2004; King, 2004). A shadow price reveals a consumer's willingness to pay for an additional unit and can be referred to as marginal product value (MPV) of water. MPV or shadow prices of water are deemed useful to measure in economic terms the effects of degradation, resource depletion and the opportunity cost of water (Louw, 2001; Conradie, 2002; King, 2004; Williams *et al.*, 2008; Garrido *et al.*, 2010; De Lange & Mahamani, 2013). This is because shadow prices of water provides potential values that could be used to achieve economic efficiency, maximize social welfare and ensure optimal resource allocation (Conradie, 2002; King, 2004). King (2004) states that policy makers will be better equipped to price water resources more appropriately and evaluate the efficiency of allocations between water users. The argument for full cost pricing stems from the theory that if water is valued correctly water will be allocated to its most efficient user (King, 2004). Therefore, authors have argued that shadow values are useful as they could be used to develop pricing strategies to assist in efficient allocations of water (King, 2004; De Lange & Mahamani, 2013).

Garrido *et al.* (2010) multiplied shadow prices (obtained in literature search for each basin) by total water use for each basin. Scarcity levels were then derived based on storage thresholds for each basin. If the volume stored was higher than the 50<sup>th</sup> percentile, between the 25<sup>th</sup> and 50<sup>th</sup> percentile, between the 10<sup>th</sup> and 25<sup>th</sup> percentile or lower than the 10<sup>th</sup> percentile scarcity levels were defined between one and four respectively (Garrido *et al.*, 2010). Garrido *et al.* (2010) also calculated the economic value of water quality by accounting for the opportunity cost of clean water represented by the cost of treating the water. Dumont *et al.* (2013) also argue that although measures such as EWP can constitute as an estimation of the average value generated by water use, it is MPV or shadow values that need to be considered for reallocation of water. Dumont *et al.* (2013) however do advocate that EWP values can provide initial insight into which crops are generating more economic value than others.

Hastings & Pegram (2012) comment that the most relevant environmental, social and economic criteria to understand local context of water use are not identified and criteria to quantify impacts is unclear in the WF assessment framework. The scope for exploring indicators as part of a WF assessment is therefore huge. More practical studies including a number of social, economic variables will assist in refining the WF assessment method

#### **2.4.4 Life Cycle Assessment and the aggregation and weighting of impacts versus water footprint assessment**

##### ***a) Aggregation and weighting of impacts***

The notion of some indexes being aggregated, while others are simply just presented<sup>4</sup> has also been extensively debated with sustainability literature. Some authors remain fixed on the idea of a composite numeric value or index for sustainability (Moffat, 1996; Gallopín, 1997; Moldan *et al.*, 2012). Others argue it is impossible to take a concept like that of sustainability and transform it into one comprehensive measure or index, as it would hide potentially valuable information and would be difficult to defend philosophically, practically and statistically (Riley, 2001; Reed *et al.*, 2006; Spangenberg, 2005). Bohringer & Jochem, (2007) critically assessed eleven indices and concluded that normalisation and weighting of indicators are often associated with a high degree of arbitrariness and subjectivity and can therefore often be misleading. Scientific rules for consistency and meaningfulness were also disregarded pertaining aggregation (Bohringer & Jochem, 2007). Nardo *et al.* (2005) argues that weighting and aggregation are problematic as it aims to compare variables that are not comparable. This is one of the core debates between the LCA and WF assessment water footprint methodologies.

---

<sup>4</sup> Examples of presented data include, sustainability polygons (Herweg *et al.*, 1998), AMOEBA's (Ted Brink *et al.*, 1991), webs (Bockstaller *et al.*, 1997), kite diagrams (Garcia, 1997), barometers (Prescott-Allen, 2001), wheel diagrams (Reed *et al.*, 2004) and sustainable livelihood asset pentagons (Scoones, 1998).

## ***b) Water footprints in Life Cycle Assessment versus the water footprint assessment***

While water inventories can be useful, pure inventory based water footprints have been argued by Ridoutt & Pfister (2010) as being incomplete, meaningless and misleading. Authors pointed out that it is necessary to 'characterise' water footprints (Berger & Finkberger, 2012; Ridoutt & Pfister, 2010). Ridoutt & Pfister, (2010) and Pfister & Hellweg (2009) proposed a spatially varying water stress index to weigh water consumption as a function of water scarcity to distinguish the origins of water use. The authors also argue that this characterisation makes water footprint more consistent with the current practice of carbon footprinting. They also exclude green water footprints as they deem the impacts to be zero (Pfister & Hellweg, 2009; Ridoutt & Pfister, 2010).

Hoekstra *et al.* (2009b) however states that their arguments are framed within the logic of LCA, which focuses on the weighting and aggregation of impacts due its product focus. Hoekstra *et al.* (2009b) argue that the primary role of the WF is in water resource management and characterised indexes will weaken the water footprints stance in this regard. To contribute to water resource management requires terms containing highly relevant information, therefore spatial and temporal information and impacts need to be expressed in real volumes. By aggregating information into indices, authors have argued that important information is lost through questionable weighting choices (Hoekstra & Mekonnen, 2012a). Furthermore, without physical interpretation, indices are completely meaningless within a water resource management as they ignore key environmental impact routes such as variability in time and environmental flow requirements (Hoekstra *et al.*, 2009b). Criticisms by Hoekstra *et al.* (2009b) toward characterisation are however directed particularly for the accounting phase of the WF. Authors within the water footprint community have always acknowledged the need to place water footprints within the context of their withdrawal and recognised the need for an 'impact assessment' to complete the WF and aid in the understanding of how water use volumes affect watersheds and its users (Hoekstra *et al.*, 2009a; Hoekstra *et al.*, 2011), hence the development of the sustainability assessment phase.

Boulay *et al.* (2013) recently reflected on both approaches emphasising that both could benefit from each other. In particular, Boulay *et al.* (2013) state that LCA could benefit from the use the

blue WF and the blue water scarcity indicator to emerge best practices with other scarcity indicators used in LCA. They also recommend that the WFA could benefit from the use of the inventory databases used in LCA, which are well developed. Further, they state that WFA could benefit from considering some of the impact assessment methods evolving within LCA and joint efforts could lead to some consensual metrics to better assess the sustainability of fresh water use (Boulay *et al.*, 2013). A number of authors acknowledge the potential for WF accounting and assessment to be “incorporated” within the LCA and footprints (Koehler, 2008; Jefferies *et al.*, 2012; Chapagain & Orr; 2008). Hoekstra *et al.*, (2011) argue that green, blue and grey WFs of products can be directly used as indicators in LCA.

## **2.5 The relevance of water footprint assessments for policy and the private sector**

A number of countries have already begun to include estimates of water footprints within policy documents. These include Spain (Aldaya *et al.*, 2010b) and Germany (Flachmann *et al.*, 2012). South Africa also makes reference to water footprints in their new draft NWRS (DWA, 2012) as do Netherlands (Witmer & Cleij, 2012) and India (Government of India, 2012) in policy documents.

Many authors have emphasised the role that WF analyses provide in identifying optimal resource allocation by assisting in more efficient water allocations and alleviating water scarcity (Aldaya *et al.*, 2010b; Schyns & Hoekstra, 2014). According to Schyns & Hoekstra (2014), by examining supply chains and end-uses of water, one can determine efficient and equitable allocations within sustainable boundaries. WF assessments have also been stated as being a useful tool for informing water managers on identifying how much water is being allocated to which activities, whether water allocations are allocated efficiently and if ecosystem integrity is comprised through the identification of environmental hotspots (Hoekstra *et al.*, 2011).

At the same time Galli *et al.* (2012) found the WF in particular to have a restricted range of applicability and be sufficiently informative for EU water policies only. It was shown to only partially inform policies addressing water scarcity and resource productivity but not the Drinking Water Directive Policy. Grey WFs were said to be potentially useful for informing water pollution policies but were hindered by reliability and robustness of data (Galli *et al.*, 2012). Authors therefore suggest that the WF assessment be used in conjunction with other complementary

tools (Witmer & Cleij, 2012). In particular, studies also emphasised the need to conduct WF assessments at lower levels with more accurate, site-specific data (Chico *et al.*, 2010; Salmoral *et al.*, 2010; Zeng *et al.*, 2012). This would enable the complexity of trade-offs to be examined and enable a better understanding of impacts and conflicting environmental and socio-economic variables.

In terms of the private sector, WF assessments have provided a means by which companies can more comprehensively understand their water usage and examine their subsequent water related risks (Morrison *et al.*, 2010; Sikirica, 2011; Ruini *et al.*, 2013). Cazcarro *et al.* (2014:99) emphasise that “the knowledge of flows, demands and pressures associated with WF assessments assist in identifying critical impacts and solutions for better water governance.” This is applicable to both private and public sectors. Garrido *et al.* (2010) declare that incorporating WF assessments in local and regional planning allow for better diversification of crops, crop replacement strategies and create consumer awareness regarding diets. Companies need to know their water use and the resulting impacts in order to manage it effectively and avoid reputational risks. In particular, a number of other potentially useful key strategies that have emerged from WF literature that are worth discussing are: strategies to reduce WFs such as water neutrality and WF caps and benchmarks. Another important ideology that has emerged is one of shared responsibility.

### **2.5.1 Water neutrality and reduction of WFs**

Water footprint researchers have also explored many of the concepts that have evolved within CF research. One of the two main strategies to reduce greenhouse gas emissions is through reduction and offsetting of CFs. Similarly, WF researchers have suggested a number of ways to reduce blue, green and grey WFs and explored the concepts of water neutrality, WF labelling, WF permits (Hoekstra, 2007; Erkin & Hoekstra, 2012).

Water neutrality refers to nullifying the external externalities of the WF of an activity within the hydrological unit where impacts occur. Where impacts remain, like in the case of agriculture, compensation is required in the form of investments or contributing to the equitable and

sustainable use of water within the appropriate hydrological unit (Hoekstra, 2008). Compensation should ultimately reflect the vulnerability of where the residual footprint is located. While climate change and global warming are deemed as a global issue and hence CF can be offset anywhere, WF related impacts are local and require knowledge regarding the location of water withdrawals. As a result 'water neutrality' is more complicated than 'carbon neutrality', therefore, questions still remain regarding how to determine the appropriate water-offset price, what type of efforts count as offsetting and how much of a reduction can be reasonably expected (Hoekstra, 2008; Hastings & Pegram, 2012). Despite uncertainties, the water neutral concept can promote awareness to reduce water footprints and generate funds towards sustainable and equitable water use (Hoekstra, 2008). SABMiller in South Africa has already collaborated with Working for Water in exploring the water neutral concept (SABMiller & WWF, 2010). Suggestions for nullifying and reducing WFs have included recycling of water, leakage prevention, capturing and reusing energy and chemicals from waste flows (Hoekstra, 2008; Hoekstra *et al.*, 2011; Hoekstra, 2014b).

### **2.5.2 Benchmarks, caps and WF allocations**

Hoekstra (2014a; 2014b) has suggested that government and companies need to work together to establish WF benchmarks for water intensive products. Mekonnen & Hoekstra (2013; 2014a) have already started research within this area providing benchmark values for 124 crops. Hoekstra (2014a) also suggests WF caps to set limits on the maximum water volume that can be consumed or polluted by specific activities, aiding in fairer WF consumption. It is however emphasised that benchmarks, caps and allocations would need to be implemented simultaneously as alone are not sufficient (Hoekstra, 2014a). He predicts these initiatives would create the incentives needed to reduce WFs to a reasonable 'benchmark level.' (Hoekstra, 2014a). Only a few studies could be found that have made comparisons to the global benchmark levels (Schyns & Hoekstra, 2014; Mekonnen *et al.*, 2014). Schyns & Hoekstra (2014) show that lowering WFs of main crops to benchmark levels could lead to potential blue and green water savings of 2.8 billion m<sup>3</sup>/yr in Morocco (Schyns & Hoekstra, 2014).

### **2.5.3 Shared risk and responsibility**

Water related risks include preventing water stress, maintaining the functioning of ecosystems and promoting economic and social development (Pegram *et al.*, 2009). Given that companies or sectors and government share these risks equally, creates a common ground for dialogue between stakeholders through joint efforts (Pegram *et al.*, 2009; WWF, 2014). Information regarding potential reduction strategies, water scarcity, water related risks, benchmarks and allocations provided through WF assessments can aid in better understanding for water related issues and can foster communication (Zhang *et al.*, 2013; Zhang *et al.*, 2014). This is important in order for policies to be effective as there is no prevailing solution when it comes to effective water management. Pegram *et al.* (2009) emphasised the water management initiatives need to be developed for the context in which risks occur. Shared responsibility also provides accountability for multiple users responsible for impacts and allows for the development of more comprehensive strategies (Witmer & Cleij, 2012).

### **2.6 Water footprint assessments and its relevance to South African water policy**

The South African NWA, as briefly discussed in chapter one aims to ensure that “water is protected, used, developed, conserved, managed and controlled in a sustainable and equitable manner for the benefit of all persons” (DWAF, 1998:10). The key reforms of the NWA include amongst others new local and regional institutions and water use registration and licencing. Through decentralisation, the establishment of a hierarchy of institutions at lower levels of government were said to provide assistance in carrying out functions more effectively and efficiently and to allow for greater participation of all stakeholders in the decision making process (Funke *et al.*, 2007; Hassan & Crafford, 2006). The hierarchy of institutions included the DWA at a national level; Catchment Management Agencies (CMAs) at a regional level and Water User Associations (WUAs) at a local level (DWA, 1998). CMAs are anticipated to be a key institution in overseeing water resources, co-ordination of water resources and managing institutions within specific areas of South Africa (Funke *et al.*, 2007; Tewari, 2009). A critical role of decentralisation was to increase efficiency and equitable distribution of water resources by delegating governance to its lowest level by means of a bottom up approach facilitating IWRM (Hassan & Crafford, 2006).

However, the process of establishing CMAs and converting irrigation boards into WUA has been slow.

Water allocations are proving to be even more challenging to implement. One of the key issues faced by government authorities is how to allocate water among many competing users and achieve the potentially contradicting objectives of resource protection, social and economic equity and efficiency (DWAF, 1998). Water use through permits (as opposed to the previously Riparian rights principle) requires the DWA to control water through regulation and authorisation of water and know exactly what water use is taking place and how much water is being used (DWAF, 1998). Water use is authorised through schedule one authorisations, general authorisations and water user licences (DWAF, 1998). Water user licences are used to control amounts of water that exceed the quantities allowed in schedule one and general authorisations (DWAF, 1998).

Water use licences are evaluated according to specific criteria outlined by the NWA with factors pertaining to environmental, economic and social development impacts and sustainability (DWAF, 1998). Other factors that also need to be considered include; existing water users, new existing water users, previously disadvantaged individuals and reserve quantities (Nieuwoudt *et al.*, 2008). Government institutions need to factor these issues into their stakeholder engagement processes and ensure engagement with stakeholders is uniform (Funke *et al.*, 2007). Dealing with these challenging tasks requires better knowledge by water managers and policy makers of the economic contributions, environmental impacts and effectiveness of pricing strategies (Hassan & Crafford, 2006; Nieuwoudt *et al.*, 2008).

South Africa could potentially benefit from WF assessments as they provide a more comprehensive measure of accounting and help assist in allocation decisions, stakeholder engagement, reduction strategies, examining value, identifying hotspots, risks and trade-offs in water use through the adoption of indicators. WF assessments could potentially be useful in creating dialogue between a broad range of stakeholders and help foster decision making of WUAs and CMAs. Additionally, WF assessments could help assist private sectors and government sectors in identifying water usage, risks, impacts and strategies for more sustainable water use.

# CHAPTER THREE:

## SOUTH AFRICAN AGRICULTURAL CONTEXT AND STUDY AREA

*“Future demands for agriculture will to a large extent depend on crop selection and financially attractive opportunities of increasing water efficiencies”*

*DWA (2012:54)*

Lemon orchard, Hermitage

Photo: S.A Munro

### 3.1 The South African agricultural sector

Approximately 8.5 million people directly or indirectly gain employment or income through the agricultural sector in South Africa (DWA, 2012). The economic value of water in agriculture is generally low in comparison to other sectors however, the multiplier effects are crucial for socio-economic development (Nieuwoudt *et al.*, 2004; De Lange & Mahumani, 2013). Agriculture in South Africa contributes 3% to GDP and 7% to formal employment (DWA, 2012). The net revenue of agricultural production in the year 2011/12 was estimated at R162 billion with a total value for agricultural exports estimated at R52 billion (DAFF, 2013). Agriculture therefore has a huge influence on alleviating food scarcity, maintaining livelihoods as well as providing foreign exchange earnings (De Lange & Mahumani, 2013).

The sector is comprised of both commercial, subsistence and emerging farmers and consists of 1.5 million hectares of irrigated land, consuming approximately 10 486 million m<sup>3</sup> of water (Taylor & Gush, 2014). As mentioned in chapter one, the irrigated agricultural sector is the largest user of South Africa's water endowment using approximately 60% of available freshwater resources. This is because the success of high value crops requires supplemented water to meet crop water demands, due to the erratic and low rainfall patterns experienced in South Africa. Availability of water resources is therefore a major limiting factor to the growth of this sector. Poor water quality has also been shown to have significant effects on yields (Ayers & Westcot, 1976), consequently impacting exports and foreign income negatively.

Despite water quality and availability limitations, The Irrigation Strategy for South Africa aims to increase irrigated agriculture by 50% (DAFF, 2010). The amount of water allocated to the agricultural industry, however, is said to remain the same. This requires that significant improvements in water efficiency and productivity occur to meet the expanding demand of emerging farmers and new commercial developments (Gush & Taylor, 2014).

### 3.1.1 Fruit crops

Fruit production contributed 51% to the total value of horticultural agricultural production in 2011/12, with a value of approximately R40 billion (DAFF, 2013). The fruit tree industry includes a tremendous number of deciduous and subtropical cultivars, which span broad physical growing conditions (Taylor & Gush, 2014). At least 90% of South Africa's fruit tree industry is dependent on irrigation (Nieuwoudt *et al.*, 2004). Therefore, the fruit industry has been highlighted as a key risk to water stress and growth (Gush & Taylor, 2014). Taylor & Gush (2014) recognise the urgent need for fruit tree orchards in South Africa to reduce irrigation through improved irrigation scheduling and water use efficiency without affecting fruit quality and yield. According to the Department of Agriculture (DOA) (2006), apples have the highest total economic value of fruit tree species produced in South Africa followed by valencias, pears, navels, soft citrus and grapefruit. Oranges, soft citrus, lemons and grapefruit provide approximately 21% of the total value derived from fruit production in South Africa (DOA, 2006). Citrus is evidently, one of the highest economic value crops in South Africa. With regards to total production, valencias have the highest total production followed by apples, navels, grapefruit, pears, lemons and soft citrus (DOA, 2006). Valencias also occupy the greatest area of planted land of all fruit tree crops in South Africa followed by apples, pecan nuts, macadamia nuts, navels and avocados (Taylor & Gush, 2014).

Based on economic importance, total production, planted area and taking into account gaps in knowledge on water use, Taylor & Gush (2014) ranked the relative importance of a number of fruit tree species. The top eleven included valencias (ranked the most important fruit tree species), followed by apples, navels, pears, grapefruit, avocados, macadamias, soft citrus, peaches, pecans and lemons. Citrus is also deemed one of the main fruit tree crops in the world and one of the most economically important fruit crops, providing one of the main sources of vitamin C for consumers (Iglesias *et al.*, 2007).

### **3.2 Rationale for study site selection**

The Eastern Cape spans an area of 168 966 km<sup>2</sup> and has an estimated total population of 6.56 million (Statistics South Africa, 2011). It comprises approximately 10.2% of South Africa's irrigated land (DAFF, 2013) and prioritised as an area of strategic importance concerning significant future expansion (Taylor &Gush, 2014). According to the Department of Economic Affairs Environment and Tourism (DEAET) (2004), the Eastern Cape also has the highest poverty levels in the country characterised by high unemployment rates and low standards of living. Given the dire need for economic development and the limited availability of water resources, the Eastern Cape region provides a good rationale for understanding and assessing current water use activities within the region.

There are approximately 62 238 ha of citrus in South Africa. The Eastern Cape is the second largest producer of citrus after Limpopo with 13 951 ha of citrus. The three producing areas in the Eastern Cape include Paterson, Eastern Cape Midlands and Sundays River Valley (SRV) (Citrus Growers Association of Southern Africa (CGASA), 2013). Large and complex bulk water schemes have allowed for economic growth in the area that previously would not have been possible. The citrus industry within the LSRV in the Eastern Cape is no exception, and is one of many agricultural sectors that rely predominantly on an inter-basin transfer scheme (Sundays River Valley Municipality (SRVM), 2011). Citrus production and the Addo Elephant National Park are the two most noteworthy economic drivers within the (SRVM, 2012). The agricultural industry employs 47.7% of the local labour force and contributes 31.2% to the GDP of the area (SRVM, 2011). The industry is primarily export orientated and is one of the largest foreign exchange earners in the Eastern Cape (DAFF, 2011). The lower SRV is regarded as one of the key production areas for citrus farming in South Africa (DAFF, 2011). Despite the importance of citrus crops in South Africa, very little research on water use in citrus production has been done in recent years (Gush & Taylor, 2014)

Currently large amounts of research have and are currently being conducted in the SRV region, providing a great deal of data by which sustainability criteria can be assessed. The LSRV study site

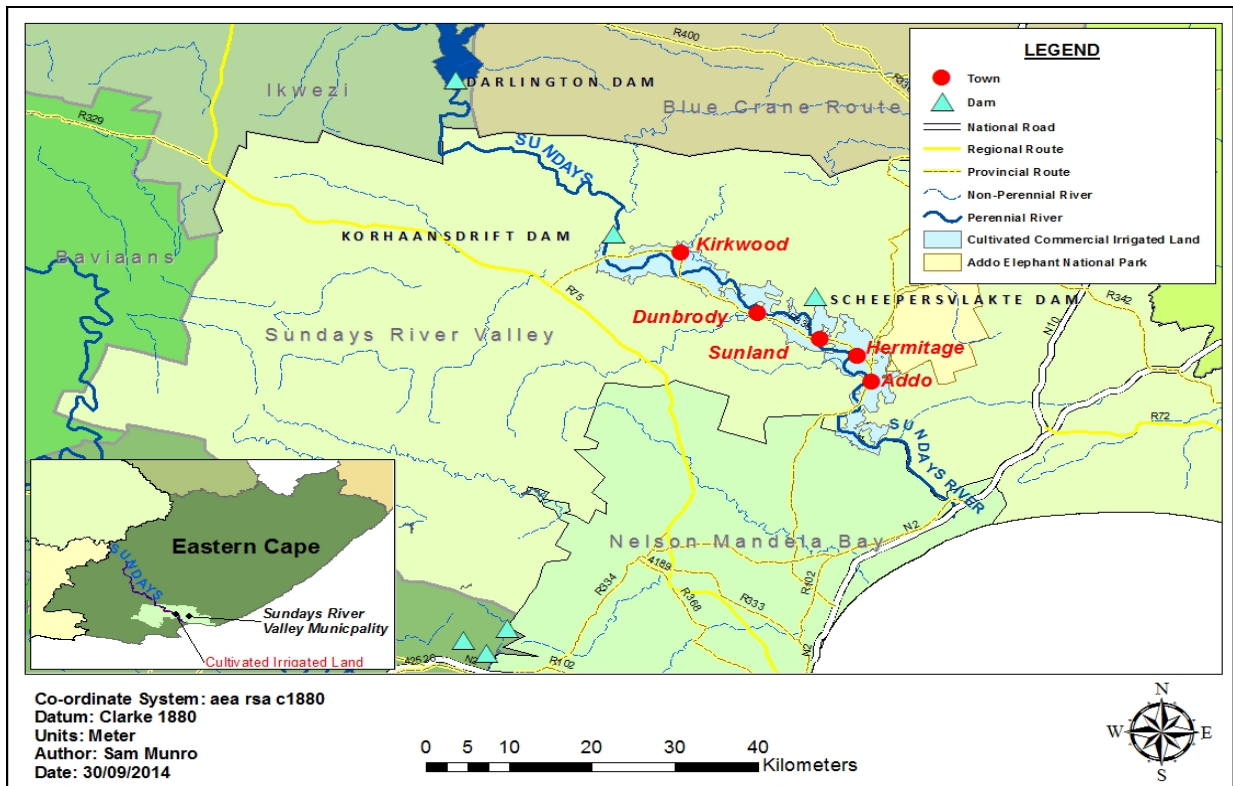
was chosen based on the fact that citrus is an important economic crop not only for South Africa, but also because a number of interdisciplinary research projects are being conducted in the area.

### **3.3. General attributes of the study site**

#### **3.3.1 Location**

The LSRV falls into the SRVM, which is one of nine municipalities within the Cacadu district of the Eastern Cape. The SRVM is located north of Port Elizabeth and forms part of the Fish to Tsitsikamma CMA (DWAF, 2005). The area can be divided into three distinct homogenous areas; the coastal zone, the river valley and the mountainous areas (SRVM, 2011).

The citrus industry extends from Kirkwood to Addo within the river valley region south of the Darlington Dam (see Figure 3.1). The areas are colloquially referred to as the upper and lower valley respectively. Cultivated irrigated land is shown in Figure 3.1, demonstrating the extent of the area. The LSRV is approximately 25 027 hectares, of this 17 173 hectares is utilised for crop production, of which 12 617 (approximately 50.4% of the LSRV) hectares are currently occupied by citrus. The remainder of the LSRV includes fallow land, green houses, chicken coops, sport fields, windrows, management and dams (LSRVWUA, 2013). The citrus industry is situated along the banks of the Sundays River. The Sundays River covers approximately 21 250 km<sup>2</sup>. The river's headwaters occur in the catchment of the Nqebwa dam, then flows mostly through the Great Karoo, and finally discharges into Algoa Bay in the vicinity of Colchester (DWAF, 2005).

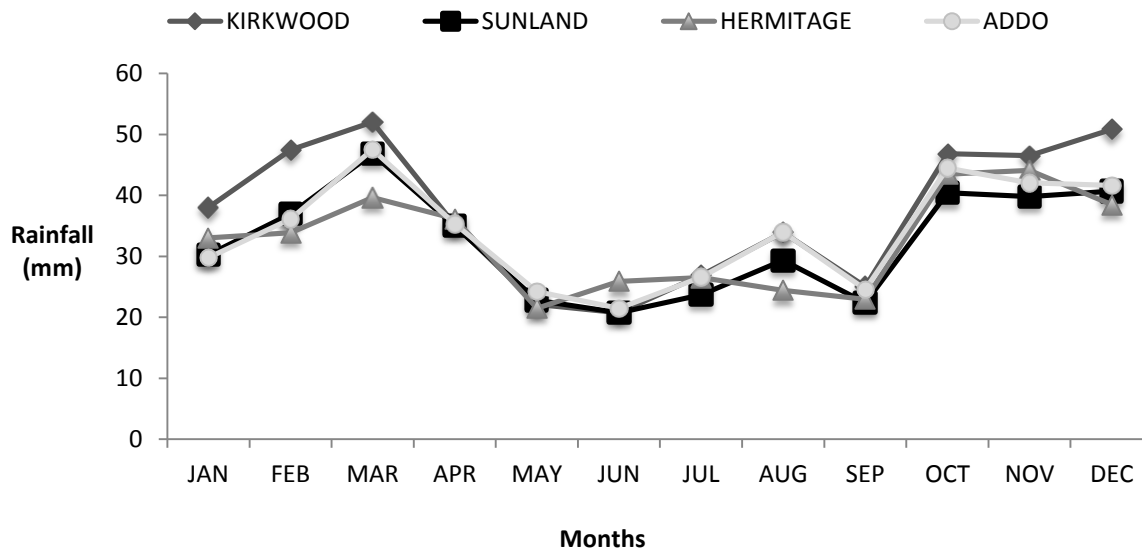


**Figure 3.1 Map of Sundays River Valley, Eastern Cape, South Africa**

*Source:* own elaboration

### 3.3.2 Biophysical context

The SRV is characterised by harsh climatic conditions with a relatively flat topography (DWAf, 2005). The lower SRV annual average rainfall is approximately 404 mm per annum on average and is classified as a summer rainfall region (LSRV WUA, 2014). Kirkwood, Sunland, Hermitage and Addo all exhibit very similar rainfall patterns as depicted in Figure 3.2. Maximum temperatures range from 31.4 °C in February to 23 °C in June. Minimum temperatures range from 17 °C in February to 2.8 °C in July.



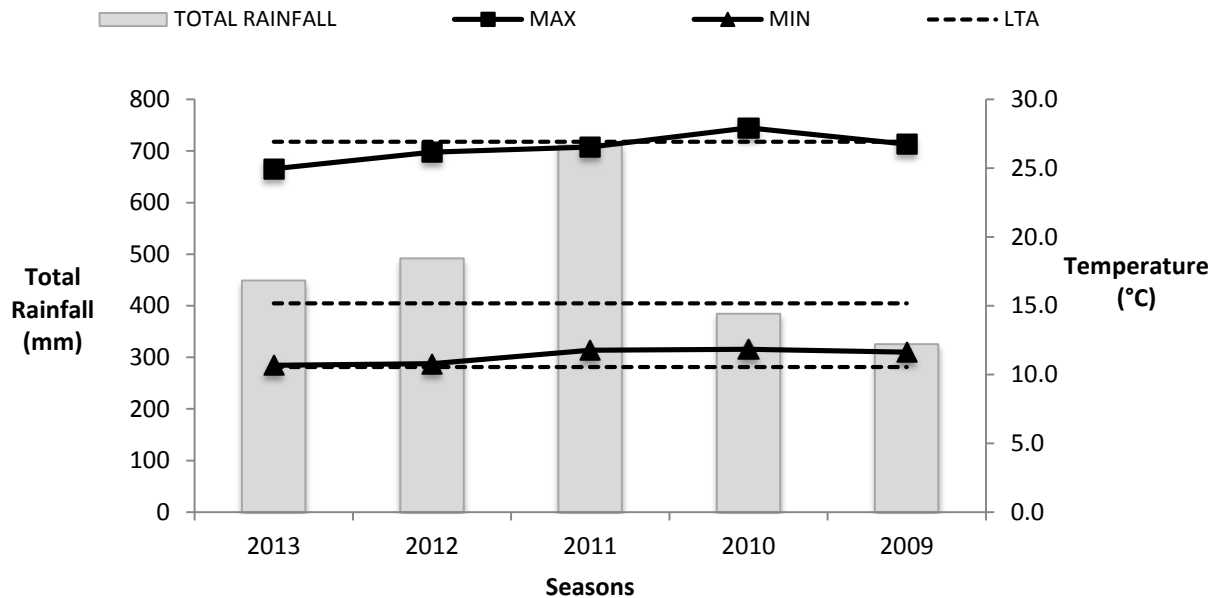
**Figure 3.2 Forty-three year average monthly rainfall (mm) for Kirkwood, Dunbrody, Sunland and Hermitage**

Source: LSRV WUA, (2014)

The region much like the broader Eastern Cape Province was subjected to severe droughts between 2009-2010 (Chris Hani District Municipality (CHDM), 2010) followed by two years of heavy rainfall and devastating floods (South African Broadcasting Commission (SABC), 2012). Climatic data for the past five years for the LSRV region is shown in Figure 3.3. The Eastern Cape has been ranked amongst the top three most vulnerable provinces in terms of climate change impacts (Gbetibouo & Ringer, 2009). It is therefore important that sectors which are vulnerable to climate, such as the citrus sector to consider the potential impacts of climate change.

The SRV possesses wide, fertile flood plains and is characterised with low-lying land and steep less fertile slopes flanking the Valley (SRVM, 2012). From the Sundays River to the Kirkwood formations in the south of Sundays River Valley, soils are mostly deep red, loamy to clay (DWAF, 2005). The inland regions of the Sundays River soils are characterised by high clay contents derived from Ecca Group shale and mudstones (Hoare *et al.*, 2006). Furthermore, near the Sundays River deep alluvial soils can be found. Despite the fact that all nine biomes occur within the Eastern Cape, a high degree of land degradation has occurred with the province because of over-grazing, alien invasive and other anthropogenic activities (Department of Environmental Affairs and Tourism (DEAT), 2004). The naturally occurring vegetation within the LSRV is thicket

biome (Mucina & Rutherford, 2006).



**Figure 3.3 Seasonal rainfall (mm) and maximum and minimum temperatures (°C) over the last five years for the Lower Sundays River Valley.**

*Source:* ARC-ISW, 2013 and LSRV WUA, 2014

### 3.3.3 Historical and current water use

The bulk raw water supplier in the area is the LSRV WUA and provides raw water to irrigated areas and emerging farmers, Nelson Mandela Bay Municipality (NMBM), recreation, tourism and the environment, development initiatives and the SRV municipality. The SRV municipality acts as the water service authority and the water service provider, providing potable water to the population. The main water systems that the SRV municipality provide for include greater Kirkwood, Addo and Enon-Bersheba (SRVM, 2011). The SRVM annual allocation is approximately 3% of the total allocation for the area with irrigation being the primary water user (SRVM, 2012).

All raw water within the area is supplied via canals and pumped to various dams where it is subsequently distributed. The canals and Korhaansdrift Weir were constructed in the early 1900's to abstract water from the Sundays River and to distribute it through the area (Dyke & Murray, 1997). To aid in supplying water for the irrigation of citrus Lake Mentz was completed in 1922, and walls were later raised in 1935 and 1952 to support the increased demand in water use

(Delpont, 1987). This project was commissioned by the WUA (previously known as the Sundays River Irrigation Board<sup>5</sup>). Lake Mentz was renamed as Darlington Dam in 1995. Additional capacity was also created in the Sunday's scheme in 1986 and the capacity of the network canal was later increased in 1992. The scheme was also extended to incorporate a connection to Port Elizabeth in 1990's (Secretary of Water Affairs, 1990). Historically, farmers were the primary funders of the construction related to dams, canals, pipelines and weirs that supply the water to the area (Clifford-Holmes *et al.*, 2013).

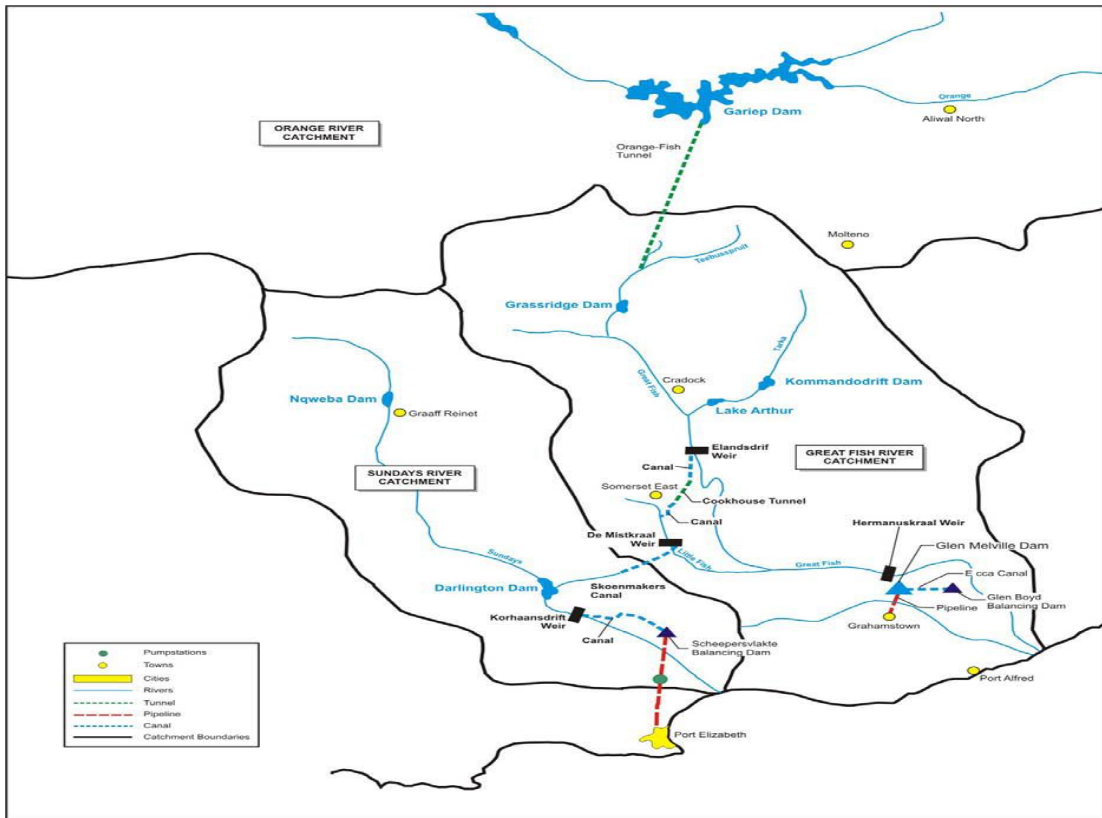
Due to rapid silting in Darlington Dam that caused problems in the 1960's and local rivers to be over-appropriated, the dam was empty for six months in 1970/71 (Delpont, 1987). These problems were alleviated in 1978 because of the Orange-Fish-Sundays inter-basin transfer (IBT) scheme (See Figure 3.4). The IBT is supplied from the Gariep Dam on the Orange River where water flows through the 83 km Orange-Fish tunnel. Approximately 123 million m<sup>3</sup> of water per annum is discharged from Schoenmakers Canal into the Schoenmakers River, which is a tributary of the Sundays River feeding into Darlington dam (DWAf, 2005). Water is released into Korhaansdrift Weir from Darlington dam. Water is then released from Korhaansdrift Weir at the start of each week into the canals and other dams such as Scheepersvlakte Dam based on weekly water orders sent in by the water users (LSRV WUA, 2014). Scheepersvlakte Dam has a capacity of 800 000 m<sup>3</sup>, from which approximately 13 million m<sup>3</sup> is diverted to NMBM annually (DWAf, 2005). In 2010 and 2013, during the drought period, the NMBM allocation usage substantially increased due to restrictions in other supplies (LSRV WUA, 2014). This was particularly the case in 2010 when NMBM used their entire allocation.

The bulk water supply provided by the WUA is reliant on transfers of water from the Orange River basin (see Figure 3.4) and it is estimated that the river supplies between 65-95% of the Fish-Sundays schemes water use (Conradie, 2002). According to DWAf (2005), a further allocation of 38 million m<sup>3</sup> has been assigned to an additional 4000 hectares of land for resource poor farmers

---

<sup>5</sup>The Sundays River Irrigation Board was converted to a WUA in 2003 as part of the transformation sanctions of the NWA of 1998. The primary role of a WUA is to enable water users to cooperate and pool their resources (financial, human resources and expertise) to ensure out water-related activities at a local level are carried out effectively.

but has yet to be implemented.



**Figure 3.4 Schematic diagram of the Orange-Fish transfer scheme.**

*Source: DWAF, 2005*

### 3.3.4 Water quality

The underlying geology of the catchment area results in local water of a very poor quality (DWAF, 2005). The Sundays River is fed by six main tributaries below Darlingtong dam (See Figure 3.4). The tributaries flowing southwest are characterised by low, intermittent flows and a high saline content. This is a result of a relatively flat topography, low mean annual runoff, high evaporation and underlying mudstones giving rise to saline base flows. The perennial rivers from the north are of relatively high quality (The Wetland Group, 2004). Water quality generally deteriorates downstream because of saline southwest tributaries but also due to agricultural return flows. The Orange River water transferred from the IBT is of a high quality but progressively worsens due to leaching of salts (this is common in irrigation schemes in arid areas) and saline return flows (DWAF,

2005). According to DWAF (2005), a significant volume of additional water from the Orange River is required solely to keep the river at an acceptable quality.

### **3.3.5 Socio-economic context**

The SRVM has a total population of 54 500 people (Statistics South Africa, 2012) and covers a total area of 3507.59 km<sup>2</sup> (SRVM, 2011). Working class individuals between the ages 15 and 64 make up 66% of the population and yet there is an unemployment rate of 48.9% and a literacy rate of 55.5% (SRVM, 2011). Despite an economic growth rate of approximately 3.5%, 60.3% of the population live below the poverty datum line (SRVM, 2011).

In terms of access to basic services such as sanitation, 33.2 % of households use either pit latrines (23.4%), bucket latrines (2.2%), septic tanks (0.2%) or ventilated improved pit latrines (7.4%) (SRVM, 2012). This equates to 25.6% of the population whose living conditions do not meet minimum RDP requirements in terms of sanitation provision. In terms of water service provision 11% of consumers are below the RDP level of service in that available water resources in the form of a communal standpipe are further than 200m away from their dwelling. A further 9.9% of consumers also have access to water through communal standpipes, but less than 200m from their residence. The remainder of consumers have their own individual erf connections (SRVM, 2012). Huge water shortages have been experienced in Kirkwood since 2009. The SRVM state that this was “due to poor infrastructure plans that was not taken into cognisance during the implementation of housing projects” (SRVM, 2012:33).

Clifford-Holmes *et al.* (2013) take note of the paradox in the area by comparing healthy oranges to unhealthy babies. The paradox highlights the co-existence of a thriving commercial agricultural industry and the poverty experienced by the majority of LSRV residents. Clifford-Holmes *et al.* (2013) attribute this paradox to a functional, efficient, profitable farming sector and an under-capacitated and severely challenged municipality. However, many of the inequitable characteristics in the LSRV are entrenched because of previous legislation including the Group Areas Act of 1950 and the NWA of 1956. These and prior legislation (including the Glen Grey Act of 1894 and The Natives Land Act of 1913) prevented people other than those of European decent

to own land, and ultimately bestowed land and water rights through a riparian rights system on the minority of white farmers who owned land near water bodies. Several 'black spots,' which refers to land occupied by Africans in previously demarcated white areas, remain in the LSRV (Japha, 1996). Unfortunately, due to apartheid legislation, unequal access to water therefore is still entrenched within areas such as the LSRV. Patterns of water use within the area are still characterised by inequality, inefficiency, and inadequacy. This is particularly the case for the informal settlements within the area such as Aquapark and Nomathamsanqa, which are often faced with issues relating to water security and water quality (Malony, 2013). Malony (2013) and Clifford-Holmes *et al.* (2013) attributed the problems of water shortages to insufficient storage reservoirs coupled with the fact the WUA does not work over weekends. This leads to reservoirs running low or empty during this period. Problems are further exacerbated during winter periods (May-July) where two days of the week are allocated as 'dry days' where no water is supplied due to canal maintenance. This is because the citrus farms use less water during the winter months (LSRV WUA, 2013; 2014).

### **3.4 The lower Sundays River Valley citrus industry**

The first fruit trees were planted in 1908 and citrus exported to Europe shortly afterwards. (Delport, 1987; Clifford-Holmes *et al.*, 2013). The Sundays River Valley Citrus Company (SRCC) was established in 1924 (known as the citrus Co-operative at the time) with the primary function of disposing of citrus fruit in the most profitable manner (Meiring, 1959). The SRCC is the current custodian of approximately 50% of exports from the area (CGASA, 2014; SRCC, 2014). Currently farmers are allocated 9000 m<sup>3</sup> of water per hectare per year (LSRVWUA, 2014). Farmers pay a flat rate for water use per hectare (see Table 3.1) (LSRV WUA, 2014). There is also an available 'pool system' which is managed by the WUA. The pool system is comprised of water allocations that farmers may not use and are credited accordingly. Other farmers in the area who require more water for a particular year can apply or request to use some of this pool system water (LSRV WUA, 2014). Almost all of the citrus is irrigated (99.01%) either in the form of drip irrigation (69%), micro irrigation (30%) or by flood channel (1%) (LSRV WUA, 2014).

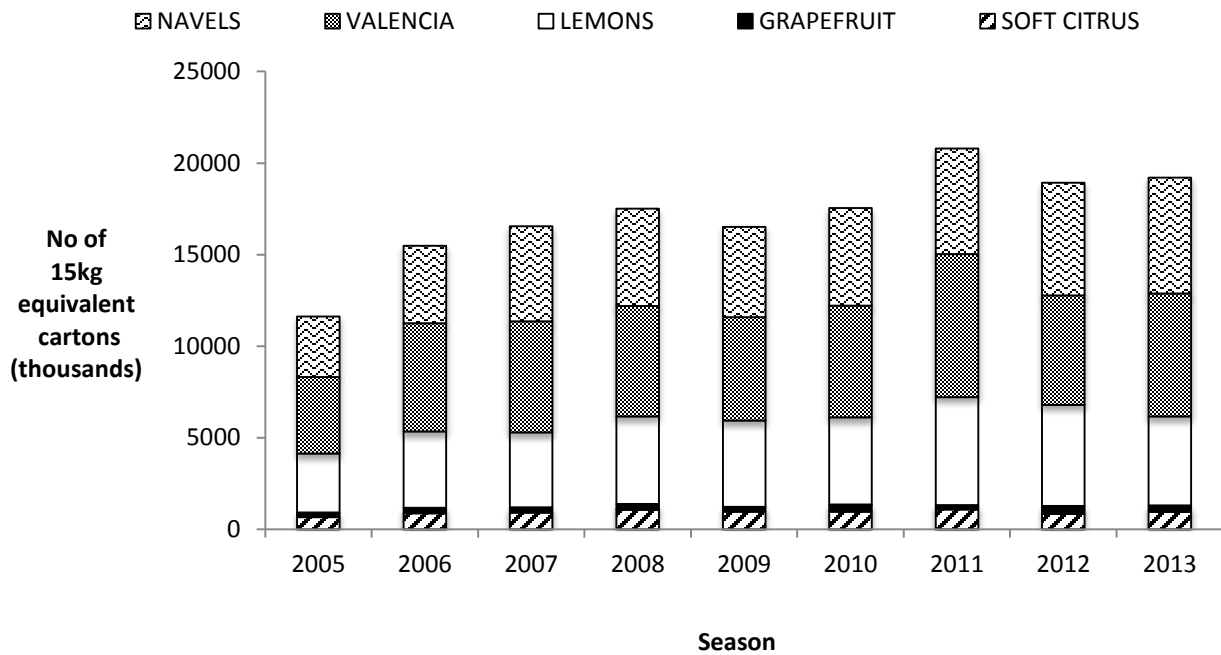
**Table 3.1 Raw water user charges (R/ha/yr) for the lower Sundays River Valley**

<b>2010/11</b>	<b>2011/12</b>	<b>2012/13</b>	<b>2013/14</b>	<b>2014/15</b>
906.30	966.11	1055.70	1188.00	1309.50

*Source:* LSRV WUA, (2014)

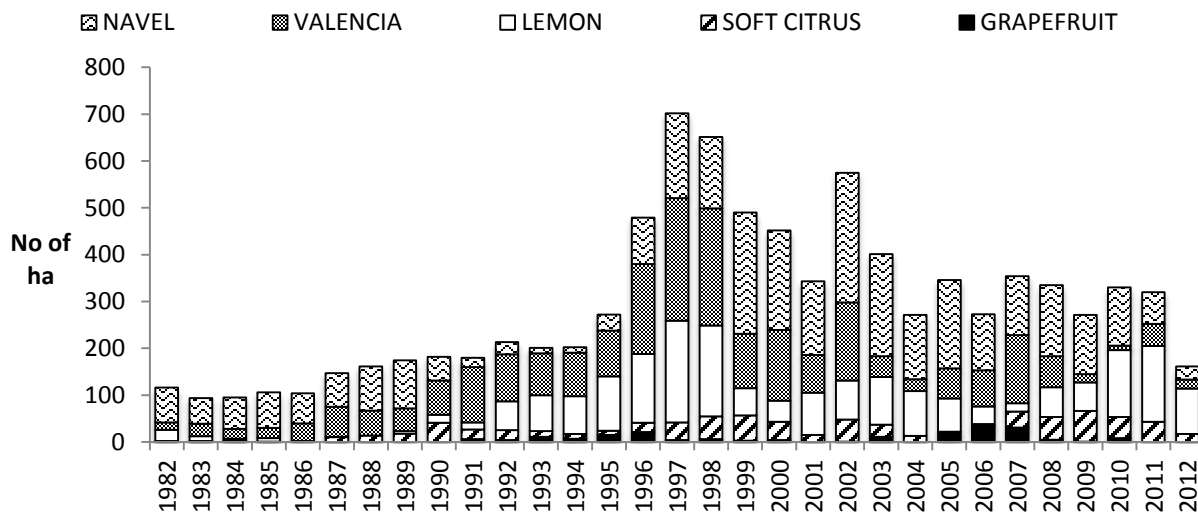
Approximately 25% of South Africa’s navel oranges and 50% of lemons are produced in the SRV earning more than R1 billion in foreign exchange (SRVM, 2012). Figure 3.5 demonstrates that citrus exports are dominated by valencias (32-38%), navels (27-33%) and lemons (25-29%). Soft citrus and grapefruit make up much smaller proportions in comparison. The general trend shows that exports are increasing, and that the percentage share of each cultivar has remained relatively the same, deviating by only 1-2% each year. Exports increased by approximately 6% per year between 2006-2008. Exports declined in the years 2009 and 2012, but increased by 16% in 2011.

The SRV plantings show noticeable cycles in the planting of navels, valencias and lemons. ‘Planting booms’ occurred between 1996 and 1998 and again in 2002 (Figure 3.6). Plantings each year have increased gradually since 1982. Very little grapefruit has been planted in the last five years. There has also been a gradual decrease and stabilisation of new plantings each year since 2002. This could be as a result of the conversion of the irrigation board into a WUA and the allocation of water licences reducing areas of expansion.



**Figure 3.5 Sundays River Valley citrus exports by selected variety for 2005-2013**

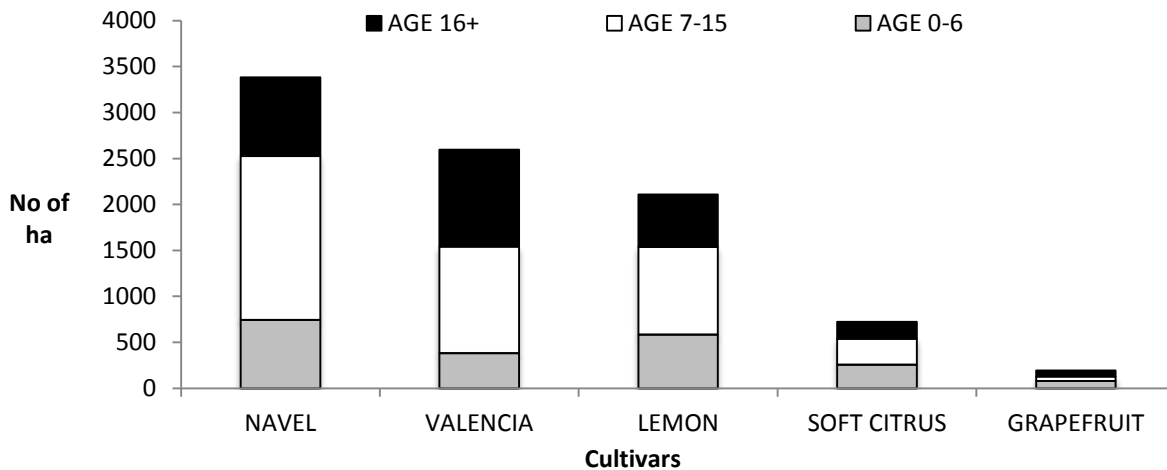
Source: CGASA, (2014)



**Figure 3.6 Sundays River Valley annual hectares of new citrus plantings by selected variety based on a voluntary survey 1982-2012**

Source: Adapted from CGASA, (2014)

Figure 3.7 represents the age structure of the citrus trees in the LSRV in 2012. Navels make up the greatest share of the area (38%) followed by valencias (29%), lemons (23%), soft citrus (8%) and grapefruit (2%). The proportion of young (0-6 years), maturing (7-15 years) and mature (16+ years) trees is 23%, 47% and 30% respectively for the whole area. This also demonstrates that there is a stable age structure of citrus trees in the area, where older trees are being subsequently replaced by younger trees. This also supports the argument that very little expansion is taking place.



**Figure 3.7 Sundays River Valley 2012 citrus tree census data showing age distribution by selected variety, based on a voluntary survey**

*Source:* Adapted from CGASA, (2014)

### 3.4.1 The scope for a water footprint assessment in the lower Sundays River Valley

Hastings & Pegram (2012) recently explored the applicability of WF assessment for the industrial sector in South Africa. The review highlighted that it was important to clarify whether the WF assessment intended to inform the public or private sector, as this would have implications on the goals, scope and methodology (Hastings & Pegram, 2012). Since the LSRV citrus sector is comprised of a number of farms located in a sub-basin that occupy 50.42% of the area and 73% of irrigated area (LSRV WUA, 2013), assessing the water use of the citrus farms provides an indication of the total WF of the sub-basin and also of the production processes within the sub-basin. Therefore, a WF assessment of the citrus farms could provide an evaluation of water use from a sub-basin perspective (public sector) as well as from a production perspective (private

sector). Furthermore, an assessment incorporating the local context is more meaningful when examining sustainability (Hoekstra *et al.*, 2011; Hastings & Pogram, 2012). Conducting a WF assessment that includes both perspectives could also potentially provide more concrete insights into how WF assessments can increase collaboration between stakeholders and the potential trade-offs that exist.

# CHAPTER FOUR:

## METHODOLOGICAL APPROACH, STUDY DESIGN AND RESEARCH METHODS

*“Water footprint assessment is an analytical tool, it can be instrumental in helping to understand how activities and products relate to water scarcity and pollution and related impacts and what can be done to make sure activities and products do not contribute to unsustainable use of freshwater. As a tool, a water footprint assessment provides insight, it does not tell people ‘what to do’ but rather what can be done”*

*- Hoekstra et al. (2011:4)*

Irrigation canals, Sunland

Photo: S.A Munro

## **4.1 Methods and study design**

The WF assessment was the outcome of the formulation of the WF Network. The WF Network aimed to develop and maintain a global shared standard on definitions and calculations for WF assessments, and hence published the first WF assessment manual in 2009, with subsequent revisions in 2011 (Hoekstra *et al.*, 2009a; Hoekstra *et al.*, 2011). As mentioned in the previous chapters a WF assessment as per Hoekstra *et al.* (2011), is divided into four stages: goals and scope, accounting, sustainability assessment and response formulation (Hoekstra *et al.*, 2009a; 2011). The WF assessment is said to provide structure to the WF by providing scientifically robust guidelines for fairer comparisons to be made between the ever-increasing number of studies (Hoekstra *et al.*, 2011; Zhang *et al.*, 2013). This study follows the terminology and methodology as specified by the WF assessment manual for the WF scope, accounting and policy response phase (Hoekstra *et al.*, 2011). For the sustainability phase, the WF assessment manual provides only a guideline for assessing the sustainability of a WF (particularly for assessing economic and social sustainability) and there have been limited applications. Additionally the economic indicators discussed in chapter two are used to evaluate the economic sustainability of the water footprint.

### **4.1.1 Study design**

In economics, case studies are often used to investigate the structure of a given industry or region (Yin, 1994). This study serves to provide a practical example of a WF assessment for the citrus sector within the LSRV. The same methodology could be applied to another sector in a different area providing the same information within a different context. A mixed methods approach was adopted, which includes the combined collection and analysis of both quantitative and qualitative techniques (Creswell & Clark, 2007). Mixed method research is defined as multi-trait or multi-method that integrates or combines methods through triangulation (Campbell & Fiske, 1959; Steckler *et al.*, 1992; Morse, 1991). As a variety of data was required, a mixed method approach allowed for the collection of both qualitative and quantitative data in order to support and inform the research objectives.

Quantitative methods included descriptive statistics that provided a number of methods and techniques by which to describe and summarise data (van Lill & Grieve, 1990). Nominal, ordinal, and interval scales were used to distinguish, rank, and compare CWU, WFs, and other relevant data. Data was presented in the form of various tabulation and graphic representations, which provided measures of central tendencies, variability, frequencies and percentages. Qualitative methods included open-ended questions from interviews and the analyses of documents, public records and other relevant literature.

Quantitative methods included descriptive statistics that provided a number of methods and techniques by which to describe and summarise data (van Lill & Grieve, 1990). Nominal, ordinal, and interval scales were used to distinguish, rank, and compare CWU, WFs, and other relevant data. Data was presented in the form of various tabulation and graphic representations, which provided measures of central tendencies, variability, frequencies and percentages. Qualitative methods included open-ended questions from interviews and the analyses of documents, public records and other relevant literature.

## **4.2. Goals and scope**

### **4.2.1 Scope of water footprint accounting**

The first phase of conducting a WF assessment as per Hoekstra *et al.* (2011) includes establishing the goal and scope of the assessment. WF studies can be applied to a number of different contexts and it is important to specify the purpose and scope of analysis (Hoekstra *et al.*, 2011). Given that the objectives of this study were to examine the WF of citrus production in the LSRV, the scope of the study pertained specifically to citrus production in the area, examining blue, green and grey WFs. Water use relating to operations, overheads and transport was excluded. This is because studies have demonstrated that operational and overhead WFs are very small in comparison to crop production (Salmoral *et al.*, 2010; Ercin *et al.*, 2011; Ercin *et al.*, 2012). The study did however include evaporation losses that occurred due to irrigation inefficiencies in micro and drip irrigation systems. Consumptive water use termed by the WF assessment manual refers to water that is evaporated, incorporated into the product and does not return to the same

catchment area or period (Hoekstra *et al.*, 2011). Although, some of this inefficient water is lost through percolation and is not “consumptive” in the sense, some is evaporated and is “consumptive”. It was deemed important to include irrigation efficiencies from the irrigation systems, as this is water to be transported or available in order to meet crop requirements and is not available for other uses at that specific point in time.

The study aimed to identify potential water related risks within the LSRV and establish strategies to reduce water footprints, thus a high degree of spatial and temporal detail was required. WFs were subsequently calculated for the different citrus varieties including navels, valencias, soft citrus and lemons. Navels included both early, mid, and late season varieties; soft citrus included novas, clementines and satsumas, and valencias included midnights and delta varieties. Grapefruit was excluded as farmers are slowly phasing it out or have already uprooted the trees (CGASA, 2014; SRCC, 2014)

WF's can and do vary across time. Therefore, the study aimed to look at the WF using long term-average data<sup>6</sup> (LTA). Seasons occurred from August to July from when the initial crop development stage was estimated to start (Allen *et al.*, 1998; Addo Research Station (ARS), 2014). The study also aimed to determine the potential effects of climate change on the WF; therefore, the last 5 seasons (2009-2013) were categorized based on temperature-rainfall combinations using the Köppen-Geiger climatic system into different climatic zones (Strahler & Strahler, 2002). The LTA, 2009, 2010 and 2013 were all classified as dry and hot, and 2011 and 2012 were classified as mild and humid with hot summers (Strahler & Strahler, 2002). Subsequently, 2009 was chosen, as the dry season and 2011 was chosen as the wet season as they had the lowest and highest rainfall respectively. Calculating and comparing WFs over humid and dry years was deemed to serve as a proxy to determine the effects of long-term climatic changes on water usage.

---

<sup>6</sup> Long-term average data was a five-year average based on the seasonal years 2009-2013, unless otherwise stated.

#### 4.2.2 Scope of water footprint sustainability assessment

As sustainability can be measured from a number of aspects (environmental, economic and social), a variety of impacts (primary and secondary) and can be assessed for each type of WF (blue, green and grey), it is important to define the scope of the assessment (Hoekstra *et al.*, 2011). The WF was conducted for essentially a process within a sub-catchment, in this case, citrus production. To assess whether a process is sustainable one needs to ask:

1. Is the process situated in a river basin where the overall water footprint is unsustainable?
2. Is the process unsustainable independent of its geographic context? (i.e. Can the WF be reduced at an acceptable societal cost?) (Hoekstra *et al.*, 2011).

Since one cannot assess the sustainability of a process without knowing the sustainability of the broader context and that a WF of the Sundays River basin or even sub-basin had not been conducted, it was important to try to establish an idea of current availability of water versus usage within the area. Examination of available data from the WUA, reports, newspapers and previous studies, therefore, were used to determine water scarcity, whether environmental flow requirements were being met and the pollution levels within the sub-basin along with blue and grey WF indicators. Further, evapotranspiration between citrus and natural vegetation within the area was examined. A discussion of a number of current social and economic indicators for the basin is provided to gauge for potential economic and social hotspots. The use of valuation methods such as marginal product values is also discussed.

In terms of examining the sustainability of the citrus sector independent of its geographic context, the WF was expressed in terms of a number of partial productivity indicators including employment and net income. Total factor productivity (TFP) was also examined as well as economic land productivity (ELP). These indicators provided a means to decipher which cultivars were providing more nature, cash and jobs per water use (Aldaya *et al.*, 2010b; Garrido *et al.*, 2010). Furthermore, WF's were compared to global and local benchmark values for citrus cultivars.

### 4.3 Data collection and sources

Primary and secondary data were used in a complementary approach to satisfy data requirements. Where secondary data was not available only then was primary data used. Table 4.1 provides a summary of all data and information collected and sourced through the execution of this project.

**Table 4.1 Data inputs and sources**

	<b>Input</b>	<b>Data Source</b>
<b><i>Climate data</i></b>	Average monthly max and min temperatures (2001-2013)	The Agriculture Research Council Institute for Soil, Climate and Water (ARC-ISCW), SRCC
	Total monthly rainfall (1969-2013)	LSRV WUA
	Wind speed, humidity, rainfall events (2008-2013)	ARC-ISCW, Addo Research Station
<b><i>Crop characteristics</i></b>	Crop-coefficients, yield response	SAPWAT 3.0
	Crop stages	Allen <i>et al.</i> (1998) and ARS, (2014)
	Rooting depths	Farm interviews
	Critical depletion fraction	Farm interviews
	Crop height	Farm interviews
	Tree census	CGASA, (2014)
	Harvesting dates	Local citrus company
	Soil texture	Farmers interviews
<b><i>Irrigation</i></b>	Irrigation practices	LSRV WUA, 2013 and farmers interviews
	Water usage	LSRV WUA, 2014; DWAF, 2005
<b><i>Grey water footprints</i></b>	Leaching-run off fractions	Franke <i>et al.</i> (2013)
	Soil application rates	Local citrus company
	$C_{max}$	DWAF, (2006a-c), DWS, (2011)
	$C_{nat}$	DWAF, (2006a-c), DWS, (2011)
	Water quality data	DWS, (2014)
<b><i>Yield, Employment, Budgets</i></b>	Yield	Local citrus company
	Employment	Farm interviews and companies
	Crop enterprise budgets	Local citrus company
	Export and local market price	Farm interviews
<b><i>Benchmarks</i></b>	Global benchmarks	Mekonnen & Hoekstra, (2013)
	South African and Eastern Cape WFs	Mekonnen & Hoekstra, (2010b)

#### **4.3.1 Secondary data collection**

Secondary data used in the study was obtained from a number of sources. Firstly, the local citrus company (SRCC), research stations (Addo) and institutes (ARC-ISCW), CGASA and the LSRV WUA were consulted as to what relevant information and records were available. Furthermore, experts and knowledgeable individuals from the citrus corporations and research institutes were approached to learn more about the study area and the intricacies of citrus farming that required consideration. Secondary information was also obtained from databases including the WF Network, government departments including the DOA and DWA. A number of literary sources (Outspan, 2004; Smith, 2006; Coetzee, 2007) were also consulted such as Outspan citrus research documents and various studies commissioned by the Water Research Commission (Conradie, 2002; Taylor & Gush, 2014).

Secondary information is said to enhance the efficiency of primary research efforts (Stewart & Kamins, 1993). Secondary data is also less expensive and time consuming and can provide higher quality data as records are often kept over long periods and are more representative of areas or populations (Stewart & Kamins, 1993). Secondary data is also useful for providing data for comparisons. Nearly every organisation generates data as part of their operations and this provides a starting point that a researcher can seek to go beyond (Stewart & Kamins, 1993). Secondary information was checked for inconsistencies and validated where possible. For example, climate data comparisons were made between three weather-monitoring points in the area and outliers were noted and queried.

#### **4.3.2 Primary data collection**

Where secondary data was unavailable, supplementary research in the form of interviewing farmers was conducted to provide information that was more specific, primary data. A list of 35 farmers and their relevant contact details was obtained for the area. A pilot questionnaire (approved by the Rhodes University ethics committee) and interview was first conducted on two local farmers in October 2013 to determine whether information was relevant, clear and comprehensive. This was followed by subsequent revisions to the questionnaire. Farmers were

initially emailed the questionnaire in December 2013, but due to the lack of response, farmers were subsequently telephoned and a face-to-face interview was arranged.

#### ***a) Questionnaire design***

The questionnaire was divided into three sections. The first section-included questions regarding farm size and practices, soil applications, soil types, storage dams, tree census data, yield and market prices for different cultivars. The second section pertained to irrigation practices and irrigation records. The final section asked farmers to list any concerns for the future that may affect their profitability and their opinions about future concerns regarding water quantity and water quality. The original questionnaire can be found in Appendix 6. This questionnaire was revised once secondary sources of information became available and questions were removed so the questionnaire could be reduced in length.

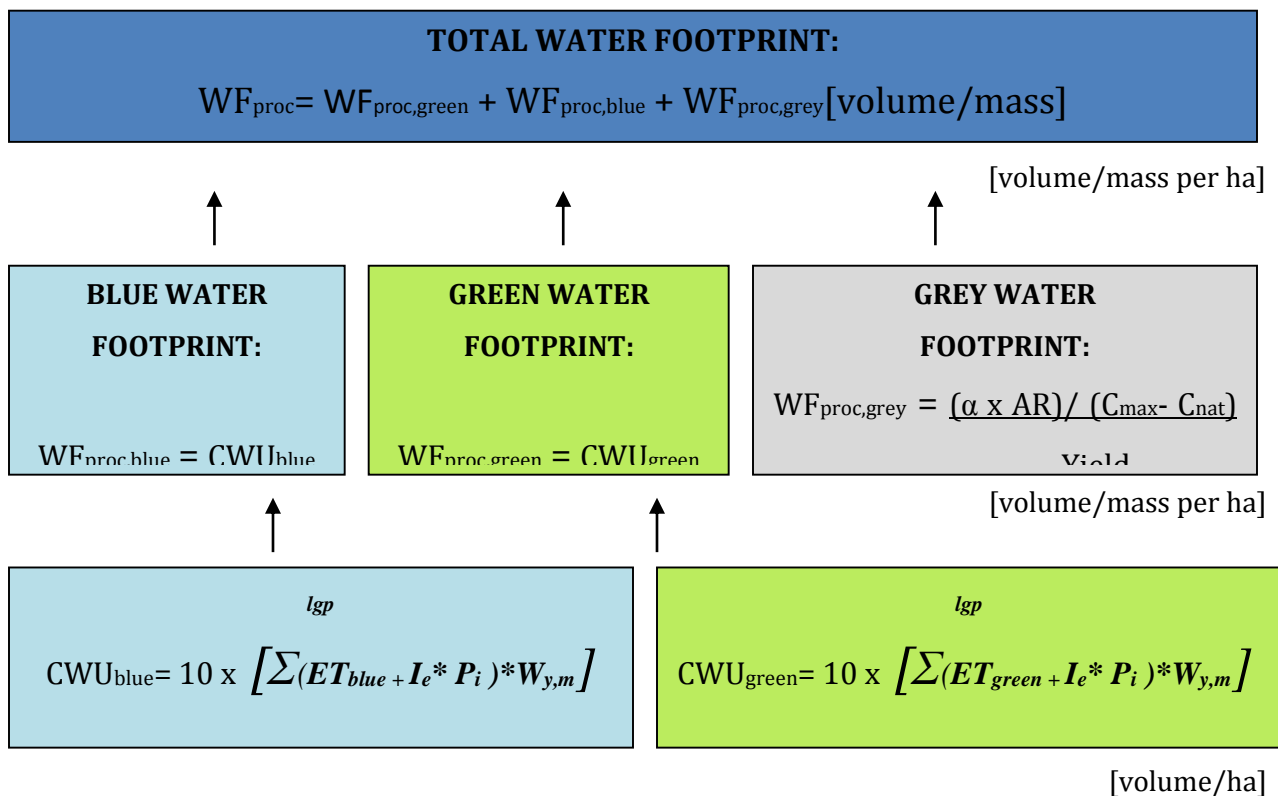
#### ***a) Sample and representation***

Interviews took place from February – September 2014. Ten farmers and two production units (comprised of four and six farms respectively) were interviewed or provided some information relevant for the study. The two production units represented 502.6 and 280 hectares of citrus respectively. Each unit was taken to be representative of one farm despite being comprised of a number of smaller farms. This was because information was provided as an average of all the smaller farms. Twelve farms ( $n= 12$ ) were included, with a cumulative total of approximately 3100 hectares, which included windbreaks. This provided a representation of approximately 25% of the area allocated to citrus production in the area. The remaining farmers could not be contacted or were not interested in participating in the study. The response rate out of the initial 35 farmers was 34%. Where answers within the questionnaire were not answered or certain information was not provided by a farm this lead to a sample size lower than twelve. Therefore, the sample size for certain results is indicated to show a lower representation. The data nonetheless was deemed sufficient to meet the objectives of the study.

Most information was not available off hand to farmers; therefore, office administration or the farmer himself would later provide the remainder of the information either by filling out the remainder of the questionnaire or sending through raw records. Only eight farms completed and provided most of the information required in the questionnaire. This implied that farmers either did not keep such detailed records, were simply too busy or were not comfortable with providing them. Nonetheless, the information gathered was deemed sufficient when supplemented with secondary sources.

#### 4.4 Water footprint accounting

According to Hoekstra *et al.* (2011), the total WF of the process of growing trees ( $WF_{proc}$ ) is the sum of green, blue and grey components. The WF is expressed in units per product, which in this instance is  $m^3$  per ton of each citrus cultivar. Figure 4.1 illustrates the components used to calculate the blue, green and grey WF as per Hoekstra *et al.* (2011).



**Figure 4.1: Blue, green and grey water footprint calculations**

Source: adapted from Hoekstra *et al.* (2011) and Salmoral *et al.* (2010; 2011)

Both green and blue components in the process of growing a citrus tree are calculated as Crop Water Use (CWU) divided by crop yield (ton/ha). CWU ( $\text{m}^3/\text{ha}$ ) is calculated as the accumulation of daily evapotranspiration ( $\text{ET}_c$ , mm/day) throughout the growing period of the crop. It is the water needed by a crop for evapotranspiration (ET) under ideal growth conditions (Hoekstra *et al.*, 2011).  $\text{ET}_{\text{green}}$  represents evapotranspiration of green water, and  $\text{ET}_{\text{blue}}$  evapotranspiration of blue water. Factor 10 is representative of the conversion of water depth in millimetres (mm) into water volumes per land surface ( $\text{m}^3$ ) and  $l_{gp}$  is the length of the growing period in days (Hoekstra *et al.*, 2011).

To obtain an average WF of each cultivar factors such as age, soil texture and irrigation method were taken into consideration to account for the varying water requirements that can be influenced by these factors. The method by Salmoral *et al.* (2010; 2011) was adopted to factor in the proportion of each textural class ( $P_i$ ) to account for all soil textures within the area. The WF assessment recommends that in the case of perennial crops, consideration needs to be given to the average yield over the full lifespan of the crop, as yields will differ depending on age (Hoekstra *et al.*, 2011). Citrus trees can live up to 20- 30 years, which can make it difficult to obtain yields over their entire lifespan. CWU was therefore calculated for young (0-5 years) and mature (6 years +) citrus varieties and then weighted according to proportion of young ( $W_y$ ) and mature ( $W_m$ ) trees of each cultivar based on tree census data for the area. Furthermore,  $\text{CWU}_{\text{blue}}$  was calculated for both drip and micro systems and weighted according to the proportion by which they are found within the area. Thus, an average  $\text{CWU}_{\text{blue,green}}$  was calculated for the area taking into account soil, age and irrigation system.

CWU was calculated for navel, valencia, soft citrus and lemon varieties for an average year (LTA), a dry year (2013) and a wet year (2011). CWU for each cultivar was divided by their respective yield for that season. A mean yield between novas, satsumas and clementines was used to represent soft citrus cultivars.

#### 4.4.1 Blue and green water footprints: calculating crop water use

Crop water requirements (CWR) are the sum of soil evaporation and plant transpiration, collectively known as evapotranspiration ( $ET_c$ ) (Allen *et al.*, 1998). Measuring  $ET_c$  directly<sup>7</sup> seldom occurs and is expensive. A number of methods and models have been developed to measure CWR indirectly because of the difficulty, time constraints and cost in obtaining accurate site-specific data evapotranspiration data (Doorenbos & Pruitt, 1977; Hoffman *et al.*, 1982). There are a number of models and empirical formulas to derive  $ET_c$  based on climatic data and crop characteristics. The CROPWAT model (Smith, 1992) developed by the FAO is the most commonly applied method used in WF calculations. However, the South African Water Research Commission has also established a decision-making procedure for the estimation of crop water requirements called SAPWAT 3.0. SAPWAT 3.0 aims to cater specifically for Southern African irrigation and water requirements (Van Heerden *et al.*, 2009).

Both CROPWAT 8.0 and SAPWAT 3.0 employ the use of the FAO Penman-Monteith equation, which is the current globally accepted standard for calculating evapotranspiration (Allen *et al.*, 1998; Steduto *et al.*, 2009). The Penman-Monteith method is said to have a high accuracy of predicting  $ET_c$  for a range of locations and climates and makes provision for circumstances when data is limited or not available (Allen *et al.*, 1998). The Penman-Monteith equation calculates a reference ET ( $ET_0$ ) of a hypothetical grass surface area using longitude, latitude, altitude, air temperature, humidity, radiation and wind speed under optimal conditions (Appendix 1.2). The reference  $ET_0$  is then multiplied by a crop-coefficient ( $K_c$ ) value to obtain either daily, weekly, ten-day or monthly  $ET_c$  under optimal conditions (equation one). The  $K_c$  value accounts for physical and physiological differences such as crop height, albedo, aerodynamic properties or canopy resistance and soil evaporation between a specific crop and the reference crop (Allen *et al.*, 1998) (Appendix 1.2). Crop coefficients can be calculated as a single crop coefficient (equation one) or separated into a basal crop ( $K_{cb}$ ) and a soil evaporation coefficient ( $K_e$ ) (equation two) CROPWAT

---

<sup>7</sup> Other direct methods include the pan method, lysimeters, micrometeorological instruments such as the Eddy covariance technique and a scintillometer device and soil evaporation and transpiration combination methods such as the heat pulse velocity technique (heat radio method) (Taylor & Gush, 2014).

8.0 utilizes the single crop coefficient approach (equation one), whereas SAPWAT 3.0 utilizes the dual coefficient approach (equation two) (see Appendix: Figure 1.2b).

$$ET_c = (ET_0) \times (K_c)[mm.d^{-1}] \quad (1)$$

$$ET_c = (ET_0) \times (K_{cb} + K_e)[mm.d^{-1}] \quad (2)$$

#### 4.4.2 Models for calculating crop water use: SAPWAT 3.0 versus CROPWAT 8.0

This study used the SAPWAT 3.0 model to estimate blue and green CWU. CROPWAT 8.0 is the FAO software for irrigation scheduling (Allen *et al.*, 1998) and has been utilised in a number of WF studies to calculate CWU. CROPWAT 8.0 is the recommended model within the WF assessment manual to estimate both green and blue crop water requirements (Hoekstra *et al.*, 2011). SAPWAT 3.0 also fully incorporates FAO methodologies. Both models have similar objectives and can be used to estimate reference  $ET_0$ , estimate crop water and irrigation requirements under both rain-fed and irrigated conditions to assist with design and management of irrigation schemes. Preliminary calculations revealed a similar range of results between the two models however,  $ET_{blue}$  estimates were greater in CROPWAT 8.0 than SAPWAT 3.0.  $ET_{green}$  results produced in CROPWAT 8.0 had less variation across the different climatic years. Differences regarding effective rainfall were observed due to CROPWAT 8.0 estimating effective rainfall prior to calculating irrigation requirements. The recommended and most commonly applied method for estimating effective rainfall in CROPWAT 8.0 is The USDA Soil Conservation Service (Aldaya & Llamas, 2008; Hoekstra *et al.*, 2011). SAPWAT 3.0 calculates effective rainfall based on the soil profile at the time of rainfall, it does not estimate the rainfall before calculating  $ET_c$  as CROPWAT 8.0 does (Van Heerden, 2014). Based on the number of rainfall events for a given month, SAPWAT 3.0 calculates  $ET_{green}$  on a randomised basis. Although a number of problems with SAPWAT 3.0 were encountered, DWAF have indicated that the SAPWAT 3.0 computer program for determining annual irrigation requirement is the method to be used in South Africa (Van Heerden *et al.*, 2009). SAPWAT 3.0 was therefore the model chosen by which to estimate irrigation requirements due to the fact it was developed for the sole purpose of providing a water-planning tool specifically for South Africa.

It is important to note that the aim of this thesis was not to test, compare or validate models such as SAPWAT 3.0 and CROPWAT 8.0. Both methods provide means for estimating  $ET_c$ , and both have their limitations. What is important was that they provided an estimate or representation of potential green and blue water.

#### **4.4.3 Modelling crop water use: SAPWAT 3.0 input and output data**

SAPWAT 3.0 uses a variety of data and parameters to estimate irrigation requirements. Inputs include: climate data, crop data, type of irrigation system and soil data (Appendix 1 and 2). Outputs simulated include reference  $ET_0$  (see Appendix: Figure 1.2b), effective rainfall (Appendix 1.2 and 2.1) and an irrigation schedule (Appendix 1.3) Appendix: Figure 1.3. SAPWAT 3.0 incorporates different irrigation systems and their efficiencies to calculate crop water requirements (Appendix: 1.3).

##### ***a) Climate data***

Mean monthly climate data was manually imported into SAPWAT 3.0 in order to calculate  $ET_0$  and effective rainfall. Maximum, average and minimum temperature ( $^{\circ}C$ ), humidity (%), wind-run (km/day) and radiation ( $MJ.m^2/day$ ) was obtained for Kirkwood, Dunbrody and Addo for the period January 2008 to December 2013 from ARC-ISCW. An average climate for the three areas was used as a representative climate for the area (based on Figure 3.2) and imported into SAPWAT 3.0 along with longitude, latitude, altitude and mean annual precipitation (MAP) (see Appendix 1.1). Data was imported for the 2009-2013 seasons, with each season starting in August and ending in July. The LTA season was computed using thirteen-year average (2000-2013) temperature data obtained from the SRCC and the six-year average (2009-2013) humidity, wind-run and radiation data obtained from the ARC-ISCW. Some months where data was unavailable or unreliable because of equipment failures, an average of the remaining two locations was used, or in the case of Addo, missing data was supplemented with climate data supplied from the Addo Research Station.  $ET_0$  was calculated on a monthly-time step.

Rainfall data was obtained from the LSRV WUA for Kirkwood, Sunland, Hermitage and Addo. An average for all four areas was used as the representative rainfall for the area. The number of monthly rainfall events was based on ARC-ISCW rainfall data. Effective rainfall was calculated by maximising rainfall by not refilling the soil profile with each irrigation application so that there is always room to store rainwater. Effective rainfall was determined by the space available in the soil profile at the time rain events occurred (Van Heerden, 2014). Climate data inputs for SAPWAT 3.0 can be found in Appendix 1.1

## ***b) Crop data***

### *Crop coefficients*

As a crop develops ground cover, crop height and leaf area change,  $K_c$  will therefore vary during various growth stages. Only three  $K_c$  values are required during the growing period of a crop:  $K_{c\text{ini}}$  for the initial stage,  $K_{c\text{mid}}$  for the mid-season stage and  $K_{c\text{end}}$  for the late season stage (Allen *et al.*, 1998). Evergreen trees such as citrus will have different crop-coefficients during different stages of their lifespan (e.g. young and mature). SAPWAT 3.0 provide  $K_c$  values for citrus that were said to be slightly closer to South Africa's situation than average  $K_c$  values provided by Allen *et al.* (1998) (Van Heerden, 2014) (Appendix 1.2). SAPWAT 3.0 provides  $K_c$  values for mature trees under stress because of salinity or bad water management (below average), normal trees (average) and very luxurious growth (above average) (Van Heerden, 2014). Below average  $K_c$  values were used for all mature cultivars, not because of bad management but because they were similar to that of previous studies in the Eastern and Western Cape (Green, 1985; Gush & Taylor, 2014). Previous studies in similar areas estimated  $K_c$  values to range between 0.45 (*ini*), 0.55 (*mid*) and 0.6 (*late*), and  $k_{cb}$  between 0.25 and 0.55 for valencias and 0.6 (*ini*), 0.3 (*mid*) and 0.8 (*late*) for navels values (Green, 1985; Gush & Taylor, 2014).  $K_c$  values for young varieties were calculated by halving  $K_c$  values for mature citrus trees. This was based on research that shows young trees use approximately half the amount of water that mature trees do (du Plessis, 1989 in Outspan, 2004).

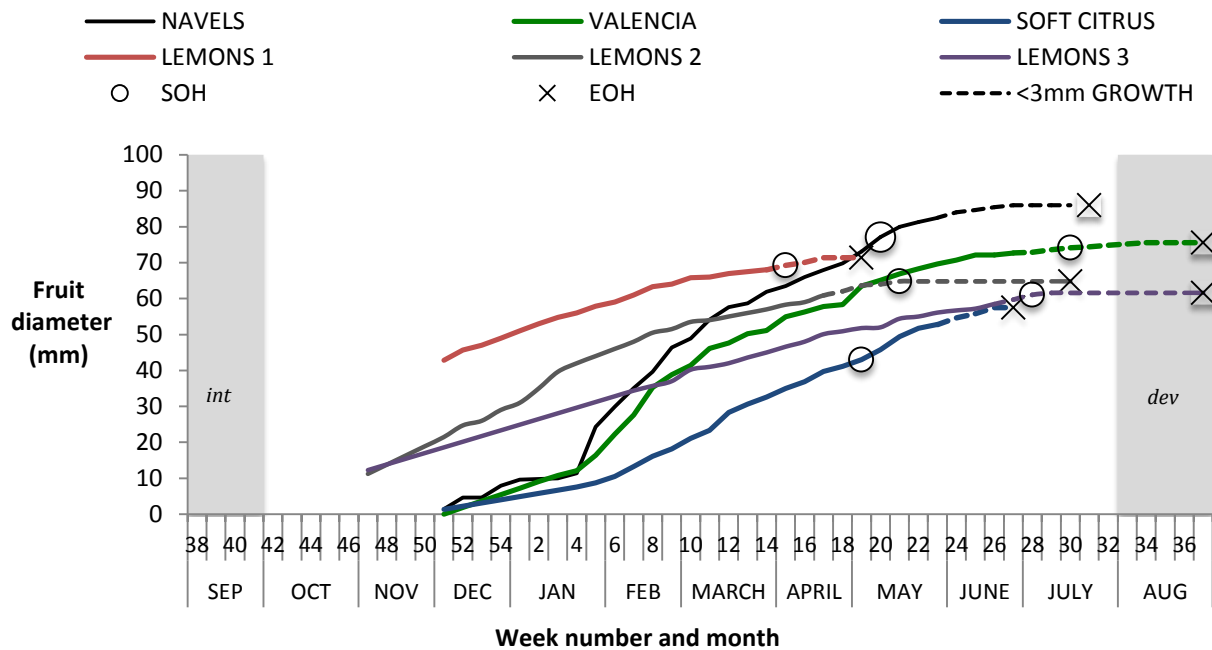
SAPWAT 3.0 adapts  $K_c$  values according to canopy cover and climatic factors. As citrus canopy cover remains relatively similar and has stomatal control, which occurs during mid-season stages to reduce transpiration, the  $K_{cb}$  curve inverts itself. This means that mid-season stages have lower  $K_c$  values than initial and late stages. This same pattern was exhibited with  $K_c$  values provided by Allen *et al.* (1998) for citrus trees with varying crop heights, canopy covers and ground cover.

### *Crop development stages*

In coherence with Allen *et al.* (1998), SAPWAT 3.0 utilises the four-stage crop cycle approach to distinguish the different growth stages of a plant (Van Heerden *et al.*, 2009). The four stages of crop development for perennials, such as evergreen citrus trees, are described below with a general guideline for the length of each stage. The lengths of the crop development stages provided by Allen *et al.* (1998) are only indicative of general conditions and can vary substantially from region to region. It, therefore, is strongly recommended to obtain appropriate local information.

- *The initial stage:* Time when initiation of new leaves occur, this replaces the planting date in perennial crops (60 days).
- *The crop development stage:* Leaf area index reaches three to effective full cover or the initiation of flowering (90 days)
- *The mid-season stage:* From full effective full cover or initiation of flowering towards the start of maturity or senescence, where leaves drop or browning of fruit (120 days)
- *Late season stage:* Start of maturity until harvest (95 days) (Allen *et al.*, 1998)

Citrus growth curves for navel, valencia and clementines were obtained from the ARC for the year 2000 and for lemons for the year 2004 (Figure 4.2). Start of harvest (SOH) and end of harvest (EOH) dates for each cultivar for the year 2013 were provided by local citrus companies (Figure 4.2). Based on the growth curves, local information from farmers, harvesting dates and the guidelines for the duration of each stage in citrus trees provided by FAO Irrigation and Drainage Paper No. 24 crop stages for each cultivar were estimated (Table 4.2).



**Figure 4.2 Citrus growth curves and average start and end of harvest dates for lemons, navel, valencia and clementine cultivars**

Source: own elaboration based on Allen *et al.* (1998) and ARS, (2014)

Initial leaf flush of all varieties according to interviews with farmers, to take place around early August with flowering occurring in September or early October, depending on climatic factors. Therefore, planting date was taken from the 1 August and mid-season stage from the 1 October for all cultivars. Some cultivars grow at a faster rate than others and mature more quickly. Lemons flower have three sets of fruit throughout the year. Therefore, mid and late season crop stages were adjusted according to characteristics exhibited by each cultivar. The duration of the mid-season stage for each cultivar was adjusted according to either the SOH date or where fruit growth reached less than 3mm. For lemons, end of mid-season stage was calculated according to the third fruit set. The late season stage was subsequently taken from SOH date or where fruit growth reached less than 3mm to date of initial leaf flush in August.

**Table 4.2 Derived crop-growth stages for navel, valencia, lemon and soft citrus Cultivars**

CULTIVAR	INITIAL (L <sub>INT</sub> )	DEV (L <sub>DEV</sub> )	MID (L <sub>MID</sub> )	LATE (L <sub>LATE</sub> )	TOTAL
NAVELS	30	30	225	80	365
VALENCIA	30	30	260	45	365
LEMON	30	30	260	45	365
SOFT CITRUS	30	30	215	90	365

Source: own elaboration

### *Crop characteristics*

Other crop information required for SAPWAT 3.0 included crop height, rooting depth, allowed depletion, yield response ( $K_y$ ), salinity threshold, sensitivity values and leaf resistance values. Crop heights were based on tree measurements obtained from the Addo Research Station. Rooting depth and allowable depletion of available soil moisture were based on probe readings. The remaining factors were based on default information provided by SAPWAT 3.0 (see Appendix: 1.2 and 1.3).

### ***b) Soil data***

SAPWAT 3.0 requires field capacity, wilting point, total evaporative water, readily evaporative water, effective depth, evaporation depth and infiltration rate to estimate irrigation requirements. These soil water characteristics and evaporation parameters can be derived from soil types. Allen *et al.* (1998) provide soil water characteristics and evaporation parameters for a number of loam, clay, sand and silt soil types. Calculations were therefore based on typical values provided by Allen *et al.* (1998) for the soil types found within the study area (see Appendix 1.3).

Soil types for the study area were derived from primary data, as secondary high-resolution maps of soil data for the area could not be obtained. Data was provided by the primary data from

farmers and production units (n=12) across a total of 2057 hectares was thus used as representative of the proportion of sand, clay and loam soil types in the area (Table 4.3).

**Table 4.3: Mean percentage of soils across farms (n=12)**

	TOTAL HECTARES	p <sub>i</sub>
Loam	697	0.3
Sandy loam	777	0.4
Clay	333	0.2
Sand	55	0.1
<b>TOTAL</b>	<b>2057</b>	<b>1</b>

Source: farmer interviews

### **c) Irrigation schedules**

The irrigation requirement is the minimum amount of irrigation that together with effective rainfall will satisfy the total crop water requirement for the achievement of the target yield (Green, 1985). Starting from field capacity, daily levels of soil water depletion are calculated by accumulating daily evapotranspiration losses. Recorded daily rainfall is used throughout to adjust the level of soil water depletion. As rainfall and rainfall events were imputed on a monthly basis SAPWAT 3.0 calculates rainfall events on a randomised basis based on the number of the number of rain events for that specific month (Van Heerden, 2014). When depletion reaches the permissible maximum value, which in this case was 50% the application of the appropriate irrigation amount becomes necessary. SAPWAT 3.0 includes irrigation systems and on-farm water distributions. Calculations were conducted for drip and micro sprayers using the default efficiencies provided by SAPWAT 3.0 (Appendix 1.3).

It was assumed that crop requirements were met and that no crop stress occurred. Blue CWU was obtained from gross irrigation requirements for each cultivar; this included the amount of water that had to be made available to match evapotranspiration and any losses that resulted due to inefficiencies of the irrigation system as discussed in section 4.2.1.

#### 4.4.4 Grey water footprints

The grey WF is calculated as the volume of water required to dilute pollutants so that the quality of water remains above ambient water quality standards (Franke *et al.*, 2013). Grey water is calculated as the critical load divided by the difference between the maximum acceptable concentration ( $C_{max}$ ) and the natural background concentration ( $C_{nat}$ ) (Hoekstra *et al.*, 2011; Franke *et al.*, 2013). The critical load is the leaching-runoff fraction ( $\alpha$ ) multiplied by the application rate (AR) of soil applications per hectare (ton/ha) (see Figure 4.1).

Grey WFs were calculated for navel, valencia, soft citrus and lemon varieties for an average year (LTA), a dry year (2013) and a wet year (2011) by dividing grey water by their respective yields obtained by a citrus company in the area. The grey WF is calculated using the most critical pollutant, which requires the highest ambient volume of water to assimilate it for each cultivar (Hoekstra *et al.*, 2011).

As all active ingredients were direct soil applications, grey WF calculations pertained to diffuse sources of water pollution. A tier one approach was adopted, and guidelines for calculating the leaching runoff fraction, maximum acceptable concentration and natural concentration followed the methods set out in the grey WF tier one supporting guidelines (Franke *et al.*, 2013). Although a tier one approach does not describe the interaction and transformation of chemical substances along the different flow paths (like a tier two and three approaches), it is adequate in demonstrating a rough estimate of grey water (Franke *et al.*, 2013).

##### **a) Application rates**

The study aimed to take into account local ARs of fertilizers, pesticides, herbicides and insecticides, however the only soil applications applied to the citrus cultivars were Urea Ammonium Nitrate (UAN) (32% N) or Ammonium Sulphate (AS) (21% N, 24% S), Superphosphate (SP) (8.3% P), gypsum and humic acid. All other fertilizer, pesticides and herbicides were applied in the form of a foliar spray and not directly applied to the soil. Programs only vary slightly from year to year, therefore application rates were assumed the same across LTA, wet and dry years.

ARs used were based on fertilizer programs supplied by the various corporations and distributed to the farms for the 2013 and 2014 seasons for each cultivar (see Appendix 4.1).

Gypsum and humic acid were excluded from the calculations, as these are considered organic substances and were assumed not to pose any threat to water pollution (Grosskopf, 2004). Sulphate was also excluded due to lack of confidence in estimating the leaching-run off fractions. Ammonia ( $\text{NH}_3$ ), ammonium ( $\text{NH}_4$ ), nitrite ( $\text{NH}_2$ ) and nitrate ( $\text{NH}_3$ ) are all major components of inorganic nitrogen (DWAF, 1996a). The AR for nitrogen load was calculated as the sum of all applications containing nitrogen (regardless of the chemical state that they were applied). Total inorganic phosphate, orthophosphates and total dissolved phosphorus (including organically bound phosphorus and all phosphates) all determine phosphorus concentrations (DWAF, 1996a), therefore application of SP pertained to the AR of phosphorus.

#### **a) Leaching runoff fractions**

The leaching runoff fraction is the percentage of a chemical substance applied to soils that reaches surface water systems through runoff or groundwater systems due to leaching (Hoekstra *et al.*, 2011; Franke *et al.*, 2013). Leaching runoff fractions are dependent on factors such as the physical and chemical properties of the contaminant, environmental factors and agricultural management practices (Franke *et al.*, 2013).

The leaching runoff fractions used in this study were based on the tier one supporting guidelines and supplemented with local site-specific qualitative information. These guidelines provide simple tables and equations that can be used to derive the leaching runoff of nitrogen, phosphorus, metals and pesticides. Tables provide specific criteria used to score ( $s$ ) and weight ( $w$ ) different influencing factors ( $i$ ) of the leaching runoff fraction (Franke *et al.*, 2013). Scoring factors ( $s_i$ ) denote how high or low the leaching runoff potential is and the weight ( $w_i$ ) represents the importance of the factor. Influencing factors included environmental factors such as soil and climate and agricultural practices including application rates, plant uptake and management practices. Local information obtained from interviews and secondary sources were used to score factors when the information was available. When information was not available, or specific

information regarding a chemical was required, an average score value of 0.5 was used. Tables illustrating the specific criteria used to score and weight the influencing leaching runoff fractions for nitrogen and phosphorus can be found in Appendix 4.2

The leaching runoff fractions ( $\alpha$ ) for nitrogen and phosphorus were calculated using equation three. The equation is based on the notion that the value of  $\alpha$  will lie between the minimum ( $\alpha_{min}$ ) and maximum ( $\alpha_{max}$ ) leaching runoff fractions for each substance. If the scores for all influencing factors are the lowest ( $s=0$ ) the resultant leaching fraction will be equal to the minimum  $\alpha$ , and *vice versa* if factor scores are the highest ( $s=1$ )

$$\alpha = \alpha_{min} + \left( \frac{\sum_i S_i \times w_i}{\sum_i w_i} \right) \times (\alpha_{max} - \alpha_{min}) \quad (3)$$

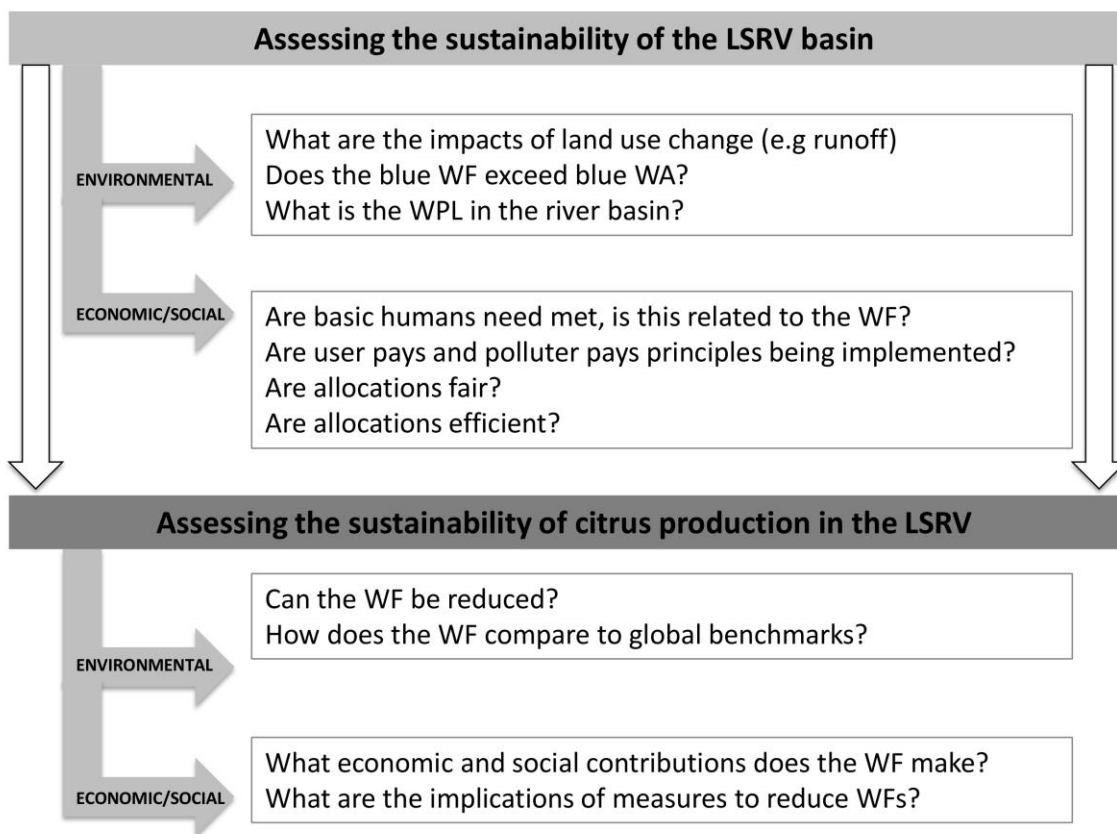
### ***c) Maximum acceptable and natural background concentration***

The natural background concentration ( $C_{nat}$ ) refers to the concentration in the water body that would occur if no anthropogenic disturbances occurred (Hoekstra *et al.*, 2011; Franke *et al.*, 2013). The maximum acceptable concentration ( $C_{max}$ ) refers to the maximum allowable amount of a substance that can occur without harming human or ecological health (Hoekstra *et al.*, 2011; Franke *et al.*, 2013). Since the chemical state of nitrogen varies,  $C_{max}$  and  $C_{nat}$  concentrations for total ammonia (sum of  $NH_4 + NH_3$  concentrations),  $NO_3 + NO_2$  and total inorganic nitrogen were all examined in relation to the AR of nitrogen to determine which would have the greatest impact on water resources. These parameters were chosen based on the fertilisers that were applied. As suggested per the WF assessment manual, local ambient water quality standards were taken into account (Hoekstra *et al.*, 2011). Mackies Eye monitoring point, which is at the headwaters of the Sundays River, was used to obtain an estimate of local  $C_{nat}$  concentrations (Department of Water and Sanitation (DWS), 2014).  $C_{max}$  concentrations were obtained from the South African Water Quality Guidelines (DWA, 1996a-c). Concentrations for phosphorus and phosphate however differed significantly across data sources and natural concentrations of phosphate were higher than concentrations recommended within literature (see Appendix 4.3). Therefore, a number of concentrations were applied and the results examined and discussed but were not included in

the examination of the grey WF due to the great range of discrepancies. The grey WF therefore refers only to nitrogen based pollution.

#### 4.5 Water footprint sustainability assessment

The sustainability assessment aimed to place the WF of the citrus sector in context of the basin to determine potential impacts and contributions of current water use. The sustainability assessment aimed to answer a number of questions pertaining to water use. These questions are summarized in Figure 4.3.



**Figure 4.3 Questions relating to the sustainability of water use by the LSRV citrus sector**

Source: own elaboration based on Hoekstra *et al.* (2011)

#### 4.5.1 The sustainability of the LSRV basin

In order to assess the sustainability of the LSRV basin, data was obtained on  $ET_c$  of natural vegetation occurring in the area with relevant comparisons being made with citrus cultivars. In terms of examining physical blue water scarcity and water pollution level (WPL), current water usage and availability of water was examined for the basin using grey and blue water from the LTA and dry year. Grey water and blue water values were extrapolated to estimate overall citrus for the area according to share of cultivar and maturity identified in the tree census survey. According to Hoekstra *et al.* (2011), a blue WF forms a hotspot in a specific period and catchment when the blue WF exceeds blue water availability. The blue water availability ( $WA_{blue}$ ) in a certain period (t) and catchment (x) is the natural run-off ( $R_{nat}$ ) minus the environmental flow requirement (EFR). When the ratio of the blue WF exceeds blue water availability and EFR are violated the blue WF is unsustainable (equation 4) (Hoekstra *et al.*, 2011). Given that the LSRV has an IBT this was taken into account within the calculations and was adapted according to available data. The same was applied when calculating the WPL. The WPL measures the fraction of waste assimilation capacity consumed. It is calculated as the ratio of total grey WFs in a certain period (t) and catchment (x) to the actual run-off in that catchment ( $R_{act}$ ). When the ratio of grey WFs exceeds actual run-off ambient water quality standards are violated (equation 5) (Hoekstra *et al.*, 2011).

$$WS_{blue} [x, t] = \frac{\sum WF_{blue} [x, t]}{\sum WA_{blue} [x, t]} \quad (4)$$

$$WPL [x, t] = \frac{\sum WF_{grey} [x, t]}{R_{act} [x, t]} \quad (5)$$

Comparisons of results were made between actual raw data provided by the LSRV WUA and the DWS. The marginal product value and the allocative efficiency of the fish-Sundays scheme based on the study done by Conradie (2002) was also discussed.

#### 4.5.2 The sustainability of citrus production in the LSRV

##### *a) Economic indicators*

In order to gauge productivity and efficiency water usage was expressed using a number of partial productivity indicators these included: physical water productivity (WP), economic water productivity (EWP), labour water productivity (LWP) as well as economic land productivity (ELP). Total factor productivity (TFP) was also measured. WP is calculated or measured as the ratio of net benefits received based on crop outputs to the amount of water inputs required to produce those benefits (Molden *et al.*, 2010; Chouchane *et al.*, 2013) (equation 6). Water usage (m<sup>3</sup>) was representative of both blue and green water use, with blue water measured as water depletion. According to Savenjie (2000), exclusion of green water can skew water scarcity results. Thus, both sources of water were included. The same equation was also used to express water usage in terms of employment to determine LWP by substituting mass in tons for employment in hours. Employment accounted for permanent and seasonal labour but excluded staff, management and administrative staff.

$$WP = \frac{\text{tons}}{\text{m}^3} [\text{mass. volume. ha}^{-1}] \quad (6)$$

EWP (R/m<sup>3</sup>) is used in a number of studies to assess the economic efficiency or performance of the water consumed by dividing the market price of the crop (R/ton) by water use (m<sup>3</sup>/ton) (Salmoral *et al.*, 2010; Chico *et al.*, 2010; Garrido *et al.*, 2010; Hoekstra & Schyns, 2014) (equation 7). It expresses the value of water in terms of farm output per unit of water consumed (Schyns & Hoekstra, 2014) or earnings per unit of virtual water (Chouchane *et al.*, 2013). Market prices used in this study were taken from average prices received for each cultivar based on figures provided by farmers for the seasons 2009-2013. These prices are overestimated, as some farmers gave average prices, while most provided export prices. Local prices were very difficult to obtain however, very little citrus produced in the LSRV is aimed for local or factory production. In an average year, the pack-out percentage for the LSRV is 74% (SRCC, 2014). Export prices for the years 2009-2013 were expressed in terms of real 2013 prices in order for comparisons to be made

between different climatic years. Indices of producer prices of horticultural products were obtained from DAFF (2013). The LTA used the average price for the last five years for each cultivar.

$$EWP = \frac{\text{monetary value}}{m^3} [\text{ton. ha}^{-1}] \quad (7)$$

While average farm gate price is a useful indicator to express value in terms of earnings, it is important that costs also be taken into account. Therefore, the EWP was also expressed in terms of net farm revenue. Net revenue was calculated by multiplying export price by the number of tons per hectare of each cultivar to determine gross production value. Directly allocatable costs<sup>8</sup> were deducted as well as general farm costs<sup>9</sup> to obtain net revenue per hectare for each cultivar. A citrus company in the area provided cost data. To obtain EWP per ton per hectare, net revenue per hectare was divided by each cultivars respective yield (ton) per hectare.

ELP (R/ha) was also calculated to provide a monetary value of agricultural production or farm output per hectare (Garrido *et al.*, 2010) (equation 8). Again, ELP was expressed in terms of gross production value as well as net revenue was used to provide a better representation of monetary value

$$ELP = \frac{\text{monetary value}}{\text{hecares}} [\text{rand. ha}^{-1}] \quad (8)$$

TFP was also measured by monetising and aggregating all inputs and outputs. Inputs were monetised by using the cost of each input per hectare. The monetary value of outputs were indicated by NFI (equation 9).

---

<sup>8</sup> Allocatable costs are associated with the production of the crop and included irrigation, labour, fertilisers, pesticides and weed control.

<sup>9</sup> General farm costs included depreciation, overheads (e.g. salaries), maintenance and repairs (buildings and vehicles), insurance, administration costs, fuel, training, consumer bills, machinery hire, transport and electricity.

$$TFP = \frac{\text{monetary value of outputs}}{\text{monetary value of inputs}} [\text{rand. ha}^{-1}] \quad (9)$$

#### **a) Benchmarks**

Given that global benchmarks for products have recently been published, comparisons were made between the WF's of the LSRV cultivars and that of the global percentiles. Furthermore, Mekonnen & Hoekstra (2010b) provide WFs of a number of crop and crop-derived products, for specific countries and provinces. Comparisons between the WFs derived by Mekonnen & Hoekstra (2010b) for the Eastern Cape and South Africa for a number of citrus varieties were also compared.

#### **4.6 Policy Responses**

Policy responses were subsequently formulated based on findings and the sustainability assessment. Ways in which both government institutions and the citrus sector could reduce water related risks and impacts were discussed and linked to the policy objectives of the South African NWA.

#### **4.7 Limitations**

The study required rather comprehensive sets of data. Not all farmers had detailed records of irrigation, production or production prices and had limited time to give information. Unfortunately, in most instances, questionnaire responses had missing information or certain records were not provided. Therefore, where secondary data was unavailable data had to be compiled using very limited farm data. This was the case with data such as market prices, both export and local, and pack-out percentages for each cultivar. Local price data was only supplied by one farmer, therefore, average and export prices were used as a proxy for income causing an overestimation of net income. Crop budgets providing costs of each cultivar per hectare were assumed not to change over each climatic season because data was only available for the 2013 season. However, farmers did say that costs per hectare generally only increase because of inflation.

CWU was calculated based on the assumption that optimal irrigation occurs and crop stress does not occur. This is not met in reality for citrus crops as farmers often expressed concerns relating to high degrees of salinity and pests, such as the false codling moth, during interviews. Although estimates tried to incorporate losses resulting from irrigation inefficiencies, values are conservative in that calculations fail to include losses due to storage and transport. These losses would be significant given the amount of water transported because of the inter-basin transfer. Type of rootstocks and arrangement of trees can also affect tolerance levels and water use of citrus (Westwood, 1988). These factors were not taken into account.

The accuracy of evapotranspiration estimates are also dependent on a number of variables including crop factors. Given that crop factors and stages of each cultivar were not available, values had to be estimated or default values were used. Citrus also has a complex phenology that does not necessarily fit into the recommended four-stage crop cycle, because some cultivars such as lemons continuously flower and produce fruit throughout the year. Models such as SAPWAT 3.0 and CROPWAT 8.0 have also been described as not being able confidently to simulate water use (Taylor & Gush, 2014). It must therefore be noted again that calculations are only approximations of irrigation requirements. Results could potentially change with more accurate information regarding cropping patterns and crops stages for each cultivar, or using more direct and precise modelling approaches. Raw irrigation data and secondary data was therefore used to try to verify results where possible.

Finally, in terms of the grey WF, pesticides, fungicides and herbicides were not included as these were applied in the form of a foliar spray. The grey WF tier one supporting guidelines do not provide a means by which to calculate the effect of foliar sprays on surrounding water bodies which would generally result due to wind so would therefore be difficult to determine. Furthermore, it was assumed that application rates did not vary over the climatic years.

#### **4.8 Ethical considerations**

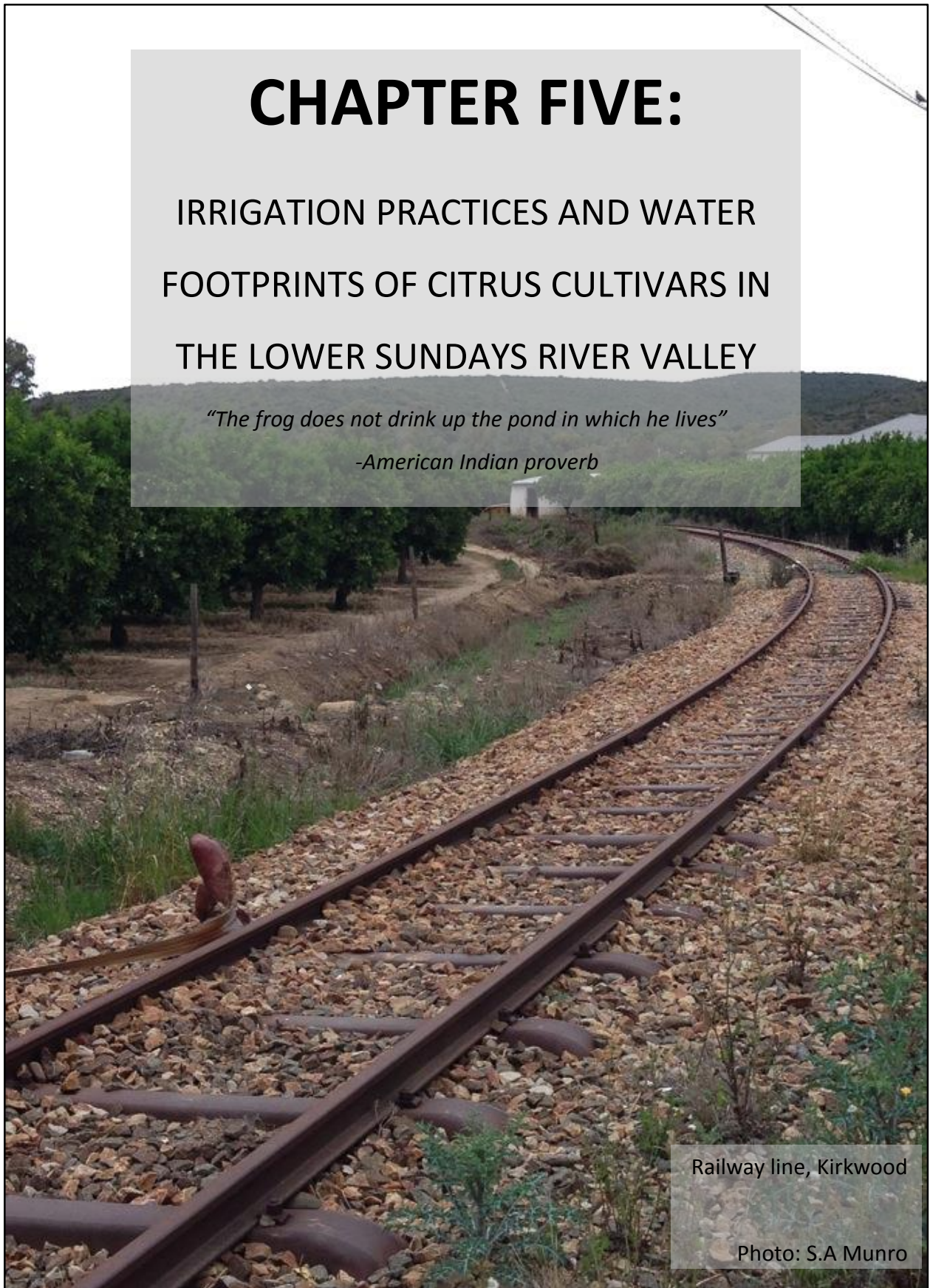
While carrying out and conducting this research, it was ensured that all requirements of the Rhodes University Research Ethical Standards Policy were observed. The survey instrument (questionnaire) was given ethical clearance by the Department of Economics Ethical Standards Sub-committee. This ensured that the rights, privacy and anonymity of any participants were acknowledged and respected, with no subject being offended or harmed in any manner. All participants were provided with consent forms giving precise details of the study's aim and objectives and how data would be used. Participants reserved the right to exit participation at any point in the study. Feedback will also be provided to all participants in the form of a summary report. The higher degrees ethical board of Rhodes University approved this research project.

# CHAPTER FIVE:

## IRRIGATION PRACTICES AND WATER FOOTPRINTS OF CITRUS CULTIVARS IN THE LOWER SUNDAYS RIVER VALLEY

*"The frog does not drink up the pond in which he lives"*

*-American Indian proverb*



Railway line, Kirkwood

Photo: S.A Munro

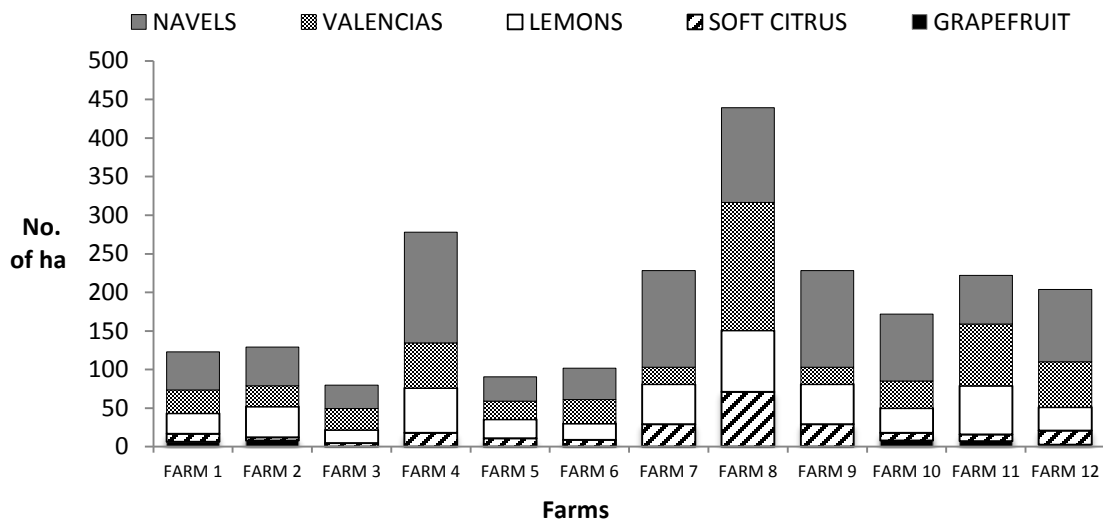
## **5.1 Introduction**

As per Hoekstra et al. (2011) calculating blue, green and grey WFs makes a distinction between different types of water, providing the basis for a more detailed assessment of water use (Hoekstra *et al.*, 2011). CWU, yields and irrigation practices assist in understanding WFs and placing them into context allowing for better understanding of possible determinants. This allows one to examine potential risks and conduct applicable sustainability assessments. This chapter, therefore, aims to put WFs into context by examining variables and factors that influence blue, green and grey WFs.

## **5.2 Farm profiles and farming practices**

Although yield, enterprise budgets and tree census data were obtained from secondary sources, it is still useful to examine the farmers who were interviewed and their farming practices. Farming practices vary and will influence a farmer's decision-making when it comes to future water use related risks. Of the farmers interviewed, all were Caucasian and male. Farms ranged from 94 to 503 hectares with an average of 180 hectares (see Figure 5.1). These figures are of actual citrus hectares planted and not total farm size. Farms were spread across the valley with two farms located in Kirkwood, three in Dunbrody, two in Sunland and three within the Addo region. The production units comprised a number of farms with locations that were not specified.

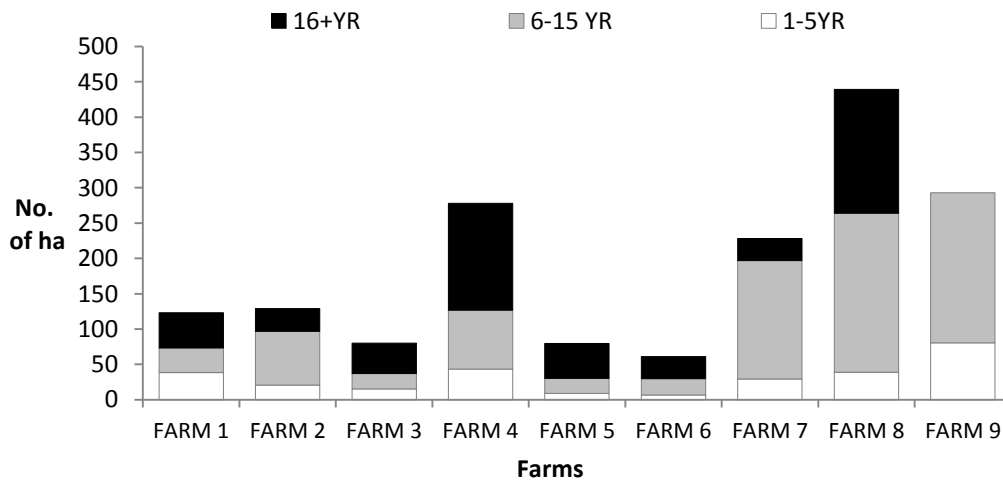
The average proportion of cultivars across all twelve farms was comprised of 42% navels, 25% valencias, 22% lemons, 10% soft citrus and 1% grapefruit. These proportions are similar to tree census data obtained for the area (Figure 3.5), thus providing consensus that the sample of farms were representative.



**Figure 5.1 Size of farm (ha) and proportion of each cultivar within each sampled farm**

Source: Farm interview data (n=12)

On average 52% of farms citrus varieties were between the ages of 6-15 years and 30% were 16 years and older. Farm nine had only recently been established so as a result the oldest trees were only 15 years (Figure 5.2). Not all farmers provided data on the age profiles of the citrus trees on their farms. Individual age distribution profiles of each variety can be found in Appendix 7.1.



**Figure 5.2 Age distribution of tree data from sampled farms**

Source: Farm interview data (n=9)

Individual and family ownership of the farms ranged between seven and 91 years. The Department of Rural Development and Land Reform had recently purchased two farms that were relatively young in terms of ownership but were older in terms of having established mature

citrus trees. All farms used conventional methods with a high farming intensity and were using either integrated pest management programmes, implementing Fairtrade criteria, or had their fertiliser and pest management programme approved through various companies in the area based on soil and leaf analyses. Generally, no mulches were used however, one farmer said that they sometimes used pruned trees for mulch around citrus trees aged five years. Another farmer had his own earthworm farm to produce his own on-site compost.

The LSRV have conventional plantings of less than 1000 trees per ha<sup>-1</sup> (Taylor & Gush, 2014). Most cultivars have an average plant density of 555 trees per hectare or a spacing of 6m x 3m (based on farm interview data). According to Outspan (1997) in Taylor & Gush (2014), SRV is considered a cold area for citrus production and planting systems should have smaller tree spacing than other areas and therefore a higher density of trees per hectare. Very hot areas have a recommended tree spacing of approximately 7m x 4m depending on the rootstock.

Only three farms used solely drip irrigation and two farms solely micro irrigation. The remaining farms all used a combination of drip and micro (n=11). Farmers generally irrigated during the day. Two farmers however, irrigated during the night during certain off-peak periods to save on electricity costs. Irrigation hours varied in summer and winter months. Irrigation scheduling practices from the farms is summarised in Table 5.1. These were approximate schedules provided by the farmers, which demonstrated how irrigation practices varied between summer and winter seasons, as well as between farmers with varying irrigation systems.

**Table 5.1 Summary of farmers irrigation schedules according to farm type**

Farm type	Scheduling practices	
	Summer	Winter
<b>Drip irrigation</b>	1.2-5 litre drippers for 4-8 hours per orchard 5 days a week	1.2-5 litre drippers for 2 hours a day 3 times a week
	1.2-3.2 litre drippers for 4-10 hours	1.2-3.2 litre drippers for 2 hours twice a week
<b>Micro irrigation</b>	17 hours (06:00-22:00) 103 hours per week	8 hours (08:00-16:00) 84 hours per week
<b>Combination of drip and micro</b>	7-21 hours 15 hours (07:00-22:00) 6 hours a week (lemons 7 hours) between 06:00-20:00	8-17 hours 9 hours (08:00-17:00) 6 hours every second week (lemons 7 hours) between 06:00-20:00

Source: Farm interview data

All farms used probes to measure soil moisture to determine irrigation scheduling; some farms even additionally dug test holes each week or used the calendar method in conjunction with probes. All farmers received their water via canals from which they would pump into their own storage dams and distribute accordingly on their farms.

Farmers did state that you could irrigate 300 hectares of land with 300 hectares of allocated water with micro irrigation, whereas with drip you can irrigate 300 hectares of land with 250 hectares of allocation. Another farmer stated, similarly, that you could irrigate 150 hectares using drip irrigation with a water allocation for 100 hectares. According to the interviews with the farmers, the type of irrigation system did not influence yield.

Two farmers mentioned that they were planning on switching back from drip irrigation to micro. Both farmers stated that drip irrigation requires more irrigation lines that take up space so fewer trees can be planted per hectare. One farmer also claimed that drip systems could not provide

sufficient water for the trees. There therefore seems to be some discrepancies between some farmers as to whether or not drip irrigation is more beneficial despite its higher irrigation efficiency.

In terms of water quality six farmers noted that the water quality was good or 'of good enough' quality. Two said that water was either 'okay' or not of good quality (n=8). Five farmers also noted that the pH of the water was quite high and could range between 7.7 and 8.6. One farmer also stated that the ideal pH would be 6.5 (n=8).

### **5.3 Theoretical crop water use, irrigation requirements and yield**

#### **5.3.1 Green and blue water use**

According to the SAPWAT 3.0 results, shown in Table 5.2, the LTA year 60% of crop water requirements were met through blue water (irrigation water) and 40% via green water (effective rainfall). The ratio of blue water consumption to green water consumption reduced by approximately 30% during the wet year, with the dominant water source for crop requirements being rainfall. In the dry year crop requirements increased to a ratio of 70% blue water to 30% green water. Timing, the number of rainfall events, and the amount of rainfall would have predominantly influenced effective green water. SAPWAT 3.0 calculates effective rainfall as the sum of seasonal rain that can be absorbed by the soil. Any rainfall more than the available soil space on the day of rainfall would be deemed ineffective and assumed to be lost through deep percolation (Van Heerden, 2014). It was assumed that farmers would try to maximise rainfall efficiency by not filling the soil profile completely during irrigations so there is always room to store rainwater. This may not be the case and therefore green water use could have been over estimated.

**Table 5.2 Crop water use (m<sup>3</sup>) and yield (tons) for each citrus cultivar per hectare**

Cultivar	2009 (dry)			LTA			2011 (wet)		
	CWU <sub>Green</sub>	CWU <sub>Blue</sub>	Yield	CWU <sub>Green</sub>	CWU <sub>Blue</sub>	Yield	CWU <sub>Green</sub>	CWU <sub>Blue</sub>	Yield
<b>Navels</b>	2380	6864	30	3240	4509	30	4555	2579	31
<b>Valencia</b>	2380	6892	33	3240	4957	34	4544	2914	42
<b>Lemons</b>	2380	7937	51	3240	5905	52	5039	3376	65
<b>Soft Citrus</b>	2380	6329	36	3240	4412	33	4653	2564	35

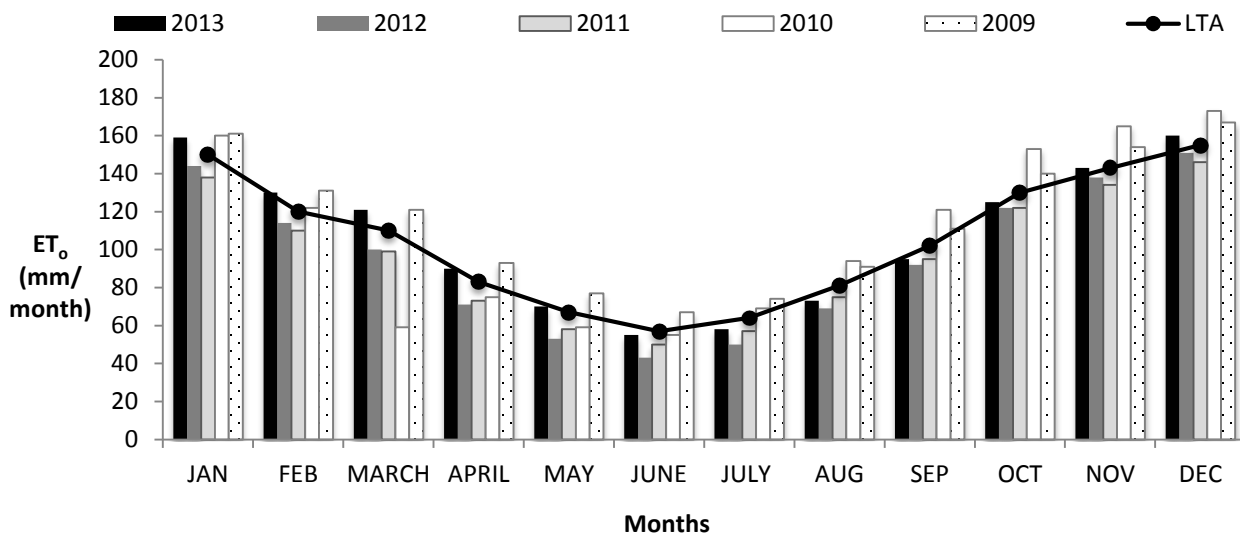
*Source:* own elaboration using SAPWAT 3.0

Because farmers measure and monitor soil water content using probes, farmers most likely schedule their irrigation according to available soil water content. After the 2011 heavy rainfall season, the LSRV WUA chairman’s report stated “These rains [also] affected the water use out of the pool system which reduced the demand dramatically and accordingly the cash flow returns on the pool system was also substantially reduced” (LSRV WUA, 2012:1). Each year farmers who are not planning on using a water allocation (9000 m<sup>3</sup>/ha) possibly due to fallow land or new plantings will get money refunded by the WUA. The sum of these allocations are referred to as the pool system. Farmers who need more water for a certain year can approach the WUA to obtain more water through this pool system. What the statement does demonstrate is that farmers may try to maximize rainfall where possible and only irrigate when necessary based on the probe data and other scheduling methods previously mentioned. Whether farmers could essentially consider strategies like not irrigating so that the soil profile is full, to accommodate for potential rain would need to be further investigated.

One farmer specifically stated that they would use more water in drier years in order to keep the soil wet, otherwise this would result in physical stress and the “citrus trees don’t look as healthy”. Another farmer emphasised that there was no substitute for rainfall and that size and quality of fruit is affected. He specifically referred to 2013 as a low rainfall season and that they had had a lower average fruit size as a result. These are all indications that some farmers would try and maximise rainfall efficiency as they deemed green water of greater value. Taking into account rainfall and maximising green water use is an important sustainable farming practice that farmers

can use to decrease their blue water usage and potential fertiliser use. That being said farmers all stated that they relied entirely on irrigation to meet CWR. Evidently, this is true since to meet the average CWR of citrus 60% of water is required through irrigation. Therefore, blue water is of vital importance to the survival of the industry.

The SAPWAT 3.0 results also revealed that the theoretical CWU of each cultivar was highest in the dry year followed by the average year and wet year respectively. Total CWU ranged from 7651- 9149 m<sup>3</sup>/ha/yr in an average year, 8709-10317 m<sup>3</sup>/ha/yr in the dry year and 7217-8430 m<sup>3</sup>/ha/yr in the wet year. This was primarily due to the difference in reference ET<sub>0</sub> for each year (Figure 5.3). ET<sub>0</sub> in drier rainfall years, such as 2009 and 2010, was higher than the LTA, whereas 2011 and 2012 fell below the LTA. The year 2013 had a similar ET<sub>0</sub> to the LTA with an average monthly ET<sub>0</sub> of 107 mm/month and 105 mm/month respectively. The Penman-Monteith method employed by SAPWAT 3.0 has been said to have a minimum possible error of approximately 10% in summer and approximately 20% under low evaporative conditions (Doorenbos & Pruitt, 1977).



**Figure 5.3 Average monthly ET<sub>0</sub> (mm/month) for the 2009-2013 seasons**

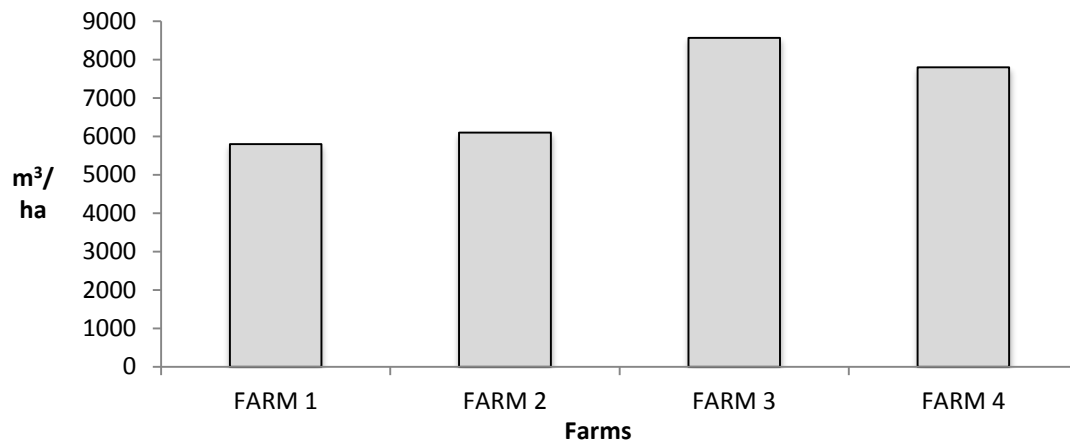
Source: own elaboration using SAPWAT 3.0 computations

CWU was calculated for each cultivar taking into account the different soil types, age and irrigation systems and then weighted accordingly. Based on SAPWAT 3.0, recommended application efficiencies for drip and micro were 95% and 90% respectively (Van Heerden *et al.*, 2009). Therefore, blue water is 5% and 10% higher for drip and micro systems respectively than

if irrigation losses were not taken into account. In terms of CWU for each cultivar, lemons had the highest CWR followed by valencias, navels and soft citrus across all years. Lemons used 8-14% more in an average year than valencia and navels respectively, and navels used 3% more than soft citrus. Very few studies have examined the difference in CWU of different citrus cultivars; therefore, it was difficult to verify the results. However, according to Wright (2000), grapefruit and lemons use 20 % more water than navels, whereas soft citrus such as mandarins use about 10% less than navels. Of all the farmers interviewed, none kept or were able to provide exact records of water use per orchard or cultivars. Most farmers did however note that lemons used more water than the other cultivars.

### **5.3.2 Verifying data through comparative studies and irrigation records**

Only four farms provided actual usable irrigation records and data. Irrigation records can only be obtained via the farmers, as the WUA is not permitted to give out such records. The records that farmers do have are based on irrigation use at certain pumping points on their respective farms; therefore, it is difficult to almost impossible to determine from the available data the water use per orchard. Furthermore, irrigation records are not necessarily representative of water use per hectare as some farmers are using reserves of their allocations to irrigate land for which they do not have water rights. A summary of average yearly water usage per hectare is given below in Figure 5.4 for four farms for the 2013 season where actual water use per hectare was obtained (these values accounted for land that is irrigated, but for which farmers do not have water rights).



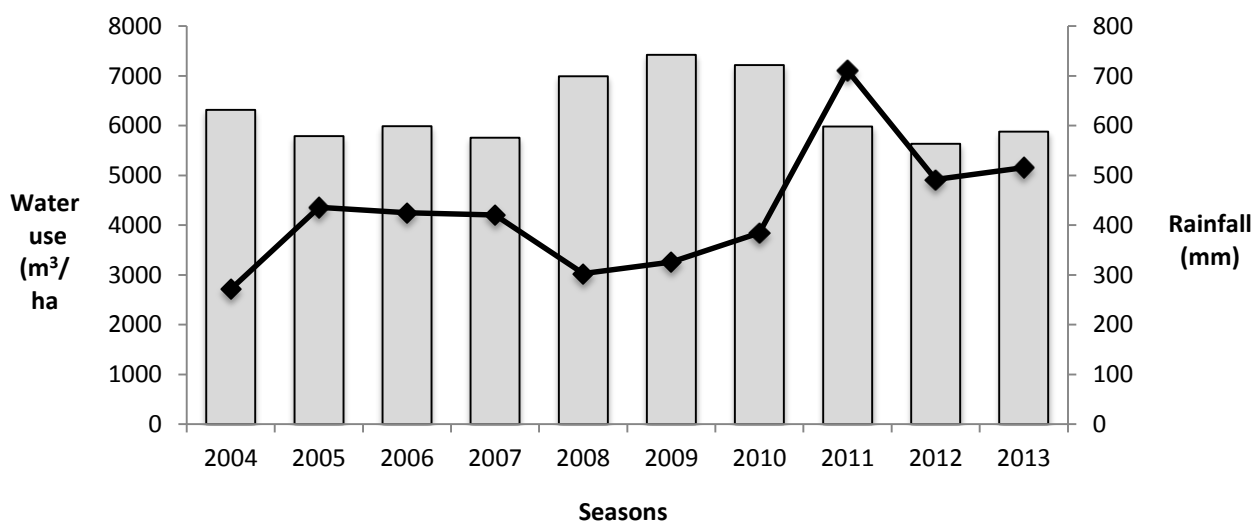
**Figure 5.4 Average water use (m<sup>3</sup>/ha/yr) for four farms in the LSRV for the 2013 season**

*Source:* Farm interview data

Irrigation data showed that farmers use between 5700 and 8567 m<sup>3</sup> per hectare per annum. Although actual records were not provided, a number of other farmers (3) mentioned that they use approximately 6000 to 6300 m<sup>3</sup> of water per hectare per year. Potential variation in average CWU per hectare in reality can be caused by a number of factors and variables (Green, 1985). Firstly, type and age distribution of cultivars, secondly irrigation systems and thirdly physical variables such as soil, stress and salinity (Green, 1985). To account for some of this variation we can examine each farms profiles based on their irrigation practices and tree census data. Farm two had a higher proportion of lemons and farm three and four had a greater proportion of mature cultivars. Farm one and farm three used solely drip and micro irrigation respectively, whereas farms two and four used a combination. Therefore, it is possible farm three has a higher average water use as a result of its micro system and farm four due to its higher proportion of mature cultivars.

By examining the available irrigation data (based on water usage from the canals) for the area and dividing it by the number of hectares of irrigated land in the LSRV, the average water use per hectare per annum for the last ten years can be calculated. This data however is not representative of just citrus production, as it includes other forms of irrigated land uses such as cash crops (985 ha), lucerne (3040 ha) and pastures (531 ha) which make up 27% of the area. However, since 73 % of this land is for citrus it can provide a good indication of average annual water use per hectare. It also includes canal losses. Figure 5.5 demonstrates that on average approximately 6298 m<sup>3</sup>/ha, which is almost identical to the figures some of the farmers gave. The

range of average water use per hectare between 2004-2013 was between 5638 m<sup>3</sup> and 7422 m<sup>3</sup> per season. By examining seasonal rainfall figures for the same years it is demonstrated that farmers generally use a higher amount of water in lower rainfall years. Although, in 2011 the amount of water use per hectare did not reduce drastically contradicting the statement by the LSRV WUA, (2012). Therefore, it is unclear whether farmers do in fact maximise green water.



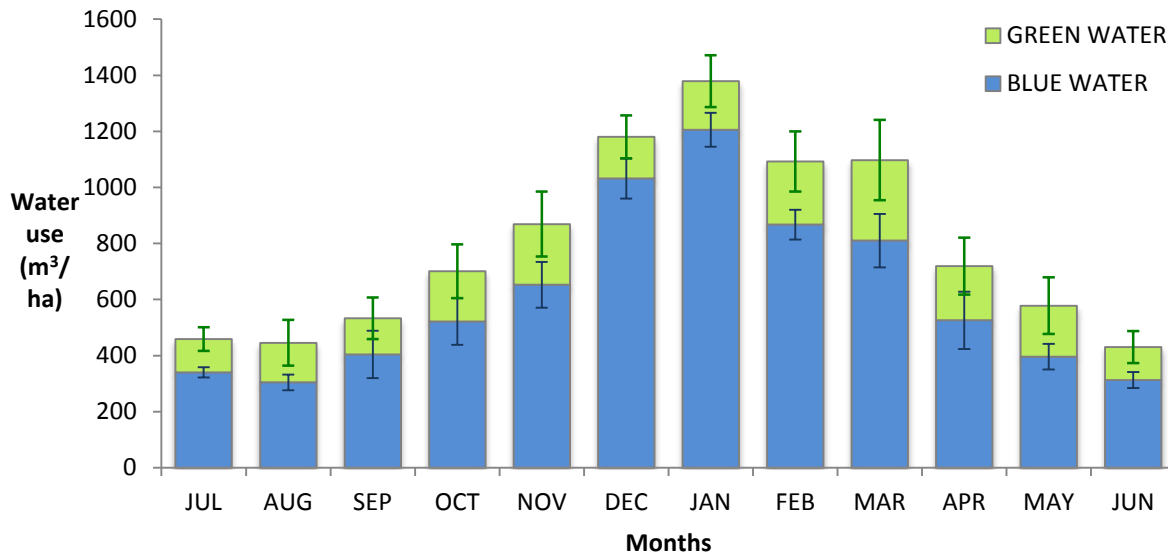
**Figure 5.5 Annual water use (m<sup>3</sup>) per hectare in irrigated areas and mean annual rainfall (mm) in the lower Sundays River Valley basin**

*Source:* LSRV WUA, (2014)

In comparison to other studies, Gush & Taylor (2014) estimated water use of navel and valencia varieties using an eddy covariance and heat pulse velocity systems across different climatic areas in South Africa. Total evaporation for navels ranged between 8610- 9950 m<sup>3</sup> and valencias ranged between 6250- 7320 m<sup>3</sup> per hectare per season. In comparison, estimates from SAPWAT 3.0 ranged between 7134- 9244 m<sup>3</sup> for navels and between 7458- 9272 m<sup>3</sup> for valencias per hectare per season.

Green (1985) also estimated irrigation requirements and effective rainfall for citrus for the Addo region using a soil water balance approach based on daily class A pan evaporation and rainfall recorded over the period 1964-1974. The model was run for a range of irrigation applications (5mm to 100 mm) corresponding to maximum allowable soil water deficits determined by different soil types. It was assumed irrigation efficiency was 100%. The results showed that

average seasonal crop use was 9680 m<sup>3</sup> with effective rainfall ranging from 1290-3200 m<sup>3</sup> and irrigation requirements 6480 m<sup>3</sup> to 8390 m<sup>3</sup> depending on the irrigation application (Figure 5.6). These results demonstrate the influence that different irrigation practices and soil types can have on the total CWU.



**Figure 5.6 Effective rainfall and irrigation requirements (m<sup>3</sup>) per hectare per season for citrus in the Addo region for different irrigation applications (5mm to 100 mm)**

*Source:* adapted from Green (1985)

The results from SAPWAT 3.0 showed that CWU<sub>blue</sub> was an average of approximately 7006 m<sup>3</sup>/ha in a dry year (2009), 4946 m<sup>3</sup>/ha over the LTA and 2858 m<sup>3</sup>/ha in a wet year (2011). CWU<sub>green</sub> was an average of 2380 m<sup>3</sup>/ha for the dry year, 3240 m<sup>3</sup>/ha over the LTA and 4698 m<sup>3</sup>/ha in the wet year. CWU<sub>green</sub> surprisingly did not vary across cultivars for the dry and average season. This could be due to the timing and low number of rainfall events.

In comparison to other studies and available irrigation data, it is evident the SAPWAT 3.0 model potentially underestimates CWU<sub>blue</sub> of the citrus cultivars. Although LTA CWU<sub>green</sub> were similar to the higher ranges produced by Green (1985), LTA CWU<sub>blue</sub> or effective irrigation was 2425 m<sup>3</sup> less than average CWU<sub>blue</sub> estimated by Green (1985). Potential reasons for this could be that younger cultivars were taken into account so would be lower than estimates by Green (1985) or also because of different K<sub>c</sub> values. These results are also interesting since CWU<sub>blue</sub> estimated by

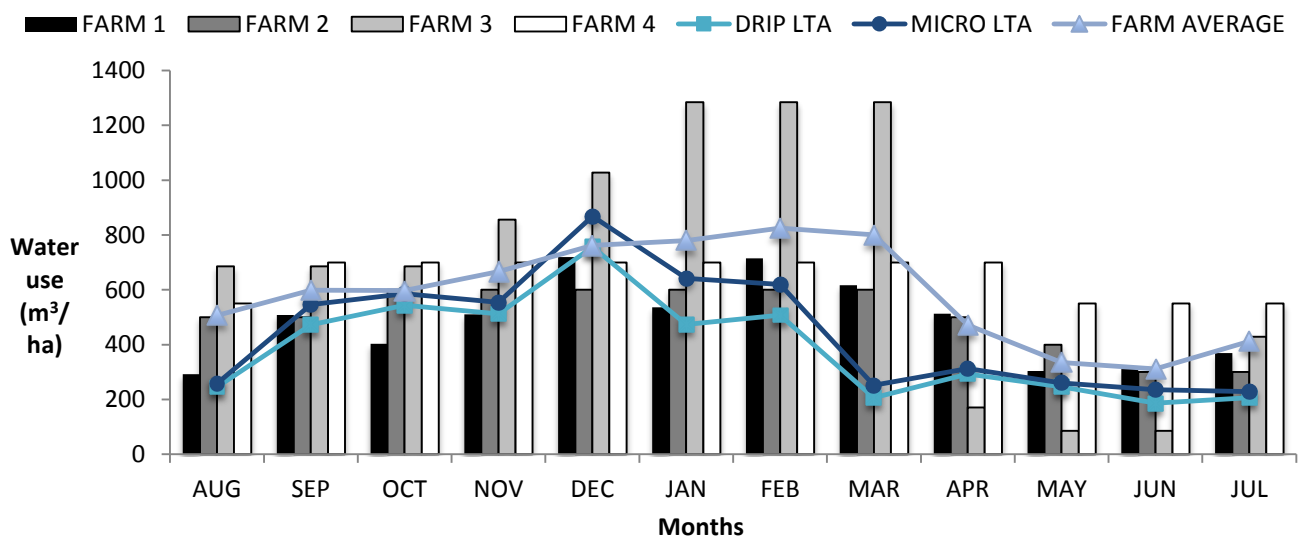
SAPWAT 3.0 included irrigation inefficiencies so should theoretically be higher than estimates that do not. However, the same result is apparent when compared to available irrigation data. Although, differences could be due to losses because of transportation and evaporation from storage dams as these are not accounted for in CWU. Evaporation from storage dams have shown to contribute significantly to blue water use. A study in Morocco showed that evaporation from storage reservoirs is the second largest form of blue water consumption (Schyns & Hoekstra, 2014).

What is important is that the 9000m<sup>3</sup> allocation that farmers currently receive is more than sufficient to meet farmers' irrigation requirements for all citrus cultivars and for all irrigation systems even within dry years. While the SAPWAT 3.0 results are slightly lower than estimates by other studies the same is demonstrated in other results. Nonetheless, the SAPWAT 3.0 and other models that estimate ET<sub>c</sub> are exactly that, estimations. Taylor & Gush (2014) also acknowledge that irrigation scheduling in citrus through FAO methods, using crop coefficients and evaporation from Class A pans will have uncertainties. This is particularly the case with citrus as water use changes depending on crop load (Syvertsen *et al.*, 2003) and according to light interception (Consoli *et al.*, 2006). Results would always be more accurate if measurements that are more direct were conducted, for example, lysimeters or eddy covariance instruments. These tools are however, expensive and long-term data cannot be obtained (Singh *et al.*, 2006).

### **5.3.3 Monthly green and blue water use and demand**

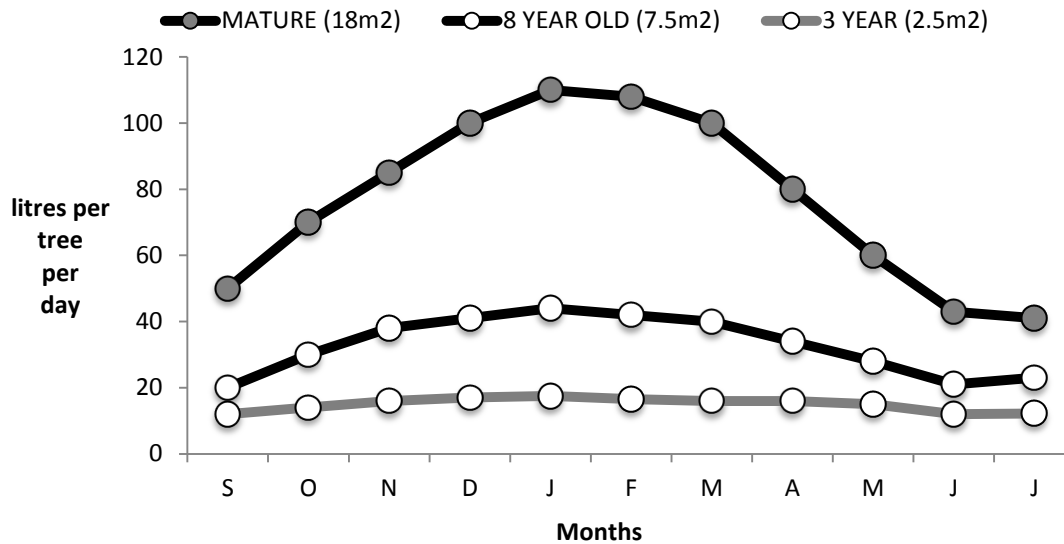
One of the nuances that have developed out of the WF assessment is the importance to examine water usage over temporal and spatial scales to account for the variability that occurs (Hoekstra *et al.*, 2011; Hoekstra *et al.*, 2012; Zhang *et al.*, 2014). It is therefore useful to also examine irrigation demand and crop water requirements from a monthly perspective to determine periods of high demand and where potential stress to water resources and subsequently yields may occur.

The average monthly CWU<sub>blue</sub> estimated with SAPWAT 3.0 are shown below in Figure 5.7 for both drip and micro irrigation systems for the LTA year for an average of all cultivars (weighted according to their relative proportion within the area), as well as for each farm that provided irrigation records and estimates. The SAPWAT 3.0 results demonstrated that approximately 50% of irrigation requirements occur between November and February and 65% between October and March. In comparison to actual data provided by the farms an average of approximately 43% of irrigation occurs between November and February and 63% between October and March. Again, LTA monthly CWU<sub>blue</sub> calculated by SAPWAT 3.0 use was slightly lower than most farms.



**Figure 5.7 Monthly blue water use (m<sup>3</sup>/ha) in the lower Sundays River Valley based on farm data and modelled data using SAPWAT 3.0**

Falivene *et al.* (2006) found that 54% of annual water use occurs between November and February and 74% between October and March, during fruit growth and development. Falivene *et al.* (2006) also note that young citrus trees can use up to 50% less water than mature trees due to their smaller canopies and root zones. du Plessis (1989) in Outspan (2004), similarly demonstrated the significant changes in water use that occurs between young and mature cultivars, as well as that peak water use occurs between December and March (Figure 5.8).



**Figure 5.8 Average monthly water consumption for different sized citrus trees (based on soil surface and surface leaf canopy in m<sup>2</sup>)**

Source: adapted from du Plessis (1989) in Outspan, (2004)

It is therefore evident that a greater stress and demand for water resources is between the months of November to February, where approximately 40-50% of water allocations take place.

## 5.4 Grey water and water quality

### 5.4.1 Application rates and grey water

Grey water here refers to the amount of water required to assimilate a pollutant so that it is no longer harmful given natural and maximum concentrations of the pollutant (Hoekstra *et al.*, 2011; Franke *et al.*, 2013). It is not the universally accepted grey water that refers to, and is defined as “wastewater without any input from toilets, which means that it corresponds to wastewater produced in bathtubs, showers, hand basins, laundry machines and kitchen sinks, in households, office buildings, schools, etc.” (Eriksson *et al.*, 2002:85).

Based on AR (tons/ha/yr), leaching run-off fractions and  $C_{nat}$  and  $C_{max}$  concentrations, grey water (m<sup>3</sup>/ha/yr) was calculated for each cultivar for nitrogen and phosphorus. The amount of grey water calculated was highly dependent on the  $C_{nat}$  and  $C_{max}$  concentrations used. Results showed that with a given load, the greater the range between  $C_{nat}$  and  $C_{max}$  the lower the amount of water required to assimilate a given pollutant. Theoretically, if  $C_{nat}$  of a water body is of a low water

quality, a lower volume of water should be required to assimilate pollutants for it to remain at the same quality. This was not illustrated within the grey WF calculations. Since natural concentrations exhibited from headwater-monitoring points for Sundays River were similar to the range of  $C_{\max}$  concentrations within a number of literary sources (see Appendix 4.3) this resulted in a greater quantity of grey water than if lower  $C_{\text{nat}}$  concentrations were used. In this regard, the grey WF methodology does not consider water bodies that are of naturally a low water quality.

Furthermore, without accurate site-specific data for both  $C_{\max}$  and  $C_{\text{nat}}$  concentrations one can be faced with numerous ranges of values that can drastically change results (DWAF, 1996a; Franke *et al.*, 2013). This was exhibited with calculations for phosphorus where grey water ranged between approximately  $0.01 \text{ m}^3/\text{ha}$  to  $42\,000 \text{ m}^3/\text{ha}$ . This variation can also be exhibited in results shown for nitrogen (Table 5.3). Since load and AR were the same for each cultivar, grey water differences were attributed to differences in concentrations.

**Table 5.3 Application rates (tons/ha/yr) and grey water (m<sup>3</sup>/ha/yr) for citrus cultivars**

	Total ammonia		Total inorganic nitrogen		NO <sub>2</sub> + NO <sub>3</sub>	
	AR	Grey water	AR	Grey water	AR	Grey water
<b>Concentrations</b>	0.2 – 10 mg/l		0.5 – 2.5 mg/l		0.2 – 5mg/l	
Navels	0.22	381	0.22	1865	0.22	777
Valencia	0.12	201	0.12	987	0.12	411
Lemons	0.31	534	0.31	2615	0.31	1865
Soft citrus	0.22	381	0.22	1865	0.22	777

Source: own elaboration

Grey water calculations, therefore, were only based on the nitrogen that was applied through irrigation in liquid forms of AS (21% N) and UAN (32% N). Results showed that the most critical pollutant for all the cultivars requiring the most amount of assimilation water so that ambient water quality standards were met was for total inorganic nitrogen. Total inorganic nitrogen is therefore the critical pollutant and the grey water required to assimilate it is assumed sufficient for the other pollutants (Hoekstra *et al.*, 2011; Franke *et al.*, 2013)

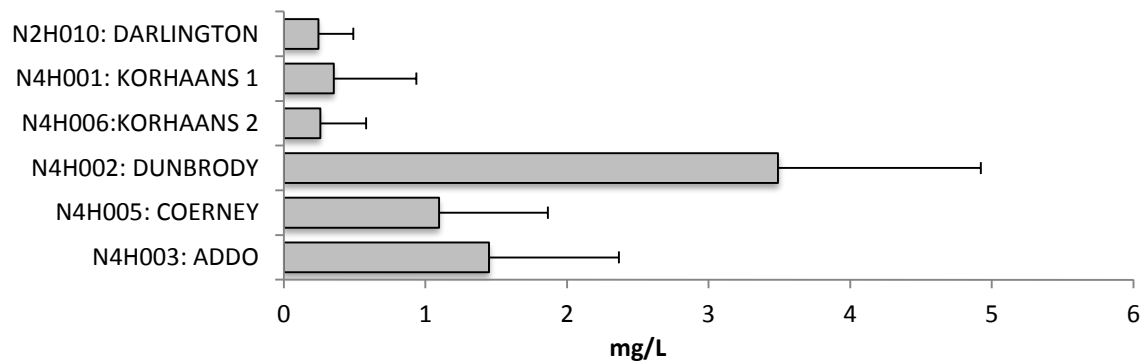
Despite the fact that grey water could potentially be underestimated due to the exclusion of phosphate and sulphate, what is evident from the results is the importance of obtaining accurate, local concentrations and how results can vary substantially based on the criteria chosen. What is also evident from the ARs is that lemons require more fertilisers per hectare than the other cultivars and valencias required the least. This was largely attributed to the fact that lemons required applications for a longer period than other cultivars.

#### 5.4.2 Water quality data

Based on a number of upstream and downstream monitoring points within the LSRV (see Appendix 4.3b), data for a number of water quality parameters, including NO<sub>3</sub> + NO<sub>2</sub>, NH<sub>4</sub>, PO<sub>4</sub> and SO<sub>4</sub> for 1988-1998 could be obtained. Unfortunately, no recent data was available, but from

Figures 5.9a-b, one can still examine downstream patterns based on yearly averages for the above parameters to give an indication of potential impacts on the current water quality.

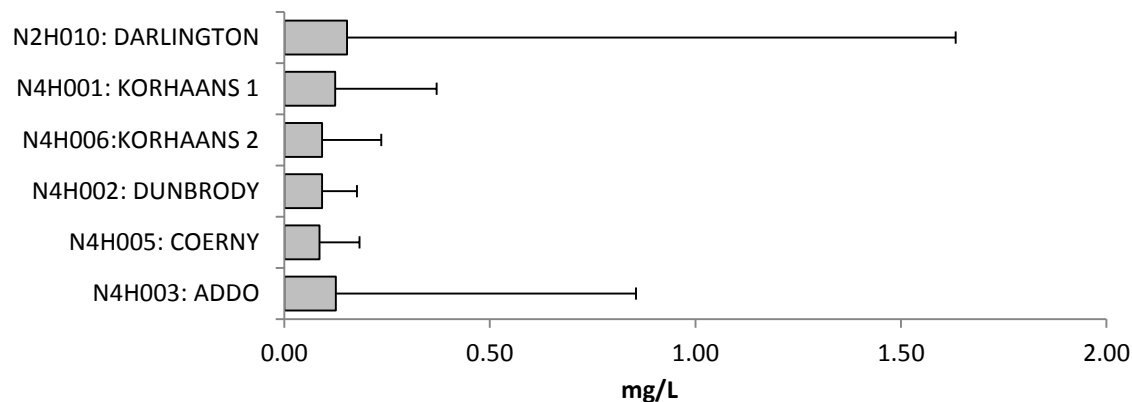
Figure 5.9a demonstrates that  $\text{NO}_3$  and  $\text{NO}_2$  levels are substantially higher at downstream monitoring points than upstream monitoring points. The maximum acceptable level of  $\text{NO}_3 + \text{NO}_2$ , according to DWAF (1996c), is 5 mg/L, therefore generally nitrogen levels are below the recommended threshold. This will also however be dependent on levels of  $\text{NO}_2$ . Midstream in Dunbrody, levels do reach up 5 mg/L which is potential harmful to fruit crops. What is evident is that concentrations of  $\text{NO}_2 + \text{NO}_3$  do increase downstream. Oxidized forms of inorganic nitrogen such as  $\text{NO}_3$  can occur naturally due to mineral salts. As discussed in chapter three, the natural water in the LSRV basin is of a very poor quality naturally because of southwest tributaries giving rise to saline base flows, despite high quality irrigation water (Wetland Group, 2004; DWAF, 2005). This could exacerbate  $\text{NO}_3$  concentrations along with leaching of fertilisers from the soil as shown in Dunbrody (DWAF, 1996b). However, it is important to note that not all high concentrations are a result of runoff from fertilisers.



**Figure 5.9a Mean ( $\pm$  s.d) nitrite ( $\text{NO}_2$ ) and nitrate ( $\text{NO}_3$ ) at monitoring points within the LSRV**

Source: Own elaboration from DWS, (2014)

The concentration of  $\text{NH}_4$  ranged from 0.09-0.15 mg/L with a high standard deviation for Darlington Dam and Addo. Despite this variation,  $\text{NH}_4$  concentrations were still below the DWAF (1996) maximum concentration level for total ammonia (10mg/L) and did not on average increase downstream. The values obtained through grey WF calculations for grey water also implied that  $\text{NO}_3 + \text{NO}_2$  would have greater impacts than total ammonia.



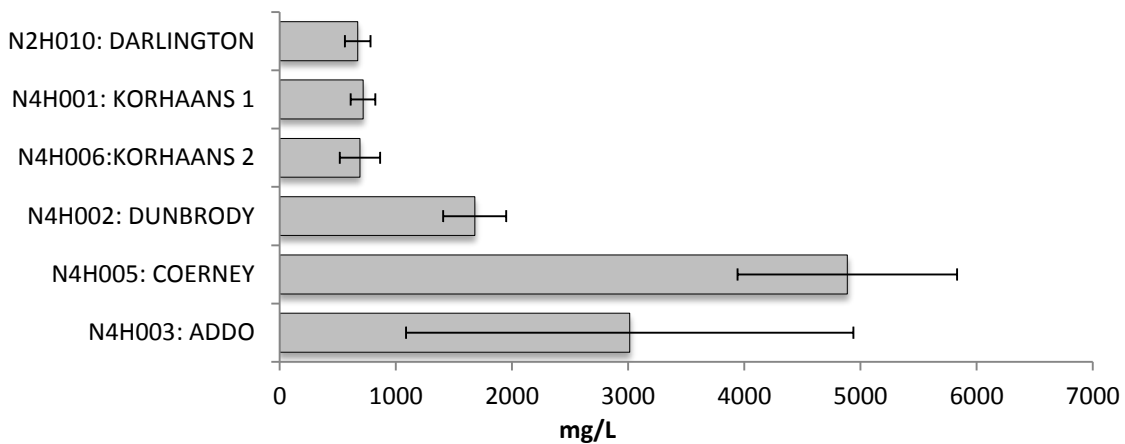
**Figure 5.9b Mean ( $\pm$  s.d) for ammonium ( $\text{NH}_4$ ) (mg/L) at monitoring points within the lower Sundays River Valley**

Source: Own elaboration from DWS, (2014)

It is evident from the above data that  $\text{NO}_2 + \text{NO}_3$  and ammonium concentrations are within the acceptable range. Sulphate concentrations also increased downstream and exceeded maximum acceptable values of 250 mg/l from Dunbrody onwards (DWA, 2012b) (see Appendix 4.4). In terms of  $\text{PO}_4$  the average concentration decreased downstream (see Appendix 4.4) but also had high standard deviations for Darlington and Addo monitoring points as exhibited with  $\text{NH}_4$ . This is interesting since DWAF (1996b) state that assessments of inorganic phosphorus and nitrogen should be evaluated together. Furthermore, the impacts of phosphorus and nitrogen are highly dependent on water temperature and pH (DWAF, 1996b; Franke *et al.*, 2013). Although temperature and pH should be taken into account when concentrations for the grey WF calculations are selected, the relationship between elements such as phosphorus and nitrogen cannot be illustrated by examining the parameters alone.

According to DWS (2011), the surface water quality status for the period 2006-2008 in the Sundays River was deemed as unacceptable and of a deteriorating water quality status for elements and components such as electrical conductivity, pH and  $\text{SO}_4$ . An unacceptable but improving water quality status was found for  $\text{PO}_4\text{-P}$  and chloride. An acceptable, but deteriorating, quality of surface water was found concerning  $\text{NH}_3$  (see Appendix 4.2).

According to Conradie (2002), water quality standards for workhorse or class D<sup>10</sup> rivers such as the LSRV can be defined in terms of total dissolved solids (TDS). TDS are the combined presence of organic and inorganic dissolved solutes of which a number of constitutes can include calcium, magnesium, sodium, sulphate, nitrate anions and chloride (World Health Organisation (WHO), 2003). Both Conradie (2002), and DWAF (2005) state the target level for Darlington dam is 600 mg/L, which is based on the maximum tolerable chloride level for citrus which is 200-250 mg/L. One third of TDS in the Sundays River is comprised of Chloride. The water quality data available from 1988 - 1998 for the monitoring points within the study area showed that TDS ranged from an acceptable level of 662 mg/L at Darlington dam to unacceptable levels of 3013 and 4887 mg/L for Addo and Coerney monitoring points respectively (Figure 9c).



**Figure 5.9c Total dissolved salts (TDS) at monitoring points within the lower Sundays River Valley**

*Source:* Own elaboration from DWS, (2014)

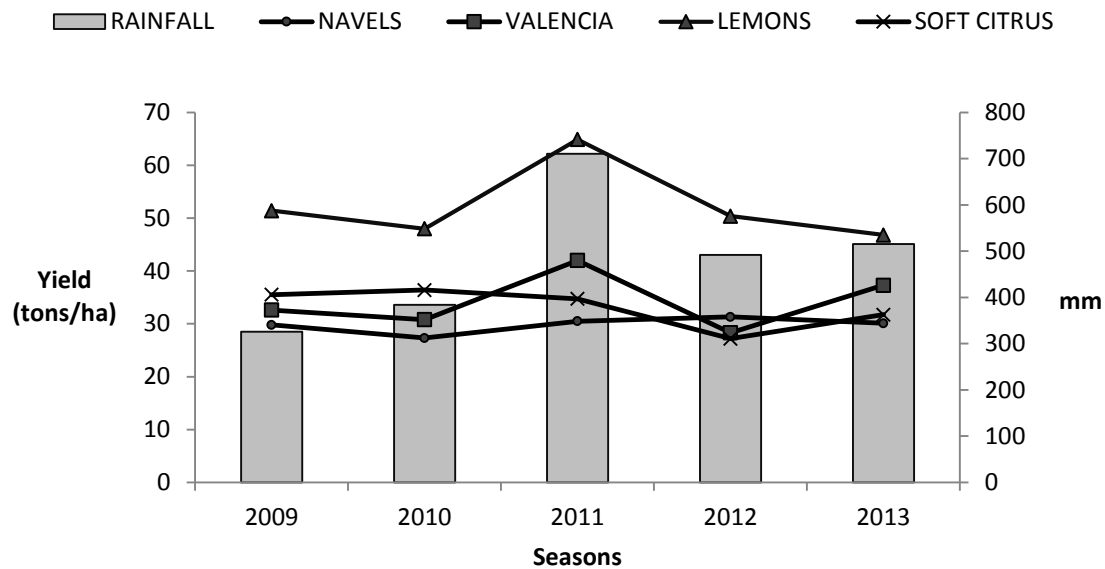
Although not all parameters were included in grey water calculations, what is evident from the available water quality data that is that there are more concerning parameters other than nitrogen but also combined effects of parameters are not reflected in the grey WF. Particularly since a number of parameters contribute to TDS (WHO, 2003), one therefore needs to include all variables with local concentrations in order to provide a more accurate representation of local

<sup>10</sup> Class D rivers are largely modified ecosystems characterized by considerable modification from the natural state where the sensitive biota is reduced in numbers and extent (Smakhtin & Anputhas, 2006)

conditions. While grey water is potentially a useful value it fails to provide detail as to when this water needs to be available and the accumulative impacts that arise with, for example and increase in nitrogen-phosphorus ratios during certain times of the year (DWAF, 1996a). Measuring the rate of leaching and how long it takes to reach surface water is highly complex, it may be more useful to directly examine water quality data to provide estimates of how much water on a monthly basis would be required to dilute pollutants. This would however be impossible to differentiate between different basin users therefore grey water with accurate data could potentially be useful in combination with actual water quality data.

## **5.5 Yield data**

Yields in citrus varieties are influenced by a wide variety of factors such as fertilisers, pests, rootstock, planting arrangement, orchard orientation, soil, pH, water quality, temperature, fertilisers and the timing of water applications (Outspan, 2004, Falivene *et al.*, 2006; Smith, 2006; Coetzee, 2007; Taylor & Gush, 2014). The yield data is deemed representative of the area and these factors, as it covered an average of 4420 hectares of the area (approximately 35%) (see Appendix 3 for detailed yield data). Yield data (ton/ha) for each cultivar did not vary substantially across each climatic year, apart from lemons and valencias, which increased noticeably in the wet year (2011) (Figure 5.10). Lemons exhibited the highest yield across all climatic years followed by either soft citrus or valencias and, finally, navels. Figure 5.10 demonstrates yield fluctuations over the last five seasons along with rainfall data. Valencias and lemons follow a similar yield pattern in comparison to each other over the different climatic years, with both yields notably increasing within the high rainfall year. However, navels and soft citrus show no apparent variation in relation to rainfall. This could also potentially demonstrate that navels and valencias are less sensitive to changes in climate than soft citrus and lemon cultivars.



**Figure 5.10 Rainfall (mm) and yield data (tons/ha) for the seasons 2009-2013**

Sources: LSRV WUA, (2014); Farm interview data

Despite the lack of a concrete pattern between yield and rainfall, a number of authors have shown that water stress during flowering, fruit set, cell division and cell development can affect fruit size, yield, internal fruit quality and canopy development (Coetzee, 2007; Falivene *et al.*, 2006). It would therefore seem that through irrigation CWRs for all cultivars are being met. Therefore, no pattern would emerge unless a higher proportion of green water to meet CWR had beneficial effects on yield. There is no apparent evidence of this despite green water having nutrients such as nitrogen, which is one of the most important nutrient elements in the fertilisation of citrus (Coetzee, 2007). This however could be due to the high fertiliser usage that takes place by farmers. Smith (2006) also states that temperatures reaching certain low or high temperatures during critical growth periods can reduce yields by approximately 6%. Coetzee (2007) also demonstrated the influence of soil pH on yield of citrus and showed that an increase in a pH level of 4 to 7 can increase yield from 11 tons/ha to 61 tons/ha respectively (averaging 555 trees/ha). What this data demonstrates is that water will not be the only component affecting yield and one must be cognisant of this when analysing WFs.

Potential citrus fruit yields, according to Alleman & Young (1993), are shown in Table 5.4. Citrus production in the LSRV is much lower than the potential production for all varieties and

approximately 10 to 20 tons less per hectare than likely production for navels and valencias shown in Figure 5.4. Lemons are however similar to the likely production figures demonstrated by Alleman & Young (1993). Taylor *et al.* (2014) cited production for a number of orchards in summer-rainfall regions of South Africa. In an orchard in Groblersdaal, navels had an annual orchard yield of approximately 60 tons/ha (833 trees/ha) and valencias 75-80 tons/ha (661 trees/ha), but did exhibit a low yield of 28 tons/ha and 15 tons/ha in a previous season for valencias and navels respectively. Another orchard in Malelane exhibited annual orchard yields in the region of 30 tons/ha (571 trees/ha) for valencias.

The long-term production data in the SRV over the last ten years measured over 6000 hectares, suggests a maximum potential yield for mature cultivars of 34 tons/ha for navels, 35 tons/ha for valencias, 55 tons/ha for lemons and 36 tons/ha for soft citrus with a spacing of 555 trees/ha. Therefore, one can conclude that yield per hectare in the LSRV is lower than other areas. However, this could be attributed to the average tree spacing of 555 trees/ha, which is lower than the areas described above.

**Table 5.4 Potential citrus fruit yields for navel, valencia and lemon varieties**

	NAVEL	VALENCIAS	LEMONS
First crop	4	4	3
Expected life (years)	33	33	25
Potential yield mature trees (tons/ha)	60	80	80
Likely production (tons/ha)	40	50	55

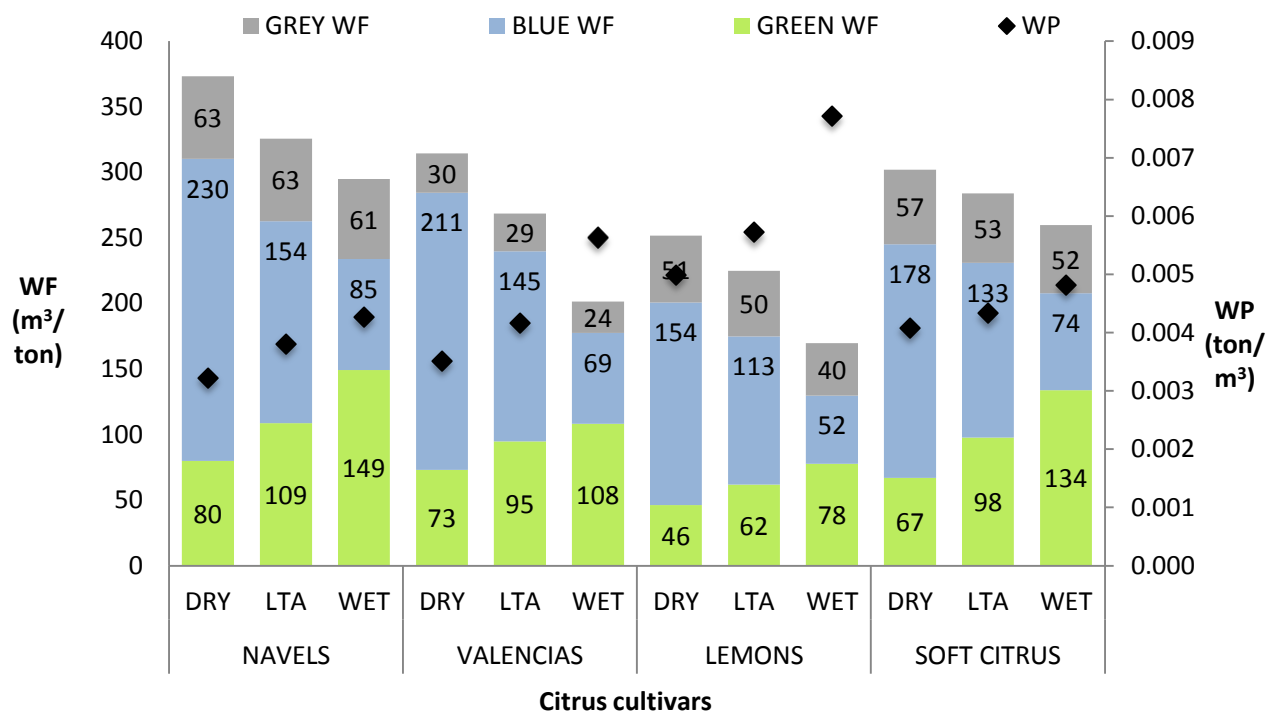
Source: Alleman & Young (1993)

## 5.6 The water footprint and water productivity of the lower Sunday River Valley citrus sector

Using the data mentioned and discussed above the green, blue and grey WF (m<sup>3</sup>/ton) and WP (tons/m<sup>3</sup>) for each variety of citrus was calculated (Figure 5.11).

### 5.6.1 Total green, blue and grey water footprints

The total WF is highest for all cultivars in the dry year and lowest in the LTA and wet years respectively. This would be a result of the lower evaporative demands of the crops during wetter years and higher yields that resulted for cultivars such as lemons and valencias. Despite lemons having the highest virtual water content or CWU in comparison to other cultivars, lemons exhibited the lowest total WF across all climatic years. Conversely, navels had the highest total WF across all three climatic scenarios, despite having a lower virtual water content or CWU. This would be a result of the higher annual yields demonstrated by lemons in comparison to navels. Therefore, lemons use less water ( $m^3$ ) per ton produced than navels. Valencias had a higher total WF than soft citrus in the dry year, but in the LTA and wet year soft citrus had a higher total WF in comparison to valencias. If we examine the total WF without including the grey WF, the analysis is the same except in the LTA year valencias have a greater WF than soft citrus. This demonstrates that although valencias had a greater total green and blue WF than soft citrus in dry and LTA year, its total WF was lower than that of soft citrus due to the greater grey WF of soft citrus in the LTA year.



**Figure 5.11 Average green, blue and grey WF (m<sup>3</sup>/ton) and WP (ton/m<sup>3</sup>) per hectare for citrus cultivars in wet, dry and average rainfall years under micro and drip irrigation**

Comparisons between total blue and green WFs showed that some cultivars were more susceptible to changes in climate. The WF of valencias was particularly affected by climatic changes, exhibiting the highest degree of variation over the different climatic years, followed by navels, lemons and soft citrus respectively. Lemons greater yield than other cultivars also explain their lower WF, despite their higher water use and soil application rates. Navels and valencias generally have lower yields than other cultivars and consequently have a higher green and blue WF's.

**a) Green and blue water footprints**

As discussed in chapter two, it is recommended that WFs be analysed separately (Boulay *et al.*, 2013). If one examines the green and blue WFs in Figure 5.11, as would be expected, it is evident that green WFs increase from dry to wet years, and blue WFs decrease during the wet years. Navels had the highest green and blue WFs, and lemons had the lowest green and blue WFs across all climatic years. Valencias exhibit a higher blue WF than soft citrus for the dry and LTA

year but is lower than soft citrus in the wet year. Regarding the green WF, valencias have a larger blue WF than soft citrus for only the dry year and with soft citrus exhibiting a higher green WF in the LTA and wet year.

Blue WFs increased by approximately 65% between wet and dry years and by 33% between the LTA year and dry year. Therefore, if the LSRV were to experience more severe drought years, blue WFs and subsequent irrigation use could potentially increase by approximately 49% for navels, 46% for valencias, 36% for lemons and 34% for soft citrus. Conversely, if the LSRV were to experience an increase in rainfall blue WFs would decrease by 45% for navels, 52% for valencias, 54% for lemons and 44% for soft citrus. These two scenarios could influence demands on water resources substantially.

#### ***b) Grey water footprints***

As already pointed out in section 5.4, the most critical pollutant contained in fertilisers used by farmers that requires the highest ambient volume of water to assimilate it is total inorganic nitrogen. This was the case for all cultivars. Lemons required the greatest application rates of nitrogen followed by navels and soft citrus and then valencias. Navels, however, had the highest grey WF across all three climatic years, presumably due its lower yield; therefore, a greater amount of grey water is required to assimilate the critical pollutant per ton of navels produced. Valencias had the lowest grey WF across all climatic years, presumably due to its low fertiliser application rates.

Soft citrus had a greater grey WF than lemons, in all climatic years. Given that application rates did not vary across the three climatic years, grey WF's were primarily influenced by yield. Therefore, the lower grey WF of lemons within the dry is due to lemons having a greater yield. It is important to note that the satsumas had a much lower grey WF than the other soft citrus cultivars (novas and clementines), due to their higher yield and lower application rates and nitrogen requirements. In fact, satsumas even had a lower grey WF than valencias. Given that yield had no apparent relation with rainfall and the same AR was taken for each year, comparisons of grey WFs across the different climatic years do not have much meaning. Data of

ARs across each year would have shown any potential variation that would occur. Since yield did not show any evident relationship with rainfall, it would be useful to make comparisons with fertiliser applications to see if ARs increase or decrease providing a buffer for yield.

Grey WFs should be just as representative of water usage as green and blue WFs. However, as discussed in section 5.4.2, grey WFs may not be representative of actual water quality and dilution requirements needed in the area. Refinements in the methods to incorporate more parameters need to be addressed particularly if the grey WF is to be used for decision making. Grey WFs could potentially be used or included in future water allocations to provide freshening flows downstream in areas that are reliant on IBTs or to account for water that is needed beyond the reserve requirement to maintain water quality. This however would require knowing exactly how many pollutants are diffused annually and the appropriate concentrations for assimilation. Lui et al. (2012) do acknowledge there is no way to verify grey WF results, therefore, interpretations need to be used in conjunction with water quality data. Zarate (2010) also note the difficulty in quantifying diffuse pollution as leaching and loads are dependent on a number of physiochemical properties and environmental variables.

### ***c) Physical water productivity***

The WP (tons/m<sup>3</sup>) of each cultivar is the inverse of the WF and demonstrates or measures the output produced per unit input, which in this case is water. Firstly, WP included both green and blue water use; this is because examining only blue water would skew the results providing higher productivities than would occur if all water use were accounted for. Despite the fact that lemons require the most amounts of water and fertiliser per hectare, they are the most efficient or productive of all the cultivars in terms of water use (Figure 5.11). Since lemons had the lowest WF and navels highest WF this directly translates into lemons having the highest WP and navels the lowest. In other words, lemons are more efficient in that they provide more output per m<sup>3</sup> in comparison to other cultivars.

WP was also higher within wet years than dry years. WP gives an indication of which cultivars provide more crop per drop and, subsequently, identifies opportunities for redistribution from

less efficient crops to more efficient crops (Cook *et al.*, 2004). Given that lemons only constitute 23% of the irrigated citrus land and less efficient cultivars such as navels constitute a dominant share of 38%, one could postulate that there is room for efficiency improvements based on the WF and WP indicators. However, one would also need to consider the potential result of an absolute increase in water since lemons do use more water than other cultivars.

Chouchane *et al.* (2013) recently examined green WP used in irrigated agriculture based on the yield that would be obtained if only rainfall was consumed and blue WP as the additional yield obtained, therefore trying to make a distinction. This provided a more accurate indication of the productivity contribution per blue and green water use. However, this requires the use of plant-water relationship models and data pertaining to water-stress coefficients. Nonetheless, the results without such models still demonstrate that total WP (green and blue) is an important indicator in terms of water use as it clearly makes a distinction between the efficiency of different cultivars. It also highlights that increases in productivity can occur through better use of both blue and green water. Molden *et al.* (2007) identified that WP and yield can substantially be improved through sounder management practices in rain-fed agriculture. The same could therefore apply in irrigated rain-fed agriculture regarding green water use.

### **5.7 Farmer's perception on future risks, price increases in water and a decrease in allocation**

Farmers were asked to list a number of variables or factors that they considered potential risks for the future, as well as any factors that previously affected or threatened their yield and profitability over the last five years. With regard to factors effecting yield and profitability more than one farmer listed variables pertaining to insecticides (8), weather patterns (4) and labour shortage and instability (4). Insects and pests specifically included black spot, false codling moth and the lemon borer moth. Other factors listed included: average tree age, cultivar spread, soil quality, incorrect application of fertiliser, exchange rate, lack of government support (for example maintenance of roads) and restrictions placed by importing countries.

Key potential risks for the future listed by farmers included increased production costs (6), of which farmers specifically referred to costs in electricity, petrol and labour. Electricity was

particularly emphasised and one farmer mentioned that they had an agreement with Eskom where during peak demands the farm would get its electricity cut off in exchange for a reduced price, as the electricity price was already so high. Two farmers mentioned water costs. Other risks included land reform, exchange rate, overproduction and the export market. Only one farmer explicitly stated he was concerned about potential water rights being taken away and that water reductions was a huge concern to him. Water, however, was evidently not a primary concern to majority of the farmers. The fact that most farmers were unwilling or not interested in participating in the study could also demonstrate the farmers' lack of interest in issues surrounding water. However, based on the emphasis the farmers placed on electricity, which is used to pump irrigation, this could indirectly show concerns. Annual reports from the LSRV WUA unequivocally mention that on-going concerns are the high increases in water charges that the DWA continually try to impose and protecting existing rights of water user licenses (LSRV WUA, 2012). Farmers were also reluctant to provide irrigation records; this could be as they were concerned that sharing such information could result in reductions of water allocations as they are using less m<sup>3</sup> per hectare than their allocated amount.

When farmers asked how they would be affected by a decrease in allocation farmers unanimously stated that without water they could not survive. Farmers also emphasised that it would lead to huge economic losses in production and profitability, decreased expansion and would restrict the number of trees that could be planted. Regarding an increase in prices, two farmers did note that water was relatively cheap and would not cause a substantial difference to profits but would 'not be ideal' as it would inevitably decrease profitability. Another farmer noted that if they were to have a poor production year they would not be in a financial position to pay for water. De Lange & Mahumani (2013) state that farmers generally can only respond in two ways to increases in prices. Firstly, to increase efficiency of water use or secondly cut back on production. Based on farmers' responses the latter option seems to be the case. This is most likely due to the fact that farmers are already irrigating with high efficiency irrigation systems and therefore the scope for increasing efficiency is limited (De Lange & Mahumani, 2013).

## **5.8 The importance of identifying virtual water and water footprints and potential risk prevention and reduction strategies**

Identifying green, blue and grey WFs give a good indication of total resource consumption and use of waste assimilation capacity related to citrus cultivars in the LSRV. Navel varieties, which currently constitute the greatest proportion (38%) of the cultivated citrus area in the LSRV, currently have the highest consumption of water resources per ton per hectare in comparison to other cultivars. Lemons which constitute a smaller proportion (23%), have the lowest consumption of water resources per ton per hectare, and valencias (29%) the lowest use of waste assimilation capacity per ton per hectare. Despite criticisms and arguments against reporting of volumetric figures (Ridoutt & Pfister, 2010), WF figures alone can provide useful information to compare demand for different types of water use for different scenarios. This has also been demonstrated by a number of other authors (Aldaya *et al.*, 2010b; Gerben-Leenes *et al.*, 2013; Ercin & Hoekstra, 2014; Zhang *et al.*, 2014) Results of this study indicate variations that occur in blue WFs across the different climatic years and demonstrate the dependence of blue water to buffer and stabilize the variable precipitation patterns that occur.

Correct irrigation scheduling and knowledge of WFs and WPs is crucial to improve water conservation, water demand management and water-use productivity (Taylor & Gush, 2014). By calculating green water, this highlights that improved management is not only relevant to blue water resources. Further, knowing the virtual water content of water can aid in demonstrating seasonal trends and when maximum demands will be placed on water resources. Soft citrus cultivars have shown to be less susceptible to changes in climatic variations that other cultivars and valencias were the most susceptible, lemons had the lowest WF and highest WP and valencias the lower grey WF. Farmers can use this information to develop strategies to use water more efficiently and plan appropriately for potential future changes in climate. If farmers were to take into account WFs and WPs and produce the most productive crop with the lowest WF, such as lemons one would need to assess the impacts on total increase in blue water usage for farms and the area. Farmers can still use this information to make informed decisions regarding water use and cropping strategies that would reduce WFs and increase WP.

In terms of WF reductions, farmers could reduce blue WFs firstly by adopting more efficient irrigation techniques (Hoekstra *et al.*, 2011). Figures on irrigation systems in comparison to Conradie (2002) already demonstrate farmers have switched from micro irrigation to drip. In 1999, 57% of fruit production was irrigated with micro irrigation and 18% with drip (Conradie, 2002), therefore drip irrigation has subsequently increased to 69% (LSRV WUA, 2014). Favilene *et al.* (2006) state that citrus trees irrigated by drip can withstand higher salinity levels. Therefore, since drip irrigation has a 95% irrigation efficiency in comparison to the 90% micro irrigation one would assume switching to drip systems would reduce the WF. However, given that some farmers are planning to switch back to micro irrigation, drip irrigation systems need to be further investigated before one can state conditions in licences that would require farmers to switch to the more efficient drip irrigation system. The Wetland Group (2004) also noted the trend in farmers installing drip irrigation but claimed that due to the transmissive soils in the Sundays River Valley demand could be greater than delivery with drip irrigation. What is also evident is that although citrus CWR are less than the annual allocation to farmers of 9000 m<sup>3</sup> per hectare, a reduction in water will have different impacts on different farmers as some are using their full allocation to water additional land.

Hoekstra (2014b) emphasise the increasing pressures that are being placed on businesses by communities and environmental organisations to disclose relevant data relating to unsustainable water use. Identifying water usage and productivity is the first step for farmers and companies to identify reduction strategies and targets (Hoekstra 2014b).

# CHAPTER SIX:

## SUSTAINABILITY ASSESSMENT AND POLICY RESPONSES

*“As water scarcity increases the need for a framework to judge beneficial use becomes more pressing. The answers provided by such a tool are the basis on which society decides who gets access to the resource and who does not”*

*- Conradie, (2002:1)*

Young cultivar, Hermitage

Photo: S.A Munro

## **6.1 Introduction**

As has been highlighted, volumetric accounts are useful but need to be carefully interpreted (Berger & Finkbeiner, 2012; Hastings & Pegram, 2012; Hoekstra & Tickner, 2012; Wichelns, 2014). Numerous studies have examined the environmental sustainability of the WF (Mekonnen *et al.*, 2012; Hoekstra *et al.*, 2012; Zeng *et al.*, 2012; Ercin *et al.*, 2013; Schyns & Hoekstra, 2014; Zhang *et al.*, 2014) as the WF assessment manual provides clear and comprehensive criteria by which to do so (Hoekstra *et al.*, 2011). Very limited applications of economic and social sustainability have been examined and the criterion within the WF assessment manual is not as comprehensive as the environmental criteria. This chapter therefore aims to examine both the environmental and socio-economic sustainability of firstly the sub-catchment and then subsequently the process of citrus production. Further, since authors have advocated that WFs need to be considered in its context (Hoekstra 2014b), this chapter examines a number of environmental, economic and social considerations specifically pertaining to the LSRV and incorporates local data.

## **6.2 Measuring the sustainability of the LSRV river basin**

As mentioned in chapter four, no WF assessment has been conducted for the LSRV sub-basin or the greater Sundays River basin. Since citrus uses the majority of the water resources within the areas as it covers 73% of the irrigated area in the LSRV basin (LSRV WUA, 2014), it was deemed a good proxy for assessing overall water use within the basin. Based on available data blue water scarcity, WPL, land use changes, social disputes and allocation efficiencies were examined.

### **6.2.1 Water availability and scarcity**

Due to the substantial volumes of water transferred via the IBT, the condition of the lower Sundays River is more complex than other rivers. Flows have been completely altered with options of restoring the river to pre-transfer conditions deemed as highly unlikely (Conradie, 2002). Prior to transfer, flows were intermittent with a relatively small and highly variable yield (DWAF, 2005; LSRV WUA, 2014). The natural runoff and estimated ecological flow requirements (EFR) according to DWAF (2005) are shown below in Table 6.1.

**Table 6.1 Natural mean annual run-off (MAR) and estimated environmental flow requirement (EFR) for Sundays River (million m<sup>3</sup>/yr) at a 1:50 year assurance**

Hydrological sub-division	Natural MAR	Incremental natural MAR	EFR	Incremental EFR
Upper Sundays	43.7	43.7	3.0	3.0
Middle Sundays	217.6	173.9	13.1	10.1
Lower Sundays	279.9	62.3	19.8	6.7
<b>Total Sundays</b>	<b>279.9</b>	<b>279.9</b>	<b>19.8</b>	<b>19.8</b>

Source: DWAF, (2005)

Midgley *et al.* (1994) recorded a mean naturalised stream flow of 206 Mm<sup>3</sup>/a ( $\pm 184$  Mm<sup>3</sup>/a) and a cumulative flow of 244 Mm<sup>3</sup>/a ( $\pm 279$  Mm<sup>3</sup>/a) at Darlington Dam for the period 1923-1977. The hydrological characteristics of the natural flows in the Sundays River are therefore highly variable with standard deviations often exceeding mean flows (Stassen, 1997). Table 6.2 demonstrates the extreme variability of the tributary flows in the Fish-Sundays scheme, as well as their small contribution in comparison to the IBT. Currently it is estimated that the Sundays River main tributaries contribute less than 5% of water required by municipal and irrigation use (Conradie, 2002). Therefore, the estimates provided by DWAF (2005) for MAR and EFR do not seem to incorporate the variability that occurs each year naturally.

**Table 6.2 Tributary flows and transfer volumes (Mm<sup>3</sup>/yr) for the Fish-Sundays scheme**

	1993/94	1994/95	1995/96	1996/97	1997/98
Sundays	23.7	16.1	13.1	101	2.19
Total tributaries <i>(including Sundays)</i>	96.39	96.37	55.79	270.30	35.01
Transfer volume	446.37	538.55	528.41	508.27	650.51

Source: DWAF hydrological database in Conradie (2002)

According to DWAF (2005), the LSRV has enough water available to meet current water requirements (Table 6.3). Annual local yield<sup>11</sup> for the lower Sundays River is comprised of natural resources which includes surface (14 Mm<sup>3</sup>) and ground water (2 Mm<sup>3</sup>) as well as usable return flow from irrigation (10 Mm<sup>3</sup>) and urban usage (1 Mm<sup>3</sup>). The transfers into the lower Sundays are from upstream. Local water requirements include irrigation requirements of 104 Mm<sup>3</sup>/yr, which are inclusive of canal losses, and urban and rural usage of 2 Mm<sup>3</sup>/yr, which incorporates the basic human needs reserve of 25 litres per day (DWAF, 2005). Transfers out include 7 Mm<sup>3</sup>/yr for freshening downstream and irrigation return flows and 11 Mm<sup>3</sup>/yr to NMBM. According to DWAF (2005), total freshening flows contribute approximately 6% of the 575 Mm<sup>3</sup> IBT from the Upper Orange into the Fish-Sundays scheme. Freshening flows allow for river and canal transportation losses and for 'making poor quality water usable.' Blue water usage according to the figures provided by DWAF (2005) does not exceed blue water availability minus the annual environmental flow requirements. DWAF (2005) do acknowledge that yield balances are based on estimates and reserve requirements for the lower Sundays were determined by rapid one assessments, therefore more accurate and reliable data would improve estimates.

---

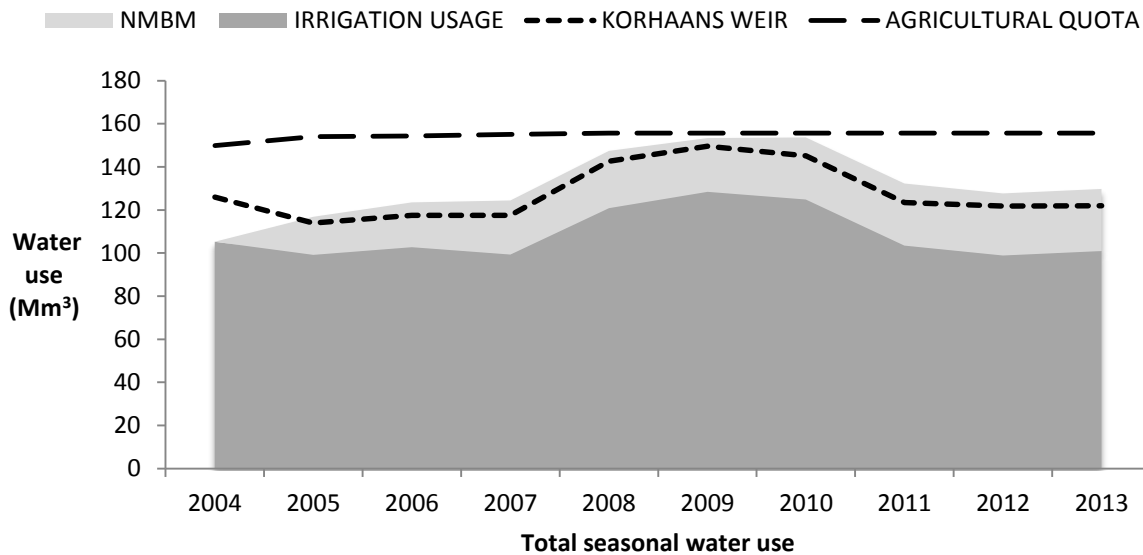
<sup>11</sup> The available yield is the amount of water expected to be "available" during any one year from dams, rivers or groundwater as a result of existing infrastructure supplying water, usable return flows as well as transfers (DWAF, 2005).

**Table 6.3 Water requirements and availability for the year 2000 at 1:50 year assurance (Mm<sup>3</sup>/yr)**

Sub-area	Available yield				Water requirements			Balance
	Local yield	Transfers in (1)	River losses (2)	Total	Local requirements	Transfer s out (1)	Total	
Upper Sundays	14	0	0	14	10	5	15	-1
Middle Sundays	53	128	0	181	66	115	181	0
Lower Sundays	27	115	-18	124	106	18	124	0
<b>Total Sundays</b>	<b>94</b>	<b>123</b>	<b>-18</b>	<b>199</b>	<b>182</b>	<b>18</b>	<b>200</b>	<b>-1</b>

Source: DWAf, (2005)

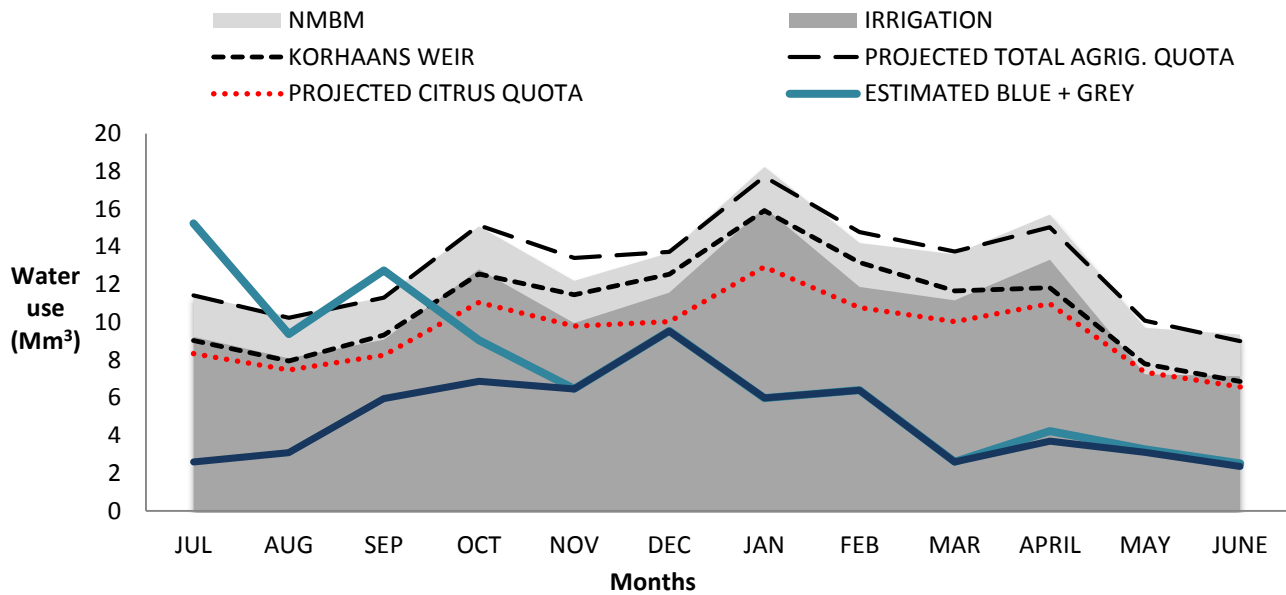
According to raw data obtained from the LSRV WUA (2014), the agricultural quota of water has been underutilised by approximately 30% over the past 10 years (Figure 6.1). In a dry season such as 2009, water usage increased to 80% of the quota and in a wet year decreased to 66%. The agricultural quota per annum is based on the area scheduled (number of licence permits) multiplied by 9000 m<sup>3</sup> per hectare per annum which is approximately 155 Mm<sup>3</sup>. The area scheduled has remained at approximately 17 000 hectares for the last nine years and has only increased by just less than 1000 hectares over the last ten years. This is attributed to the difficulty and expense in applying for and gaining new water user licenses for the area. Farmers specifically stated that applying for additional water user licences was just too expensive and that they need to make do with the water they have. All water users in the area have been registered and are provided with allocations in line with NWA. NMBM, however are using their full allocation. Raw water usage for the SRVM was not available, however, they are said to be utilizing approximately 60% of their allocation per annum (LSRV WUA, 2014). According to SRVM (2010), raw water purchased is estimated at 2 Mm<sup>3</sup> but was expected to increase to 2.7 Mm<sup>3</sup> over the following five years.



**Figure 6.1 Total seasonal blue water usage and quotas in the lower Sundays River Valley from 2004-2013**

*Source:* Own elaboration based on LSRV WUA, (2014)

Although it is evident there is more than enough water to meet current requirements, the availability of water at Korhaans Weir on a monthly basis is evidently lower than the current abstractions (Figure 6.1 and 6.2). This would indicate that water users are abstracting more than what is being released. However, according to LSRV WUA (2014), water is also stored in Scheepervlakte Dam where data is not available. Farmers order water on Thursdays in order to receive water on the Monday. Based on the levels of the Scheepersvlakte Dam and Korhaans Weir water is released accordingly from Darlington Dam. If farmers wish to cancel their orders, they can do so but must give 24 hours notice. Water not used will then be allocated elsewhere or diverted into Scheepersvlakte Dam, which is said to account for the differences (LSRV WUA, 2014). The irrigation usage in Figures 6.1 and 6.2 include losses. In contrast to DWAF (2005), the WUA did state that they do not have freshening releases and that no extra water other than the orders they receive from the water users is released from Darlington Dam (LSRV WUA, 2014). Although IBT's are an out-dated policy response (Jury & Vaux, 2005), one can assume that the transfer of water to the LSRV will continue.



**Figure 6.2 Current water use abstractions based on data from the LSRV WUA and estimated LTA grey and blue water use per month.**

*Source:* Own elaboration based on LSRV WUA, (2014) and SAPWAT 3.0 calculations

The hydrological monitoring point at Addo Drift East (the most downstream monitoring point before water flows into the sea) only has data recordings up until 1997; therefore, it is not possible to examine water availability downstream of the citrus sector. The data available does demonstrate that the total water availability downstream ranged between 26-128 Mm<sup>3</sup> between the 1993-1996 seasons. DWAF (2005) state that the surplus flows at the bottom of Sundays River is comprised of return flows downstream of the last point of abstraction and unused irrigation releases. Furthermore, it was also observed that the Sundays River used to be a perennial river classified by high variability of flows and now because of the IBT and return flows there is now a constant flow throughout the year (LSRV WUA, 2014). Basson (1999) argues that the IBT guarantees a stable aquatic environment and subsequently there is no need for further provisions for an environmental reserve. According to the DWAF (2005) water balance, the estimated reserve for the lower Sundays translates into a yield reduction of 7Mm<sup>3</sup>.

It is also important to demonstrate the differences in the estimated water use based on LTA blue WF calculations and actual water use. Again, as observed in Figure 6.2 the blue WF could have been underestimated based on total irrigation abstractions and the fact that the blue WF shows that citrus farmers are only using 52% of their allocation for the year. However, the data from the

WUA, shown as irrigation in Figure 6.2 is based on all irrigators in the area and includes evaporative losses, whereas the blue WF only accounts for citrus production. Therefore, along with data for other irrigators this could also be an indication to the amount of water that is lost during transportation. Water demands are also highest in December based on WFs, in comparison to actual highest water demand occurring in January. Therefore, while the blue WF provides a good estimation since similar monthly trends were exhibited, it also demonstrates the importance in verifying data and high accuracy of inputs needed to measure CWU. A sensitivity test by Zhuo *et al.* (2014) revealed that WF calculations are most sensitive to reference evapotranspiration ( $ET_0$ ) and crop coefficients ( $K_c$ ).

Based on the available data, the ratio of LTA blue water consumption for citrus ( $58.7 \text{ Mm}^3/\text{yr}$ ) and availability for citrus ( $113.6 \text{ Mm}^3/\text{yr}$ )<sup>12</sup> minus EFR ( $19.8 \text{ Mm}^3/\text{yr}$ ) there is no blue water scarcity on an annual basis. In a dry year, total blue water consumption for citrus is approximately  $89.2 \text{ Mm}^3/\text{yr}$  there is still no blue water scarcity. If we assume all other irrigators are using their full allocation ( $42 \text{ Mm}^3/\text{yr}$ ) and calculate water scarcity based on all the irrigators (water availability of  $155 \text{ Mm}^3/\text{yr}$ ) there would still be no water scarcity for both LTA and dry years. Furthermore, water availability is underestimated, as it does not include run-off for the area and uses EFR from DWAF (2005) which is higher than average. Therefore, based on the above local data we can assume that there is no water scarcity in an average year. EFR are not available on a monthly basis and therefore monthly variation cannot be examined. Hoekstra *et al.* (2011) state that measuring water scarcity on an annual basis is deemed crude and insensitive to fluctuations that occur throughout the year. However, based on Basson (1999) and LSRV WUA (2014) it is evident that no water scarcity occurs because of the IBT.

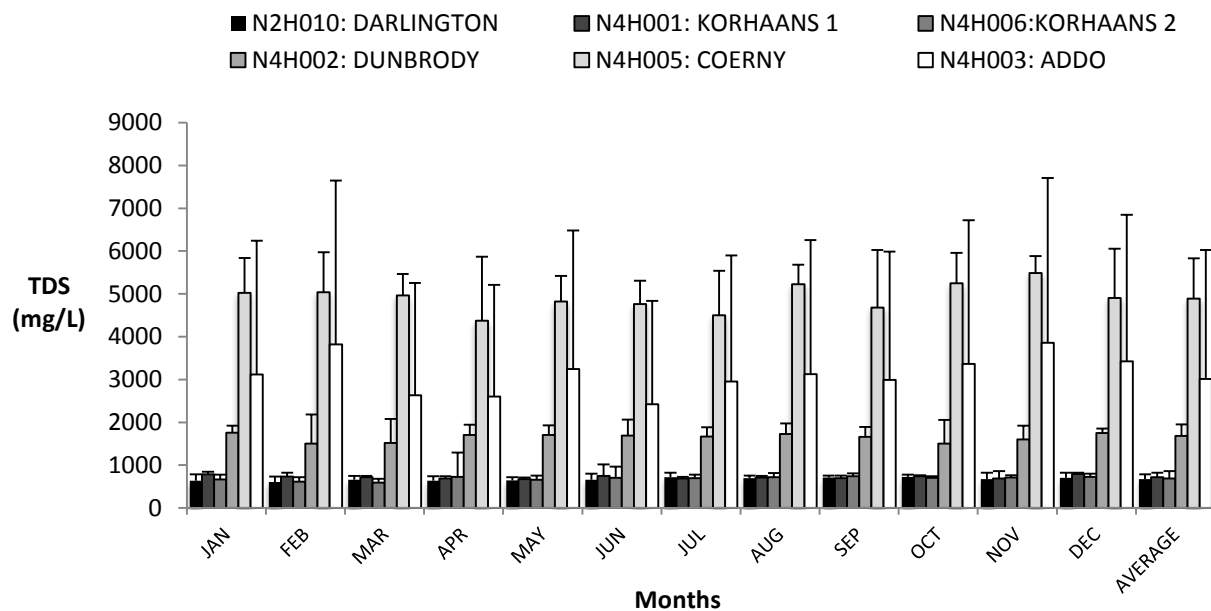
### 6.2.2 Water pollution level

While water scarcity may not be an issue within LSRV, water quality potentially is. The monthly grey water footprint was estimated based on timing of applications (see Appendix 4.1) and then

---

<sup>12</sup> This was calculated based on the number of hectares for citrus and the allocation of  $9000 \text{ m}^3$ . Essentially it is 73% of the whole irrigated agricultural quota of  $155 \text{ Mm}^3$  for the area

extrapolated based on the number of hectares and maturity of cultivars.<sup>13</sup> Based on timing of applications, grey water was required only between the months of April and September. This would not necessarily be true, as this would depend on how long it would take pollutants to diffuse into water sources. The grey WF therefore does not provide an accurate estimation of the amount of water required to dilute all pollutants on a monthly basis using tier one methods. If we examine water quality on a monthly basis, specifically Total Dissolved Solids (TDS), it is demonstrated that there is not much variation for each monitoring point on a monthly basis (Figure 6.3). The same pattern was demonstrated for other parameters. Therefore, the discussion on water quality and grey WFs in chapter five can also be reiterated in this section. While the theoretical concept of grey WF is potentially useful, the results shown based on tier-one guidelines are not, particularly when examining monthly trends. Again, it would be more useful to examine water quality on a monthly basis and determine grey water from data such as TDS, as it is a more accurate indicator of water quality (Grosskopf, 2004).



**Figure 6.3 Mean ( $\pm$  s.d) monthly TDS (mg/L) for monitoring points in the LSRV taken by DWS from 1999-1998**

Source: DWS, (2014)

<sup>13</sup> Young cultivars were assumed to require half the amount of grey water ( $m^3$ ) to assimilate pollutants.

Nonetheless, annual calculations of the WPL demonstrated that there might not be enough water for grey WFs to be assimilated in dry years. WPL was calculated based on total sum of grey WFs, estimated at 28.7 Mm<sup>3</sup>/yr and the downstream water availability values at Addo Drift East monitoring point (26-128 Mm<sup>3</sup>)<sup>14</sup>. Therefore in some years there may not be enough water to assimilate the grey WF and potentially exceeds the assimilation capacity by 10%. These values are also potentially underestimated given that the summation of grey water only includes citrus and not grey WFs from other irrigated land uses pertaining to lucern, pastures and cash crops. The calculations also require more accurate data based on return flows (Addo Drift East data is only used as a representation) and whether or not ARs increase in dry years. Based on the results one can conclude though that on average ambient water quality is met and only in some dry years ambient water quality standards would not be met. This shows the importance of considering dry years and also the potential changes that would occur if farmers continue to expand their farms with current water allocations. Again, however, the impacts of grey WFs would be more useful if examined on a monthly basis with more accurate data. Furthermore, actual water quality data does indicate that the quality of water is unacceptable on average (DWS, 2011; DWS, 2014). The salinity of surplus flows at the bottom of the Sundays River is too high for direct beneficial use without blending or treatment (DWAf, 2005). Hastings & Pegram (2012) do note that converting a measure such as water quality into quantity results in a loss of information the harm a constitute can cause and also that it does not account for ecotoxicity and biodegradability.

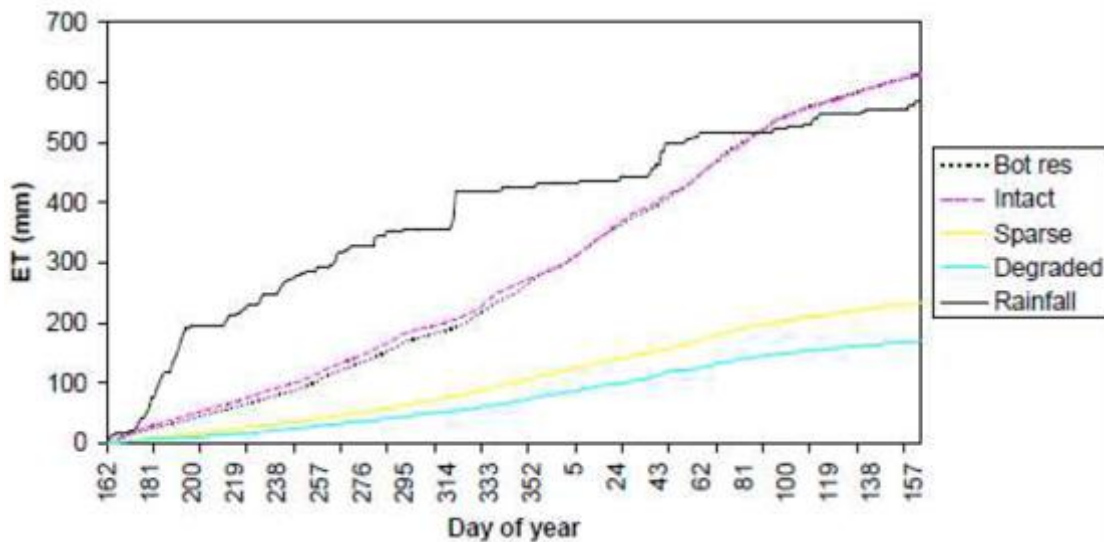
### **6.2.3 Evapotranspiration and land use change**

Palmer *et al.* (2014) emphasise the importance of estimating ET of land cover types in order to defend the sustainable functionality of natural rangelands in comparison with other land use options. Palmer *et al.* (2014) also states that estimations of ET are important in determining catchment-scale water balance and defining the health of an ecosystem and the quantity of water used by the vegetation. Palmer *et al.* (2012) modelled and examined the ET for three vegetation types within the Addo Elephant National Park. The study demonstrated that ET in intact, sparse

---

<sup>14</sup> Downstream water availability was used as these values are return flows and unused irrigation releases so provide a more accurate estimate of actual run-off than the natural run-off estimates by DWAf (2005) in Table 6.1.

and degraded thicket vegetation, which is the natural biome occurring in the LSRV, has a total evaporation of approximately 610 mm, 240 mm and 160 mm respectively per year (Figure 6.4). In comparison, the total ET of citrus ranges between 238-504mm of green water in dry and wet years respectively and 256-793 mm of blue water in wet and dry years respectively (Table 5.1). Since the figures calculated by Palmer *et al.* (2012) were for a dry year (season 2009), it is evident that citrus has a higher total ET than the natural vegetation and as result would decrease natural run-off. Increases in runoff do occur because of irrigation losses; therefore, it would potentially be useful to determine the net losses in evaporation because of land use change, but also changes that occur in run-off. Changes in runoff will also be useful in providing more accurate estimates for grey WF calculations.



**Figure 6.4 Addo Elephant National Park accumulated ET and rainfall from the 10 June 2008- 8 June 2009**

Source: Palmer *et al.* (2012)

#### 6.2.4 Social and economic sustainability

Despite their being no physical water scarcity in the LSRV, currently there are many on-going social disputes regarding water availability and service delivery. Recently during service delivery protests because of 'irregular expenditure' and water cuts, buildings were burnt down with even schools and businesses having to close (Knotze, 2014; Matroos, 2014; News 24, 2014). Water cuts were said to have occurred from three weeks to up to three months (Knotze, 2014; Matroos, 2014). Malony (2013) demonstrated in her sample study of Aquapark and Nomathamsanqa, two

informal settlements surrounding Kirkwood and Addo that only 18% of households had access to water through taps within their house. Most households relied on two or more sources of water because of water shortages. Water cuts were said to occur one to three times a week for 54% of households and daily for 19% of households. Alternative sources for 39% of households were more than 30 minutes walking distance away with the burden of carrying the water from these far distances falling on women (Malony, 2013). Aquapark was particularly affected by these water shortages more so than Nomathamsanqa with 30% of households experiencing daily shortages in comparison to 7% of Nomathamsanqa. As discussed in chapter three, this is a combined result of insufficient storage capacity and the WUA not working on weekends (Clifford-Holmes *et al.*, 2013; Malony, 2013).

The quality of water, particularly in Nomathamsanqa, was a concern to households with 74% of respondents that the water quality from the municipality and alternative sources such as the canal to be of poor quality. According to Malony (2013: 18), “many respondents state that the poor or very poor water quality is due to water being dirty, having red worms in it and the water having a sour taste or smell.” According to the SRVM (2010), this is a result of poorly managed stormwater systems, blocked sewers and pump failures leading to leaked sewage, runoff from informal settlements, inappropriate disposal of sludge from latrine pits, runoff from solid waste sites where no leachate collection system exists and run-off from agricultural areas. This is important, as agricultural runoff is only one of a numerous sources of diffuse pollution within the area. Therefore, the unacceptable water levels would be a combined result of water users and does not solely lie on the citrus farmers. This is potentially where the grey WF would be useful is by measuring these distinctions. From the assessment of the grey WF in terms of WPL, in an average year, the unacceptable levels of water quality would not be attributed to agriculture runoff because of citrus. This mirrors the argument made by a number of authors emphasising that there is a shared risk and responsibility between stakeholders (Pegram *et al.*, 2009; Hoekstra *et al.*, 2011)

Furthermore, the issues of conflict regarding water access within the LSRV cannot be attributed to the production of citrus as there is more than enough water supplied to the municipality to

meet current demands. Therefore, issues of water conflict within the area pertain to the SRVM to infrastructural and institutional water scarcity and not physical water scarcity.

### **6.2.5 Efficiency of allocations**

Conradie (2002) simulated agricultural water values using parametric linear programming models and a series of binding water constraints for sixteen typical commercial farms on the Fish-Sundays scheme. Conradie (2002) reported both marginal and total water values to confirm the financial feasibility and the efficiency of allocations and gains from reallocation respectively for the Fish-Sundays Scheme. Shadow prices were also converted to per hectare rental values and land values; land carries the water rights in the area. The optimal enterprise mix under perfect certainty demonstrated that shadow prices for citrus farms in Sundays had the highest water values with lemons dominating crop mix. As optimal enterprise mixes showed no resemblance to observed mixes, a simulated observed enterprise mix was derived using risk coefficients. Only when limiting soft citrus and lemons to 40 % and using high-risk coefficients of the total area could a representative cultivar mix for citrus be observed. Since citrus farms in Sundays on average irrigated a larger area than their current allocation and most other irrigators in the scheme use close to their allocation positive marginal values were observed (Conradie, 2002). However, some irrigators within the Fish River reserve some of their water rights for assurance against climate risk as a result marginal values were zero therefore a non-binding water constraint indicated that farmers were willing to sell rather than buy water. Based on the reflected risk adjusted farm level production at the current water constraints, citrus production contributed 71% to the value of water with small expanding farms contributing the greatest proportion and exhibiting the highest water values. The study indicated that water should be used for citrus production to promote efficient use and therefore current water allocation was not efficient. Based on the simulated results water should theoretically migrate from Fish to Sundays (Conradie, 2002).

In comparison to current water usage of citrus farmers, it is evident based on the percentage of water allocations used that possibly more farmers within the LSRV are not exercising their water rights. One can therefore assume that current water values would range substantially across

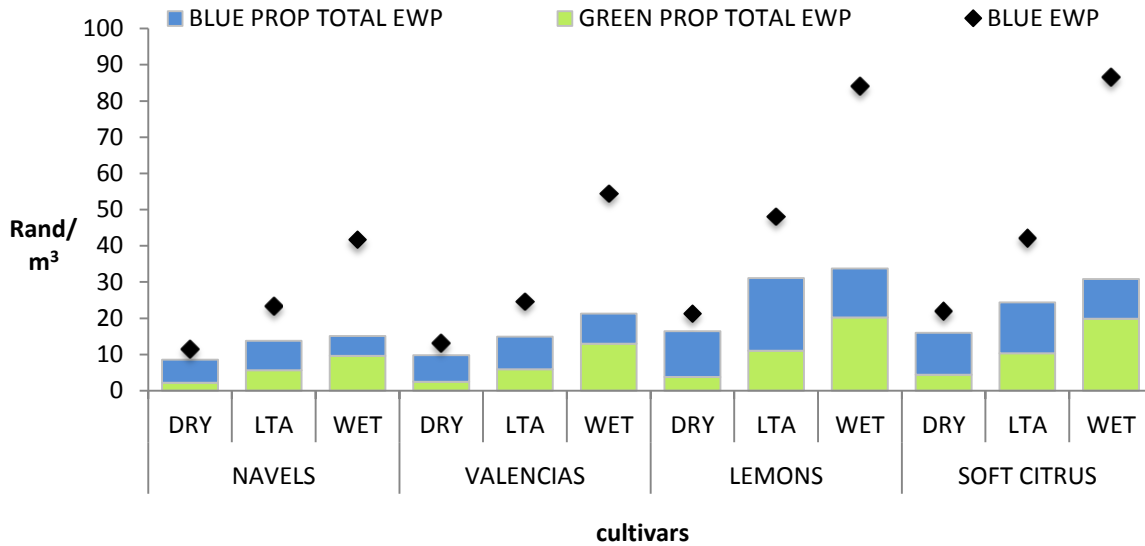
citrus farms. Because allocations are deemed efficient if shadow prices are equal across users (Conradie, 2002). It is evident that reallocation would improve total benefit within the LSRV. Furthermore, it is also important to note that Basson (1999) concluded in a hydrological systems analysis that in a national context the economic production and employment opportunities per unit of water transferred to the Fish-Sundays region would be far greater in an industrialised economy such as Gauteng.

### **6.3 Sustainability of the citrus production process**

Despite there being no signs of physical water scarcity, and the WPL could only be directly be attributed to the citrus sector in dry years, the sector still falls into a context plagued by economic scarcity. However, the potential of increasing future droughts could lead to increased levels of physical water scarcity and WPLs. Furthermore, there is the potential scope for more allocative efficient allocations. It is therefore valuable to examine the technical efficiency and productivity of current water resources as well as the possibility of benchmarks for WFs pertaining to the citrus process.

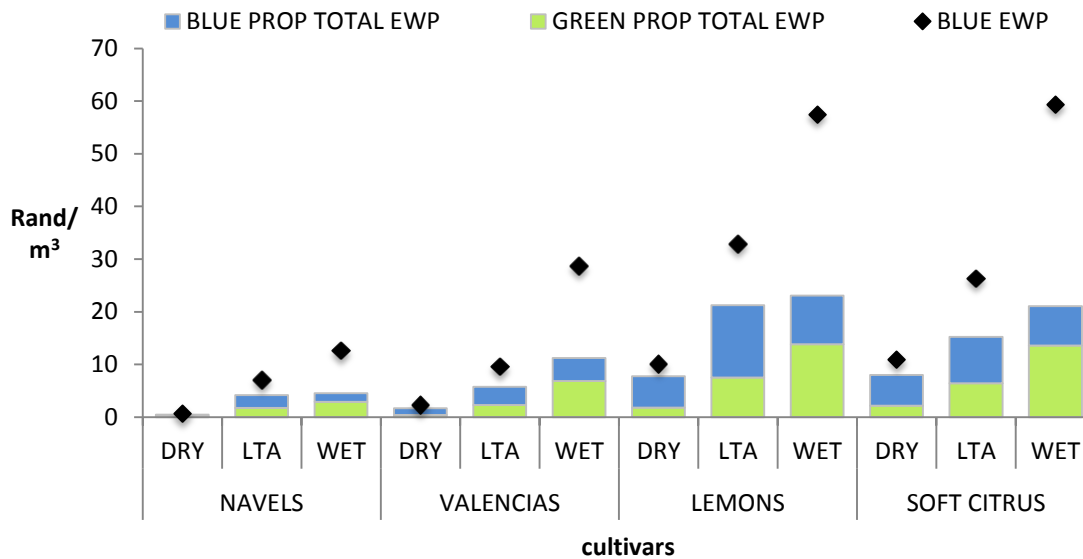
#### **6.3.1 Economic water productivity**

Both blue and total (green and blue) EWP were calculated for each cultivar across the three climatic years. Blue EWP was also calculated to demonstrate the differences that result when green water is excluded, but also because allocations, management practices and reduction strategies pertain to blue water (Aldaya *et al.*, 2008). The same method employed by Chouchane *et al.* (2013) discussed in chapter five could be used to provide indications of the actual contributions made by green and blue water. However, since these models were not adopted the proportion of green and blue is indicated just to give an indication of the potential contribution of each. EWP was calculated using farm gate price as well as using net income. Results for EWP using farm gate price is shown in Figure 6.5. EWP increased progressively from dry to wet years for all cultivars. Lemons had the highest total EWP in comparison to other cultivars across all climatic years followed by soft citrus and valencias. Navels had the lowest EWP values across all climatic years in comparison to other cultivars.



**Figure 6.5 Total economic water productivity and blue economic water productivity (R/m<sup>3</sup>) for citrus cultivars across different climatic years based on farm gate prices**

In comparison, total EWP based on net revenue (Figure 6.6) for each cultivar demonstrated a reduction in total EWP and blue EWP but exhibited the same pattern as using farm gate export prices for each cultivar across the different climatic years. Differences between using farm gate prices and net revenue ranged between 21-31 R/m<sup>3</sup> for lemons, 15-24 R/m<sup>3</sup> for soft citrus, 6-15 R/m<sup>3</sup> for valencias and 4-14 R/m<sup>3</sup> for navels per hectare for LTA years. Therefore, total EWP was almost half the value when net revenue was used as the monetary value.



**Figure 6.6 Total economic water productivity and blue economic water productivity (R/m<sup>3</sup>) for citrus cultivars across different climatic years based on net revenue**

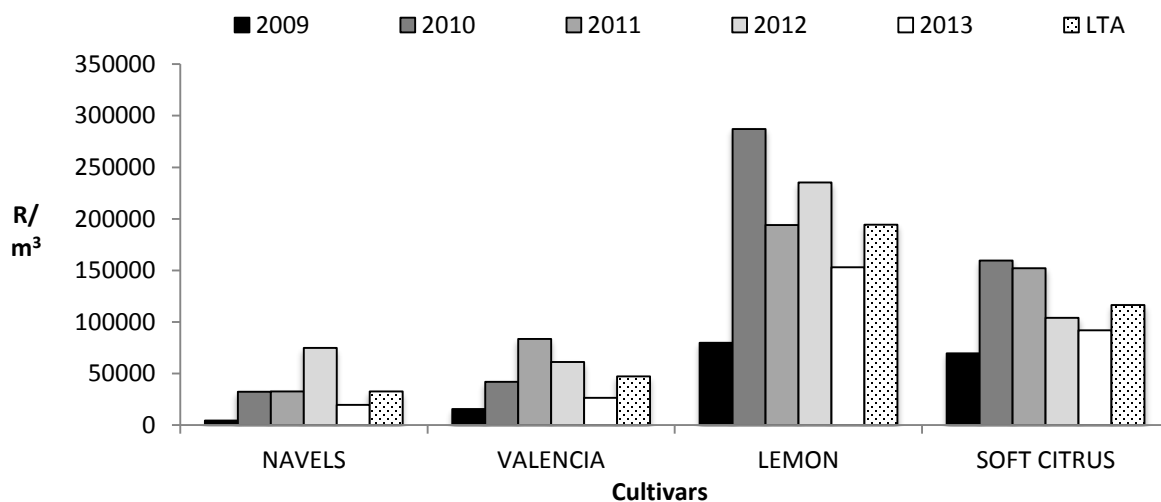
In terms of total EWP and blue EWP values also differ substantially, particularly within wet years as result of the increase in proportion of green water used and not necessarily because of management practices. Examining both total and blue EWP each have their own advantages. Total EWP gives a more accurate representation of the total water usage. Furthermore, the value obtained per m<sup>3</sup> is due to both blue and green water resources being used and not just blue, therefore, expressing blue water in terms m<sup>3</sup> derived from both blue and green is potentially misleading. Making a distinction between blue and green water resources is also becoming increasingly important in water management (Aldaya *et al.*, 2010a).

The results showed that lemons generated more value than other crops per m<sup>3</sup> of water use across all climatic years followed by soft citrus, valencias and navels. Interestingly, the findings presented by Conradie (2002) also demonstrated that lemons had the highest marginal value of water followed by soft citrus. Both results are due to the higher profitability of these cultivars. EWP could therefore potentially provide insights into the efficiency of allocations. It is important to note though that although marginal cost pricing maximises social welfare and is therefore efficient it is not always fair (Conradie, 2002). Since allocations to emerging farmers cannot be justified through marginal cost pricing, EWP could potentially serve as a criterion by which to

justify water allocations to emerging and developing farmers. EWP is also an important indicator as it clearly makes a distinction between higher and lower value crops.

### 6.3.2 Economic land productivity

It has been argued by a number of authors that water is generally applied to increase land productivity and not WP (Chouchane *et al.*, 2013; Lautze *et al.*, 2014). ELP is often the primary indicator used to assess the viability of production practices (Wiebe *et al.*, 2001). ELP for each citrus cultivar for the years 2009-2013 is shown in Figure 6.7. Since chapter five demonstrated that rainfall had no evident effect on yield, it was important to examine the variation of ELP over a wider range of years. Lemons had the highest ELP with an average gross profit of R194341/ha followed by soft citrus (R116353/ha), valencias (R47376/ha) and finally navels (R32625/ha). This same trend was evident across all years. Results are primarily a result of the fact that lemons have a higher yield and receive a higher price per ton than navels.

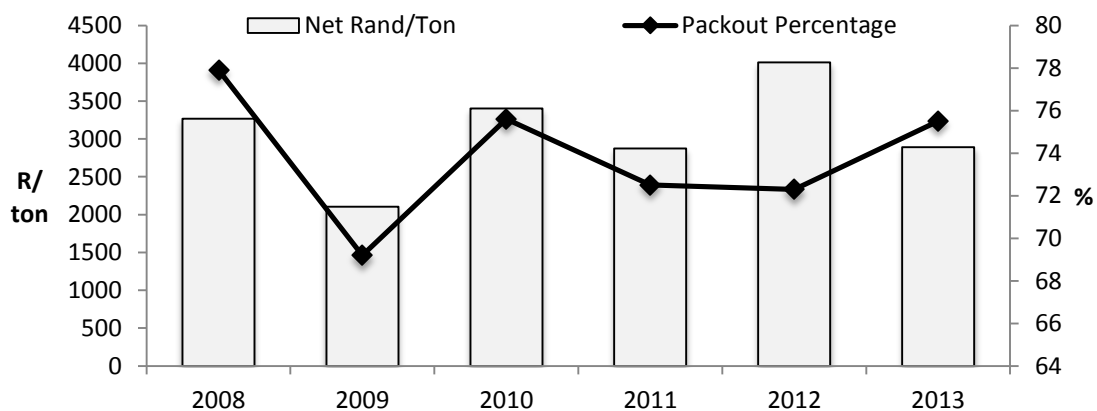


**Figure 6.7 ELP (R/ha) of cultivars in the LSRV for the 2009-2013 season using net revenue.**

It is evident that price received per ton of each cultivar significantly influences ELP as well as EWP. For fruit crops such as citrus, the average price farmers receive is determined by the quality of citrus cultivars. Macro elements of citrus include nitrogen, phosphorus, potassium, calcium, magnesium and sulphur (Coetzee, 2007). Changes in the optimal ranges of these elements can

have differing effects on fruit size, skin thickness, percentage juice, total soluble salts percentage and acid percentage (Coetzee, 2007). All of these properties are evaluated and will have an effect on whether it is appropriate for export or not. The better the quality, the higher the price received on the export market. The average price received per farmer will also depend on the age distribution of their orchards as well as the exchange rate, given that the industry is orientated for export. Therefore, a variety of factors will affect price and consequently average prices per ton will often demonstrate the quality of the cultivar. Since the data used was predominately based on export prices it, firstly, leads to an overestimation and does not demonstrate fruit quality for each cultivar. However, based on data provided by a citrus company in the area for average pack-out percentages and net rand value per ton for the season 2009-2013 some insights can be made.

The average pack-out percentages shown in Figure 6.8, demonstrate there is no evident trend relating to climate. Average quality of fruit quality did decrease in 2009 based on the decrease in average pack-out percentage to 69.2 % but it is not evident if that is a result of a drought or not. Given that there was not an increase in pack-out percentage for the wet year one can assume climate does not impact the price of fruit. This also emphasises the importance of using local price data and not national price data as well examining price over a number of years. Local prices will reflect local management practices and will be more useful when making direct comparisons between areas.



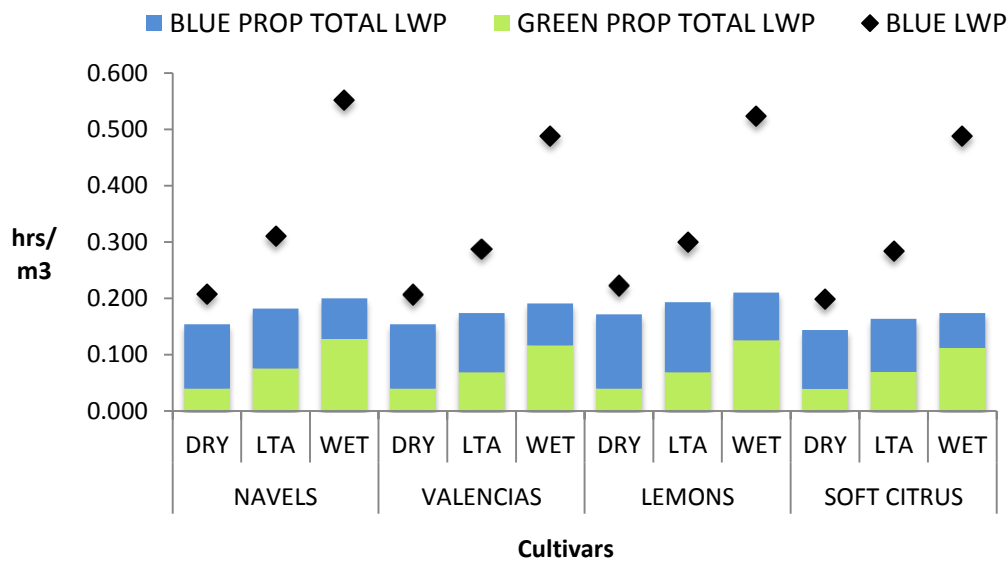
**Figure 6.8 Average net Rand per ton and pack-out percentage for all cultivars for the seasons 2008-2013 in the LSRV**

*Source:* Citrus company in LSRV

Average net revenue determined from farmer interviews does however follow the same trend across each year as aggregated figures for the area. Therefore, one can verify that the trends in EWP and ELP are representative; they may just be overestimated. What is evident, however, is that price and yield is a major determinant in placing a value on land and water. Grey WFs, although not examined in terms of its value, would potentially be useful to examine in terms of value produced, as fertilisers seem to be a key component in influencing water quality and possibly yield. This would require knowing exact application rates for a given year and cross-examining with price over a number of years.

### **6.3.3 Labour water productivity**

Based on farm interviews, farmers employ 1.16 workers per hectare. This was comprised of 0.93 seasonal workers (81%) and 0.22 permanent workers (19%) per hectare. Seasonal workers refer to the fruit pickers that work from approximately May to October, however some farmers did have their own pack-houses so this would have included packers in some cases. This was similar to the figures obtained from one of the citrus companies, which stated that one hectare of citrus required approximately  $\frac{3}{4}$  of a seasonal worker (both pickers and packers) and  $\frac{1}{4}$  of a farm permanent worker per season. They also stated that for every seasonal worker on the farm  $\frac{1}{2}$  a person in the pack-house is needed. Therefore, approximately every 1.2 hectares of citrus requires one seasonal worker and every 5.4 hectares requires one permanent worker. Based on farm interviews wages ranged from R1700- R2300 per month for seasonal workers and R2000 - R3869 for permanent workers for the 2013 season. Picking times for each cultivar varies according to yield and fruit size (Conradie, 2002). The average wage rate was estimated at R14.60 per hour. The approximate number of labour hours required per ton of each cultivar produced was calculated, and subsequently the number of employment hours created per  $m^3$  of water was derived (Figure 6.9). An employment hour is inclusive of all seasonal and permanent workers. It excludes farm managers and administration workers. LWP increases incrementally from dry to wet years due to the lower CWR of cultivars. Differences between cultivars show only a slight variation with a long-term average LWP of 0.19 hrs/ $m^3$  for lemons, 0.17 hrs/ $m^3$  for valencias, 0.18 hrs/ $m^3$  for navels and 0.16 hrs/ $m^3$  for soft citrus.



**Figure 6.9 LWP (hrs/m<sup>3</sup>/ha) for citrus cultivars in the LSRV for the 2009-2013 seasons**

Again, green and blue proportions were shown to demonstrate potential contribution, however, given that blue water is provided through irrigation, more labour per m<sup>3</sup> should be weighted on blue water since irrigation requires monitoring and maintenance in addition to yield. More research to provide separate values of employment for green and blue water could be useful in trying to evaluate the contribution of green and blue water in irrigation to employment. What is important is that lemons provide higher employment hours per m<sup>3</sup> than other cultivars. This is mainly attributed to yield as it had the lowest number of employment hours required 34 hrs per ton. Navels required the highest number of employment hours per ton (48 hrs/ton) followed by valencias (42 hrs/ton) and then soft citrus (38 hrs/ton/ha). These values demonstrate the role that the citrus sector plays in absorbing low and semi-skilled workers.

As mentioned, some farms had their own pack-houses (4) but the remainder of farms sent their fruit to external pack-houses. Pack-houses generally employ women because women are gentler when handling the fruit. This is important since the economic empowerment and role of women is continuously emphasised in policy (DWAF, 1998; DWA, 2012). DWAF (1998) states that CMAs when allocating water should promote social and economic development of communities specifically paying attention to women. It would therefore be useful to have also examined the labour hours generated per m<sup>3</sup> for both women and men per cultivar. Since actual data was not

obtained to calculate this, one can assume based on the ratio of pack-house employees and seasonal employees that out of every 0.4 hectares on average requires hiring at least one women.

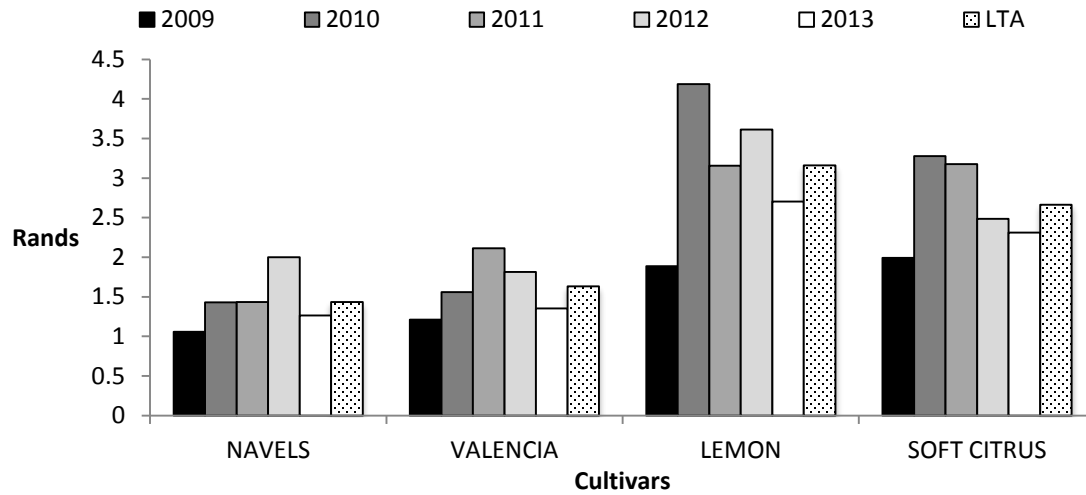
#### **6.3.4 Total factor productivity**

It is evident thus far that many variable components will affect management practices, yields and net revenue. These all play a crucial role in examining partial productivities of water and when trying to place a value on water. An indicator, which encompasses all inputs and outputs, is TFP (Figure 6.10). TFP provides an indication of the technical efficiency, which is the best possible output per unit of input and one that eliminates the most waste. TFP for citrus across the seasons 2009-2013 revealed that lemons had the highest ratio of monetary outputs to inputs followed by soft citrus, valencias and navels. Again, price is a significant determining factor and the trend shown below mirrors that ELP. Lautze *et al.* (2014) state that TFP is increasingly being used as a definitive measure of agricultural productivity. However, as highlighted in chapter two often the value of water limits the inclusion of water (Lautze *et al.*, 2014). The same could potentially be said for fertilisers and pesticides, since often these will also not reflect downstream impacts on water quality. Bessembinder *et al.* (2005) point out that agronomists and hydrologists need to work together to find the optimum combination of TFP and ELP along with WP and EWP, only then will we achieve more food with less water. Since TFP, ELP, WP and EWP indicators all demonstrated similar results; it would seem that they are potentially complementary.

#### **6.3.5 Benchmarks for water footprints**

It has been emphasised repeatedly that government and companies need to work together to establish WF benchmarks for water intensive products (Hoekstra, 2013; Mekonnen & Hoekstra, 2013; Hoekstra, 2014a; 2014b; Hoekstra & Wiedmann, 2014). Suggestions have been made to set limits on the maximum water volume that can be consumed or polluted by specific activities (Hoekstra, 2013; 2014a; 2014b). Benchmarks, caps and allocations would need to be implemented simultaneously to create appropriate incentives to reduce the WF to a reasonable 'benchmark level' (Hoekstra, 2014a; 2014b). A preliminary attempt to formulate benchmarks for a number of crops was carried out by Mekonnen & Hoekstra (2013). It was shown that if all green-

blue global WF's of crop production was reduced to the level of the 25<sup>th</sup> percentile, global water saving of 39% could occur.

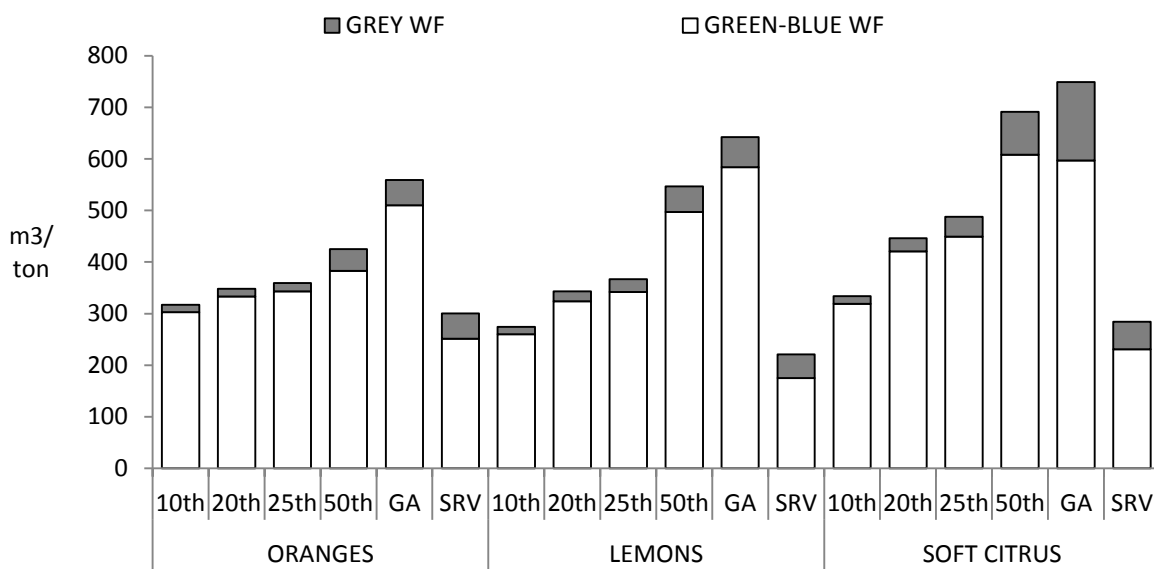


**Figure 6.10 TFP showing ratio of outputs to inputs in Rands for citrus cultivars in the LSRV for the 2009-2013 seasons.**

In comparison to these values, the LTA total WF of oranges (navels and valencias), lemons and soft citrus is below the 10<sup>th</sup> percentile (Figure 6.11). The same was revealed for the combined blue-green WF. However, grey WFs were above the 25<sup>th</sup> percentile for lemons and soft citrus and above the 50<sup>th</sup> percentile for oranges. WFs for dry years, although not shown in the graph, revealed the same results except that grey WF for lemons was greater than the 50<sup>th</sup> percentile. Although all green-blue WFs of the citrus cultivars for the LSRV were within or less than the 25<sup>th</sup> percentile, the benchmark values do not separate green and blue water use; therefore, specific comparisons to each water use type cannot be made. Disaggregating the benchmark values could have provided information that is more valuable (Witmer & Cleij, 2012; Chapagain & Tickner, 2012).

Mekonnen *et al.* (2014) compared different crops within the Latin America and Caribbean region with global benchmark values. Since most WFs were above the 25<sup>th</sup> percentile for production of crops, the authors stated that this should be an incentive to reduce WFs and demonstrated that a reduction in grey WFs to the 25<sup>th</sup> percentile would achieve an estimated 44% reduction in water pollution related to crop activities. If the LSRV reduce their nitrogen related grey WF to the 25<sup>th</sup>

percentile this would lead to a 57% decrease in the grey WF of lemons, 26% decrease for soft citrus and 67% for oranges. This could reduce nitrogen related pollution substantially. However, since nitrogen related pollution does not seem to be a problem at current levels in the LSRV, these benchmarks would be of more value if it pertained to the sum of constituents that make up water quality such as TDS. These are however the first benchmarks that have been developed and are related to nitrate. It is assumed that overtime more parameters will be measured. Nonetheless, these benchmark values do advocate for potential incentives to reduce grey WFs since water quality in the LSRV is deemed unacceptable and citrus farmers are contributors.

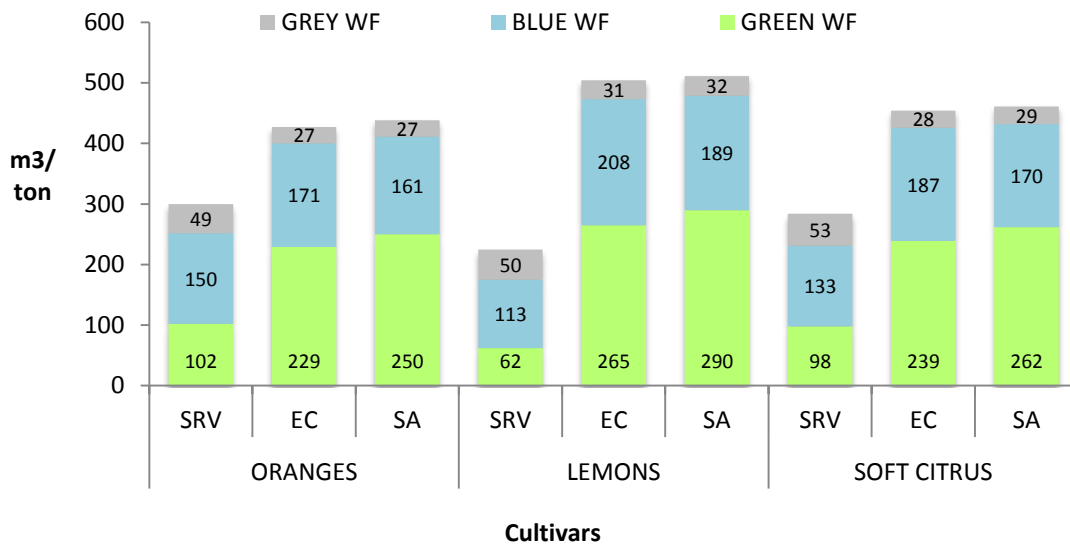


**Figure 6.11 Comparison of the LTA orange, lemons and soft citrus water footprints in SRV and green-blue and grey water footprints (m³/ton) at different production percentiles and global averages (GA)**

*Source:* own elaboration based on Mekonnen & Hoekstra, (2013; 2014a)

Mekonnen & Hoekstra (2010b) also derived estimates for citrus in the Eastern Cape (EC) and South Africa (SA) at a 5 by 5 arc minute grid for the period 1996-2005 using a grid-based dynamic water balance model and country specific nitrogen fertiliser application rates. In comparison to these estimates, green and blue WFs were lower in comparison but grey WFs were higher in comparison (Figure 6.12). It is also important to note that the proportion of green water estimated by Mekonnen & Hoekstra (2010b) was higher than that of the LSRV cultivars. Local climatic variables used in this study provide a much more accurate representation of the WF, especially the green WF than Mekonnen & Hoekstra (2010b).

It, however, has been shown that WFs need to be interpreted carefully as even large amounts of water use can be sustainable (Ercin *et al.*, 2011). Although comparisons between global benchmarks and averages are useful, they do not take into account local conditions (Witmer & Cleij, 2012). It would be more useful to draw comparisons of the impacts of WFs within different areas by possibly presenting blue WF as the proportion of water contributing to water scarcity or the proportion of the grey WF that will not be assimilated. How one could compare green WF impacts, however, is difficult and would require further research.



**Figure 6.12 Comparison between WFs of LSRV citrus cultivars and WFs derived by Mekonnen & Hoekstra, (2010) for the Eastern Cape (EC) and South Africa (SA)**

*Source:* own elaboration based own data and Mekonnen & Hoekstra, (2010b)

Benchmarks, however, would be potentially useful to provide, for example, farmers in the LSRV an indication of their water use per ton in comparison to other farmers. Hoekstra (2013; 2014b) promotes the development of benchmarks to provide incentives for producers to reduce WFs to a ‘reasonable benchmark level or WF.’ This is said to also encourage government and water users to share information to determine these reasonable benchmark WFs (Hoekstra, 2013; 2014b). Therefore, through stakeholder participation between government and water users, appropriate benchmarks for WFs for citrus could be developed. This may create increased sustainable water use by farmers who could potentially use their water more efficiently. However, it is argued that the WF alone is also not suitable for setting targets and strategies for benchmarking, as it does

not provide sufficient information for policy and decision-making, and needs to take into account local environmental, social and economic variables (Witmer & Cleij, 2012). Therefore, one could potentially also provide benchmarks for EWP, ELP, LWP and TFP in conjunction with WFs to make decisions regarding the efficiency and value of water use. Furthermore, benchmark WFs could be developed based on the environmental context.

Given that an allocation of 9000 m<sup>3</sup>/ha/yr has already been assigned to farmers in the LSRV, the government could still attach conditions to water user licences that require them to meet a certain benchmark criteria to improve efficiency of water use or reduce grey WFs. Benchmarks could be developed to ensure that WPLs and water scarcity does not occur given the current volume available for abstraction in the basin. This could be ensured over a number of climatic scenarios using WF assessments to determine potential effects. However, more information would be required as to how farmers determine their crop mixes. If it were based on demand, this would need to be taken into account given that navels are the least efficient and provide the lowest benefits in terms of water use in comparison to other cultivars. Furthermore, changing strategies for perennial crops is long term due to the lifespan of citrus trees and this would need to be considered. Hoekstra (2014b) do note that benchmarks will depend on best available technology and practice.

#### **6. 4 Policy responses and usefulness of WF assessments in decision making**

The responsibility of water institutions in South Africa is to make sound decisions to ensure development of the economy and society while maintaining ecological integrity (DWA, 2012). Decisions regarding the environment are to be made on a balance of social, economic and ecological costs and benefits (DWA, 2005; DWA, 2012). The results of this study have highlighted a number of useful aspects related to these decisions that can be informed by the adoption of a WF assessment and are discussed below.

#### 6.4.1 Determining and assessing current and future status of water resources

According to the NWA, priority for allocation is first given to the reserve, which constitutes water for basic human needs and the environment, before being allocated for other uses (DWAF, 1998). This requires that water uses within catchments be reassessed to cater for reserves and to balance supply and demand (Nieuwoudt *et al.*, 2008).

A total of 4000 hectares (38 Mm<sup>3</sup>) of allocations have been reserved for future irrigation required by resource-poor farmers to alleviate poverty within the Fish-to-Tsitsikamma management area. Approximately 66% of this allocation is expected to be used in the LSRV, with 180 hectares already been approved for Addo (DWAF, 2005). WF assessments would therefore be very useful in assisting government with assessing the status of river basins and exploring scenarios of current and future water usage across different climatic years and the potential impacts of expanding citrus farms. Zhang *et al.* (2014) assessed climate change scenarios for projected blue, green and grey WFs as well as scarcity and WPL for a number of sub-basins providing insights into future impacts. Furthermore, the green WF could be used to assess the potential impacts and changes in runoff because of new developments. Palmer *et al.* (2014) also note the importance of knowing ET of crops, as estimates of ET are important in defining the health of an ecosystem.

Examining water usage and reserves from a monthly perspective would also provide more value in identifying critical demand period and impacts as well as account for flow variability. Kounina *et al.* (2012) deem monthly temporal differentiation provided by the blue WF indicator as offering increased temporal precision for impact evaluation. In fact, government should consider water allocations on a monthly basis as opposed to an annual basis. These would need to be examined in conjunction with potential reductions to yield and subsequent EWP, ELP and LWP.

The refinement of the grey WF, or even just the concept of dilution water, would also be useful in determining water levels beyond the reserve requirement that would be needed to ensure that ambient water levels remain at a determined acceptable quality. It would also give authorities an idea of which activities are contributing to unacceptable levels of water quality and

impacts of expansion on water quality. However, the limitations discussed in chapter five hinder these options. DWAF (2005) emphasises that water availability is only as good as the quality of the water and that quality of water needs to be given similar emphasis and expenditure of resources as water quantity. Grey and blue WFs could potentially help to integrate issues of water quality and quantity. Zhang *et al.* (2014) have already demonstrated that conducting WF assessments at a sub-catchment scale can demonstrate the relationship and variations of water quality and quantity overtime.

Green and grey WFs could be incorporated into licence conditions, for example making sure farmers are adopting strategies to utilise rainfall more efficiently. This could be used in conjunction with the idea of reasonable benchmarks (Hoekstra, 2013 2014a; 2014b). The idea of including grey WFs as part of water allocations could also be effective in accounting for downstream pollution effects. However, currently the DWA nor LSRV WUA does not monitor the water quality within the river basin; a proper monitoring plan needs to be in place before this can become effective. Furthermore, natural and maximum concentrations would need to be established for each sub-basin to incorporate for local water quality within grey WF calculations. The grey WF would also need to be refined to provide a more accurate reflection of data, possibly using more complex models, particularly for diffuse pollution. Furthermore, grey WF methods also need to incorporate the fact that some water bodies naturally have poor water quality and high concentration of certain parameters this should not be translated into a higher grey WF.

Since the sustainability assessment was hampered by lack of data regarding environmental flow requirements, water yields and usage and that no recent water quality data was available, it is evident that authorities will not be able to make accurate decisions regarding water allocations. If government wants to achieve informed decision-making regarding allocations accurate data of water balances and reserves need to be determined and monitoring programmes implemented.

#### **6.4.2 Addressing issues of equity and efficiency**

A planning tool for water resource management and future planning for crop production strategies without considering economic and social considerations is deemed incomplete (Van

Heerden *et al.*, 2009). It is evident that the WF assessment and certain economic valuation tools have similar objectives to inform policy and decision-making, specifically regarding increasing the efficiency of allocations.

Government demand management strategies place continued emphasis on increasing water prices to reflect their full opportunity cost to assist in achieving efficient allocations. This is also emphasised by Hoekstra (2014b) who suggests that water users and polluters should pay differentiated prices depending on the water scarcity and quality based on a given time and period. However, while marginal cost pricing maximises social welfare and is therefore efficient, it is not always fair (Conradie, 2002). King (2004) also states that water-pricing policies are often in direct opposition to developmental goals such as agricultural growth. Conradie (2002) also argues that basic needs are not consistent with demand management and two policy objectives cannot be achieved with one instrument.

Based on farmers responses to increases in water prices it is evident that profitability would decrease. Most farmers' main concern was in fact the price of electricity. Given that electricity is used to pump irrigation and that some farmers were irrigating at night to reduce electricity costs reveals that electricity is the most limiting factor to irrigation. De Lange & Mahumani (2013) observed similar results for groundwater use in Sandveld South Africa and consequently recommends that a mixture of water and energy pricing strategies would be a more pragmatic policy approach.

Backeberg (2005) emphasises that profitability of existing farmers and ensuring secure water use entitlements for existing licence holders needs to be considered in achieving the objectives of the NWA. Farmers in the LSRV are using water efficiently through irrigation, but not in terms of cultivar mix as navels and valencias are the least productive in terms of WP and EWP. This demonstrates the need for government to have a better understanding of problems and constraints facing farmers in order to evaluate the pros and cons of policies and their potential effects. Why lemons are not the dominant cultivar needs to be investigated before changes in crop strategies are considered. Any strategies affecting income will lead to resultant changes in the EWP, ELP and LWP of that crop. Mekonnen *et al.* (2014) also argue that reallocations may

improve EWP but that ultimately optimal crop choices will need to consider a number of other factors.

It was also demonstrated that EWP could potentially be used as a means by which to advocate efficient water usage for users particularly for emerging farmers. EWP, ELP, LWP and TFP could also be used to measure the gains and efficiency of water use. South Africa's irrigation strategy key aims are to increase the contribution of agriculture to GDP, reduce poverty and create employment (DAFF, 2010). Specifically LWP and EWP provide indicators by which to measure the contribution of income and employment generated from irrigated activities. LWP could also be used to assess the extent to which water use is contributing to developing skills and promoting economic empowerment of women.

Hoekstra (2014b) also acknowledge that allocations that are efficient from a resource perspective are not always fair in terms of society. While Hoekstra (2013; 2014b) emphasises the determination of a reasonable or fair share of water resources for countries, South Africa could adopt the same concept to allocating a determined amount of water resources to the upliftment of previously disadvantaged racial groups or emerging resource poor farmers. It seems that the argument for utilising benchmark strategies as suggested in section 6.25 could potentially provide a solution for catering to the somewhat contradicting objectives of efficiency, environmental sustainability and equity. Through stakeholder collaboration, government can help identify best-fit strategies for water users while setting appropriate targets and benchmarks based on available resources for the area. Hoekstra (2014b) promote that good water stewardship within basins requires striving toward collective action and community engagement.

### **6.4.3 Planning and reduction strategies**

Taking cognisance of on-going initiatives by the government is important for sectors that rely heavily on irrigation, such as the citrus farms in the LSRV. Farmers need to be proactive and ensure they can substantiate their grounds for water use whether it be social or economic. This requires knowing their water use and assessing WFs so that they can understand their impacts and risks. Green water in particular is something that farmers need to pay more attention to even

though its benefits are not as tangible as blue water. Authors have argued that the inclusion of green water in water management is essential for alleviating future food crises and is critical in coping with climate change (Aruna, 2009; Rockström *et al.*, 2009).

Based on the objectives of the NWA the indicators explored in this study could be used by CMAs and WUAs to consider new water licence applications as well as to assess the sustainability of existing water user licences. Farmers similarly could use WFs and WP along with other economic and social indicators to demonstrate to government institutions that they are utilising their water in a productive manner. How one would weight certain criteria would need further evaluation. Aldaya & Llamas (2008) state that in order to achieve the shifting paradigm of IWRM from more 'cash per drop' to 'more nature and cash per drop', it is important to understand the WP and EWP of different crops. Furthermore, in the wake of climate change farmers can use WFs and measures of productivity to reduce risks by planting cultivars that are less susceptible to variation in climate.

## **6.5 Summary**

Taylor & Gush (2014) emphasise that there is a need to develop new and sound management regarding allocation and use of water in order to ensure long-term sustainability for fruit production industries. It is evident that WF assessments can provide some value in providing a number of strategies for consideration in both the public and private sectors. However, it is important that the local conditions and context in which water usage occurs be considered to incorporate all economic, social and environmental dimensions. Local context is deemed essential for making the WF valuable for sustainability policies (Vanham & Biglio, 2013; Hastings & Pegram, 2012; Witmer & Cleij, 2012). Although this is a data intensive process, the decentralisation of government water institutions would potentially allow for these administrative activities through increased stakeholder participation.

It is important to note that WF assessments are still in an experimental and developing phase (Witmer & Cleij, 2012). Decisions that WF assessments aim to inform require understanding of extremely complex environmental, social and economic issues (Hastings & Pegram, 2012). It is

evident that no one indicator will be able comprehensively to provide all the answers. One can therefore conclude that a multifaceted approach will be needed to balance social, economic and environmental goals. The WF assessment framework, despite its limitations can be argued that it does indeed provide an initial framework by which one can assess and explore complementary tools for evaluating the environmental, economic and social sustainability of water use.

According to Dahl (2012:15), “the most significant effect of an indicator, particularly in its early adoption can simply be to make a problem visible.” The WF assessment framework clearly provides insights into the complexity of decision-making regarding water use. WF assessments provide a rational and quantifiable foundation to initiate discussions and develop answers about the efficiency of production processes, the limits of resource consumption and the distribution of natural resources (Senbel, 2003; Galli *et al.*, 2012).

# CHAPTER SEVEN:

## CONCLUSIONS AND RECOMMENDATIONS

*“In an age when man has forgotten his origins and is blind even to his most essential needs for survival, water along with other resources has become the victim of his indifference”*

*- Rachel Carson*

First cycle lemons in March 2014

Photo: S.A Munro

## **7.1 Overview**

The natural water endowment of South Africa coupled with looming climate change and increasing pressures to develop the economy requires substantial capacity from the water sector (Muller, 2000; Schultze & Perks, 2000; Perret, 2002). Through implementation strategies such as the NWRS (DWA, 2012), South African water policy aims to steer the efficient, equitable and sustainable use of water. This requires making complex (and often contradictory) decisions regarding water allocations and demand management strategies that take into account new water uses and users (such as reserve requirements), existing water users and previously disadvantaged individuals (DWAF, 1998; DWA, 2012). Hastings & Pegram (2012) advocate that tools, such as WF assessments, could assist in creating awareness of water use, facilitate dialogue between stakeholders and inform efficiency would be beneficial to South Africa.

Given the growing literature and wide scope of applications pertaining to WFs, it was deemed useful to assess some of the specific contributions that conducting a WF assessment could potentially have for stakeholders in South Africa. The overall aim of this dissertation was to conduct a full WF assessment of the citrus farms in the LSRV. This included all four stages of the WF assessment, namely, setting goals and scope, WF accounting, WF sustainability assessment and a WF response formulation. The four stages are further summarised below along with key findings and concerns that emerged from the study.

### **7.1.1 Scope**

The study adopted the WF assessment framework (Hoekstra *et al.*, 2011) with a combination of qualitative and quantitative methods using both primary and secondary data. The combination of both primary and secondary data proved vital in generating insights that would not have been possible using only one data source. The estimation of CWU using SAPWAT 3.0 used site-specific data to calculate an accurate estimation of blue and green water WFs, accounting for a number of phenological differences between navel, valencia, lemons and soft citrus cultivars as well as local climatic characteristics. Since other studies emphasise the need to account for both spatial and temporal variability (Aldaya *et al.*, 2010b), data was collected for a number of years and WFs

were calculated for a dry, wet and a long-term average (LTA) year. Local data in this study demonstrated that water is one of many influencing factors that will ultimately determine the quality and yield of citrus. Variations will occur because of farm size, soil type, cultivar age profile, density, fertilizer, pests and farming practices in combination with irrigation practices, water quality and climate. The price or monetary value received for citrus is ultimately determined by the quality of the fruit together with demand and exchange rates. It can therefore be reiterated that it is important to examine WFs over a number of scenarios and varying parameters to provide useful and relevant data, particularly in examining climate change scenarios.

Sustainability at the sub-river basin level was also examined through blue water scarcity and the WPL indicator (Hoekstra *et al.*, 2011) and by examining the evapotranspiration of local vegetation. The broader social context and the economic efficiency of allocations were also examined. To assess the economic and social sustainability of WFs, a number of indicators were adopted to gauge productivity, efficiency and social contributions regarding employment. Furthermore, comparisons were also made with global benchmark values.

### **7.1.2 Water footprint accounting**

Volumetric WFs were calculated and examined in conjunction with relevant primary and secondary data to assist in understanding WFs and placing them into context. There was no evident relationship between yield and rainfall for each cultivar across the climatic years. Blue and green WFs did vary across each climatic year due to fluctuating CWRs. Total CWU for all cultivars ranged from 7651- 9149 m<sup>3</sup>/ha/yr in an average year, 8709-10317 m<sup>3</sup>/ha/yr in the dry year and 7217-8430 m<sup>3</sup>/ha/yr in the wet year. This translated into 60% of CWRs being met in an average year through blue water. This subsequently increased to 70% in the dry year and decreased to 40% within the wet year. The benefits of green water were acknowledged by a few farmers but did not evidently translate to higher yields or quality through the observation of pack-out percentages.

It was demonstrated through SAPWAT 3.0 estimations as well as other literature and data sources that lemons required the most water followed by valencias, navels and soft citrus with 65% of

irrigation requirements occurring between October and March for all cultivars. Lemons also required a higher amount of fertiliser in comparison to other cultivars but had the highest yield per hectare. What was also evident was that farmers were using less than their current allocation of 9000 m<sup>3</sup>/ha/yr with some farmers using the remainder of this water to irrigate land beyond their allocated amount. Farmers are using either micro irrigation or drip irrigation (99.01%), which have high irrigation efficiencies (Van Heerden *et al.*, 2009; LSRVWUA, 2013). All farmers used probes to measure soil water content, which allows for increased accuracy in irrigation scheduling. It was also evident that farmers were using reduced amounts of water in higher rainfall years, but whether or not irrigation practices maximised green water was not apparent and would need further investigation. There were also some discrepancies between farmers regarding the benefits of drip irrigation.

Calculations of blue and green WFs revealed that navels, which constituted the greatest proportion of the cultivated citrus area (38%), had the highest blue and green WFs across all climatic years. Lemons had the lowest blue and green WFs. It was demonstrated that if the LSRV were to experience more severe drought years, blue WFs and subsequent irrigation use could potentially increase by approximately 49% for navels, 46% for valencias, 36% for lemons and 34% for soft citrus. With regard to grey WFs, valencias had the lowest WF and navels the highest WF. Therefore, even though yield did not vary across the climatic years, crop water requirements do. Farmers could use WFs to account for their water use and determine potential changes regarding climate change to allow for better long-term planning.

The SAPWAT 3.0 simulations did appear to underestimate blue CWRs based on comparisons with actual irrigation data and other studies (Green, 1985; Falivene *et al.*, 2006; LSRVWUA, 2014). It however, was noted that models to estimate CWU could only simulate approximations of CWU (Taylor & Gush, 2014). Simulations that are more accurate would require better data that was not available for different citrus cultivars or the use of direct methods. Nonetheless, the calculations were important in highlighting blue as well as green water usage. It was evident that the WF is a more comprehensive water accounting indicator than other indicators as it takes into account blue, green and grey water. Franke & Mathews (2013a) highlight that the distinction between types of water use is important as each has its own impacts and opportunity costs. The

importance that green water will play in meeting future crop demands has increasingly been highlighted in literature (Obuobie *et al.*, 2005; Rockström *et al.*, 2009). It is important that both farmers and government consider green water and adopt ways to increasing green water efficiency as well as blue water.

### **7.1.3 Water footprint sustainability assessment**

Based on the total allocation for irrigating farmers in the LSRV and available environmental flow requirements, no water scarcity occurred in the dry year or in the LTA year. This was also observed in raw data and other relevant literature and was primarily attributed to run-off from irrigation, un-used irrigation releases and the IBT (Conradie, 2002; DWAF, 2005; LSRV WUA, 2014). Despite the current social disputes regarding water availability, this was attributed to infrastructural and institutional scarcity (Rijsberman, 2006; FAO, 2013). In terms of land use changes, citrus cultivation would lead to decreases in runoff. However, because of irrigation these losses could be counteracted (Palmer *et al.*, 2012). Further examination of these impacts is required.

Calculations of WPL showed the potential for nitrogen related grey WFs to exceed the assimilation capacity of the river by 10% in dry years. However, in an average year ambient water quality for nitrogen related grey WFs are met. This finding was contradictory to actual water quality data for the area that deemed the water quality downstream as unacceptable and unusable (DWAF, 2005). Water quality in the LSRV basin does however have naturally high saline flows but there is also run-off from insufficient maintenance of sewage and storm water systems (SRVM, 2010). Given that WPL could not be directly attributed to the citrus farms, this advocated that management of water quality, as well as quantity, require joint efforts. This emphasised and reiterated that integrated and good water stewardship requires collective action and shared risk and responsibility among stakeholders (Pegram *et al.*, 2009; Hoekstra *et al.*, 2011; Hoekstra, 2014b).

Regarding the average citrus farm, lemons were found to be the most efficient and productive cultivar across all climatic years and provided the greatest benefits pertaining to income, land

and employment in terms of water use. It was also the most technically efficient cultivar and had the highest water productivity. Conversely, navels had the lowest productivity, technical efficiency, and provided the least benefits related to income and land per m<sup>3</sup>. Soft citrus provided the lowest number of employment hours per m<sup>3</sup>. This was an interesting finding since lemons required a greater amount of water and fertilisers in comparison to other cultivars. Conradie (2002) also demonstrated that lemons had the highest marginal product value, suggesting that measures of economic productivity could provide potential insights into the economic efficiency of allocations.

In comparison to global benchmarks, all cultivars' blue-green WFs were below the 10<sup>th</sup> production percentile. However, in an average year, grey WFs were above the 25<sup>th</sup> production percentile for lemons and soft citrus and above the 50<sup>th</sup> percentile for oranges (navels and valencias). It was demonstrated that if farms in the LSRV reduced their nitrogen related grey WF to the 25<sup>th</sup> percentile this would lead to a 57% decrease in the grey WF of lemons, 26% decrease for soft citrus and 67% for oranges.

By conducting WFs at a lower level and considering site-specific data, one can begin to understand the complexity of trade-offs to be examined. Many WF assessments conducted assume reallocating WP and EWP would increase water efficiency. However, potential impacts of an absolute increase in water need to be examined as well as how strategies will affect profits and the subsequent benefits derived from water. Furthermore, the WF assessment framework can be used to examine a number of environmental, economic and social indicators in conjunction highlights costs and benefits of the resource. This can provide considerable value to decision making.

#### **7.1.4 Water footprint response formulations and policy implications**

In accordance with the sustainability criteria defined by Hoekstra *et al.* (2011), citrus production occurs in a sub-basin that is not characterised by water scarcity however, there are issues relating to quality that were not adequately reflected in assessing the grey WF. Assessing environmental sustainability was hampered by lack of data and therefore only crude assumptions regarding the

sustainability of the basin can be made, particularly in terms of water quality. Concerning citrus production, it was demonstrated there is potential for water efficiency to increase despite limited technology to enhance irrigation efficiency. However, based on local data and perceptions, a number of factors need to be taken into consideration before recommendations relating to reallocation of water use can be made. It was highlighted that efficient allocations are not always fair.

It was suggested that government and water users could potentially use WF assessments to collaborate and promote increased stakeholder participation with water users by developing 'reasonable benchmark levels'. Benchmarks could be used in conjunction with economic and social indicators as well as farmers' current irrigation and management practices to develop the most appropriate strategies for increased water efficiency. Benchmarks could be developed to ensure water pollution and water scarcity will not occur in the basin given a number of climatic scenarios. Benchmarks and WFs along with relevant indicators could also be used to assist government in allocations regarding water user licenses.

In summary, it was highlighted that with increased accuracy of data and the adoption of a more sophisticated grey WF methodology, the WF sustainability assessment could have great potential in providing government and water users with a supporting tool to assist in water management decisions. WF assessments can assist farmers and the government by providing a more comprehensive measure of water use and provide the first step toward examining the sustainability of water, mitigating risks and initiating collaborative efforts.

## 7.2. The need for future research

This is one of the first full WF assessments that have been conducted in South Africa. Furthermore, this is also one of the few studies that take into account perceptions and practices of water users at a local level and relate site-specific practices with broader sustainability assessments and objectives.

The WF assessment framework is a new and developing methodology and it is evident that more practical applications and refinements are needed. This is particularly the case for measuring the economic and social sustainability of WFs and incorporating local context. Given the range of factors affecting quality and yield, additional insight is required as to how farmers make decisions regarding water use and current cropping patterns and farm management strategies.

Examining local impacts and considerations is a data intensive process. Although a high level of precision reflects local impacts more accurately, this data is often expensive to collect and is rarely available (Chambers *et al.*, 2000; Hoekstra, 2007). Often there is a trade-off between precision or 'scientific quality' and applicability (Berger & Finkbeiner, 2010). This is particularly the case for WFs, which require in-depth information regarding water withdrawal, quality, scarcity and the watercourse (Berger & Finkbeiner, 2010). Furthermore, to account for fluctuations and variations that occur throughout the year, one needs to examine water usage and quality from a monthly perspective to provide a more comprehensive assessment of when potential water stress may occur. The ability and administrative capacity for CMAs and other government institutions to monitor and collect data that could be used to conduct WF assessments would need to be investigated. In turn, how this will be paid for will also need to be determined, especially if it is through increasing prices of water.

The study demonstrated that a number of methodological issues still exist regarding the grey WF despite the recent development of the grey WF accounting tier-one supporting guidelines (Franke *et al.*, 2013). The concept is however meaningful and could be used in conjunction with blue WFs to establish appropriate benchmarks for water users and identify potential freshening flows. It would also be potentially useful for future studies to examine the value and contribution that the

grey WF provides in terms of yield and quality of produce as well as within different climatic years. The grey WF is also potentially useful in identifying the contributions to deteriorating water quality to specific polluters. However, research on a more encompassing parameter that reflects actual water quality within an area that can incorporate natural concentrations of a low quality needs to be developed. More applications of the grey WF at a local level in conjunction with water quality data could shed more light on the issues encountered in this study. Such as the examination of grey WFs and green WFs in conjunction to determine changes in run-off that occur as a result of land-use changes and the consequent implications that this could have on WPLs.

Furthermore, following on from Chouchane *et al.* (2013), examining WP, EWP and ELP could be used in conjunction with plant-water relationship models to give a more specific contribution of green and blue water values. This would further assist in highlighting the role of green water in irrigated agriculture and provide for a more accurate reflection of the specific contribution of blue and green water.

One could also examine CF in conjunction with WFs. This would be particularly useful given that irrigation and electricity costs are linked. This would also ensure that problem shifting would not occur and that policy objectives for water do not contradict with energy policies.

Finally, while it is important to examine sustainability and incorporate local impacts, one also needs to examine water usage in a broader context. Hoekstra (2011) places emphasis on global water governance given that issues regarding water can extend beyond not only river basins, but also can have sub-continental and even global effects. Given that the LSRV and many irrigated agricultural areas in South Africa rely on IBTs and are predominately export orientated, impacts extending beyond the basin need to be examined.

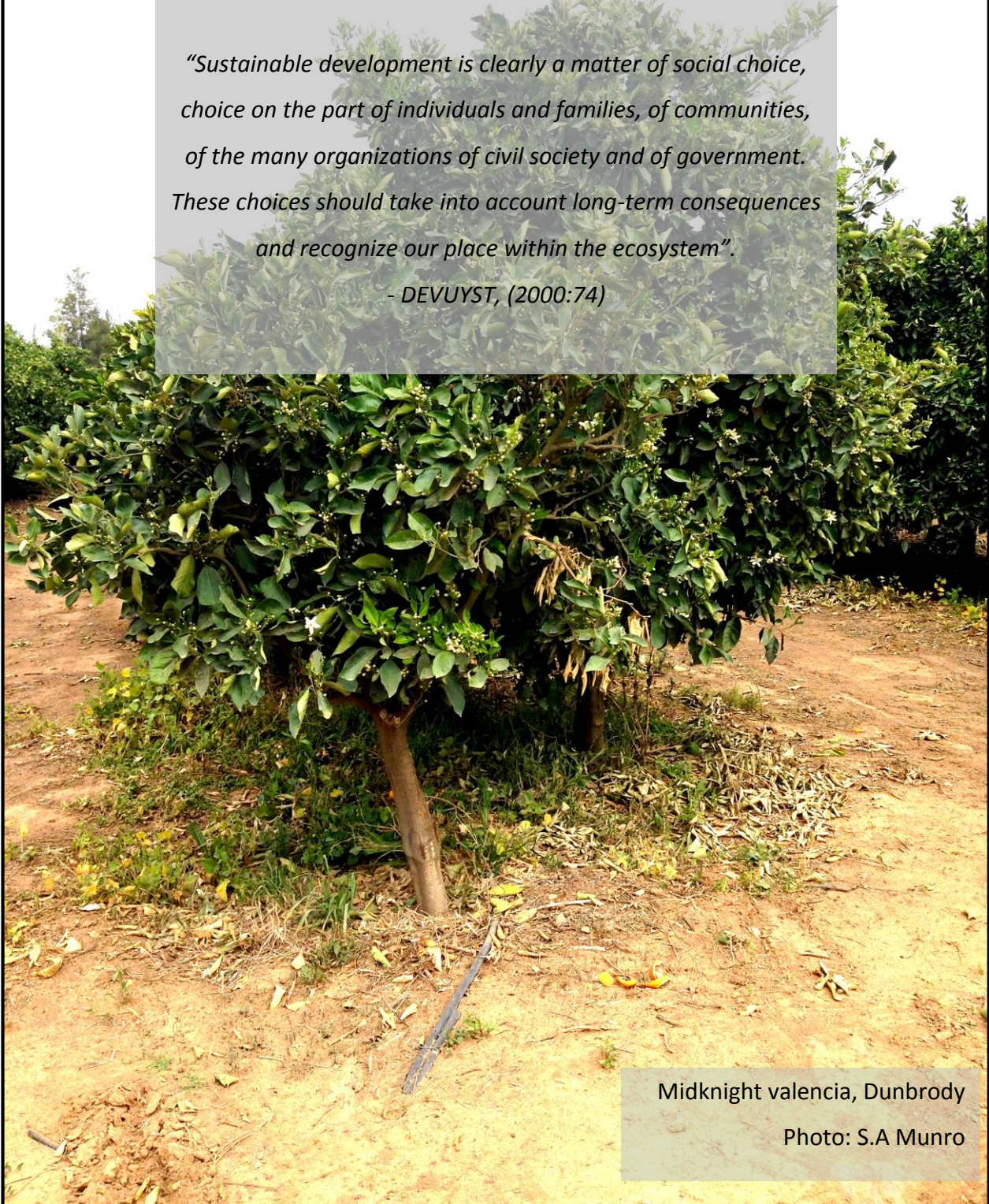
### 7.3 Concluding remarks

While the WF assessment proved to be of value providing *ways* to allocate resources, there are still questions that remain, particularly regarding exactly *how* to make decisions when facing certain trade-offs. Given the importance of the agricultural sector in South Africa, it is imperative that we find ways to maximise the efficiency and reduce water risks in order to find a concession between job and income creation and preserving our scarce resources. WF assessments allow for a more comprehensive assessment of water use and provide a framework to highlight some of the environmental, social and economic costs and benefits of resource appropriation. It is acknowledged that the WF assessment alone will not provide an encompassing solution to all water management issues; however, it does highlight a number of relevant issues that can assist in the decision-making processes of water users and government to achieve sustainable use of water. It is also important to note that designing, initiating and sustaining changes to improve water use and management, within economic and political constraints are not only a challenge in South Africa but are at the heart of the ongoing global water debate (Saleth & Dinar, 2004). What can be concluded is that the process towards sustainable water resource management requires communication and collaboration between stakeholders.

# REFERENCES

*“Sustainable development is clearly a matter of social choice, choice on the part of individuals and families, of communities, of the many organizations of civil society and of government. These choices should take into account long-term consequences and recognize our place within the ecosystem”.*

*- DEVUYST, (2000:74)*



Midnight valencia, Dunbrody

Photo: S.A Munro

ADDO RESEARCH STATION (2014). Plant Improvement - Citrus Breeding personnel. Addo, Personal Communication. 18 March-23 November.

ALCAMO, J. & HENRICHS, T. (2002). Critical regions: A model-based estimation of world water resources sensitive to global changes. *Aquatic Sciences*, 64: 1-11.

ALCAMO, J., HENRICHS, T. & RÖSCH, T. (2000). World Water in 2025: Global Modelling and scenario analysis. In: Rijsberman, J. (ed). *World water scenarios analyses*. Marseille: World Water Council.

ALDAYA, M.M. & HOEKSTRA, A.Y. (2010). The water needed for Italians to eat pasta and pizza, *Agricultural Systems*, 103: 351-360.

ALDAYA, M.M. & LLAMAS, M.R. (2008). *Water footprint analysis for the Guadiana River Basin*. Papeles de Agua Virtual no. 3, Fundación Marcelino Botín, Santander, ISBN 978-84-96655-26-3.

ALDAYA, M.M., ALLAN, J.A. & HOEKSTRA, A.Y. (2010a). Strategic importance of green water in international crop trade. *Ecological Economics*, 69(4): 887-894.

ALDAYA, M.M., HOEKSTRA, A.Y. & ALLAN, J.A. (2008). 'Strategic importance of green water in international crop trade', Value of Water Research Report Series No.25, UNESCO-IHE.

ALDAYA, M.M., MARTINEZ-SANTOS, P. & LLAMAS, M.R. (2010b). Incorporating the water footprint and virtual water into policy: Reflections from the Mancha Occidental Region, Spain. *Water Resources Management*, 24(5): 941-958.

ALLAN, J.A. (1998). Virtual water: a strategic resource, global solutions to regional deficits. *Groundwater*, 36 (4): 545–546.

ALLAN, J.A. (1998a). Moving water to satisfy uneven global needs: trading water as an alternative to engineering it. *ICID Journal*, 47(2): 1–8.

ALLAN, J.A. (1998b). Virtual water: A strategic resource: global solutions to regional deficits. *Groundwater* 36, No. 4: 546.

ALLAN, J.A. (2001a). *The Middle East Water Question: Hydropolitics and the Global Economy*. London, United Kingdom: I B Tauris.

ALLAN, J.A. (2001b). Virtual Water – economically invisible and politically silent: A Way to Solve Strategic Water Problems. *International Water and Irrigation Journal*, November 2001.

- ALLAN, J.A. (2002). Hydro-peace in the Middle East: Why No Water Wars? A Case Study of the Jordan River Basin. *SAIS Journal*, XX: 255–272.
- ALLAN, J.A. (2003). Virtual water-the water, food, and trade nexus: useful concept or misleading metaphor? *Water International* 28: 106-112.
- ALLEMAN, L. & YOUNG, B.W. (1993). *Fruit crops*. KwaZulu-Natal, Department of Agriculture. Horticulture Notes.
- ALLEN, R.G., PEREIRA, L.S., RAES, D. & SMITH, M. (1998). Crop evapotranspiration: guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper, vol. 56, Food and Agriculture Organization, Rome, Italy.
- ALLEN, T. F. H. & HOEKSTRA, T.W. (1992). *Towards a unified ecology*. Columbia University Press, New York.
- ANSINK, E. (2010). Refuting two claims about virtual water trade. *Ecological Economics*, 69: 2027-2032.
- ARUNA, (2009). “Green” and “blue” water provides hope for future food crises. Medindia. [Online] Available: <http://www.medindia.net/news/green-and-blue-water-provides-hope-for-future-food-crises-50977-1.htm> [Accessed 28 November 2014].
- AYERS, R.S. & WESTCOT, D.W. (1976). Water Quality for Agriculture. FAO. [Online] Available: [http://www.calwater.ca.gov/Admin\\_Record/C-110101.pdf](http://www.calwater.ca.gov/Admin_Record/C-110101.pdf) [Accessed: 12 January 2015].
- BACKEBERG, G.R. (2005). Water institutional reforms in South Africa. *Water Policy*, 7: 107- 123.
- BACKEBERG, G.R. & ODENDAAL, P.E. (1998). Water for agriculture: A future perspective. In: *Proceedings of the 39th Ordinary General Meeting of the Fertilizer Society of South Africa*. 24 April 1998, Sun City, South Africa. pp 49-61.
- BASSON, M.S. (1999). *Main report*. Report 32 in the Orange River Development Project Replanning Study. Department of Water Affairs and Forestry, Pretoria.
- BELI, P., ANDERSON, J.R., BARNUM, H.N., DIXON, J.A. & TAN, J. (2001). *Economic analysis of investment operations*. Washington, DC: World Bank.
- BELL, S. & MORSE, S. (2008). *Sustainability indicators: Measuring the immeasurable?* (2ed). Earthscan, London.

- BENOIT, G. & COMEAU, A. (eds) (2005). *Plan Bleu. A sustainable future for the Mediterranean: The Blue Plan's environment and development Outlook*. UNEP-MAP-Blue Plan. Earthscan, London.
- BERGER, M. & FINKBEINER, M. (2010). Water footprinting: How to address water use in Life Cycle Assessment? *Sustainability*, 2: 919-944.
- BERGER, M. & FINKBEINER, M. (2013). Methodological challenges in volumetric and impact-oriented water footprints. *Journal of Industrial Ecology*, 17 (1): 79-89.
- BESSEMBINDER, J.J.E., LEFFELAAR, P.A., DHINDWAL., T.C. & PONSIOEN, T.C. (2005). Which crop and which drop, and the scope for improvement of water productivity. *Agricultural Water Management*, 73(2): 113-130.
- BEST, A., GILJUM, S., SIMMONS, C., BLOBEL, D., LEWIS, K., HAMMER, M., CAVALIERI, S., LUTTER, S. & MAGUIRE, C. (2008). *Potential of the ecological footprint for monitoring environmental impacts from natural resource use: Analysis of the potential of the ecological footprint and related assessment tools for use in the EU's Thematic Strategy on the Sustainable Use of Natural Resources*. Report to the European Commission, DG Environment.
- BLIGNAUT, J. & LUMBY, A. (2004). Economic valuation. In: Blignaut, J. & de Witt, M. (eds). *Sustainable options: Development lessons from applied environmental economics*. University of Cape Town Press, Cape Town. pp 82-105.
- BOCKSTALLER, C., GIRARDIN, P. & VAN DER VERF, H.M. (1997). Use of agro-ecological indicators for the evaluation of farming systems. *European Journal of Agronomy*, 7: 261-270.
- BOHRINGER, C. & JOCHEM, P.E.P. (2007). Measuring the immeasurable: a survey of sustainability indices. *Ecological Economics*, 63: 1-8.
- BOSSEL, H. (1999). *Indicators for sustainable development: theory, method, applications*. A Report to the Balaton Group, IISD, Canada.
- BOULAY, A.M., HOEKSTRA, A.Y. & VIONNET, S. (2013). Complementarities of water-focused Life Cycle Assessment and Water Footprint Assessment. *Environmental Science and Technology*, 47(21): 11926-11927.
- BREEDE-OVERBERG CATCHMENT MANAGEMENT AGENCY (BOCMA). (2011). Breede-Overberg Catchment Management Strategy. South Africa. [Online] Available: <http://www.bocma.co.za> [Accessed 6 March 2013].

- BROOKES, A., EALES, R., FISHER, J. & FOAN, C.T. (2001). An approach to integrated appraisal progress by the environment agency in England and Wales.. *Journal of Environmental Assessment, Policy and Management*, 3(1): 95-122.
- BULSINK, F., HOEKSTRA, A.Y. & BOOIJ, M.J. (2010). The water footprint of Indonesian provinces related to the consumption of crop products. *Hydrology and Earth System Sciences*, 14(1): 119–128.
- CAMPBELL, D.T. & FISKE, D.W. (1959). Convergent and discriminant validation by the multitrait-multimethod matrix. *Psychological Bulletin*, 56:81-105.
- CAZCARRO, I., HOEKSTRA, A.Y. & SÁNCHEZ CHÓLIZ, J. (2014). The water footprint of tourism in Spain. *Tourism Management*, 40: 90-101.
- CENTER FOR SUSTAINABLE ORGANIZATIONS. 2011. Corporate water gauge: A context-based solution for measuring the sustainability of organizational water use. [www.sustainableorganizations.org/Corporate-Water-Gauge.pdf](http://www.sustainableorganizations.org/Corporate-Water-Gauge.pdf). [Accessed 24 November 2013].
- CCME. (2010). *Canadian water quality guidelines for the protection of aquatic life- Ammonia*. Canadian Council of Ministers of the Environment, Winnipeg, Canada.
- CCME. (2013). *Canadian water quality guidelines for the protection of aquatic life*, Canadian Council of Ministers of the Environment, Winnipeg, Canada.
- CHALLEN, R. (2000). *Institutions, transaction costs and environmental policy: Institutional reform for water resources*. Cheltenham: Edward Elgar Publishing Limited.
- CHAMBERS, N., SIMMONS, C. & WACKERNAGEL, M. (2000). *Sharing nature's interest: ecological footprints as an indicator of sustainability*. Earthscan, London.
- CHAPAGAIN, A. & JAMES, K. (2011). The water and carbon footprint of household food and drink waste in the UK, Waste & Resources Action Programme (WRAP), Banbury, Oxon, UK & WWF, Godalming, Surrey, UK.
- CHAPAGAIN, A. K. & ORR, S. (2008). UK Water Footprint: *The impact of the UK's food and fibre consumption on global water resources*. Volume 1, WWF-UK, Godalming, UK.
- CHAPAGAIN, A.K. & HOEKSTRA, A.Y. (2003). *Virtual water flows between nations in relation to trade in livestock and livestock products*. Value of Water Research Report Series No.13, UNESCO-IHE, Delft, the Netherlands.

- CHAPAGAIN, A.K. & HOEKSTRA, A.Y. (2004). *Water footprints of nations*. Value of Water Research Report Series No.16, UNESCO-IHE. Delft, the Netherlands.
- CHAPAGAIN, A.K. & HOEKSTRA, A.Y. (2007). The water footprint of coffee and tea consumption in the Netherlands. *Ecological Economics*, 64(1): 109-118.
- CHAPAGAIN, A.K. & HOEKSTRA, A.Y. (2008). The global component of freshwater demand and supply: An assessment of virtual water flows between nations as a result of trade in agricultural and industrial products. *Water International*, 33(1): 19-32.
- CHAPAGAIN, A.K. & HOEKSTRA, A.Y. (2011). The blue, green and grey water footprint of rice from production and consumption perspectives. *Ecological Economics*, 70(4): 749-758.
- CHAPAGAIN, A.K. & ORR, S. (2009). An improved water footprint methodology linking global consumption to local water resources: A case of Spanish tomatoes. *Journal of Environmental Management*, 90: 1219-1228.
- CHAPAGAIN, A.K. & ORR, S. (2010). Water Footprint of Nestlé's 'Bitesize Shredded Wheat:' A pilot study to account and analyse the water footprints of Bitesize Shredded Wheat in the context of water availability along its supply chain. WWF for WFN. [Online] Available: <http://www.waterfootprint.org/Reports/Nestle-2010-Water-Footprint-Bitesize-Shredded-Wheat.pdf> [Accessed: 20 January 2013].
- CHAPAGAIN, A.K. & TICKNER, D. (2012). Water footprint: Help or hindrance? *Water Alternatives*, 5: (3) 563-581.
- CHAPAGAIN, A.K. HOEKSTRA, A.Y., SAVENIJE, H.H.G., & GAUTAM, R. (2006a). The water footprint of cotton consumption: An assessment of the impact of worldwide consumption of cotton products on the water resources in the cotton producing countries. *Ecological Economics*, 60(1): 186-203.
- CHAPAGAIN, A.K. HOEKSTRA, A.Y. & SAVENIJE, H.H.G. (2006b). Water saving through international trade of agricultural products, *Hydrology and Earth System Sciences*, 10(3): 455-468.
- CHAPMAN, D. (ed.) (1996). *Water quality assessments: A guide to the use of biota, sediments and water in environmental monitoring* (2e). UNESCO/WHO/UNEP.
- CHENOWETH, J., HADJIKAKOU, M. & ZOUMIDES, C. (2013). Quantifying the human impact on water resources: a critical review of the water footprint concept. *Hydrological Earth Systems Science*, 18: 2325–2342.

- CHICO, D., SALMORAL, G., LLAMAS, M.R., GARRIDO, A. & ALDAYA, M. M. (2010). *The water footprint and virtual water exports of Spanish tomatoes*. Fundación Marcelino Botín.
- CHOUCHANE, H., HOEKSTRA, A.Y., KROL, M.S. & MEKONNEN, M.M. (2013). *Water footprint of Tunisia from an economic perspective*. Value of Water Research Report Series No. 61, UNESCO-IHE, Delft, the Netherlands.
- CHRIS HANI DISTRICT MUNICIPALITY (CHDM), 2010. Integrated Development Plan 2010/11. [Online] Available: <http://www.chrishanidm.gov.za/files/documents/290910151307.zip>. [Accessed: 14 August 2014].
- CITRUS GROWERS ASSOCIATION OF SOUTHERN AFRICA (CGA). (2013). Annual Report 2013. [Online]: Available: <http://www.cga.co.za/site/files/5438/CGA%20ANNUAL%20REPORT%202013%20e.pdf>. [Accessed 24 January 2014].
- CITRUS GROWERS ASSOCIATION OF SOUTH AFRICA (CGA). (2014). Personal communication. 30 January.
- CLEVELAND, C.C., HOULTON, B.Z., SMITH, W.K., MARKLEIN, A.R., REED, S.C., PARTON, P., DEL GROSSO, S.J. & RUNNING, S.W. (2013). Patterns of new versus recycled primary production in the terrestrial biosphere. *Proceedings of the National Academy of Sciences*, 110(31): 12733-12737.
- CLIFFORD HOLMES, J., MOLONY, L., MULLER, M. & RIVERS, N. (2013). *Extended Narrative of Change of the Lower Sundays River Valley*. Unpublished report. Grahamstown: Unilever Institute for Water Research, Rhodes University.
- COCA-COLA EUROPE (2011). *Water footprint sustainability assessment: Towards sustainable sugar sourcing in Europe*. Brussels, Belgium.
- COETZEE, J.G.K. (2007). Fertilization of citrus. In: *Citrus Research International. Integrated production guidelines for export citrus (Volume 2): Citriculture-Cultural Practices*. Nelspruit, South Africa.
- CONRADIE, B. (2002). *The value of water in the Fish-Sundays scheme of the Eastern Cape*. WRC Report No. 987/1/02. Water Research commission, South Africa, Pretoria.
- CONSOLI, S., O' CONNELL, N. & SNYDER, R. (2006). Measurement of light interception by navel orange orchard canopies: Case study of Lindsay, California. *Journal of Irrigation and Drainage Engineer*, 132: 9-20.

- COOK, S., GICHUKI, F. & TURRAL, H. (2004). *Water productivity: Estimation at a plot, farm and basin scale*. Basin Focal Working Project Working Paper 2. Colombo: CGIAR Challenge Program on Water and Food.
- COSTANZA, R. & DALY, H.E. (1992). Natural capital and sustainable development. *Conservation Biology*, 6: 37–46.
- CRESWELL, J. W. & PLANO CLARK, V. L. (2007). *Designing and conducting mixed methods research*. Thousand Oaks, CA: Sage.
- CUCEK, L., KLEMES, J.J. & KRAVANJA, Z. (2012). A review of footprint analysis tools for monitoring impacts on sustainability. *Journal of Cleaner Production*, 34: 9-20.
- DABROWSKI, J.M., MASEKOAMENG, E. & ASHTON P.J. (2008). Analysis of virtual water flows associated with the trade of maize in the SADC region: importance of scale. *Hydrological Earth Systems Science Discuss*, 5: 2727–2757.
- DAHL, A.L. (2012). Achievements and gaps in indicators for sustainability. *Ecological Indicators*, 17: 14–19.
- DALAL-CLAYTON, B. & SADLER, B. (2005). *Strategic environmental assessment: A sourcebook and reference guide to international experience*. London: Earthscan.
- TURE, C., CAI, X., AMARASINGHE, U., ROSEGRANT, M. & MOLDEN, D. (2004). *Does international cereal trade save water? The impact of virtual water trade on global water use*. Comprehensive assessment research report 4, Colombo, Sri Lanka: IWMI.
- DE LANGE, W.J. & MAHUMANI, B.K. (2013). The marginal product value of irrigation water for potato and vine cultivation in the Sandveld region, South Africa. *Agrekon: Agricultural Economics Research, Policy and Practice in Southern Africa*, 51(4): 129-143.
- DELPORT, J.S. (1987). *Kirkwood in the Sundays River Valley: 1921-1987*. Kirkwood Municipality.
- DEPARTMENT OF AGRICULTURE (DOA). (2006). Crops and markets. First quarter volume 87. [Online] Available: [http://www.daff.gov.za/docs/statsinfo/Crops\\_0106.pdf](http://www.daff.gov.za/docs/statsinfo/Crops_0106.pdf) [Accessed: 15 March 2013].
- DEPARTMENT OF AGRICULTURE, FISHERIES AND FORESTRY (DAFF). (2010). *Irrigation strategy for South Africa*. Pretoria.
- DEPARTMENT OF AGRICULTURE, FISHERIES AND FORESTRY (DAFF). (2013). *Abstract of agricultural statistics 2013*. Pretoria. pp 107.

- DEPARTMENT OF ENVIRONMENTAL AFFAIRS & TOURISM (DEAT). (2004). A national climate change response strategy for South Africa. [Online]: Available: [https://unfccc.int/files/meetings/seminar/application/pdf/sem\\_sup3\\_south\\_africa.pdf](https://unfccc.int/files/meetings/seminar/application/pdf/sem_sup3_south_africa.pdf) [Accessed: 12 October 2013].
- DEPARTMENT OF FISHERIES AND FORESTRY (DAFF). (2011). A profile of the South African citrus market value chain. Directorate Marketing. [Online] Available: <http://www.nda.agric.za/docs/AMCP/Citrusmvcp2011-12.pdf>. [Accessed 27 May 2013].
- DEPARTMENT OF WASTE AND SANITATION (DWS). (2011). Fish to Tsitsikamma Water Management Area: Surface water quality status (2004-2008). [Online] Available: [https://www.dwa.gov.za/Documents/Other/Water%20Resources/12626\\_WMAs\\_A3\\_Fish%20to%20Tsitsikamma.PDF](https://www.dwa.gov.za/Documents/Other/Water%20Resources/12626_WMAs_A3_Fish%20to%20Tsitsikamma.PDF) [Accessed: 12 November 2014].
- DEPARTMENT OF WASTE AND SANITATION (DWS). (2014). Hydrological database. [Online] Available: <https://www.dwa.gov.za/hydrology/> [Accessed: 9 September 2014].
- DEPARTMENT OF WATER AFFAIRS (DWA). (2012). *Draft National Water Resource Strategy 2: Managing water for an equitable and sustainable future*. Pretoria, South Africa.
- DEPARTMENT OF WATER AFFAIRS AND FORESTRY (DWAF). (1996a). *South African Water Quality Guidelines*. Volume 7: Aquatic Ecosystems.
- DEPARTMENT OF WATER AFFAIRS AND FORESTRY (DWAF). (1996b). *South African Water Quality Guidelines (2e)*. Volume 4: Agricultural Use: Irrigation.
- DEPARTMENT OF WATER AFFAIRS AND FORESTRY (DWAF). (1996c). *South African Water Quality Guidelines (1e)*. Volume 8: Field Guide.
- DEPARTMENT OF WATER AFFAIRS AND FORESTRY (DWAF). (1998). Guide to the National Water Act. Pretoria, South Africa. [Online] Available: <http://www.dwa.gov.za/documents/publications/NWAGuide.pdf> [Accessed 19 March 2013].
- DEPARTMENT OF WATER AFFAIRS AND FORESTRY (DWAF). (2004). National Water Resource Strategy. Pretoria, South Africa. [Online] Available: <http://www.dwaf.gov.za/documents/policies/NWRS/default.htm> [Accessed 15 March 2013].

- DEPARTMENT OF WATER AFFAIRS AND FORESTRY (DWAF). (2005). *Fish to Tsitsikamma Water Management Area: Fish to Sundays internal strategic perspective*. Prepared by Ninham Shand in association with Umvoto Africa, on behalf of the Directorate National Water Resource Planning. DWAF Report no. PWMA 15/000/00/0405.
- DEVUYST, D. (2000). Linking impact assessment and sustainable development at the local level: The Introduction of Sustainability Assessment Systems. *Sustainable Development*, 8: 67-78.
- DEVUYST, D. (2001). Introduction to sustainability assessment at the local level. In: Devuyt, D. (ed.) *How green is the city? Sustainability assessment and the management of urban environments*. New York: Columbia University Press. pp. 1-41.
- DÖLL, P. (2002). *Water for agriculture-a global systems analysis perspective*. University of Kassel, Centre for Environmental Systems Research, Germany.
- DOORENBOS, J. & PRUIT, W.O. (1977). *Yield response to water*. FAO Irrigation and Drainage Paper no 24. FAO. Rome. Italy.
- DU PLESSIS, S.F. (1989). *Soil requirements for citrus growing*. Farming in South Africa Pamphlet Series. Citrus B.3/1989.
- DUMONT, A., SALMORAL, G. & LLAMAS, M.R. (2013). The water footprint of a river basin with a special focus on groundwater: The case of Guadalquivir basin (Spain). *Water Resources and Industry*, 1-2: 60-76.
- DYKE, G. & MURRAY, S.L. (1997). *Existing Water Infrastructure in the Eastern Cape Region*. Report 10 in the Orange River Development Project Replanning Study. Department of Water Affairs and Forestry, Pretoria.
- EARLE, A. & TURTON, A. (2003). The virtual water trade amongst countries of the SADC. In: Hoekstra, A.Y. (ed.). *Virtual water trade – proceedings of the international expert meeting on virtual water trade*. Value of Water Research Report Series No. 12. IHE Delft, the Netherlands.
- EL FADEL, M. & MAROUN, R. (2003). The concept of 'virtual water' and its applicability in Lebanon. In: Hoekstra, A.Y. (ed.). *Virtual Water Trade – Proceedings of the International Expert Meeting on Virtual Water Trade*. IHE Delft Value of Water Research Report Series No. 12.
- ERCIN, A.E. & HOEKSTRA, A.Y. (2012). *Carbon and water footprints: Concepts, methodologies and policy responses*. United Nations World Water Assessment Programme, Side Publications Series No.4, UNESCO, Paris.

- ERCIN, A.E. & HOEKSTRA, A.Y. (2014). Water footprint scenarios for 2050: A global analysis. *Environment International*, 64: 71-82.
- ERCIN, A.E., ALDAYA, M.M. & HOEKSTRA, A.Y. (2009). *A pilot in corporate water footprint accounting and impact assessment: The water footprint of a sugar-containing carbonated beverage*. Value of Water Research Report Series No.39, UNESCO-IHE. Delft, the Netherlands.
- ERCIN, A.E., ALDAYA, M.M. & HOEKSTRA, A.Y. (2011). Corporate water footprint accounting and impact assessment: The case of the water footprint of a sugar-containing carbonated beverage. *Water Resources Management*, 25(2): 721-741.
- ERCIN, A.E., ALDAYA, M.M. & HOEKSTRA, A.Y. (2012). The water footprint of soy milk and soy burger and equivalent animal products, *Ecological Indicators*, 18: 392–402.
- ERCIN, A.E., MEKONNEN, M.M. & HOEKSTRA, A.Y. (2013). Sustainability of national consumption from a water resources perspective: The case study for France. *Ecological Economics*, 88: 133-147.
- ERIKSSON, E., AUFFARTH, K., HENZE, M. & LEDIN, A. (2002). Characteristics of grey wastewater. *Urban water*, 4: 85-104.
- EWING, B R., HAWKINS, T. R., WIEDMANN, T.O., GALLI, A., ERCIN, A.E., WEINZETTEL, J. & STEEN-OLSEN, K. (2012). Integrating ecological and water footprint accounting in a multi-regional input–output framework. *Ecological Indicators*, 23: 1–8.
- FADER, M., GERTEN, D., THAMMER, M., HEINKE, J., LOTZE-CAMPEN, H., LUCHT, W. & CRAMER, W. (2011). Internal and external green-blue agricultural water footprints of nations, and related water and land savings through trade, *Hydrology and Earth System Sciences*, 15(5): 1641-1660.
- FALKENMARK, M. (1989). The massive water scarcity facing Africa now- why isn't it being addressed? *Ambio*, 18(2): 112-118.
- FALKENMARK, M. (1995). *Coping with water scarcity under rapid population growth*. Paper presented at Conference of SADC Ministers, Pretoria, South Africa, November 23-24.
- FALKENMARK, M. (2003). Adapting to climate change: towards societal water security in dry-climate countries. *International Journal of Water Resources Development*, 29:123-136.

- FALKENMARK, M. & LINDH, G. (1974). How can we cope with the water resources situation by the year 2015? *Ambio*, 3(3–4): 114–122.
- FALKENMARK, M. & ROCKSTRÖM, J. (2004). *Balancing water for humans and nature: The new approach in ecohydrology*. Earthscan, London, UK.
- FALKENMARK, M. & ROCKSTRÖM, J. (2006). The new blue and green paradigm. Breaking new ground for water resources planning and management. *Journal of Water Resources Planning and Management*, 132:129–132.
- FALKENMARK, M. & ROCKSTRÖM, J. (2006). The new blue and green paradigm. Breaking new ground for water resources planning and management. *Journal of Water Resources Planning and Management* 132:129–132.
- FALKENMARK, M., LUNDQVIST, J. & WIDSTRAND, C. (1989). Macro-scale water scarcity requires micro-scale approaches: Aspects of vulnerability in semi-arid development. *Natural Resources Forum*, 13(4): 258–267.
- FANG, K., HEIJUNGS, R., & DE SNOO, G. R. (2014). Theoretical exploration for the combination of the ecological, energy, carbon, and water footprints: Overview of a footprint family. *Ecological Indicators*, 36, 508–518.
- FAVILENE, S., GIDDINGS, J., HARDY, S. & SANDERSON, G. (2006). Managing citrus orchards with less water. New South Wales DPI. *Primefact*, 427: 1–10.
- FENG, K., HUBACEK, K., MINX, J., SIU, Y.L., CHAPAGAIN, A., YU, Y., GUAN, D. & BARRETT, J. (2011). Spatially explicit analysis of water footprints in the UK. *Water*, 3(1): 47–63.
- FISHELSON, G. (1994). The allocation of marginal value product of water in Israeli agriculture. In: Isaac, J. & Shuval, H. (eds.). *Water and peace in the Middle East*. Elsevier Science, Amsterdam. pp. 427–440.
- FLACHMANN, C., MAYER, H., & MANZEL, K. (2012). *Water footprint of food products in Germany*. Federal Statistical Office of Germany, Wiesbaden. Germany.
- FOOD & AGRICULTURE ORGANISATION (FAO). (2013). *Food wastage footprint: Impacts on natural resources*. Food and Agriculture Organization, Rome, Italy.
- FOOD & AGRICULTURE ORGANISATION (FAO). (2014). GeoNetwork. [Online] Available: [www.fao.org/geonetwork](http://www.fao.org/geonetwork). [Accessed 3 September 2014].

- FORTUNE, J. & HUGHES, J. (1997). Modern academic myths. In: Stowell, F.A., ISON, R.L., ARMSON, R., HOLLOWAY, J., JACKSON, S. & MCROBB, S. (eds). *Systems for Sustainability: People, Organizations and Environments*. Plenum Press, New York and London. pp 125–130.
- FOSTER, C., GREEN, K., BLEDA, M., DEWICK, P., EVANS, B., FLYNN, A. & MYLAN, J. (2006). *Environmental impacts of food production and consumption*. A report to the Department of Environment and Rural Affairs. Manchester Business School. Defra, London.
- FRANCKE, I.C.M. & CASTRO, J.F.W. (2013). Carbon and water footprint analysis of a soap bar produced in Brazil by Natura Cosmetics. *Water Resources and Industry*, 1(2): 37-48.
- FRANKE, N. & MATHEWS, R. (2013a). C&A's Water Footprint Strategy: Cotton Clothing Supply Chain.
- FRANKE, N. & MATHEWS, R. (2013b). Grey Water Footprint Indicator of Water Pollution in the Production of Organic vs. Conventional Cotton in India.
- FRANKE, N.A., BOYACIOGLU, H. & HOEKSTRA, A.Y. (2013). Grey water footprint accounting: Tier 1 supporting guidelines, Value of Water Research Report Series No. 65, UNESCO-IHE, Delft, the Netherlands.
- FRANKLIN, A. & BLYTON, P. (eds). (2011). *Researching sustainability: A guide to social science methods, practice and engagement*. Earthscan: Abington, Oxon.
- FUNKE, N., NORTJE, K., FINDLATER, K., BURNS, M., TURTON, A., WEAVER, A. & HATTINGH, H. (2007). Redressing inequality: South Africa's New Water Policy. *Environment: Science and Policy for Sustainable Development*, 49(3): 10–23.
- GALLI, A., WIEDMANN, T., ERCIN, E., KNOBLAUCH, D., EWING, B. & GILJUM, S. (2012). Integrating ecological, carbon and water footprint into a "footprint family" of indicators: Definition and role in tracking human pressure on the planet. *Ecological Indicators*, 16: 100-112.
- GALLOPÍN, G. (1997). Indicators and their use information for decision making. In: Moldan, B. & Bilharz, S. (eds). *Sustainability indicators: report on the project on indicators of sustainable development*. John Wiley, Chichester, UK. pp 13-27.
- GALLOWAY, J.N., BURKE, M., BRADFORD, G.E., NAYLOR, R., FALCON, W., CHAPAGAIN, A.K., GASKELL, J.C., MCCULLOUGH, E., MOONEY, H.A., OLESON, K.L.L., STEINFELD, H., WASSENAAR, T. & SMIL, V. (2007). International trade in meat: The tip of the pork chop, *Ambio*, 36(8): 622-629.

- GARCIA, S.M. (1997). *Indicators for sustainable development of fisheries: FAO, Land Quality Indicators and their Use in Sustainable Agriculture and Rural Development*. United Nations Food and Agriculture Organisation, Rome.
- GARRIDO, A., LLAMAS, M.R., VARELA, C., NOVO, P., RODRÍGUEZ CASADO, R. & ALDAYA, M.M. (2010). *Water Footprint and Virtual Water Trade: Policy Implications*. Observatorio del Agua, Fundación Marcelino Botín, Santander.
- GAWEL, E. & BERNSEN, K. (2011). What is wrong with virtual water trading?, UFZ-Discussion paper, No. 1.
- GBETIBOUO, G.A. & RINGER, C. (2009). *Mapping South African farming sector vulnerability to climate change and variability*. IFPRI Discussion Paper 00885. IFPRI, Washing DC.
- GEORGE, C. (2001). Sustainability appraisal for sustainable development: integrating everything from jobs to climate change. *Impact Assessment Project Appraisal*, 19(1): 95-106.
- GERBENS-LEENES, P.W. & HOEKSTRA, A.Y. (2010). *Burning water: The water footprint of biofuel-based transport*. Value of Water Research Report Series No.44, UNESCO-IHE. Delft, the Netherlands.
- GERBENS-LEENES, P.W. HOEKSTRA, A.Y. & VAN DER MEER.T.H. (2009a). The water footprint of energy from biomass: A quantitative assessment and consequences of an increasing share of bio-energy in energy supply. *Ecological Economics*, 68(4): 1052-1060.
- GERBENS-LEENES, P.W., HOEKSTRA, A.Y. & VAN DER MEER, T.H. (2008). *Water footprint of bio-energy and other primary energy carriers*. Value of Water Research Report Series No.29, UNESCO-IHE.
- GERBENS-LEENES, P.W., MEKONNEN, M.M. & HOEKSTRA, A.Y. (2013). The water footprint of poultry, pork and beef: A comparative study in different countries and production systems. *Water Resources and Industry*, 1-2: 25-36.
- GERBENS-LEENES, P.W., VAN LIENDEN, A.R., HOEKSTRA, A.Y. & VAN DER MEER, T.H. (2012). Biofuel scenarios in a water perspective: The global blue and green water footprint of road transport in 2030. *Global Environmental Change*, 22: 764-775.
- GERBENS-LEENES, W. & HOEKSTRA, A.Y. (2012). The water footprint of sweeteners and bio-ethanol. *Environment International*, 40: 202-211.
- GERBENS-LEENES, W., HOEKSTRA, A.Y. & VAN DER MEER, T.H. (2009b). The water footprint of bioenergy. *Proceedings of the National Academy of Sciences*, 106 (25): 10219-10223.

- GIBSON, R.B., HASSAN, S., HOLTZ, S., TANSEY, J. & WHITELAW, G. (2005). *Sustainability assessment: criteria, processes and applications*. London: Earthscan.
- GINSON, R.B. (2006). Beyond the pillars: sustainability assessment as a framework for effective integration of social, economic and ecological considerations in significant decision-making. *Journal of Environmental Assessment and Policy Management*, 8 (3): 259–280.
- GLASSON, J., THERIVEL, R. & CHADWICK, A. (1999). *Introduction to environmental impact assessment: Principles and procedures, process, practice and prospects*. London/Philadelphia: UCL Press.
- GLEICK, P.H. (1993). Water and conflict: Fresh water resources and international security. *International Security*, 18: 79–112.
- GOVERNMENT OF INDIA. (2012). National Water Policy. [Online] Available: <http://wrmin.nic.in/writereaddata/NationalWaterPolicy/NWP2012Eng6495132651.pdf> [Accessed: 13 October 2014].
- GRACE, W. & POPE, J. (2005). *Sustainability Assessment- issues of process, policy and governance*. International Experience and Perspectives in SEA conference. Prague: International Association for Impact Assessment.
- GREEN, G.C. (1979). An analysis of seasonal water use of Valencia orange trees in the Sundays River Valley. *Crop Production*, 8:179-183.
- GREEN, G.C. (1985). *Estimated irrigation requirements of crops in South Africa*. Part 1. Memoirs on the agricultural natural resources of South Africa, No 2, Department of Agriculture and Water Supply, Pretoria, South Africa.
- GROSSKOPF, M., (2004). Towards internalising the cost of water pollution. In: Blignaut, J. & De Wit, M. (eds.). *Sustainable options: Development lessons from applied environmental economics*. UCT Press, Cape Town.
- GUAN, D. & HUBACEK, K. (2007). Assessment of regional trade and virtual water flows in China. *Ecological Economics*, 61(1): 159–170.
- GUSH, M.B. & TAYLOR, N.J. (eds). (2014). *The water use of selected fruit tree orchards (volume 2): Technical report on measurements and modelling*. WRC Report No. 1770/2/14. Water Research Commission, Pretoria, South Africa.

- HACKING, T. & GUTHRIE, P. (2008). A framework for clarifying the meaning of triple bottom-line, integrated, and sustainability assessment. *Environmental Impact Assessment Review* 28: 73-89.
- HASTINGS, E. & PEGRAM, G. (2012). *Literature review for the applicability of water footprints in South Africa*. WRC Report No. 2099/P/11. Water Research Commission, Gezina, South Africa.
- HERWEG, K., STEINER, K. & SLAATS, J. (1998). *Sustainable land management- guidelines for impact monitoring*. Centre for Development and Environment, Bern, Switzerland.
- HOARE, D.B., MUCINA, L., RUTHERFORD, M.C., VLOK, J.H.J., EUSTON-BROWN, D.I.W., PALMER, A.R., POWRIE, L.W., LECHMERE-OERTEL, R.G., PROCHES, M., DOLD, A.P. & WARD, R.A. (2006). Albany Thicket Biome. In: Mucina, L. & Rutherford, M.C. (eds) 2006. The vegetation of South Africa, Lesotho and Swaziland. *Strelitzia* 19: 540-567. South African National Biodiversity Institute, Pretoria.
- HOEKSTRA, A.Y. (2007). *Human appropriation of natural capital: Comparing ecological footprint and water footprint analysis*. Value of Water Research Report Series No.23, UNESCO-IHE, Delft, the Netherlands.
- HOEKSTRA, A.Y. (2008). *Water neutral: reducing and offsetting the impacts of water footprints*. Value of Water Research Report Series No.28, UNESCO-IHE. Delft, the Netherlands.
- HOEKSTRA, A.Y. (2011). The global dimension of water governance: Why the river basin approach is no longer sufficient and why cooperative action at global level is needed. *Water*, 3(1): 21-46.
- HOEKSTRA, A.Y. (2012). The hidden water resource use behind meat and dairy. *Animal Frontiers*, 2(2): 3-8.
- HOEKSTRA, A.Y. (2013). *Wise freshwater allocation: water footprint caps by river basin, benchmarks by product and fair water footprint shares by community*. Value of Water Research Report Series No. 63, UNESCO-IHE, Delft, the Netherlands.
- HOEKSTRA, A.Y. (2014a) Sustainable, efficient and equitable water use: The three pillars under wise freshwater allocation. *WIREs Water*, 1(1): 31-40.
- HOEKSTRA, A.Y. (2014b). Water scarcity challenges to business. *Nature Climate Change*, 4(5): 318-320.
- HOEKSTRA, A.Y. (ed). (2003). *Virtual water trade: Proceedings of the international expert meeting*

- on virtual water trade*. Value of Water Research Report Series No.12, UNESCO-IHE, Delft, the Netherlands.
- HOEKSTRA, A.Y. & CHAPAGAIN, A.K. (2007a). Water footprints of nations: water use by people as a function of their consumption pattern. *Water Resources Management*, 21(1): 35-48.
- HOEKSTRA, A.Y. & CHAPAGAIN, A.K. (2007b). The water footprints of Morocco and the Netherlands: Global water use as a result of domestic consumption of agricultural commodities. *Ecological Economics*, 64(1): 143-151.
- HOEKSTRA, A.Y. & CHAPAGAIN, A.K. (2008). *Globalization of water: sharing the planet's freshwater resources*. Oxford, UK: Blackwell Publishing Ltd.
- HOEKSTRA, A.Y. & HUNG, P.Q. (2002). *Virtual water trade: A quantification of virtual water flows between nations in relation to international crop trade*. Value of Water Research Report Series No.11, UNESCO-IHE, Delft, the Netherlands.
- HOEKSTRA, A.Y. & HUNG, P.Q. (2005). Globalisation of water resources: International virtual water flows in relation to crop trade. *Global Environmental Change*, 15(1): 45-56.
- HOEKSTRA, A.Y. & MEKONNEN, M.M. (2012a). From water footprint assessment to policy. *Proceedings of the National Academy of Sciences*, 109(22): E1425.
- HOEKSTRA, A.Y. & MEKONNEN, M.M. (2012b). The water footprint of humanity. *Proceedings of the National Academy of Sciences*, 109(9): 3232–3237.
- HOEKSTRA, A.Y. & WIEDMANN, T.O. (2014). Humanity's unsustainable environmental footprint. *Science*, 344(6188): 1114-1117.
- HOEKSTRA, A.Y., CHAPAGAIN, A.K., ALDAYA, M.M. & MEKONNEN, M.M. (2009a). Water footprint manual: State of the art 2009, Water Footprint Network, Enschede, the Netherlands.
- HOEKSTRA, A.Y., CHAPAGAIN, A.K., ALDAYA, M.M. & MEKONNEN, M.M. (2011). The water footprint assessment manual. Available: <http://www.waterfootprint.org/?page=files/WaterFootprintAssessmentManual> [Accessed 20 January 2013].
- HOEKSTRA, A.Y., GERBENS-LEENES, W. & VAN DER MEER, T.H. (2009b). Water footprint accounting, impact assessment, and life-cycle assessment. *Proceedings of the National Academy of Sciences*, 106(40): E114.

- HOEKSTRA, A.Y., MEKONNEN, M.M., CHAPAGAIN, A.K., MATHEWS, R.E. & RICHTER, B.D. (2012). Global monthly water scarcity: Blue water footprints versus blue water availability. *PLoS ONE*, 7(2): e32688.
- HOFF, H. (2009). Global water resources and their management. *Current Opinion in Environmental Sustainability*, 1: 141-147.
- HOFFMAN, G.J., OSTER, J.D. & ALVES, W.J. (1982). Evapotranspiration of mature orange trees under drip irrigation in an arid climate. *Transactions of the American Society of Agricultural Engineers*, 25: 992-996.
- HOPWOOD, B., MELLOR, M. & O'BRIEN, G. (2005). Sustainable development: Mapping different approaches. *Sustainable Development*, 13: 38-52.
- HORLEMANN, L. & NEUBERT, S. (2007). *Virtual water trade: a realistic concept for resolving the water crisis?* German Development Institute report number 25, Bonn, 118 pp.
- IGLESIAS, D.J., CERCÓS, M., JOSÉ, M., MIGUEL, C.F., NARANJO, A., RÍOS, G., CARRERA, E., RUIZ-RIVERO, O., LLISO, I., MORILLONI, R., TADEO, F.R. & TALON, M. (2007). Physiology of citrus fruiting. *Brazilian Journal of Plant Physiology*, 19(4): 333-362.
- INTERNATIONAL FINANCE CORPORATION (IFC), LIMNOTECH., JAIN IRRIGATION SYSTEMS. & TNC. (2010). *Water footprint assessments- dehydrated onion products, Micro-irrigation systems*. Jain Irrigation Systems Ltd. International Finance Corporation, Washington, D.C, USA.
- INTERNATIONAL STANDARDISATION ORGANISATION 14046. (2014). Environmental management- Water footprint- Principles, requirements and guidelines. [Online] Available: <https://www.iso.org/obp/ui/#iso:std:43263:en> [Accessed: 27 September 2014].
- JAPHA, D. (1996). *The historic missions project: a project to rehabilitate eight historic mission centres in the Eastern Cape*. Pretoria.
- JEFFERIES, D., MUÑOZ, I., HODGES, J., KING, V.J., ALDAYA, M., ERCIN, A.E., MILÀI CANALS, L. & HOEKSTRA, A.Y. (2012). Water Footprint and Life Cycle Assessment as approaches to assess potential impacts of products on water consumption: Key learning points from pilot studies on tea and margarine. *Journal of Cleaner Production*, 33: 155-166.
- JURY, W.A. & VAUX, H. (2005). The role of science in solving the world's emerging water problems. *The National Academy of Sciences of the USA*, 102 (44): 15715-15720.
- KAMPMAN, D. A., HOEKSTRA, A. Y. & KROL, M. S. (2008). *The water footprint of India*. Value of Water Research Report Series No 32, UNESCO-IHE. Delft, the Netherlands.

- KING, N. (2004). The economic value of water in South Africa. In: Blignaut, J. & de Witt, M. (eds). *Sustainable options: Development lessons from applied environmental economics*. University of Cape Town Press, Cape Town. pp 207-238.
- KNOTZE, V. (2014). Kirkwood burns after municipality writes off half of budget for irregular expenditure. Democratic Alliance [Online] Available: <http://www.dabhishe.org.za/2014/09/23/kirkwood-burns-after-municipality-writes-off-half-of-budget-for-irregular-expenditure/> [Accessed: 12 November 2014].
- KOEHLER, A. (2008). Water use in LCA: managing the planet's freshwater resources. *Journal of Life Cycle Assessment*, 13:451-455.
- KOUNINA, A., MARGNI, M., BAYART, J.B., BOULAY, A.M., BERGER, M., BULLE, C., FRISCHKNECHT, R., KOEHLER, A., MILA I CANALS, L., MOTOSHITA, M., NÚÑEZ, M., PETERS, G., PFISTER, S., RIDOUTT, B., VAN ZELM, R., VERONES, F. & HUMBERT, S. (2012). Review of methods addressing freshwater use in life cycle inventory and impact assessment. *International Journal of Life Cycle Assessment*, 18: 707–721.
- KUMAR, M.D. & SINGH, O.P. (2005). Virtual water in global food and water policy making: is there a need for rethinking. *Water Resource Management*, 19(6): 759–789.
- LANGE, G.M. & HASSAN, R. (2006). *The economics of water management in Southern Africa, an environmental accounting approach*. Boston, Massachusetts: Edward Elgar Publishing.
- LAUTZE, J. & HANJRA, M.A. (2014). Water scarcity. In: Lautze, J. (eds). *Key Concepts in Water Resource Management: a Review and Critical Evaluation*. Routledge, Earthscan: IWMI. pp 30-46.
- LAUTZE, J., XUELIANG, C. & MATCHAYA, G. (2014). Water productivity. In: Lautze, J. (eds). *Key Concepts in Water Resource Management: a Review and Critical Evaluation*. Routledge, Earthscan: IWMI. pp 87-103.
- LIU, C., KROEZE, C., HOEKSTRA, A.Y. & GERBENS-LEENES, W. (2012). Past and future trends in grey water footprints of anthropogenic nitrogen and phosphorus inputs to major world rivers, *Ecological Indicators*, 18: 42-49.
- LIU, J. & SAVENIJE, H. H. G. (2008). Food consumption patterns and their effect on water requirement in China. *Hydrology and Earth System Sciences*, 12(3): 887–898.

- LIU, J., ZEHNDER, A.J. & YANG, H. (2009). Global consumptive water use for crop production: The importance of green water and virtual water. *Water Resources Research*, 45:5 W05428, doi:10.1029/2007WR006051.
- LIU, J.G., ZEHNDER, A.J.B. & YANG, H. (2007). Historical trend in China's virtual water trade. *Water International*, 32(1): 78-90.
- LOPEZ-GUNN, E. & LLAMAS, M.R. (2008). Re-thinking water scarcity: can science and technology solve the global water crisis? *Natural Resource Forum*, 32(3): 228–238.
- LOUW, D.B. (2001). *The development of a methodology to determine the true value of water and the impact of a potential water market on the efficient utilisation of water in the Berg River Basin*. WRC Report No 943/1/02. Water Research Commission, Pretoria.
- LOWER SUNDAYS RIVER VALLEY WATER USER ASSOCIATION (2012). Annual report 2011/2012. Sunland, Eastern Cape, South Africa.
- LOWER SUNDAYS RIVER VALLEY WATER USER ASSOCIATION (2013). Geographic Information Systems Operator. Sunland, Eastern Cape. Personal communication. 29 October.
- LOWER SUNDAYS RIVER VALLEY WATER USER ASSOCIATION (2014). Technical officer. Sunland, Eastern Cape. Personal communication. 26 August- 28 November.
- MA, J., HOEKSTRA, A.Y., WANG, H., CHAPAGAIN, A.K. & WANG, D. (2006). Virtual versus real water transfers within China. *Phil. Trans. R. Soc. Lond. B*, 361(1469): 835-842.
- MALONY, L. (2013). *Water security amongst impoverished households in the Sundays River Valley: Community experiences and perspectives*. Unpublished Report. Grahamstown: Unilever Institute for Water Research, Rhodes University.
- MATROOS, J.L. (2014). South Africa Breaking News. [Online] Available: <http://www.sabreakingnews.co.za/2014/09/24/jhb-officials-scramble-to-solve-water-shortage/> [Accessed: 12 November 2014].
- MEIRING, J. M. (1959). *Sundays River Valley: its history and settlement*. Cape Town: Balkema.
- MEKONNEN, M.M. & HOEKSTRA, A.Y. (2010a). *A global and high-resolution assessment of the green, blue and grey water footprint of wheat*. Value of Water Research Report Series No.42, UNESCO-IHE. Delft, the Netherlands.

- MEKONNEN, M.M. & HOEKSTRA, A.Y. (2010b). *The green, blue and grey water footprint of crops and derived crop products*. Value of Water Research Report Series No.47, UNESCO-IHE. Delft, the Netherlands.
- MEKONNEN, M.M. & HOEKSTRA, A.Y. (2010c). *The green, blue and grey water footprint of farm animals and animal products*. Value of Water Research Report Series No.48, UNESCO-IHE. Delft, the Netherlands.
- MEKONNEN, M.M. & HOEKSTRA, A.Y. (2011a). *National water footprint accounts: the green, blue and grey water footprint of production and consumption*. Value of Water Research Report Series No.50, UNESCO-IHE. Delft, the Netherlands.
- MEKONNEN, M.M. & HOEKSTRA, A.Y. (2011b.) The green, blue and grey water footprint of crops and derived crop products. *Hydrology and Earth System Sciences*, 15(5): 1577-1600.
- MEKONNEN, M.M. & HOEKSTRA, A.Y. (2011c). *The relation between national water management and international trade. A case study for Kenya*, Value of Water Research Report Series No.52, UNESCO-IHE. Delft, the Netherlands.
- MEKONNEN, M.M. & HOEKSTRA, A.Y. (2012a). A global assessment of the water footprint of farm animal products. *Ecosystems*, 15(3): 401–415.
- MEKONNEN, M.M. & HOEKSTRA, A.Y. (2012b). The blue water footprint of electricity from hydropower. *Hydrology and Earth System Sciences*, 16(1): 179-187
- MEKONNEN, M.M. & HOEKSTRA, A.Y. (2014a). Water footprint benchmarks for crop production: A first global assessment. *Ecological Indicators*, 46: 214-223.
- MEKONNEN, M.M. & HOEKSTRA, A.Y. (2014b). Water conservation through trade: The case of Kenya. *Water International*, 39(4): 451-468.
- MEKONNEN, M.M., HOEKSTRA, A.Y. & BECHT, R. (2012). Mitigating the water footprint of export cut flowers from the Lake Naivasha Basin, Kenya. *Water Resources Management*, 26: 3725–3742.
- MEKONNEN, M.M., PAHLOW, M., ALDAYA, M.M., ZARATE, E. & HOEKSTRA, A.Y. (2014). *Water footprint assessment for Latin America and the Caribbean: An analysis of the sustainability, efficiency and equitability of water consumption and pollution*. Value of Water Research Report Series No. 66, UNESCO-IHE, Delft, the Netherlands.
- MEKONNEN, M.M. & HOEKSTRA, A.Y. (2013) Water footprint benchmarks for crop production, Value of Water Research Report Series No. 64, UNESCO-IHE, Delft, the Netherlands.

- MEISSNER, R. (2003) .Regional food security and virtual water: Some natural, political and economic implications. In: Hoekstra, A.Y. *Virtual water trade: Proceedings of the International Expert Meeting on Virtual Water Trade*. Value of Water Research Report Series No. 12. UNESCO-IHE, Delft, the Netherlands.
- MIDGLEY, D.C., PITMAN, W.V. & MIDDLETON, B.J. (1994).Surface water resources of South Africa 1990.Volume 5 Appendices. WRC Report no: 298/5.1/94. Water Research Commission, Pretoria, South Africa.
- MOFFATT, I. (1996). *Sustainable development: Principles, analysis and policies*. Parthenon: London.
- MOKGOPE, K., POLLARD, S. & BUTTERWORTH, J. (2001). *Water resources and water supply for rural communities in the Sand River Catchment, South Africa*. The 27<sup>th</sup> WEDC Conference, People and systems for water, sanitation and health, 20-24 August 2001. Lusaka, Zambia.
- MOLDAN, B., JANOUŠKOVÁ, S. & HÁK, T. (2012). How to understand and measure environmental sustainability: Indicators and targets. *Ecological Indicators*, 17: 4-13.
- MOLDEN, D. (2007). *Water for food, water for life: Comprehensive assessment for water management*. London, UK: Earthscan, Colombo, Sri Lanka: IWMI.
- MOLDEN, D., OWEIS, T., STEDUTO, P., BINDRABAN, P., HANJRAE, M.A. & KIJNE, J. (2010). Improving agricultural water productivity: Between optimism and caution. *Agricultural Water Management*, 97: 528–535.
- MOLDEN, D., OWEIS, T.Y., STEDUTO, P., KIJNE, J.W., HANJRA, M.A., BINDRABAN, P.S., BOUMAN, B.A.M., COOK, S., ERENSTEIN, O., FARAHANI, H., HACHUM, A., HOOGEVEEN, J., MAHOO, H., NANGIA, V., PEDEN, D., SIKKA, A., SILVA, P., TURRAL, H.U.A. & ZWART, S. (2007). Pathways for increasing agricultural water productivity. In: Molden, D. (ed). *water for food, water for life: A comprehensive assessment of water management in agriculture*. London, UK: Earthscan, Colombo, Sri Lanka: IWMI.
- MORDINI, M.M., NEMECEK, T. & GAILLARD, G. (2009).*Carbon and water footprint of oranges and strawberries: A Literature Review*. Federal Department of Economic Affairs FDEA. Swiss confederation.
- MORI, K. (2003). Virtual water trade in global governance. In: Hoekstra, A.Y. (ed.). *Virtual Water Trade – Proceedings of the International Expert Meeting on Virtual Water Trade*. IHE Delft Value of Water Research Report Series No. 12.
- MORRISON, J. I., SCHULTE, P., & SCHENCK, R. (2010). *Corporate Water Accounting: An Analysis of*

- Methods and Tools for Measuring Water Use and its Impacts*. Pacific Institute: Oakland, CA.
- MORSE, J.M. (1991). Strategies for sampling. In: Morse, J.M. (ed). *Qualitative nursing research: A contemporary dialogue*. Sage, Newbury Park, California.pp. 127–145.
- MUCINA, L. & RUTHERFORD, M.C. (eds). (2006). *The vegetation of South Africa, Lesotho and Swaziland*. South African National Biodiversity Institute, Pretoria.
- MULLER, M. (2000). *Inter-basin water sharing to achieve water security: A South African perspective*. Presented in the World Water Forum, Haag. Department of Water Affairs and Forestry, Pretoria, South Africa.
- MULTSCH, S., ALRUMAIKHANI, Y.A., ALHARBI, O.A., FREDE, H.G., BREUER, L. (2011). *Internal water footprint assessment of Saudi Arabia using the Water footprint Assessment Framework (WAF)*. 19<sup>th</sup> International Congress on Modelling and Simulation, Perth, Australia, 12–16 December 2011.
- NAKAYAMA, M. (2003). Implications of virtual water concept on management of international water systems – cases of two Asian international river basins. In: Hoekstra, A.Y. (ed.). *Virtual water trade: Proceedings of the International Expert Meeting on Virtual Water Trade*. Value of Water Research Report Series, No.12, UNESCO-IHE, Delft, the Netherlands.
- NARDO, M., SAISANA, M., SALTELLI, A. & TARANTOLA, S. (2005). *Tools for composite indicators building*. European Commission, Ispra.
- NEUMAYER, E. (2003). *Weak versus strong sustainability: exploring the limits of two opposing paradigms*. Edward Elgar, Cheltenham.
- NEWS 24. (2014). Chaos in Kirkwood as residents continue to protest. [Online] Available: <http://www.news24.com/SouthAfrica/News/Chaos-in-Kirkwood-as-residents-continue-to-protest-20140923> [Accessed: 12 November 2014].
- NIEUWOUDT, W., DOCKEL, J., MOSAKA, D. & POTT, A. (2008). *Towards the establishment of water market institutions for effective and efficient water allocation in South Africa*. WRC Report No 1569/1/081–168. Water Research Commission, Gezina, South Africa.
- NIEUWOUDT, W.L., BACKEBERG, G. & DU PLESSIS, H. (2004). The value of water in the South African economy: some implications. *Agrekon*, 43(2): 162-183.
- NUNEZ, M., PFISTER, S., ANTON, A., MUNOZ, P., HELLWEG, S., KOEHLER, A. & RIERADEVALL, J. (2010). Using geographic information systems and spatial data to assess water consumption

of bioenergy. Paper presented at SETAC Europe, 20<sup>th</sup> Annual Meeting, 23–27 May 2010, Seville, Spain.

OBUOBIE, E., GACHANJA, P.M. & DORR, A.C. (2005). *The Role of Green Water in Food Trade*. International Doctoral Studies, Centre of Development Research University of Bonn.

OKI, T. & KANAE, S. (2004). Virtual water trade and world water resources. *Water Science and Technology*, 49(7): 203–209.

OKI, T., SATO, M., KAWAMURA, A., MIYAKE, M., KANAE, S. & MUSIAKE, K. (2003). Virtual water trade to Japan and in the world. *Virtual water trade: Proceedings of the International Expert Meeting on Virtual Water Trade*. Value of Water Research Report Series No. 12. Delft, the Netherlands: UNESCO-IHE.

ORLOWSKY, B., HOEKSTRA, A.Y., GUDMUNDSSON, L. & SENEVIRATNE, S.I. (2014). Today's virtual water consumption and trade under future water scarcity. *Environmental Research Letters*, 9: 074007.

OUTSPAN. (2004). Methods of scheduling. In: Citrus Research International. *Integrated production guidelines for export citrus (Volume 2): Citriculture-Cultural Practices*. Nelspruit, South Africa.

OUTSPAN. (1997). *Outspan citrus production guidelines*. Nelspruit, South Africa.

PAAVOLA, J. & ADGER, N.W. (2002). *New institutional economics and the environment: conceptual foundations and policy implications*. Unpublished Report for CSERGE Working Paper EDM 02–06: University of East Anglia, Norwich, UK.

PALMER, A.R., WEIDEMAN, C., FINCA, A., EVERSON, C.S., HANAN, N. & ELLERY, W. (2014). Modelling annual evapotranspiration in a semi-arid, African savanna: functional convergence theory, MODIS LAI and the Penman-Monteith equation. *African Journal of Range and Forage Science*, 2014: 1-7.

PALMER, T., FINCA, A., WEIDEMAN, C. & SMIT, I. (2012). Has the high elephant population in Addo benefitted the citrus farmers? Modelling evapotranspiration in the Addo Elephant National Park using FAO56 and MODIS LAI. Presented as a poster at the Savanna Network Meeting, Skukuza, 4-9 March 2012.

PEARCE, D.W. & HETT, T. (1999). *Review of technical guidance on environmental appraisal*. Economics for the Environment Consultancy (EFTEC) for Department of the Environment, Transport and the Regions (DETR), UK.

- PEGRAM, G. (2010). *Shared risk and opportunity in water resources: Seeking a sustainable future for Lake Naivasha*. Godalming, UK: WWF and PEGASYS.
- PEGRAM, G., ORR, S. & WILLIAMS, C. (2009). *Investigating shared risk in water: Corporate engagement with the public policy process*. Godalming, UK: WWF-UK.
- PERRET, S.R. (2002). Water policies and smallholding irrigation schemes in South Africa: A history and new institutional challenges. *Water Policy*, 4(3): 283–300.
- PFISTER, S. & HELLWEG, S. (2009). The water “shoesize” vs. footprint of bioenergy. *Proceedings of the National Academy of Sciences of the United States of America*, 106: E93–E94.
- PINTER, L., HARDI, P., MARTINUZZIC, A. & HALL, J. (2012). Bellagio STAMP: Principles for sustainability assessment and measurement. *Ecological Indicators*, 17: 20-28.
- POPE, J., ANNANDALE, D. & MORRISON-SAUNDERS, A. (2004). Conceptualising sustainability assessment. *Environmental Impact Assessment Review*, 24: 595-616.
- POSTEL, S.L., DAILY, G.C. & EHRLICH, P.R. (1996). Human appropriation of renewable fresh water. *Science*, 271(5250): 785-788.
- PRESCOTT-ALLEN, R. (2001). *The wellbeing of nations: a country-by country index of quality of life and the environment*. Island Press, Washington, D.C., USA.
- REED, M.S. (2004). *Participatory Rangeland Monitoring and Management*. Indigenous Vegetation Project Publication 003/005, United Nations Development Programme. Government Press, Gaborone, Botswana.
- REED, M.S., FRASER, E.D.G. & DOUGILL, A.J. (2006). An adaptive learning process for developing and applying sustainability indicators with local communities. *Ecological Economics*, 59: 406-418.
- REIMER, J.J. & LI, M. (2010). Trade costs and the gains from trade in crop agriculture. *American Journal of Agricultural Economics*, 92: 1024-1039.
- RENAULT, D. (2003). Value of virtual water in food: Principles and virtues. In: Hoekstra, A.Y. (ed.). *Virtual water trade – proceedings of the international expert meeting on virtual water trade*. Value of Water Research Report Series No. 12, UNESCO-IHE, Delft, the Netherlands.
- RIDOUTT, B.G & PFISTER, S. (2010). A revised approach to water footprinting to make transparent the impacts of consumption and production on global freshwater scarcity. *Global Environmental Change*, 1: 113–120.

- RIJSBERMAN, F. (2006). More crop per drop: Realigning a research paradigm. In: Giordano, M., Rijsberman, F. & Saleth, M. (eds.). *More crop per drop: Revisiting a research paradigm: Results and synthesis of IWMI research, 1996- 2005*. London, UK: IWA Publishing, Colombo, Sri Lanka: IWMI. pp. 8-21.
- RILEY, J. (2001). Multidisciplinary indicators of impact and change: key issues for identification and summary. *Agriculture, Ecosystems and Environment*, 87:245-259.
- ROCKSTROM, J. (1999). On farm green water estimates as a tool for increased food production in water scarce regions. *Physical Chemical Earth (B)* 24(4): 375-383.
- ROCKSTRÖM, J. (2001). Green water security for the food makers of tomorrow: Windows of opportunity in drought-prone savannahs. *Water Science and Technology*, 43(4): 71–78.
- ROCKSTROM, J., FALKENMARK, M., KARLBERG, L., HOFF, H., ROST, S., & GERTEN, D. (2009). Future water availability for global food production: The potential of green water for increasing resilience to global change. *Water Resources Research*, 45, W00A12A: 1-16.
- ROSEGRANT, M.W., CAI, X. & CLINE, S.A. (2002). *World water and food to 2025: dealing with scarcity*. International Food Policy Research Institute, Washington.
- ROST, S., GERTEN, D., BONDEAU, A., LUCHT, W., ROHWER, J. & SCHAPHOFF, S. (2008). Agricultural green and blue water consumption and its influence on the global water system. *Water Resources Research* 44: W09405:1-17.
- ROTMANS, J. & DE VRIES H. J. M. (eds.) (1997). *Perspectives on Global Change: The TARGETS Approach*. Cambridge, UK, Cambridge University Press.
- RUINI, L., MARINO, M., PIGNATELLI, S., LAIO, F. & RIDOLFI, L. (2013). Water footprint of a large-sized food company: The case of Barilla pasta production. *Water Resources and Industry*, 1-2: 7-24.
- RUSHFORTH, R.R., ADAMS, E.A. & RUDELL, B.L. (2013). Generalizing ecological, water and carbon footprint methods and their worldview assumptions using embedded resource accounting. *Water Resources and Industry*, 1(2): 77-90.
- SABMILLER (2011). *Water Futures. Addressing shared water challenges through collective action*. [Online] Available: [http://content.involveondemand.com/WaterFutures/Assets/Water\\_Futures\\_Report\\_2011.pdf](http://content.involveondemand.com/WaterFutures/Assets/Water_Futures_Report_2011.pdf). [Accessed 23 August 2014].

- SABMILLER. & WORLD WILDLIFE FUND (WWF)- UNITED KINGDOM (UK). (2009). Water footprinting: Identifying & addressing water risks in the value chain, SABMiller, Woking, UK / WWF-UK, Goldalming, UK.
- SABMILLER, GTZ.&WORLD WILDLIFE FUND (WWF). (2010). *Water futures: Working together for a secure water future*. SABMiller, Woking, UK / WWF-UK, Goldalming, UK.
- SADLER, B. (1999). A framework for environmental sustainability assessment and assurance. In: Petts, J. (ed). *Handbook of environmental impact assessment (vol. 1)*. Oxford: Blackwell. pp 12-32.
- SALETH, M.R., DINAR, A. &WORLD BANK. (2004). *The institutional economics of water: A cross-country analysis of institutions and performance*. Washington: Edward Elgar Publishing.
- SALMORAL, G., ALDAYA, M. M., CHICO, D., GARRIDO, A., & LLAMAS, R. (2011). The water footprint of olives and olive oil in Spain. *Spanish Journal of Agricultural Research*, 9(4): 1089-1104.
- SALMORAL, G., ALDAYA, M.M., CHICO, D., GARRIDO, A. & LLAMAS, M.R. (2010).*The water footprint of olive oil in Spain*. Papeles de Agua Virtual no. 7, Fundación Marcelino Botín, Santander, ISBN 978-84-96655-26-3.
- SAVENIJE, H.H.G. (2000). *The role of green water in food production in sub-Saharan Africa*. Article prepared for the FAO. IHE, Delft, The Netherlands.
- SCHALLER, N. (1993). The concept of agricultural sustainability. *Agriculture, Ecosystems and Environment*, 46: 89-97.
- SCHNOOR, J.L. (2009). LCA and Environmental Intelligence? *Environment, Science and Technology*, 43: 2997.
- SCHULZE, R.E. & PERKS, L.A. (2000). *Assessment of the impact of climate change on hydrology and water resources in South Africa*. Unpublished Report for South African Country Studies for Climate Change Programme, ARCU cons Report, volume 33.Pietermaritzburg: School of BEEH, University of Natal.
- SCHYNS, J.F. & HOEKSTRA, A.Y. (2014). The added value of Water Footprint Assessment for national water policy: A case study for Morocco. *PLoS ONE*, 9(6): e99705.
- SCOONES, I. (1998). *Sustainable rural livelihoods: a framework for analysis*. IDS Working Paper 72.Institute of Development Studies, Brighton, UK.

- SCRASE, I. & SHEATE, W. (2003). Integration and integrated approaches to assessment: what do they mean for the environment? *Journal Environ. Policy Plan*, 4(1): 275-94.
- SECRETARY OF WATER AFFAIRS. (1990). *Eighth supplementary report on the proposed Orange River Development Project*. Government Printer, South Africa.
- SENBEL, M., MCDANIELS, T. & DOWLATABADI, H. (2003). The Ecological Footprint: a nonmonetary metric of human consumption applied to North America. *Global Environmental Change*, 13: 83-100.
- SHEATE, W., DAGG, S., RICHARDSON, J., ASCHEMANN, R., PALERM, J. & STEEN, U. (2003). Integrating the environment into strategic decision-making: conceptualizing policy SEA. *European Environment*, 13(1): 1-18.
- SHEATE, W., DAGG, S., RICHARDSON, J., ASCHEMANN, R., PALERM, J. & STEEN, U. (2001). Vol. 1 Main Report European Commission Contract No. B4 3040/99/136634/MAR/B4 Imperial College Consultants ICON. [Online] Available: <http://europa.eu.int/comm/environment/eia/sea-support.htm#int> [Accessed: 10 October 2013].
- SIKIRICA N. (2011). Water Footprint Assessment Bananas and Pineapples. Soil & More International. [Online] Available: <http://dolecrs.com/uploads/2012/06/Soil%20&%20More%20Water%20Footprint%20Assessment.pdf>. [Accessed: 12 February 2013].
- SINGH, R., VAN DAM, J.C. & FEDDES, R.A. (2006). Water productivity analysis of irrigated crops in Sirda district, India. *Agricultural Water Management*, 82: 253-278.
- SMAKHTIN, V. & ANPUTHAS, M. (2006). *An assessment of environmental flow requirements of Indian river basins*. Colombo, Sri Lanka: IWMI Research Report 107.
- SMITH, B. (2006). *The farming handbook*. University of Kwa-Zulu Natal Press. South Africa.
- SMITH, M. (1992). CROPWAT. A computer programme for irrigation planning and management. In: *FAO Irrigation and Drainage Paper No. 46*. Rome, FAO.
- SOUTH AFRICAN BROADCASTING COMMISSION (SABC). (2012). Eastern Cape braces for heavy rain. [Online] Available: <http://www.sabc.co.za/news/a/caff92804d24eb64a1c6bf0934d0676c/E-Capebraces-for-heavy-rain-20122010> [accessed 27 July 2013].
- SPANGENBERG, J.H. (2005). Economic sustainability of the economy: concepts and indicators. *International Journal of Sustainable Development*, 8(1/2): 47-64.

- STASSEN, R.G., HEMME, G., JANSE VAN RENSBURG, K., DE SMIDT, J., DUNN, P., BERG, R. & GORGENS, A. (1997). *Hydrology and systems analysis- Eastern Cape Rivers*. Report 27 in Orange River Development Project Replanning Study. Department of Water Affairs and Forestry, Pretoria.
- STATISTICS SOUTH AFRICA. (2011). Census 2011: Statistical release. [Online] Available: <http://www.statssa.gov.za/publications/p03014/p030142011.pdf> [Accessed: 5 May 2013].
- STECKLER, A., MCLEROY, K.R., GOODMAN, R.M., BIRD, S.T. & MCCORMICK, L. (1992). Toward integrating qualitative and quantitative methods: An introduction. *Health Education Quarterly*, 19(1): 1-8.
- STEDUTO, P., HSIAO, T.C., RAES, D. & FERERES, E. (2009). Aquacrop - The FAO crop model to stimulate yield response to water: Concepts and underlying principles. *Agronomy Journal*, 101 (3): 426-437.
- STEEN-OLSEN, K., WEINZETTEL, J., CRANSTON, G., ERCIN, A.E. & HERTWICH, E.G. (2012). Carbon, land, and water footprint accounts for the European Union: Consumption, production, and displacements through international trade. *Environmental Science and Technology*, 46(20): 10883-10891.
- STEWART, D.W. & KAMINS, M.A. (1993). *Secondary research information, sources and methods* (2e). Newbury Park, CA: Sage Publications.
- STRAHLER, A.H. & STRAHLER, A.N. (2002). *Physical geography: Science and systems of the human environment*. John Wiley and Sons, Inc. New York, USA.
- SUNDAYS RIVER VALLEY CITRUS COMPANY (SRCC). (2014). Agronomist. Sunland, Eastern Cape. Personal Communication. 21 February- 1 October.
- SUNDAYS RIVER VALLEY MUNICIPALITY (SRVM). (2010). *Water Services Development Plan*. Kirkwood, Eastern Cape.
- SUNDAYS RIVER VALLEY MUNICIPALITY (SRVM). (2011). Draft Integrated Development Plan (IDP) 2011- 2016 (5 year plan). Available: <http://led.co.za/document/sundays-river-valley-lm-idp-2011-2016> [Accessed: 24 April 2013].
- SUNDAYS RIVER VALLEY MUNICIPALITY (SRVM). (2011). Draft Integrated Development Plan (IDP) 2011- 2016 (5 year plan). [Online] Available: <http://led.co.za/document/sundays-river-valley-lm-idp-2011-2016> [Accessed: 24 April 2013].

- SUNDAYS RIVER VALLEY MUNICIPALITY (SRVM).(2012). Integrated Development Plan (IDP) 2011-2016. [Online] Available: <http://mfma.treasury.gov.za/Documents/01.%20Integrated%20Development%20Plans/2011-12/02>. [Accessed: 17 February 2013].
- SYVERTSEN, J.P., GOŃI, C. & OTERO, A. (2003). Fruit load and canopy shading affect leaf characteristics and net gas exchange of 'Spring' navel orange trees. *Tree Physiology*, 23:899-906.
- TAYLOR, N.J. & GUSH, M.B. (eds). (2014). *The water use of selected fruit tree orchards (volume 1): Review of available knowledge*. WRC Report No. 1770/1/14, RSA. Water Research Commission, Pretoria, South Africa.
- TEN BRINK, B.J.E., HOSPER, S.H. & COLIJN, F. (1991). A quantitative method for description and assessment of ecosystems: the AMEOBA approach. *Marine Pollution Bulletin*, 23:265–270.
- TEWARI, D.D. (2009). A detailed analysis of evolution of water rights in South Africa: An account of three and a half centuries from 1652 AD to present. *Water SA*, 35(5): 693–710.
- THE COCA-COLA COMPANY (TCCC). & THE NATURE CONSERVENCY (TNC). (2010). *Product water footprint assessments: Practical application in corporate water stewardship*. The Coca-Cola Company, Atlanta, USA / The Nature Conservancy, Arlington, USA.
- THE WETLAND GROUP. (2004). Catchment N40: The Sundays River. [Online] Available: <http://www.ru.ac.za/static/institutes/iwr//wetland/data/Sundays/SUNDAYSreport.pdf>[Accessed: 22 April 2013].
- TURPIE, J.K., MARAIS, C. & BLIGNAUT, J.N. (2008). The working for water programme: evolution of a payments for ecosystem services mechanism that addresses both poverty and ecosystem service delivery in South Africa. *Ecological Economics*, 65: 788-798.
- TURTON, A.R. (2000). *Precipitation, people, pipelines and power: towards a "virtual water" based political ecology discourse*. MEWREW Occasional paper, Water issues study group, School of Oriental and African Studies (SOAS). University of London.
- TURTON, A.R., MOODLEY, S., GOLDBLATT, M., VAN WYK, J.A. & MEISSNER, R. (2000). *An analysis of the role of virtual water in Southern Africa in meeting water scarcity: An applied research and capacity building project*. Johannesburg: Group for Environmental Monitoring (GEM).
- USDA. (2013). Soils, Natural Resources Conservation Service, United States Department of Agriculture, Washington, D.C, USA. [Online] Available: [www.nrcs.usda.gov/wps/portal/nrcs/site/soils](http://www.nrcs.usda.gov/wps/portal/nrcs/site/soils). [5 September 2014].

- VAN DER ENT, R. J., SAVENIJE, H.H.G., BETTINA, S. & STEELE-DUNNE, S. C. (2010). *Origin and fate of atmospheric moisture over continents*. *Water Resources Research* 46.doi:10.1029/2010WR009127.
- VAN DER ENT, R.J. & SAVENIJE, H.H.G. (2011). Length and time scales of atmospheric moisture recycling. *Atmospheric Chemistry and Physics*, 11:1853–1863.
- VAN HEERDEN, P.S. (2014). Personal communication. 23 September.
- VAN HEERDEN, P.S., CROSBY, C.T., GROVÈ, B., BENADÈ, N., THERON, E., SCHULTZE.&TEWOLDE, M.H. (2009). *Integrating and upgrading of SAPWAT and PLANWAT to create a powerful and user-friendly irrigation planning tool*. WRC Report No TT391/08. Water Research Commission, Gezina, South Africa.
- VAN LILL, J.B. & GRIEVE, K.W. (1990). *Descriptive statistics for students in the human sciences*. Human Resources Information, Pretoria.
- VAN OEL, P.R. & HOEKSTRA, A.Y. (2012). Towards quantification of the water footprint of paper: A first estimate of its consumptive component. *Water Resources Management*, 26(3): 733-749.
- VAN OEL, P.R., MEKONNEN M.M. & HOEKSTRA, A.Y. (2008). *The external water footprint of the Netherlands: Quantification and impact assessment*. Value of Water Research Report Series No.33, UNESCO-IHE, Delft, the Netherlands.
- VAN OEL, P.R., MEKONNEN M.M. & HOEKSTRA, A.Y. (2009). The external water footprint of The Netherlands: Geographically-Explicit Quantification and Impact Assessment. *Ecological Economics*, 69(1): 82-92.
- VANHAM, D. (2013.) An assessment of the virtual water balance for agricultural products in EU river basin. *Water Resources and Industry*, 1-2: 49-59.
- VANHAM, D. & BIDOGLIO, G. (2013). A review on the indicator water footprint for the EU28. *Ecological Indicators*, 26: 61–75.
- VANHAM, D. & BIDOGLIO, G. (2014). The water footprint of agricultural products in European river basins. *Environmental Research Letters*, 9: 064007.
- VANHAM, D., HOEKSTRA, A.Y. & BIDOGLIO, G. (2013a). Potential water saving through changes in European diets. *Environment International*, 61: 45-56.

- VANHAM, D., MEKONNEN, M.M. & HOEKSTRA, A.Y. (2013b). The water footprint of the EU for different diets. *Ecological Indicators*, 32: 1-8.
- VELÁZQUEZ, E., MADRID, C., & BELTRAN, M. J. (2011). Rethinking the Concepts of Virtual Water and Water footprint in Relation to the Production–Consumption Binomial and the Water–Energy Nexus. *Water Resource. Management*, 25: 743-761.
- VERHEEM, R. (2002). Recommendations for Sustainability Assessment in the Netherlands. In: *Commission for EIA: Environmental Impact Assessment in the Netherlands, views from the Commission for EIA in 2002*. The Netherlands.
- VERMA, S., KAMPMAN, D.A., VAN DER ZAAG, P. & HOEKSTRA, A.Y. (2009). Going against the flow: A critical analysis of inter-state virtual water trade in the context of India’s National River Linking Pro- gram. *Physics and Chemistry of the Earth*, 34:261-269.
- WARNER, J. (2003). Virtual water – virtual benefits. In: Hoekstra, A.Y. (ed.). *Virtual Water Trade- Proceedings of the International Expert Meeting on Virtual Water Trade*. IHE Delft Value of Water Research Report Series No. 12.
- WESTWOOD, M.N. (1988). Temperate-zone pomology. Revised edition, Timber Press: Portland, Oregon, USA.
- WICHELNS, D. (2004). The policy relevance of virtual water can be enhanced by considering comparative advantages. *Agricultural Water Management* 66: 49-63.
- WICHELNS, D. (2010a). Virtual water: A helpful perspective, but not a sufficient policy criterion. *Water Resources Management* 24: 2203-2219.
- WICHELNS, D. (2010b). Virtual water and water footprint offer limited insight regarding important policy questions. *International Journal of Water Resources Development* 26: 639-651.
- WICHELNS, D. (2014). Virtual and water footprints. In: Lautze, J. (eds). *Key Concepts in Water Resource Management: a Review and Critical Evaluation*. Routledge, Earthscan: IWMI. pp 108-123.
- WIEBE, K., SOULE, M. & SCHIMMELPFENNIG, D. (2001). Agricultural productivity for sustainable food security in sub-Saharan Africa. In: Zepeda, L. (ed). *Agricultural Investment and productivity in developing countries*. Rome, FAO. pp 55-75.
- WILLIAMS, C.J., VECK, G.A. & BILL, M.R. (2008). *The value of water as an economic resource in the Greater Letaba River Catchment*. WRC Report No. 989/1/2008. Water Research Commission, Pretoria.

- WITMER, M.C.H. & CLEIJ, P. (2012). *Water footprint: Useful for sustainability policies?* PBL Netherlands Environmental Assessment Agency, The Hague, the Netherlands.
- WORLD BUSINESS COUNCIL FOR SUSTAINABLE DEVELOPMENT (WBCSD). (2010). The global water tool. [Online] Available: [www.wbcsd.org/web/watertool.htm](http://www.wbcsd.org/web/watertool.htm). [Accessed 30 June 2013].
- WORLD COMMISSION ON ENVIRONMENT AND DEVELOPMENT (WCED). (1987). *Our common future*. Oxford: Oxford University Press.
- WORLD HEALTH ORGANISATION (WHO). (2003). Total Dissolved Solids in drinking-water. Background document for development of WHO guidelines for drinking-water quality. World Health Organisation. [Online] Available: [http://www.who.int/water\\_sanitation\\_health/dwq/chemicals/tds.pdf](http://www.who.int/water_sanitation_health/dwq/chemicals/tds.pdf) [Accessed 24 November 2014].
- WORLD WATER COUNCIL. (2004). Virtual Water Trade – Conscious Choices. E-Conference Synthesis, March 2004.
- WORLD WILDLIFE FUND (WWF). (2014). Water footprint of Italy. WWF Rome, Italy. [Online] Available: [http://www.waterfootprint.org/Reports/wf\\_english\\_version\\_final.pdf](http://www.waterfootprint.org/Reports/wf_english_version_final.pdf) [Accessed 4 August 2014].
- WRIGHT, G.C. (2000). Irrigating citrus trees. Cooperative Extension. University of Arizona. College of Agriculture. AZ1151. [Online] Available: <http://extension.arizona.edu/sites/extension.arizona.edu/files/pubs/az1151.pdf> [Accessed 15 May 2014].
- YANG, H. & ZEHNDER, A. (2007). *Virtual water: an unfolding concept in integrated water resources management*. *Water Resources Research* 43, W12301, doi:10.1029/2007WR006048.
- YANG, H., REICHERT, P., ABBASPOUR, K.C. & ZEHNDER, A.J.B. (2003). A water resources threshold and its implications for food security. *Environmental Science and Technology*, 37(14): 3048-3054.
- YANG, H., WANG, L., ABBASPOUR, K. C. & ZEHNDER, A. J. B. (2006). Virtual water trade: an assessment of water use efficiency in the international food trade. *Hydrology and Earth System Science*, 10(3): 443–454.
- YANG X., POST W.M., THORNTON P.E. & JAIN A. (2013). The distribution of soil phosphorus for global biogeochemical modeling. *Biogeosciences*, 10(4): 2525–2537.
- YIN, R.K. (1994). *Case study research design and methods* (2e). Thousand Oaks, CA: Sage Publications.

- YOUNG, R.A. (2006). *Measuring economic benefits of water investment and policies*. The World Bank, Washington.
- ZARATE, E. (ed) (2010). *WFn grey water footprint working group final report: A joint study developed by WFn partners*. Water Footprint Network, Enschede, the Netherlands.
- ZARATE, E., ZENG, Z. & HOEKSTRA, A.Y. (2011). *Grey water footprint as an indicator of levels of water pollution in the production of organic vs. conventional cotton in India*. Water Footprint Network in collaboration with C&A and Cotton Connect, Enschede, the Netherlands.
- ZENG, Z., LIU, J., KOENEMAN, P.H., ZARATE, E. AND HOEKSTRA, A.Y. (2012) Assessing water footprint at river basin level: a case study for the Heihe River Basin in northwest China, *Hydrology and Earth System Sciences*, 16(8): 2771-2781.
- ZEPEDA, L. (2001). *Agricultural Investment and productivity in developing countries*. FAO, Rome.
- ZHANG, G.P., HOEKSTRA, A.Y. & MATHEWS, R.E. (2013). Water Footprint Assessment (WFA) for better water governance and sustainable development, *Water Resources and Industry*, 1(2): 1-6.
- ZHANG, G.P., HOEKSTRA, A.Y. & TICKNER, D. (EDS.) (2012). *Proceedings of the session solving the water crisis: Common action toward a sustainable water footprint*. Planet under Pressure Conference, London, 26 March 2012, Value of Water Research Report Series No. 60, UNESCO-IHE, Delft the Netherlands.
- ZHANG, G.P., MATHEWS, R.E., FRAPPORTI, G. & MEKONNEN, M.M. (2014). Water Footprint Assessment for the Hertfordshire and North London Area, Report RESE000335, Environment Agency, London, UK.
- ZHAO, X., CHEN, B. & YANG, Z.F. (2009). National water footprint in an input-output framework: A case study of China 2002. *Ecological Modelling*, 220(2): 245-253.
- ZHUO, L., MEKONNEN, M.M. AND HOEKSTRA, A.Y. (2014). Sensitivity and uncertainty in crop water footprint accounting: A case study for the Yellow River basin. *Hydrology and Earth System Sciences*, 18(6): 2219-2234.
- ZIMMERMAN D. & RENAULT D. (2003). Virtual water in food production and global trade: Review of methodological issues and preliminary results. In: Hoekstra A.Y. (ed). *Virtual water trade: proceedings of the International Expert Meeting on Virtual Water Trade*. Value of Water Research Report Series 12, UNESCO-IHE, Delft, the Netherlands.

ZOEBL, D. (2006). Is water productivity a useful concept in agricultural water management?  
*Agricultural Water Management*, 84: 265-273.

# APPENDIX



Citrus orchard, Dunbrody

# 1. EXAMPLES OF DATA INPUTS FOR SAPWAT 3.0

## 1.1 CLIMATE

SAPWAT3

Monthly averages: Sundays, long term average

Item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg_Tot
Temperature_avg (°C)	23.2	24.2	22.4	19.4	16.6	13.8	13.4	14.6	16.3	18.4	20.4	22.1	18.7
Temperature_max (°C)	30.2	31.4	30.1	27.3	25.3	22.9	23.0	24.2	25.4	26.3	28.0	29.0	26.9
Temperature_min (°C)	16.2	17.0	14.6	11.6	8.0	4.8	3.8	5.0	7.2	10.5	12.8	15.1	10.5
Humidity_avg (%)	62.0	63.0	63.0	63.0	63.0	62.0	63.0	59.0	58.0	64.0	61.0	66.0	62.0
Humidity_min (%)	42.0	43.0	41.0	40.0	39.0	37.0	36.0	30.0	29.0	41.0	38.0	43.0	38.0
Windrun (km/day)	146.0	136.0	116.0	99.0	89.0	99.0	85.0	106.0	129.0	137.0	146.0	145.0	119.0
Sunshine (hrs/day)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Radiation (Mj/m <sup>2</sup> /day)	21.1	19.5	16.5	13.2	10.3	8.8	9.8	12.9	16.8	17.9	21.6	22.1	15.9
ETo (mm/day)	4.8	4.5	3.7	2.7	2.0	1.9	1.9	2.7	3.6	3.9	4.8	4.9	3.4
Rain (mm)	33.0	39.0	47.0	36.0	23.0	22.0	25.0	31.0	25.0	39.0	43.0	43.0	406.0
Rain events	8.0	9.0	9.0	10.0	8.0	8.0	7.0	6.0	5.0	10.0	7.0	9.0	96.0

Find weather station | Weather station record | Monthly averages | Data

Figure 1.1a Mean monthly long-term average climatic data inputted into SAPWAT 3.0 for the lower Sundays River Valley

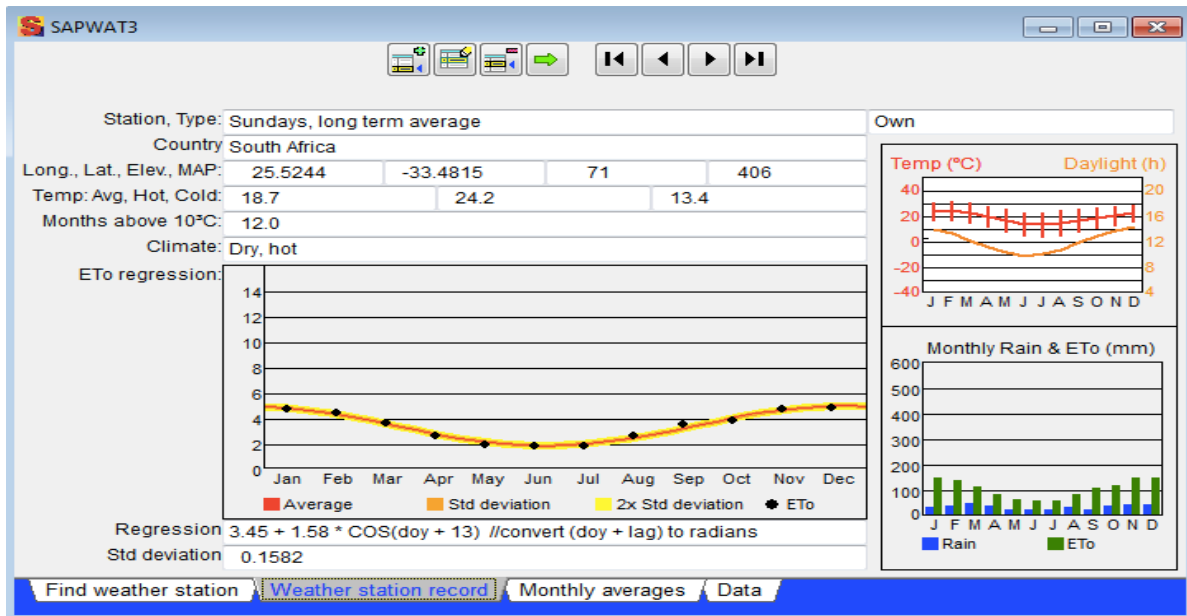


Figure 1.1b Summary produced of long-term weather station data inputted into SAPWAT 3.0 for the lower Sundays River Valley

## 1.2 CROP CHARACTERISTICS

Figure 1.2a The crops table where data pertaining to a specific crop is inputted into SAPWAT 3.0, for example mature lemons

The screenshot shows the 'Crop data' window in SAPWAT3. The 'Crop' list on the left includes 'LEMON MATURE' which is selected. The 'Option' table shows 'MATURE' with a yield of 55.0. The 'Plant' table shows 'August 1'. The 'Detail' table shows two climate options: 'Dry, hot' and 'Mild, humid, hot summers', both with 'Selected' checked and various Kcb values.

Option	Identifier	Yield
MATURE		55.0

Month	Day
August	1

Climate	Selected	Initial	Develop	Mid	Late	Total	KcbIni	KcbMaxs	KcbMaxe	KcbEnd	Updated
Dry, hot	<input checked="" type="checkbox"/>	30	30	260	45	365	0.70	0.80	0.80	0.70	/ /
Mild, humid, hot summers	<input checked="" type="checkbox"/>	30	30	260	45	365	0.70	0.80	0.80	0.70	/ /

The screenshot shows the 'Crops' window in SAPWAT3 for 'LEMON MATURE'. It displays various parameters such as crop height, EC threshold, leaf resistance, and crop growth stages (Ini, Dev, Mid, Late, Season) with their respective Kcb values and lengths.

Crop / Crop group: LEMON MATURE      Fruit Trees

Also known as / Botanical name:

Crop height: 4.00

EC (mS/m) Threshold / Reduction / Tolerance: 170    16.00    S

Leaf resistance: 100

Description:

Crop growth stage:	Ini	Dev	Mid	Late	Season
Rooting depth (m):	1.20		1.20		
Allowed depletion (Fract):	0.50		0.50	0.40	
Ky:					1.20

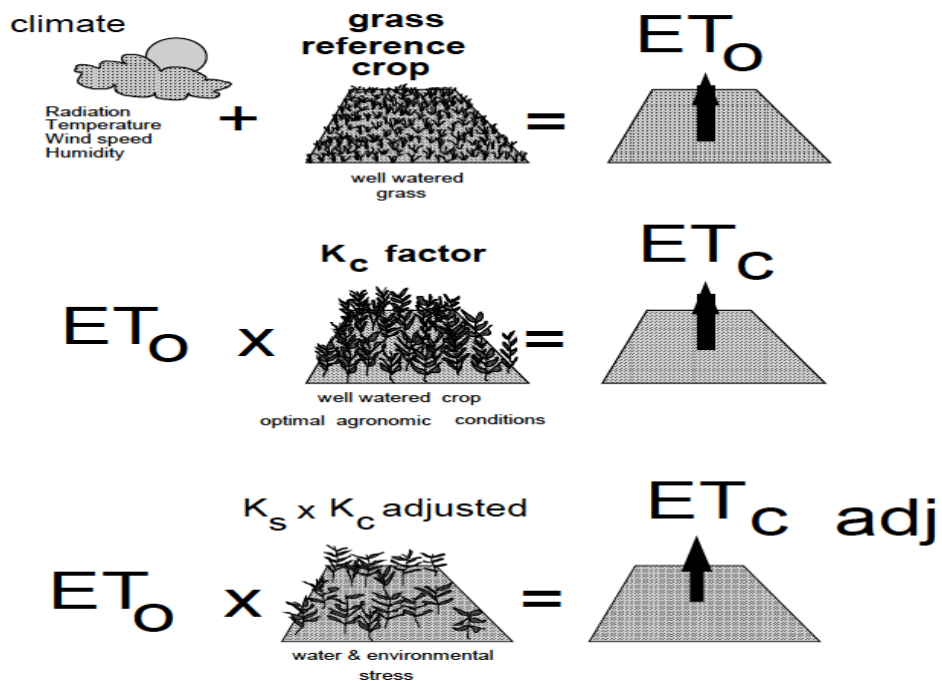
Short reference:

Figure 1.2b Crop data table where  $K_{cb}$  values and length of crop stages are specified for a specific crop, for example mature lemons

**Table 1.2  $K_{cb}$  values, potential cover (%) and crop height inputted into SAPWAT 3.0 for each cultivar**

		$K_{cb\ int}$	$K_{cb\ mid}$	$K_{cb\ end}$	Potential cover (%)	Height (m)
NAVELS	Mature	0.6	0.7	0.6	80	3.5
	Young	0.3	0.35	0.7	50	1.5
VALENCIAS	Mature	0.6	0.7	0.6	80	3.5
	Young	0.3	0.35	0.3	50	1.5
SOFT CITRUS	Mature	0.6	0.7	0.6	75	4
	Young	0.3	0.35	0.3	40	4
LEMONS	Mature	0.6	0.7	0.6	70	4
	Young	0.3	0.35	0.3	35	2

Source: SAPWAT 3.0; du Plessis, 1989



**Figure 1.2c Reference (ET<sub>o</sub>), crop evapotranspiration under standard (ET<sub>c</sub>) and non-standard conditions (ET<sub>c adj</sub>)**

Source: Allen et al. (1998)

### 1.3 SOIL AND IRRIGATION

**Field**

**Field data**

Field: Field a

Field size (ha/m<sup>2</sup>): 1.0000 | 0

Irrigated (ha/m<sup>2</sup>): 1.0000 | 0

**Irrigation system**

System: Drip

System efficiency (%): 95

DU (%): 100

Wetted area (%): 33

**Soil**

Soil: Sandy loam

Effective depth (m): 1.20

Field capacity (mm/m): 230

Wilting point (mm/m): 110

Total available water (mm/m): 120

Evaporation depth (m): 0.10

Readily evaporable water (mm): 8

Total evaporable water (mm): 17

Infiltration (mm/day): 40

Soil salinity (ECE) (mS/m): 200

Irrigation water salinity (mS/m): 50

Figure 1.3a Field edits where soil and irrigation system is specified e.g.) for drip irrigation and sandy loam

**Crop Irrigation Requirements**

Choose crop: Find: lem

Crop	Option	Identifier	Month	Day
Lavender	MATURE		August	1
Leeks				
LEMON MATURE				

**Planning period:**

Planning: Average

**Crop set-up:**

Crop: LEMON MATURE

Crop option: MATURE

Plant / Start date: 01/01/2014

Potential / Actual cover at full growth: 70 / 70

Crop height: 4.0

Potential / Target yield: 55.0 / 55.0

Hectare planted: 1.0000

Weather station: Sundays, long term average

Climate: Dry, hot

Soil: Sandy loam

Irrigation system: Micro spray

Go to the "Irrigation Management" page to complete the Crop and Irrigation Setup.

Crop set-up | Irrigation management | Irrigation requirement (mm) | ETo, ETC (mm) | Irrigation, Rain, Losses (mm) | Daily

Figure 1.3b Crop set up to estimate irrigation requirements for timing and application of irrigation for mature lemons in the LTA year with sandy loam soil and micro spray irrigation

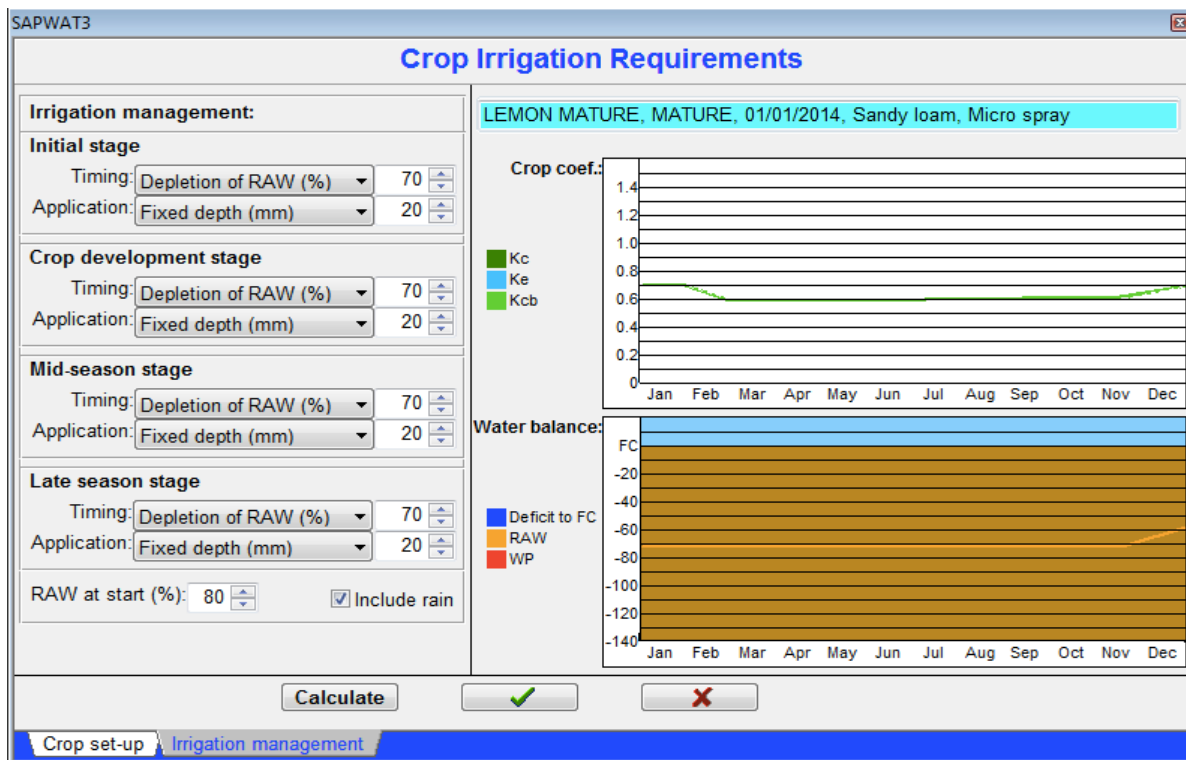


Figure 1.3c Irrigation management to estimate crop irrigation requirements for mature lemons in the LTA year with sandy loam soil and micro spray irrigation

## 2. EXAMPLES OF DATA OUTPUTS FROM SAPWAT 3.0

### 2.1 CROP IRRIGATION REQUIREMENTS

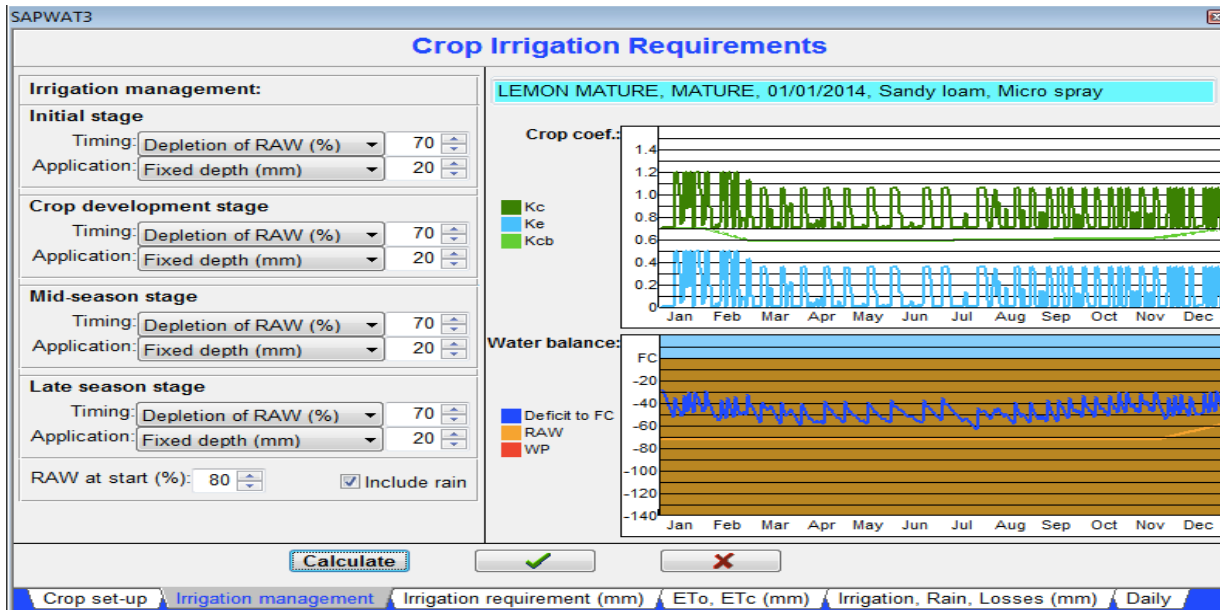


Figure 2.1a Results of crop-coefficient curve and soil water balance over duration of irrigation period for mature lemons in the LTA year with sandy loam soil and micro spray irrigation

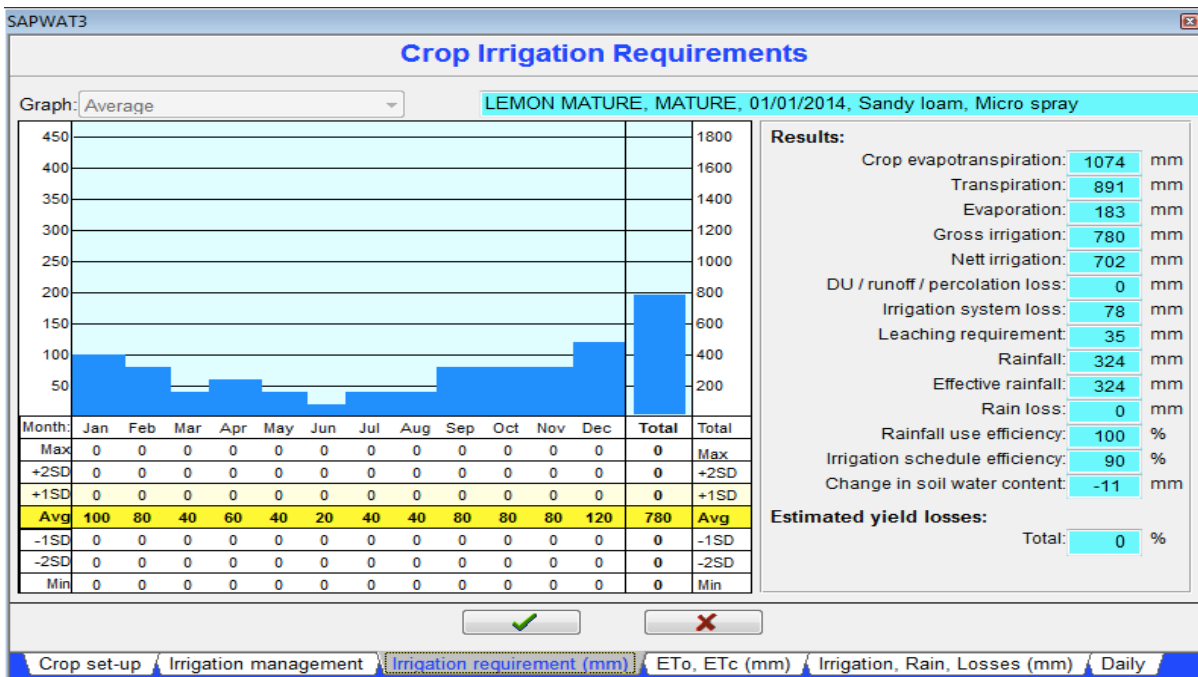


Figure 2.1b Estimated irrigation requirement results (mm) with average and standard deviation graph along with water balance results for mature lemons in the LTA year with sandy loam soil and micro spray irrigation

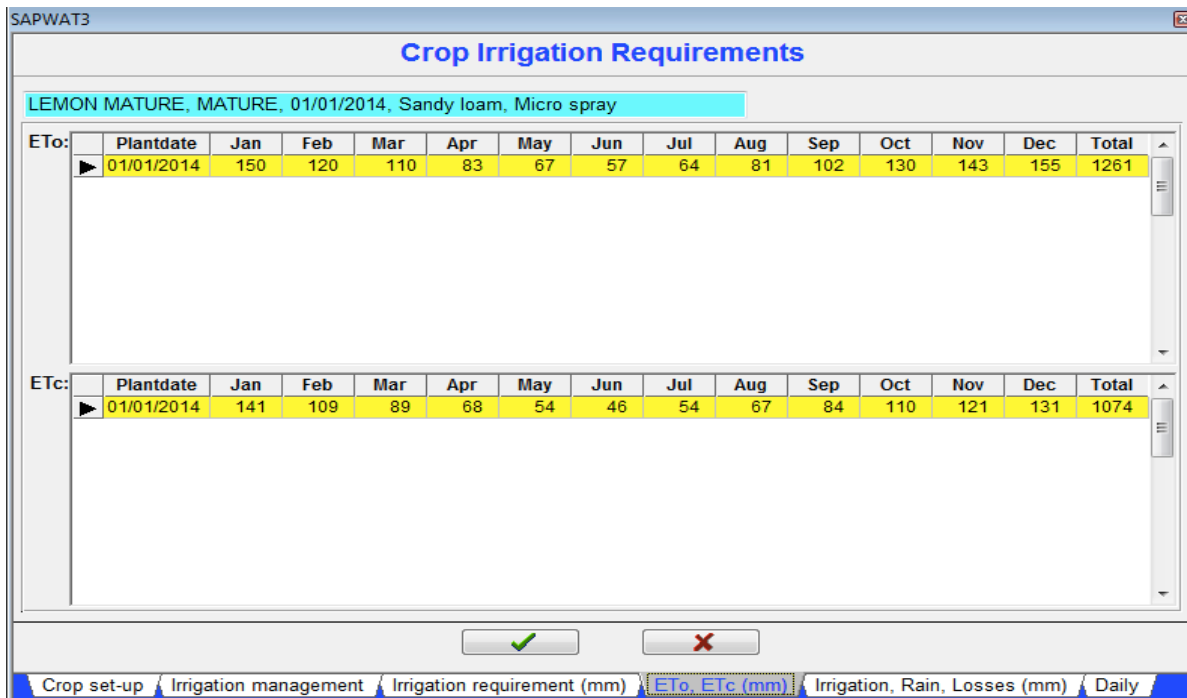


Figure 2.1c LTA Seasonal  $ET_0$  and  $ET_c$  in the Sundays River Valley (mm)

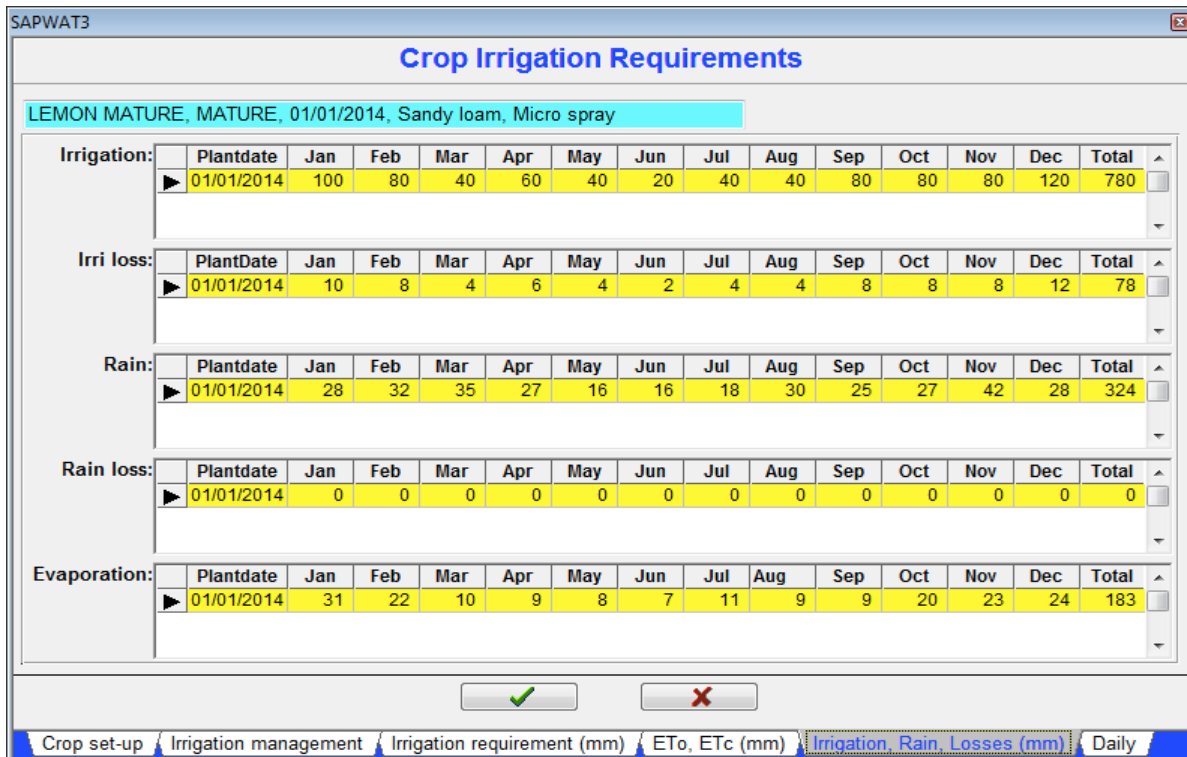


Figure 2.1c LTA seasonal results of irrigation, irrigation loss, rain, rain loss and evaporation results (mm)

### 3. YIELD

**Table 3.1 Yield data for lower Sundays River Valley**

	<b>LTA</b>	<b>2009</b>	<b>2010</b>	<b>2011</b>	<b>2012</b>	<b>2013</b>
<b>Navels</b>	29.8	29.8	27.3	30.5	31.3	30.1
<i>Hectares</i>	1816	1716	1736	1806	1892	1932
<b>Valencia</b>	34.2	32.6	30.8	42	28.3	37.3
<i>Hectares</i>	1375	1302	1320	1426	1417	1411
<b>Novas</b>	30.7	40.3	31.6	31.1	26.1	24.4
<i>Hectares</i>	91.6	62	78	87	104	127
<b>Satsumas</b>	41.2	38.1	50.1	41.0	34.2	42.5
<i>Hectares</i>	50	66	57	53	48	24
<b>Clementines</b>	27.5	28.2	27.5	32.1	21.3	28.3
<i>Hectares</i>	82	85	94	96	84	50
<b>Lemons</b>	52.3	51.4	48	64.9	50.4	46.8
<i>Hectares</i>	1005	926	957	928	1032	1183
<b>Total hectares</b>	<b>4420</b>	<b>4157</b>	<b>4242</b>	<b>4396</b>	<b>4577</b>	<b>4727</b>

Source: Local citrus company

## 4. GREY WATER DATA

### 4.1 APPLICATION RATES

**Table 4.1 Annual soil application rates of active ingredients applied to navel, valencia, soft citrus and lemon cultivars in the lower Sundays River Valley citrus farms**

	<b>N<sup>1</sup></b> <b>(tons/ha)</b>	<b>P</b> <b>(tons/ha)</b>	<b>S</b> <b>(tons/ha)</b>	<b>Monthly Applications</b> <b>(Microjets)</b>	<b>Monthly Applications</b> <b>(Drip)</b>
<b>Navels</b>	UAN- 0.02 AS- 0.2	SP- 0.07	AS- 0.23	UAN- $\frac{2}{3}$ July, $\frac{1}{3}$ Sept AS- $\frac{2}{3}$ July, $\frac{1}{3}$ Sept SP- Sept	6-8 equal weekly applications from July to Sept
<b>Valencias</b>	UAN- 0.01 AS- 0.1	SP- 0.07	AS- 0.12	UAN- $\frac{2}{3}$ July, $\frac{1}{3}$ Sept AS- $\frac{2}{3}$ July, $\frac{1}{3}$ Sept SP- Sept	6-8 equal weekly applications from July to Sept
<b>Soft citrus</b> <i>(clementine and nova)</i>	UAN- 0.02 AS-0.2	SP- 0.07	AS- 0.23	UAN- $\frac{2}{3}$ July, $\frac{1}{3}$ Sept AS- $\frac{2}{3}$ July, $\frac{1}{3}$ Sept SP- Sept	6-8 equal weekly applications from July to Sept
<b>Soft citrus</b> <i>(Satsuma)</i>	UAN- 0.01 AS- 0.1	SP- 0.07	AS- 0.12	UAN- $\frac{2}{3}$ April, $\frac{1}{3}$ Aug AS- $\frac{2}{3}$ April, $\frac{1}{3}$ Aug SP- Sept	6-8 equal weekly applications from April to Aug
<b>Lemons</b>	UAN- 0.02 AS- 0.29	SP- 0.07	AS- 0.33	UAN- $\frac{1}{2}$ July, $\frac{1}{4}$ Sept, $\frac{1}{4}$ Oct AS- $\frac{1}{2}$ July, $\frac{1}{4}$ Sept, $\frac{1}{4}$ Oct SP- Sept	8-10 equal weekly applications from July to Oct

Source: Own elaboration: Secondary data and farmer interviews

## 4.2 CRITERIA FOR ESTIMATING LEACHING-RUN OFF FRACTION

Table 4.2a Nitrogen leaching run-off potential

Category	Factor		Leaching runoff potential	Very low	Low	High	Very High
			Score (s)	0	0.33	0.67	1
			Weight (w)				
Environmental factors	Atmospheric	N-deposition (g N m <sup>-2</sup> yr <sup>-1</sup> ) <sup>a</sup>	10	<0.5	>0.5	<1.5	>1.5
	Soil	Texture (relevant for leaching) <sup>b</sup>	15	Clay	Silt	Loam	Sand
		Texture (relevant for runoff) <sup>b</sup>	10	Sand	Loam	Silt	Clay
		Natural drainage (relevant for leaching) <sup>c</sup>	10	Excessively to extremely drained	Well drained	Moderately to imperfectly drained	Poorly to very poorly drained
		Natural drainage (relevant for run-off) <sup>c</sup>	5	Poorly to very poorly drained	Moderately to imperfectly drained	Well drained	Excessively to extremely drained
	Climate	Precipitation (mm) <sup>d</sup>	15	0-600	600-1200	1200-1800	>1800
Agricultural practice	N-fixation (kg/ha) <sup>e</sup>		10	0	>0	<60	>60
	Application rate <sup>e</sup>		10	Very low	Low	High	Very High
	Plant uptake (crop yield) <sup>e</sup>		5	Very high	High	Low	Very low
	Management practice <sup>f</sup>		10	Best	Good	Average	Worst
<b>Σs*w</b>			45.95				

Source: <sup>a</sup>Cleveland *et al.* (2013); <sup>b</sup>Farm interviews; <sup>c</sup>FAO (2014); <sup>d</sup>LSRV WUA, (2014); <sup>e</sup>Coetzee, (2007);

<sup>f</sup>Franke *et al.*(2013)

**Table 4.2b Phosphorus leaching run-off potential**

Source: <sup>a</sup>Farm interviews; <sup>b</sup>USDA (2013); <sup>c</sup>Yang *et al.* (2013); <sup>d</sup>LSRV WUA, 2014); <sup>e</sup>Coetzee, (2007);

Category	Factor		Leaching runoff potential	Very low	Low	High	Very High
			Score (s)	0	0.33	0.67	1
			Weight (w)				
Environmental factors	Soil	Texture (relevant for run-off) <sup>a</sup>	15	Sand	Loam	Silt	Clay
		Erosion <sup>b</sup>	20	Low	Moderate	High	Very High
		P-content (g P m <sup>-2</sup> ) <sup>c</sup>	15	<200	200-400	400-700	>700
	Climate	Rain intensity <sup>d</sup>	10	Light	Moderate	Strong	Heavy
Agricultural practice	Application rate <sup>e</sup>		15	Very low	Low	High	Very High
	Plant uptake (crop yield) <sup>e</sup>		10	Very high	High	Low	Very low
	Management practice <sup>f</sup>		15	Best	Good	Average	Worst
$\Sigma s*w$			35.78				

<sup>f</sup>Frankeet *al.* (2013)

#### 4.3 MAXIMUM ALLOWABLE AND NATURAL BACKGROUND CONCENTRATIONS

Table 4.3a review of maximum and natural background concentrations for chemical states of nitrogen and phosphorus

Parameter	Concentrations	Source	Comment	Cnat (mg/L)	Cmax (mg/L)
<b>Total ammonia (NH<sub>3</sub> + NH<sub>4</sub>)</b>	Sum of NH <sub>3</sub> and NH <sub>4</sub> domestic use should range between 0.2- 10 mg/l	DWAF, (1996c)		0.2	10
<b>Total ammonia (NH<sub>3</sub>)</b>	Maximum concentrations range from 0.171- 15.3 mg/l for water temperatures ranging from 5-20° C and pH levels 7-8.5.	CCME, (2010) in Franke <i>et al.</i> (2013)	Can be converted to total ammonia-N by multiplying by 0.8224		0.71- 15.3
<b>Ammonium N-NH<sub>4</sub></b>	Natural background concentration of 0.015 mg/l  Average concentrations for NH <sub>4</sub> for Darlington Dam monitoring point averaged 0.2 mg/l and averaged 0.1 mg/l for Mackies eye monitoring point	Chapman, (1996) in Franke <i>et al.</i> (2013)  DSW, 2014		0.015  0.1-0.2	
<b>Nitrate and Nitrogen</b>	Domestic water use range is from 0-6 mg/l  For irrigation range is from 0.5- 5 mg/l  5 mg/l NO <sub>2</sub> and 22 mg/l of NO <sub>3</sub> in typical water. Reach up to 100 mg/l before diverse effects on livestock  Average concentrations for NO <sub>2</sub> + NO <sub>3</sub> Darlington Dam monitoring point averaged 0.2 mg/l and also averaged 0.2 mg/l for Mackies eye monitoring point	DWAF, 1996c  DWAF, 1996b  DWAF, 1996b  DWS, 2014	Concentrations between ranges of South African literary sources as well as local data are consistent.	0.5    0.2	5    0.06

	Maximum allowable concentration for NO <sub>3</sub> is 13 mg/l and for NO <sub>2</sub> -N 0.06 mg/l	CCME, (2013) in Franke <i>et al.</i> (2013)			
<b>Inorganic nitrogen (NH<sub>3</sub> + NH<sub>4</sub> + NO<sub>3</sub> + NO<sub>2</sub>)</b>	Irrigation water use range is 0.5 mg/l and 5-10 mg/l for enriched waters. Some can reach 150 mg/l naturally due to high NO <sub>3</sub> -N	DWAF, (1996b)		0.5	10
	Aquatic systems 0.5 for oligotrophic conditions with a maximum of 2.5 mg/l before eutrophic conditions.	DWAF, (1996a)		0.5	2.5
<b>Phosphate and phosphorus</b>	Ideal ≤ 0.015 mg/l, acceptable 0.015- 0.044 mg/l, tolerable 0.044- 0.073 mg/l and unacceptable > 0.073 mg/l ranges for PO <sub>4</sub> -P	DWA, (2012)	Based on water quality fitness for Fish to Tsitsikamma WMA (see Appendix 4.4a)  Criteria for oligotrophic and eutrophic conditions vary substantially between sources, therefore units are questionable	0.015	0.044
	Inorganic phosphorus concentrations of 10-15g/L are commonly found. Oligotrophic conditions < 5 g/l, mesotrophic conditions 5-25 g/l and eutrophic conditions 25-250 g/l	DWAF, (1996a)		5000	25000
	Total phosphorus maximum allowable concentrations: oligotrophic 0.01 mg/l and eutrophic 0.1 mg/l	CCME, (2013) in Franke <i>et al.</i> (2013)		0.01	0.1
	Average concentrations for PO <sub>4</sub> for Darlington Dam monitoring point averaged 0.1 mg/l with a range of 0- 0.3 mg/l and an average of 0.07 mg/l for Mackies eye monitoring point with a range of 0.004- 0.31 mg/l	DWS, (2014)		0.3	

## 4.4 WATER QUALITY DATA

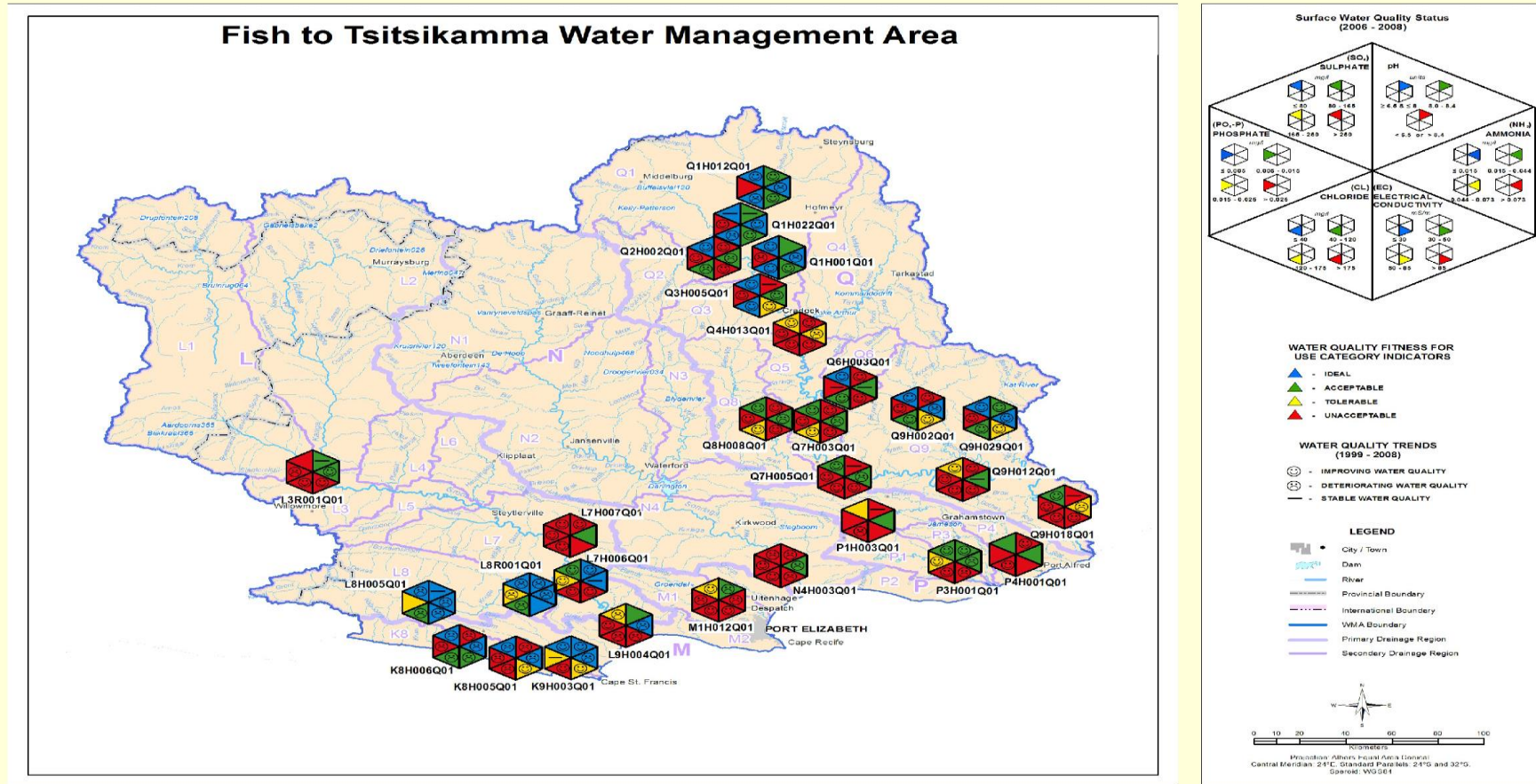
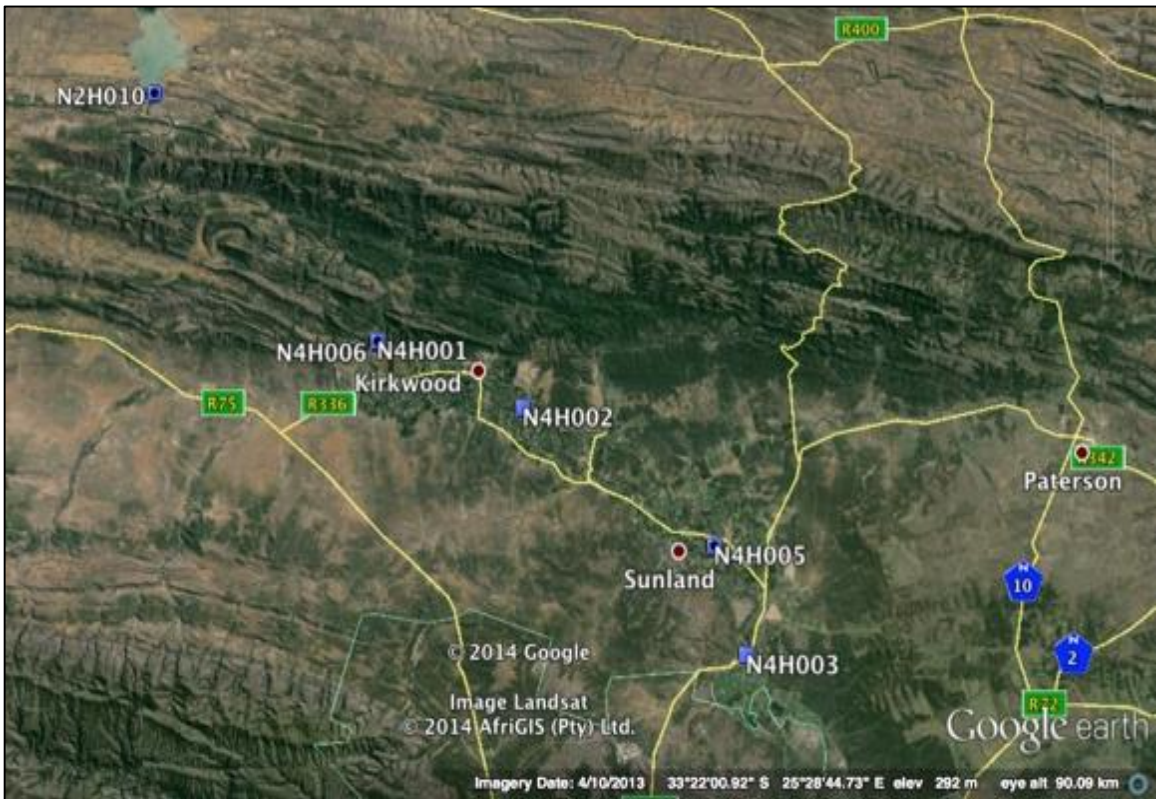
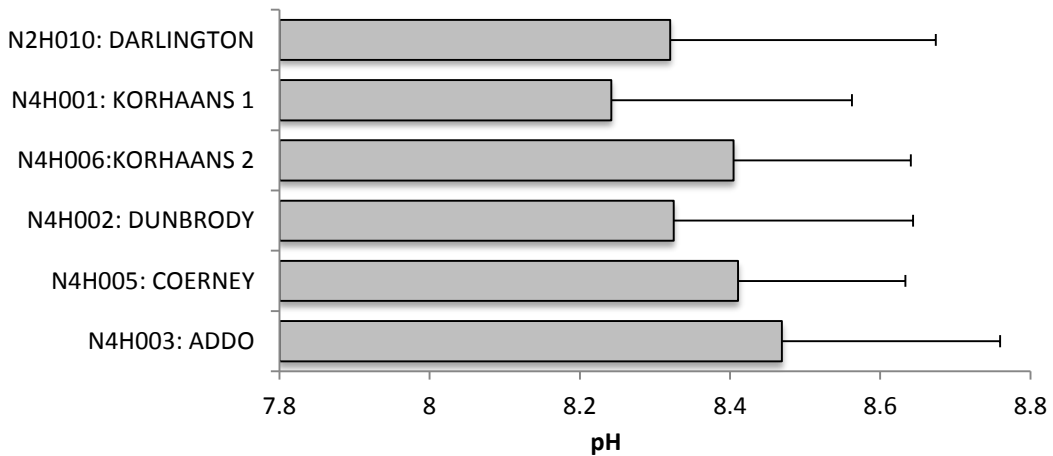


Figure 4.4a Surface Water quality status and trends of the Fish to Tsitsikamma Water Management Area (2006-2008)

Source: DWS, (2011)

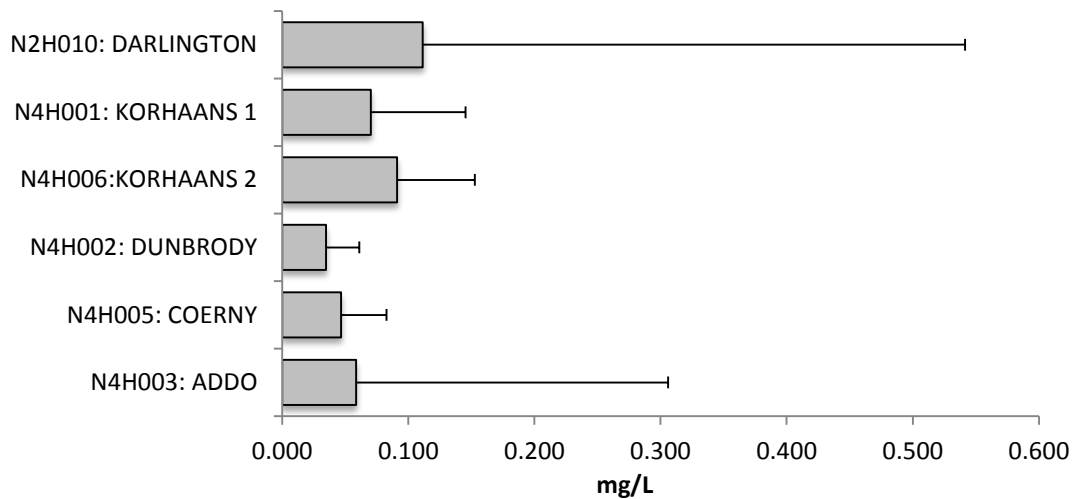


**Figure 4.3b** Map illustrating monitoring points where water quality parameters were measured from 1988-1998 by DWS



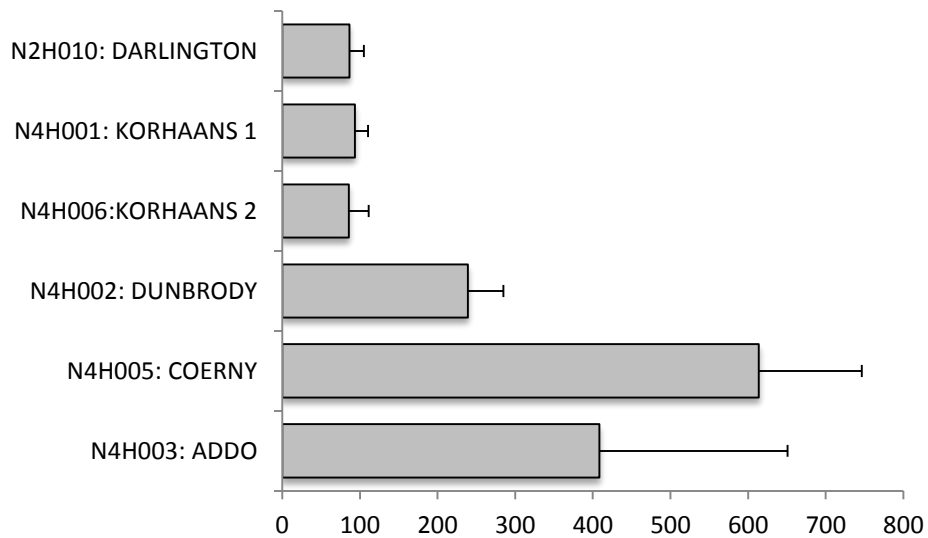
**Figure 4.3c** Mean ( $\pm$  s.d) pH for monitoring points in the LSRV taken by DWS from 1999-1998.

Source: Adapted from DSW, (2014)



**Figure 4.3d Mean ( $\pm$  s.d) of PO<sub>4</sub> for monitoring points in the LSRV taken by DWS from 1999-1998.**

*Source:*Adapted from DSW, (2014)



**Figure 4.3f Mean ( $\pm$  s.d) SO<sub>4</sub> for monitoring points in the LSRV taken by DWS from 1999-1998**

*Source:*Adapted from DSW, (2014)

## 5. CROP BUDGETS

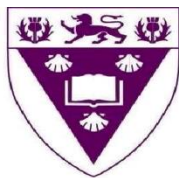
**Table 5.1 Enterprise cost budgets for 2013 season in the LSRV**

	NAVELS	VALENCIAS	LEMONS	SOFT CITRUS
<b>PRE AND POST HARVEST COSTS</b>				
<i>Water</i>	<b>1570.00</b>	<b>1570.00</b>	<b>1570.00</b>	<b>1570.00</b>
<i>Electricity</i>	<b>2700.00</b>	<b>2700.00</b>	<b>3200.00</b>	<b>2100.00</b>
<i>Fertilisers</i>	<b>4800.00</b>	<b>5600.00</b>	<b>8000.00</b>	<b>4800.00</b>
<i>Insecticides</i>	<b>14400.00</b>	<b>13000.00</b>	<b>12000.00</b>	<b>13000.00</b>
<i>Wages (harvest and general)</i>	<b>20800.00</b>	<b>20800.00</b>	<b>25800.00</b>	<b>18300.00</b>
<b>OVERHEAD COSTS</b>				
<i>Overheads</i>	<b>14000.00</b>	<b>13000.00</b>	<b>14000.00</b>	<b>13000.00</b>
<i>Depreciation</i>	<b>1550.00</b>	<b>1700.00</b>	<b>2500.00</b>	<b>1325.00</b>
<b>OTHER COSTS</b>	<b>15180.00</b>	<b>16630.00</b>	<b>22930.00</b>	<b>15905</b>
<b>TOTAL COSTS</b>	<b>R75000.00</b>	<b>R75000.00</b>	<b>R90000.00</b>	<b>R70000.00</b>

Source: Local citrus company

<sup>a</sup> Overheads (e.g. salaries), maintenance and repairs, consumer bills, fuel, machinery hire, transport, tools, protective clothing, pruning, fungicides, growth, training and weed control

## 6. QUESTIONNAIRE



**RHODES UNIVERSITY**  
*Where leaders learn*

• SAM MUNRO • DEPARTMENT OF ECONOMICS AND ECONOMIC HISTORY •  
•Tel: 083 448 6066 • Email: [sammunro31@gmail.com](mailto:sammunro31@gmail.com)•

This questionnaire is being conducted as part of a Masters research project in the Department of Economics and Economic History at Rhodes University. The title of the Thesis is ***“An application of a full water footprint assessment: A case study of the Sundays River citrus farms.”*** All the data acquired will be used as part of conducting a full water footprint assessment. This requires data pertaining to irrigation use and practices, farming practices, yield data, market and export prices, crop budgets, fertiliser, and pesticide use.

The data collected will also be used work out the water footprint of navel, valencia, lemon, soft citrus and grapefruit cultivars and to examine the environmental and economic sustainability of the water footprint according to the water footprint assessment framework. The study also aims to examine potential risks to the citrus industry regarding future climatic patterns and how a decrease in water allocation would affect farmers through the implementation of the National Water Act (Act 36 of 1998). All participants will remain anonymous and the data will not be used without consent for any research other than what is indicated. Feedback will be provided where indicated.

All information collected is purely for academic purposes. Due to participation being voluntary, please indicate below that you have read and understood the terms of the survey and are willing to participate in this survey.

**The questionnaire is divided into 4 categories:(1) Farm details (2) Farm characteristics (3) cultivar characteristics, (4) Irrigation practices, (5) Fertilizer and pesticide use, (6) Farm budgets and (7) other.**

---

**After reading the conditions of this survey, I consent to answering the questionnaire**

**Signed:** \_\_\_\_\_

Please tick if you would like to receive feedback from this study and provide your email:

\_\_\_\_\_

## 1. FARM DETAILS

<b>FARM OWNER</b>	
<b>AREA WITHIN SUNDAYS</b> (e.g. Kirkwood, Addo, Dunbrody, Sunland)	
<b>FARM NAME</b>	
<b>YEARS OF OWNERSHIP</b>	
<b>SIZE OF FARM (HA)</b>	
<b>DO YOU DO ANY OTHER FARMING OTHER THAN CITRUS?</b> (If yes please specify and with no. of ha)	

## 2. FARM CHARECTERISTICS

2.1 What method of farming do you practice? Please indicate under remarks if you do/do not use some of the examples mentioned or if it differs in anyway.

<b>TYPE</b>	<i>Mark with X</i>	<b>REMARKS/COMMENTS</b>
<b>Conventional</b> (e.g. Use of synthetic manufactured fertilizers and pesticides (which include herbicides, insecticides and fungicides), plant growth regulators such as hormones and human sewage sludge)		
<b>Organic</b> (e.g. Techniques such as, green manure, compost, cultural and biological pest control. (Strictly excludes any of the practices under conventional farming)		
<b>Other</b> (e.g. Integrated Pest Management/ Integrated Production or Integrated Crop Management Systems- mixture of biological control, registered products and cultural control, Identifying appropriate cultivars for different area through soil preparation) or Resistance Management with/without IPM (pesticide mixtures, rotation and alternation, mosaics)		

2.2 Please fill in all the citrus cultivars you have on your farm and their attributes in the Table below

NAME OF CULTIVAR	NO. OF TREES	NO. OF HA	% AGE			ROOTING DEPTH	SCION/ ROOT STOCK
			1-5	6-15	16 +		
NAVELS							
VALENCIAS							
LEMON							
SOFT CITRUS							

2.3a If you have any storage dams on your farms, please indicate the size, as well as to what

STORAGE DAM	PERCENTAGE CAPACITY												DEPTH (m)	AREA (m <sup>2</sup> )
	J	F	M	A	M	J	J	A	S	O	N	D		

percentage capacity it is *generally* kept throughout the year?

2.3b Do you share these storage dams with other farms or is it used solely for your farm?

Just my farm

I share with other farms      How many?

Other      Please specify: \_\_\_\_\_  
 \_\_\_\_\_

2.4 Please mark (with an X) next to the soil types found on your farm and indicate the estimated percentage. Please indicate if there is a specific cultivar of citrus tree that you plant on this soil type.

SOIL TYPE		PERCENTAGE OF FARM	CULTIVAR PREFERENCE
Sand			
Loamy Sand			
Sandy Loam			
Loam			
Clay			
Saline soil			

### 3. CULTIVAR CHARECTERSITICS

*The information provided in this section will be used to calculate the crop water requirements of each cultivar through the use of a soil water balance model. Along with the crop water requirements, yield is also needed to work out the water footprint per ton of each cultivar.*

3.1 Based on the attached criteria, please indicate the growth characteristics (average number of days of the duration of the growth stage indicated) of each cultivar.

	DURATION OF GROWTH STAGE (days per season/year)				COMMENTS
	Initial	Developing	Mid-Season	Late-Season	
NAVELS					
VALENCIAS					
LEMON					
SOFT CITRUS					

3.2 Do you use any techniques such as tillage, mulching, cover crops etc?

3.3 On average what percentage of your yield per season is sent to the citrus pack houses?

What factors affect your pack out percentage

3.4 Please indicate your farms production (yield in tons/ha) for the seasons 2009-2013 for each cultivar. Please also indicate the average price you received per ton for local and export markets for the given year.

<b>CULTIVARS</b>		<b>2013</b>		<b>2012</b>		<b>2011</b>		<b>2010</b>		<b>2009</b>	
		<b>TON/HA</b>	<b>ZAR</b>	<b>TON/HA</b>	<b>ZAR</b>	<b>TONS/HA</b>	<b>ZAR</b>	<b>TONS/HA</b>	<b>ZAR</b>	<b>TONS/HA</b>	<b>ZAR</b>
<b>NAVELS</b>	<i>Export</i>										
	<i>Local</i>										
<b>VALENCIAS</b>	<i>Export</i>										
	<i>Local</i>										
<b>LEMONS</b>	<i>Export</i>										
	<i>Local</i>										
<b>SOFT CITRUS</b>	<i>Export</i>										
	<i>Local</i>										

## 4. IRRIGATION PRACTICES

*This section aims to determine the amount of consumptive water use, source and quality of water that is used by the farm for irrigation purposes. This section also seeks to collect information on the farmer's perception of water and current risks they face.*

4.1 How many ha of the total farm is irrigated on average? Is this different to your water allocation?

4.2 During which period of the day do you irrigate?

4.3 Please indicate which irrigation systems you use and how many hectares. How are irrigation pumps operated? (e.g. electric/diesel)

4.4 Please describe your methods of scheduling irrigation (e.g. calendar method, measurements of climate, water content of soil) i.e. What criteria do you use to decide the frequency and amount of irrigation?

4.5 How often do you generally irrigate? Please indicate both the frequency and duration for each cultivar and elaborate on the irrigation technique.

CULTIVAR	Freq (daily/weekly/monthly/yearly) and duration	IRRIGATION TECHNIQUE (Please elaborate)
NAVELS		
VALENCIAS		
LEMON		
SOFT CITRUS		

4.6 Please indicate your farms average irrigation volume (m<sup>3</sup>/ha) use per month from 2009-2013.

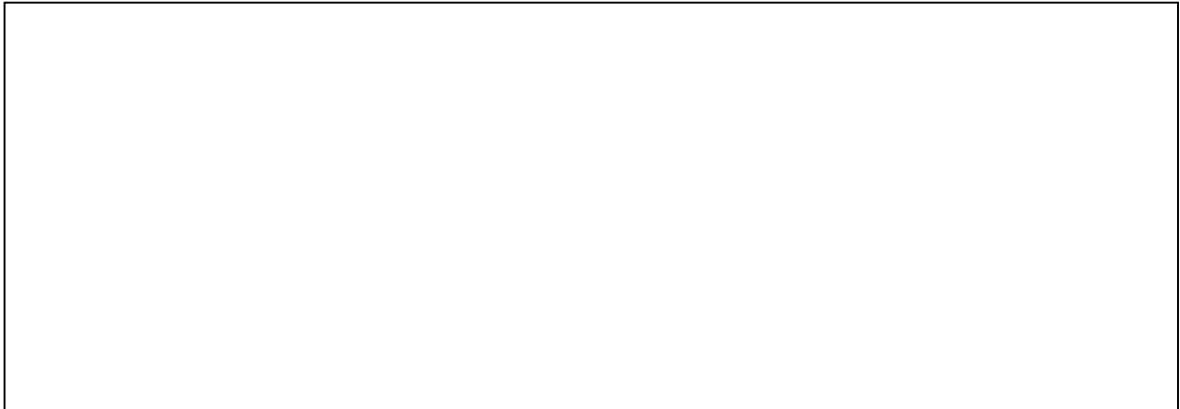
YEAR	JAN	FEB	MARCH	APRIL	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC
2013												
2012												
2011												
2010												
2009												

4.7a Is the water of good quality?

	v	COMMENTS
Yes		
No		
Sometimes		

4.7b If you answered sometimes or no to the above, how does this affect your farming practices and costs?

4.8 How will a decrease in water allocation or an increase in the price of water affect your farm? Is this even a concern to you at all?





OTHER															
BRAND/ PRODUCT	AMOUNT APPLIED	CULTIVARS APPLIED	APPLICATION METHOD	J	F	M	A	M	J	J	A	S	O	N	D

5.2 What criteria (if any) do you use to determine the frequency and amount of fertilisers/ pesticides etc. to apply?

## 6. FARM BUDGETS

*This section is to determine a 'typical farm budget.' This information will be used to work out the marginal product value of water. Please note if you are uncomfortable filling out this information you may omit some questions. All data will be aggregated so no individual results will be published.*

6.1. Please indicate the average cost per hectare for each cultivar for the specified harvest and overhead costs for the 2013 season.

	NAVELS	VALENCIAS	LEMONS	SOFT CITRUS
<b>PRE AND POST HARVEST COSTS</b>				
<i>Water</i>				
<i>Electricity</i>				
<i>Fertilisers</i>				
<i>Insecticides</i>				
<i>Wages (harvest and general)</i>				
<b>OVERHEAD COSTS</b>				
<i>Overheads</i>				
<i>Depreciation</i>				
<b>OTHER</b>				
<b>TOTAL COSTS PER HECTARE</b>				

6.2. Please fill in the general labour costs of your farm

	No of workers	Labour days/hours required per year	Average monthly wage (R)
<b>Seasonal labour</b>			
<b>Contract labour</b>			
<b>Permanent labour</b>			

## 7. OTHER

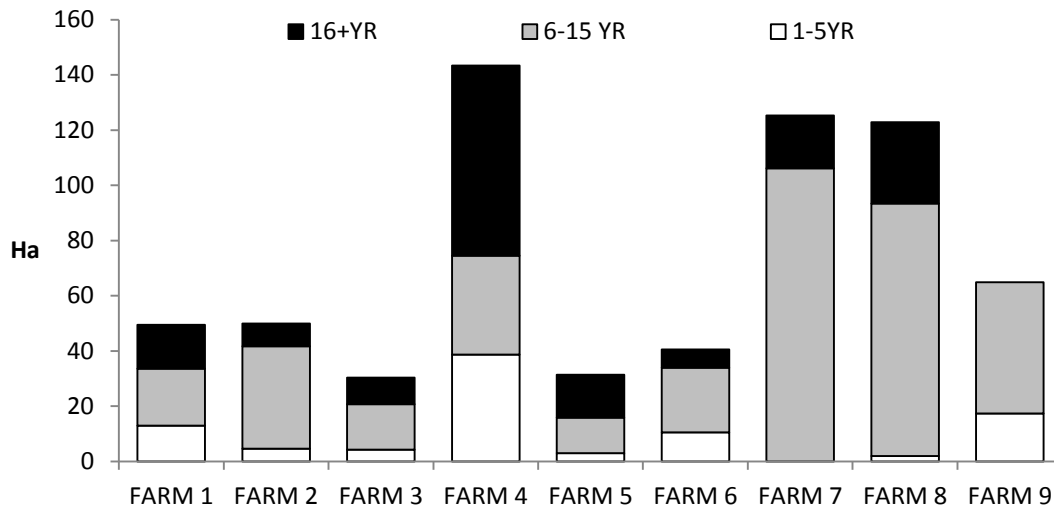
7.1 Please list the factors that have affected/threatened the yield and profitability of your farm over the last 5 years

7.2 If and how are you impacted during drought years?

7.3 What do you consider as potential risks for the future?

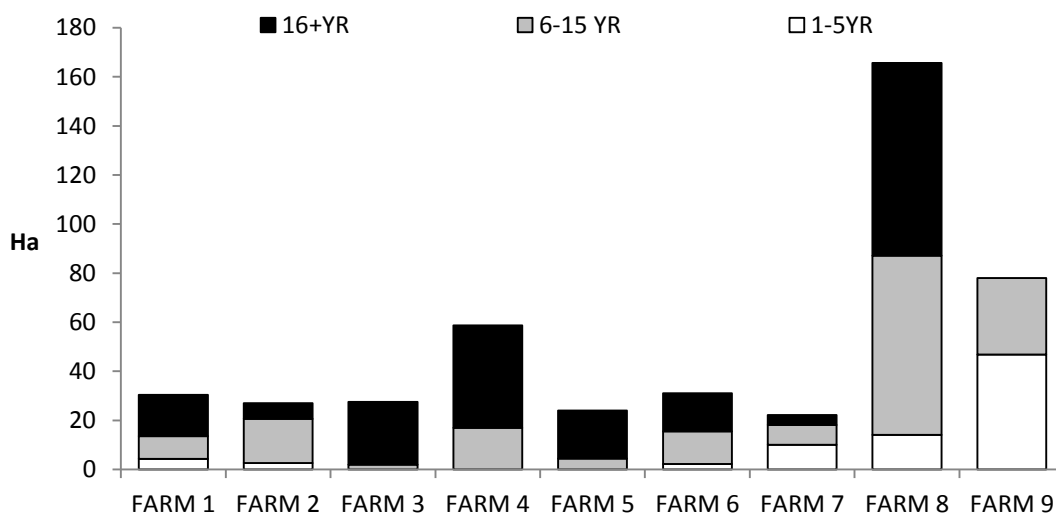
## 7. FARM INTERVIEW DATA

### 7.1 AGE DISTRIBUTION OF EACH VARIETY ON SAMPLED FARMS



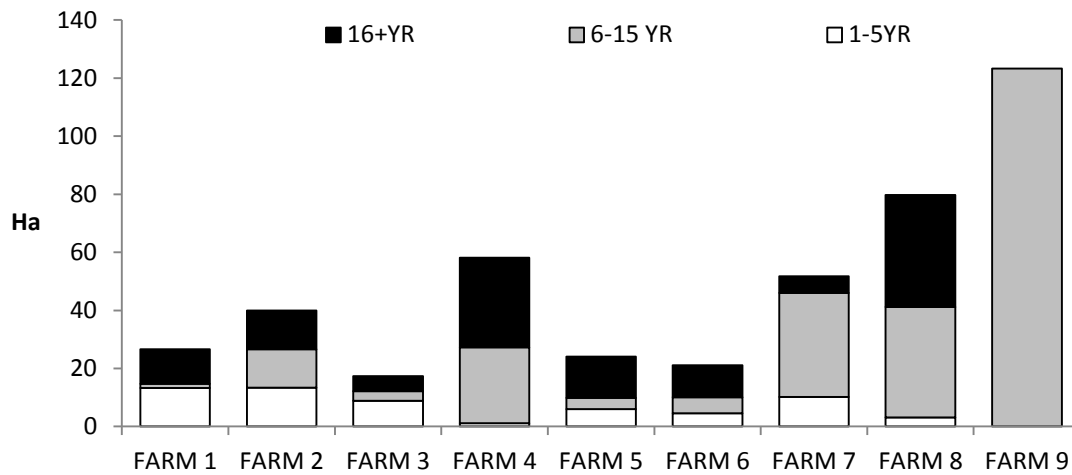
**Figure 7.1a** Age distribution for navel varieties from sampled farms

Source: Farm interview data (n=9)



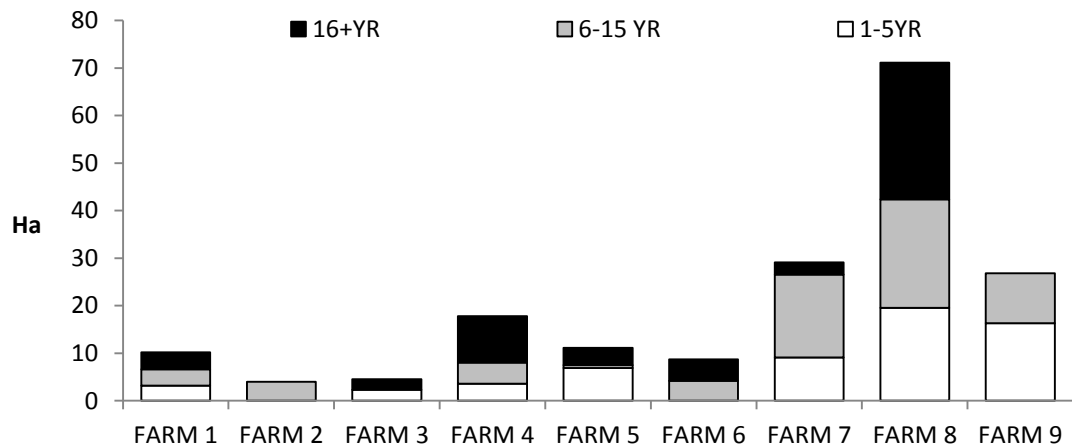
**Figure 7.1b** Age distribution for valencia varieties from sampled farms

Source: Farm interview data (n=9)



**Figure 7.3c Age distribution and number of hectares for lemon varieties from sampled farms**

Source: Farm interview data (n=9)



**Figure 7.1d Age distribution and number of hectares for soft citrus varieties from sampled farms**

Source: Farm interview data (n=9)



**Figure 7.1e Age distribution and number of hectares for grapefruit varieties from sampled farms**

*Source:* Farm interview data (n=9)