DETERMINING THE WATER FOOTPRINTS OF SELECTED FIELD AND FORAGE CROPS, AND DERIVED PRODUCTS IN SOUTH AFRICA

Report to the
WATER RESEARCH COMMISSION

by

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Executive summary

Background to the Research

The global water scarcity phenomenon has become a major issue of distress to governments, policymakers, water users and water managers, as well as private and non-governmental organisations and professional bodies interested in environmental and sustainability issues. It is estimated that about four billion people across the globe face severe water scarcity. Freshwater is one of the planet's most valuable resources and is essential for the survival of all organisms, including humans. Freshwater, however, is an alarmingly scarce resource, with the strain on the world's water resources becoming more and more acute. Significant amounts of water are used in the agricultural sector to produce food, feed, and fibre to meet the ever-increasing world-wide demands. An assessment of water sustainability indicators across various sectors of the global economy has identified that the greatest share of the world's freshwater is utilised in food production. About 86% of all the freshwater resources in the world are consumed in food production. This implies that the relative importance of water to food production and human survival cannot be overlooked. As a result of that, researchers and policymakers in recent years have become interested in the study of sustainable and economical water utilisation in the food sector.

According to DWA (2012), 60% of freshwater in South Africa is used by irrigated agriculture, making it by far the largest single user of water in South Africa. While being the largest user of freshwater, irrigated agriculture is also expected to contribute significantly towards poverty alleviation in South Africa through job creation and increased economic activity in rural areas. The allocation of freshwater to irrigated agriculture thus holds substantial social and economic benefits for South Africa, given that South Africa is a water-scarce country. Climate change adds another dimension of stress to the pressure on water resources by causing more erratic precipitation patterns and increased variability in river flows and aquifer recharge. Thus, irrigated agriculture is faced with significant water-related risks that constrain the contribution of irrigated agriculture towards poverty alleviation in South Africa. According to DWS (2012), water requirements already exceed availability in the majority of water management areas in South Africa, despite receiving significant transfers from other catchments. The pressure is thus mounting on the effective management of our freshwater resources. In the proposed National Water Resource Strategy 2 (NWRS 2), it is acknowledged that appropriate strategies, skills and capabilities are required to ensure the effective management of the freshwater resource (DWA, 2012). DWS (2012) further acknowledges that economic growth has to be planned in the contexts of sector-specific water footprints, as well as of the relevant socio-

economic impacts and contributions, since economic growth targets cannot be achieved at the expense of the ecological sustainability of water resources, or the obligation to meet people's basic needs.

An important water use indicator in the agriculture and food sectors that has emerged in recent years is the water footprint. Hoekstra et al. (2011) define the water footprint of a product as the volume of fresh water (direct and indirect) that is used to produce the product, measured over the whole supply chain (or life cycle) of the product. A distinction is made between green, blue and grey water footprints. The green water footprint refers to the volume of green water (i.e. rainwater insofar as it does not become run-off) that is used to produce the product. The blue water footprint refers to the consumption of surface and ground water (blue water resources) along the life cycle of the product. The grey water footprint, on the other hand, refers to pollution and is defined as the volume of fresh water that is required to assimilate the load of pollutants, given natural background concentrations and ambient water quality standards. Importantly, all components of the water footprint are also specified geographically and temporally.

After the introduction of the concept, its usage received some meaningful attention and application across various sectors of the economies, globally. Much of the efforts in research are made by the Water Footprint Network which has assessed different types of water footprints for different products, geographical regions, businesses and countries. The methodological aspects of water footprinting have received (and still receive) a significant amount of research attention. Notwithstanding the growing attention of researchers internationally to calculate the water footprints of different products, businesses, and nations, the topic of water footprinting has received a very limited amount of attention within South Africa. Prior to the start of this project, very little had been done in South Africa to calculate water footprints. SABMiller and the World Wildlife Fund (WWF) quantified the water footprints of the beer value chains in South Africa and the Czech Republic in order to understand the ecological and business risks they face. Within the second study, the water footprint for the Breede River catchment was calculated. In a third study that has, to a certain extent, considered the water footprint in South Africa, the blue water footprints of raisins, and certain vegetable crops that were produced by smallholder irrigation farmers, were calculated. Clearly, the volume of research within the South African context is insufficient to effectively guide the management of water resources, and to set benchmarks for sustainable water use in different agri-food industries. Given the important role of irrigated agriculture in contributing towards poverty alleviation in a water-scarce South Africa, and the type of information that is *captured within the water footprint of a product, there has been a major need to obtain accurate information on water footprints in the irrigated agricultural sector in South Africa.*

Since water use at farm level often represents in excess of 90% of the water footprints of agricultural products, special attention was given to measuring green, blue and grey water use in the production of these crops at farm level. Special attention was also directed to the calculation of water use in the livestock industry since, as part of their life cycles, forage crops and some field crops are used as important inputs to produce animal products for human consumption. The consumption of meat and dairy products is widely documented as an important driver of water scarcity around the world, while ignoring the fact that different livestock production systems have different water footprints. Blue and green water footprints were calculated for different production systems to derive benchmarks that are appropriate for different livestock production systems that use irrigated forage crops and/or field crops as inputs in South Africa. Furthermore, we combined the water footprint applications with economic and social analytical tools to assess the economic and social impacts of recommended changes in water use behaviour.

Contextualisation of the Research

The research has addressed very important issues in agricultural sustainability and human survival as a whole in South Africa. The research established country-specific standardised procedures for calculating blue and green water footprints for irrigated field and forage crops, and this can contribute towards the setting of accurate benchmarks for fresh water use along the life cycle of the crops. The research has linked the water footprint applications to economic and social analytical tools. The inclusion of the social and economic impacts of proposed changes in water use behaviour provides detailed insights and understanding of water management. The analysis of consumer awareness, preference and willingness to pay for water footprint information on product labels gives insight into the scope for incentivising water users through price premiums to use fresh water efficiently.

Purpose of the research

According to the memorandum of agreement, the main purpose of the research was to assess the water footprints of selected field and/or forage crops in South Africa, and to evaluate the social and economic implications of changing water use behaviour towards achieving more efficient use of fresh water when producing the crops under irrigation. In support of the main purpose, the following sub-objectives were formulated:

1. *Evaluation of water footprints of selected field and/or forage crops in South Africa in order to develop benchmarks for fresh water use for the production of the selected crops under irrigation in South Africa;*

2. *Establishment of standardised procedures for calculating green and blue water footprints of field and forage crops in South Africa;*

3. *Development of benchmarks for fresh water use in South Africa through the application of the standardised procedures to calculate the green and blue water footprints for selected field and forage crops;*

4. *Assessment of consumers' awareness of the concept of water footprints and their willingness to pay a price premium for information on the water footprint of the product on its label;*

5. *Modelling the economic and social impacts that will result from the implementation of recommended actions to improve the efficiency with which fresh water is used along the life cycles of the selected field and/or forage crops in South Africa.*

Research outcomes

The main outcome of the research is the achievement of a better understanding and insights regarding water usage in the production of field and forage crops, and its corresponding economic, social and welfare implications on water users, consumers, the environment and the economy as a whole. The following specific outcomes were obtained:

- *Standardised procedures formulated for calculating green and blue water footprints of irrigated field and forage crops (Chapter 2). The standardised procedures ensure that water footprints can be compared and they allow for benchmarks to be derived for water use along the life cycle of the crops;*

- *Benchmarks established for fresh water use for the production of selected field and forage crops under irrigation (Chapters 3, 4, 5 and 10). The estimates provided in these chapters can act as benchmarks to inform water users with regard to the efficient use of fresh water along the life cycles of the crops under consideration;*

- *Standardised procedures compiled for calculating the economic values of green and blue water footprints of irrigated field and forage crops (Chapter 8). The standardised procedures allow for the accurate comparison of the economic returns from different* *water allocations to inform water managers in terms of the economic and efficient use of fresh water;*

- *Information gathered regarding consumers' awareness of the concept of water footprints and their willingness to pay for water footprint information to be included on product labels (Chapters 6 and 9). The findings provide insight into the prospects for price premiums being paid by consumers to incentivise water users to capture and report water use information on the labels of products as a means to incentivise the efficient use of fresh water;*

- *Knowledge acquired regarding the social and economic impacts that can be expected to arise from the implementation of policies and incentives to oblige role-players to capture accurate water footprint information for inclusion on product labels (Chapter 7). This knowledge provides insight into the economic and social consequences that can be expected to result from the implementation of incentives and/or penalties to ensure the capturing and reporting of water footprint information on the labels of products.*

Reporting

This research is presented in report in a single volume. The report is structured into different chapters according to the research objectives. Each chapter can be read as an entity with a summary, and list of references for their respective chapters. The report is structured in eleven chapters.

Executive summaries for each of the chapters are set below.

Introduction

The research background and motivation, research problem and objectives are outlined in Chapter 1. This chapter also provides detailed explanations of the research aim, the innovativeness and the contribution of the research.

Literature Review

A thorough literature review provided for gaining a better understanding of what is being done locally and internationally on theoretical frameworks and methods for water footprint accounting, as discussed in Chapter 2. The chapter reviewed related research that assesses product water footprints of field and forage crops and derived products, economic values of water in South Africa's agricultural sector, and sustainability assessments. It also reviewed consumer awareness of and willingness to pay for water footprint labelling; social and economic impacts of proposed changes in water use behaviour; and conclusions and implications for this research.

Case Study of Milk and Irrigated Pastures

Chapter 3 focused on the water footprint of milk and irrigated pasture. The financial value that was added to the water used to produce milk was also explored in order to get an understanding of how the value of the water increases along the milk value chain, from the feed producers to the end consumer. The assessment reveals that the water footprint indicator of lucerne production at Vaalharts was 456.6 $m^3.ton^{-1}$. Of this, 206.9 $m^3.ton^{-1}$ of water originates from effective rainfall (green water footprint), 171.3 $m^3.ton^{-1}$ from surface and groundwater (blue water footprint), and the remaining 78.4 $m^3.ton^{-1}$ of water was used to assimilate the salts leached during production to achieve acceptable levels (grey water footprint). Milk production in the South African case study uses more water than the global average and slightly less than the country average estimate for South Africa, but remains environmentally sustainable from water perspective. Importantly, water is not simply used as an input for producing milk, but value is added to the water along the milk value chain. The findings on pastures have provided different pasture combinations, with different dry-matter yields and water usage for different seasons and production systems. The findings reveal that the yield and water usage for sole pasture crops and mixed pastures vary from season to season. Different forage crops have different water footprint values. However, blue water usage dominates in the pasture production, and green water usage is minimal.

Case Study of Broilers Produced using Maize Feed

The assessment of the water footprint of broilers, as derived from irrigated maize production in the Free State, is discussed in Chapter 4. The method of the Water Footprint Network (WFN) was identified as being suitable for achieving the aim and objectives of this study. At a yield level of 14.3 $ton.ha^{-1}$, the total water footprint of maize was found to be 584.2 $m^3.ton^{-1}$. This comprises a green water footprint of 186.9 $m^3.ton$, a blue water footprint of 275.6 $m^3.ton^{-1}$, and a grey water footprint of 121.7 $m^3.ton^{-1}$. The total broiler water footprint was found to be 1 474.6 $m^3.ton^{-1}$ of chicken meat produced. The water footprint of farm-level broiler production, excluding feed, is equivalent to 38.8 $m^3.ton^{-1}$, while the water footprint associated with broiler feed was 1 430.3 $m^3.ton^{-1}$. The slaughtering and processing stages for the broiler chickens used 2.7 $m^{3.}ton^{-1}$ each. The economic water productivity (EWP) was found to be higher for *fresh chickens than for frozen chickens. Chicken portions had a higher associated EWP than whole chickens did. Maize production and broiler production were found to be sustainable from December to May.*

Case Study of Bread Produced from Wheat

The focus of Chapter 5 is on the assessment of the water footprint of wheat in South Africa, being an important input in the wheat-bread value chain. The water footprints of flour, and that of bread, are also calculated in order to determine the total water footprint of bread along the wheat-bread value chain in South Africa. Water productivities at each stage of production within the wheat-bread value chain are also determined. The study was conducted as a case study of the Vaalharts region. The water footprint of wheat in the Vaalharts region was estimated to at 991 $m^3.ton^{-1}$. At the processing stage, 86 percent of the total water footprint in the processing stage of bread along the wheat-bread value chain is from the bakery, with only 14 percent from the mill process. The amount of water used at farm level is the largest contributor to the total water footprint of bread along the wheat-bread value chain, accounting for 99.95 percent of the total water footprint, whereas the processing is only accountable for 0.06 percent. Economically, more value is generated per cubic metre of water used from wheat than any other product along the wheat-bread value chain. Total value added to water from the water footprint assessment of the wheat-bread value chain is ZAR 11.4 per kilogram. About 65 percent of this value is from the processing level and only 35 percent from farm level.

Consumer Awareness and Willingness to Pay for Water Footprint Information

The aim of Chapter 6 was to investigate the possibility of creating a niche market for beef products that are produced sustainably. This aim was pursued by examining consumer preferences and Willingness to Pay (WTP) a premium for beef products that contain labels of their environmental sustainability claims, in particular focusing on water footprint information labelled on the products. Choice experimental survey data was collected from 201 beef consumers in the Gauteng province of South Africa. Discrete choice experimental data and a random parameter logit model were employed in the study. It was found that there are heterogeneous preferences for water footprint sustainability attributes. The heterogeneity in preferences for water footprint sustainability attributes are significantly related to an individual's age, gender, income, and education, as well as awareness of water scarcity. The findings suggest that, to communicate potential benefits and costs of water usage effectively, policymakers and interested groups should identify different heterogeneous consumer segments, and assess potentially simpler or more direct awareness or labelling methods that *signal ecological sustainability as a new water scarcity and carbon emission campaign strategy.*

Social and Economic Analysis of Changed Water Use Behaviour

Chapter 7 applied a slightly modified version of the International Food Policy Research Institute Computable General Equilibrium (CGE) model and the SWIP – E (Soil Water Irrigation Planning – Energy) model. A recent Social Accounting of South Africa was utilised as a database, with other behavioural parameters being considered. Results from SWIP – E and the CGE models revealed that if water restrictions are set, it is more profitable to reduce the number of hectares planted and rather to apply full irrigation to produce higher yields. The increase in irrigation water tariffs does have an impact to some extent; however, the impact is at a minimal level. The main challenge is the availability of the scarce resource (water), and not the incremental increases in water tariffs. It was found that without the behavioural change of farmers, it would not achieve the desired output. A government with different stakeholders should introduce a mechanism to educate farmers and enhance their understanding about the past, current and future trends of water and drought in order to plan for future and mitigate unexpected shock.

Water Footprint and Economic Water Productivities of Feed Crops and Dairy Products along the Dairy Value Chain in South Africa

The focus of Chapter 8 is on the analysis of economic water productivities along the dairy value chain in South Africa. The findings reveal that the value added to milk and water as it moves along the value chain varies from stage to stage, with the highest value being attained at the processing level, followed by the retail and farm gate levels, respectively. Milk production in South Africa is economically efficient in terms of water use. Feed production accounts for about 98.02% of the total water footprint of milk with 3.3% protein and 4% fat. Feed production is economically efficient in terms of costs and water use. Value addition to milk and economic productivity of water are influenced by packaging design. Not all economically water productive feed products are significant contributors to milk yield.

Compensating Welfare Estimates of Water Footprint Sustainability Policy Changes in South Africa

The focus of Chapter 9 is on the use of a choice experiment and latent class model to estimate consumers' preferences as well as compensating surplus estimates for water footprint policy changes in South Africa. The findings reveal that there is profound preference heterogeneity *at the segment level for water and carbon footprint attributes. Three distinct consumer segments were identified. This chapter reveals that, beside socio-economic factors, public awareness creation and campaigns regarding threats posed by climate changes, trust in food labelling regulatory bodies, and subjective and objective knowledge on environmental sustainability significantly explain consumers' choices of environmentally sustainable products. Compensating surplus estimates indicate that the welfare effects arising from water footprint sustainability policies vary from one class to another. It was also found that there are pertinent segmental equity issues that need to be addressed when designing environmental sustainability policies.*

Productive Water Use Benchmarks along the Wheat-Bread Value Chain

Chapter 10 focuses on an examination of the water footprint and economic water productivities of the wheat-bread value chain. The assessment methodology of the Water Footprint Network was employed. The findings reveal that 954.07 m^3 and 1026.07 m^3 of water are utilised in the production of a ton of wheat flour in Bainsvlei and Clovelly in South Africa, respectively. The average water footprint for wheat bread was 954.53 m^3 per ton in Bainsvlei and 1026.53 m^3 per ton in Clovelly. More than 99% of the water is used in producing the grain at the farm level. The processing stage of the value chain uses less than 1% of the total water footprint. About 80% of all the water utilised along the wheat-bread value chain is attributed to blue water. The findings revealed a significant shift from green water consumption to higher blue water use, and this is a major concern for water users and stakeholders along the wheat-bread value chain, given that blue water is becoming scarce in South Africa. The groundwater contributes about 34% and 42% of the average total water footprint of wheat at the farm level in Clovelly and Bainsvlei respectively, suggesting the need to have an idea of the contribution of groundwater in water footprint evaluation and water-management decisions of farmers. This insight will aid in minimising irrigation water use and in relieving pressure on groundwater resources. Water footprint assessment has moved away from sole indicator assessment, as a deeper awareness of and insight into the productive use of water at different stages has become vital for policy. To make a correct judgment and to assess the efficient and wise use of water.

Summary, Conclusions and Recommendations

Chapter 11 focuses on the summary, conclusions and recommendations drawn from the research. Also provided in this chapter are suggestions for future research and policy options *that could be adopted by different stakeholders towards sustaining the environment in terms of efficient water usage and management.*

The research within this study has contributed towards knowledge in four ways. Firstly, standardised procedures have been established for the calculation of the green and blue water footprints of irrigated field crops and forage crops in South Africa. The research within this study has provided recommendations and suggestions for future research that would investigate the water footprints of other agricultural products to guide future research in South Africa. Secondly, the findings from this research study can act as water use benchmarks for different agri-food industries that are involved in the life cycles of irrigated field crops and forage crops considered in this research. Such benchmarks will contribute towards the sustainable use of fresh water in the production of irrigated field crops and forage crops in South Africa. Thirdly, social and economic analyses have been linked to the water footprint analysis to ensure that recommendations are made for change in water use behaviour that is socially and economically sustainable.

Potential financial gains that may result from using water more efficiently throughout the life cycle of the product have also been quantified to explore their scope for serving as an incentive for more efficient water use. Fourthly, consumer awareness of the concept of water footprints has been assessed, and the scope for incentivising efficient water use through price premiums that are paid for products that contain water footprint information on its label has been examined. Ultimately, the knowledge generated through this research can potentially contribute to improved water resource information to achieve effective water governance and developmental water management.

Innovation

The integration of the water footprint analysis with economic and social analytical tools into one research framework is innovative. The integrated framework will allow for determining water use behaviour that is environmentally, economically, and socially sustainable, and hence satisfies the Triple Bottom Line. The research is also innovative in paying special attention to the potential role of the consumer to act as an agent for change by paying a price premium for products that have their water footprints reported on their labels. Ultimately, it is the consumer who attributes value to the characteristics of agricultural products by being willing to pay for such characteristics.

Capacity Building and Knowledge Dissemination

Seven postgraduate students participated in the project. Two students have already obtained their doctorate degrees. Four students have obtained their masters degrees and are working full time after graduation. One student is enrolled for his honours degree. Knowledge dissemination was one of the important outcomes of this research. Research results have been presented at local and international conferences, as well as in international DHET accredited journals. Five articles have been published in peer-reviewed journals. Ten conference papers have been presented at both local and international conferences to share the knowledge and insights gained from this project. Details of these are provided in Appendix A.

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List of Acronyms and Abbreviations

CE	Choice Experiment
CGE	Computable General Equilibrium
CIE	Centre for International Economics
CM	Choice Modelling
CV	Contingency valuation
CWR	Crop Water Requirement
DAFF	Department of Agriculture, Forestry and Fisheries
DEA	Department of Environmental Affairs
DWA	Department of Water Affairs
DWS	Department of Water and Sanitation
EC	European Commission
EFR	Environmental Flow Requirement
ELP	Economic Land Productivity
EWP	Economic water productivity
FAO	Food and Agriculture Organization
FCE	Feed conversion efficiency
FSSA	Fertilizer Society of South Africa
GDP	Gross domestic product
GWFNS	Global Water Footprint Network Standard
HFMS	High Fructose Maize Syrups
IFPRI	International Food Policy Research Institute
IPCC	Intergovernmental Panel on Climate Change
IWMI	International Water Management Institute
LC	Latent Class
LCA	Life Cycle Assessment
MAV	Multi-Attribute Valuation
Milk SA	Milk South Africa

NPC	National Planning Commission
NT	National Treasury
NWRS	National Water Resource Strategy
PWP	Physical Water Productivity
SEDA	Small Enterprise Development Agency
STATS SA	Statistics South Africa
SWIP – E	Soil Water Irrigation Planning – Energy
UN	United Nations
UNEP	United Nations Environment Programme
USA	United States of America
USDA	United States Department of Agriculture
VF	Variation Factor
WA	Water Availability
WF	Water Footprint
WFA	Water footprint assessment
WFN	Water Footprint Network
WFP	World Food Program
WSI	Water Stress Index
WTA	Willingness to Accept
WTP	Willingness to Pay
WU	Water Usage
WWF	World Wildlife Fund

CHAPTER 1
INTRODUCTION

1.1 BACKGROUND AND MOTIVATION

Freshwater is one of the planet's most valuable resources (Koehler, 2008) and is essential for the survival of all organisms, including humans. Freshwater, however, is an alarmingly scarce resource (Ridoutt *et al*., 2009) with the strain on the world's water resources becoming more and more acute (Chapagain and Tickner, 2012). Significant amounts of water are used in the agricultural sector to produce food, feed, and fibre to meet the ever-increasing world-wide demands (Wu *et al*., 2009). According to DWS (2012), 60% of fresh water in South Africa is used by irrigated agriculture, making it by far the largest single user of water in South Africa. While being the largest user of fresh water, irrigated agriculture is also expected to contribute significantly towards poverty alleviation in South Africa through job creation and increased economic activity in rural areas (NPC, 2011). The allocation of fresh water to irrigated agriculture thus holds substantial social and economic benefits for South Africa.

A problem is that South Africa is a water-scarce country. Climate change adds another dimension of stress to the pressure on water resources (DWS, 2012) by causing more erratic precipitation patterns, and increased variability in river flows and aquifer recharge (Chapagain and Tickner, 2012). Thus, irrigated agriculture may face significant water-related risks that will constrain the contribution of irrigated agriculture towards poverty alleviation in South Africa. According to DWS (2012), water requirements already exceed availability in the majority of water management areas in South Africa, despite significant transfers from other catchments. The pressure is thus mounting on the effective management of our freshwater resource. In the proposed National Water Resource Strategy 2 (NWRS 2), it is acknowledged that appropriate strategies, skills and capabilities are required to ensure the effective management of the freshwater resource (DWS, 2012). DWS (2012) further acknowledges the point that economic growth has to be planned in the context of sector-specific water footprints, as well as in the context of the relevant socio-economic impacts and contributions, since economic growth targets cannot be achieved at the expense of the ecological sustainability of water resources, or the obligation to meet people's basic needs.

Water footprints are emerging as an important sustainability indicator in the agriculture and food sectors (Ridoutt *et al*., 2010). Hoekstra *et al*. (2011) define the water footprint of a product as the volume of fresh water (direct and indirect) that is used to produce the product, measured over the whole supply chain (or life cycle) of the product. A distinction is made between green, blue and grey water footprints. The green water footprint refers to the volume of green water (i.e. rainwater insofar as it does not become run-off) that is used to produce the product. The blue water footprint refers to the consumption of surface and ground water (blue water resources) along the life cycle of the product. The grey water footprint, on the other hand, refers to pollution and is defined as the volume of fresh water that is required to assimilate the load of pollutants, given natural background concentrations and ambient water quality standards. Importantly, all components of the water footprint are also specified geographically and temporally.

Since its inception in the early 2000s, the concept of water footprinting has received a significant amount of attention by researchers, internationally. A search in Google Scholar for the topic of 'water footprints' revealed 8 900 hits, with 3 890 hits since 2010. Leading the research efforts is the Water Footprint Network, which has assessed different types of water footprints and published in excess of 50 peer-reviewed journal articles, together with a large number of other research publications on the topic of water footprinting (Water Footprint Network, 2013). While the methodological aspects of water footprinting have received (and still receive) a significant amount of research attention, other researchers have applied existing methods to calculate water footprints of, among others, nations, different agricultural and industrial products, bio-energy, and corporate businesses.

1.2 PROBLEM STATEMENT

Despite the growing attention of researchers internationally to calculate the water footprints of different products, businesses and nations, the topic of water footprinting has received a very limited amount of attention within South Africa (Buckley, Friedrich and von Blottnitz, 2011; Jordaan and Grové, 2012). As a matter of fact, only two studies have yet been undertaken in South Africa to calculate water footprints. SABMiller and the World Wildlife Fund (WWF) quantified the water footprints of the beer value chains in South Africa and the Czech Republic in order to understand the ecological and business risks they face. Within the second study, the water footprint for the Breede River catchment was calculated by Pegasys Consultants (2010).

In a third study that has, to a certain extent, considered the water footprint in South Africa, Jordaan and Grové (2012) calculated the blue water footprints of raisins, and of some vegetable crops that were being produced by smallholder irrigation farmers. Clearly, the volume of research within the South African context is insufficient to effectively guide the management of water resources, and to set benchmarks for sustainable water use in different agri-food industries. It also has to be accepted that changes in water use behaviour will have economic and social implications. Economic and social models, however, have not yet been linked to water footprint analyses to assess the economic and social implications of changing water use behaviour. Thus, it is not clear what the economic and social implications will be of changing water use behaviour towards achieving the more efficient use of fresh water. Given the important role of irrigated agriculture in contributing towards poverty alleviation in a water-scarce South Africa (NPC, 2011), there is a major need to get accurate information on water footprints, and the economic and social implications of changing water use behaviour in the irrigated agricultural sector in South Africa.

1.3 AIMS AND OBJECTIVES

The aim of this research is to contribute to the limited body of knowledge by calculating the water footprints of selected field and/or forage crops in South Africa, and by assessing the social and economic implications of changing water use behaviour towards achieving the more efficient use of fresh water when producing the crops under irrigation.

The aim will be achieved through the completion of the following sub-objectives:

Objective 1: To calculate the water footprints of selected field and/or forage crops in South Africa in order to develop benchmarks for fresh water use for the production of the selected crops under irrigation in South Africa.

Objective 2: To establish standardised procedures for calculating green and blue water footprints of field and forage crops in South Africa.

Objective 3: To develop benchmarks for fresh water use in South Africa through the application of the standardised procedures to calculate the green and blue water footprints for selected field and forage crops.

Objective 4: To assess consumers’ awareness of the concept of water footprints and their willingness to pay a price premium for information on the water footprint of the product on its label.

Objective 5: To model the economic and social impacts that will result from the implementation of recommended actions to improve the efficiency with which fresh water is used along the life cycles of the selected field and/or forage crops in South Africa.

1.4 INNOVATION AND CONTRIBUTION OF THE STUDY

The integration of the water footprint analysis with economic and social analytical tools into one research framework is innovative. The integrated framework will allow for determining water use behaviour that is environmentally, economically and socially sustainable, and hence satisfies the Triple Bottom Line.

The research within this study will contribute towards knowledge in three ways. Firstly, standardised procedures will be established for the calculation of the water footprints of irrigated field crops and forage crops in South Africa. The research within this study will guide future research in South Africa that investigates the water footprints of other agricultural products. Secondly, the standardised procedure will be applied to set water use benchmarks for different agri-food industries that are involved in the life cycles of the selected crops in South Africa. Such benchmarks will contribute towards the sustainable use of fresh water in the production of the selected crops in South Africa.

Thirdly, social and economic analyses will be linked to the water footprint analysis to ensure that recommendations for change in water use behaviour will result in behaviour that is also socially and economically sustainable. Potential financial gains that may result from using water more efficiently throughout the life cycle of the product will also be quantified to explore their scope for serving as an incentive for more efficient water use. Ultimately, the knowledge that will be generated through this research will contribute to improved water resource information, as prescribed by DWS (2012), to achieve effective water governance and developmental water management.

1.5 LAYOUT OF THE REPORT

The report is organised into eleven chapters. The background and motivation of the research, an explanation of the research problem, and the objectives of the research were outlined in Chapter 1. Chapter 2 of the report presents a review of literature pertaining to theoretical frameworks, methods for water footprint accounting, related research studies assessing product water footprints of field and forage crops and derived products, economic value of water in South Africa's agricultural sector, sustainability assessment, consumer awareness and willingness to pay for water footprint labelling, social and economic impacts of proposed changes in water use behaviour, and conclusions and implications for this research. Thus, this chapter is categorised into seven sections.

The first section discusses the theoretical framework that outlines the water footprint concept, the Life Cycle Assessment, and ISO 14046. Section Two outlines methods for water footprint accounting. Under this section, the consumptive water-use-based volumetric water footprint, the Life Cycle Analysis (LCA, by Pfister et al., 2009), the Life Cycle Analysis (LCA) approach proposed by Milà i Canals et al. (2008), and the hydrological water balance method will be discussed. Section Three reviews related research studies assessing product water footprints of field and forage crops and derived products such as lucerne, irrigated pasture, milk, maize, broilers, and wheat and bread. The fourth section discusses the economic value of water in South Africa's agricultural sector. The following section discusses sustainability assessment with detailed emphasis on contextualising sustainability assessment, methods for sustainability assessment, and related research assessing sustainability of water footprints. Consumer awareness and willingness to pay for water footprint labels are discussed and presented in Section Six. Section Seven outlines the social and economic impacts of proposed changes in water use behaviour.

Chapter 3 of the report focuses on an assessment of the water footprint of milk and irrigated pasture crops, which are then used as an important feed input for the production of livestock products such as milk. The financial value that is added to the water that is used to produce milk is also explored in order to get an understanding of how the value of the water increases along the milk value chain, from the feed producers to the end consumer.

Chapter 4 discusses a case study of the water footprint of maize and broilers as derived from irrigated maize production in the Free State. This chapter firstly quantifies the volumetric water footprint indicators for the production of maize and broilers, as derived from maize production. Thereafter, a sustainability assessment is conducted, followed by the formulation of response strategies to inform the sustainable use of freshwater.

In Chapter 5, we assess the water footprint of wheat in South Africa, which is an important input in the wheat-bread value chain. The water footprints of flour and that of bread are also calculated in order to determine the total water footprint of bread along the wheat-bread value chain in South Africa. Water productivities at each stage of production within the wheat-bread value chain are also determined. The study was conducted as a case study of the Vaalharts region. Farm-level data was obtained from van Rensburg et al. (2012). A commercial processor with both a mill and bakery was used for the processing level of the value chain.

Chapter 6 investigates the possibility of creating a niche market for beef products that are produced sustainably. We examined consumer preferences and Willingness to Pay (WTP) a premium for beef products that contain labels of their environmental sustainability claims, in particularly focusing on water footprint information labelled on the products. The research specifically examines consumers' stated preferences for water footprint sustainability attributes. Discrete choice experimental data and random parameter logit model were employed in the study.

Chapter 7 examines the social and economic analysis of changed water use behaviour in South Africa. Irrigated agriculture contributes significantly to the agricultural output of South Africa. The recent worst drought in South Africa forced government, policymakers and different stakeholders to change the behaviour of direct, indirect and end use of water by policy interventions (increasing of water tariffs) and implementing water restriction interventions. This research applies a slightly modified version of International Food Policy Research Institute Computable General Equilibrium (CGE) and the SWIP – E (Soil Water Irrigation Planning – Energy) model. A recent Social Accounting of South Africa utilised as a database with other behavioural parameters.

Chapter 8 examines the water footprint and economic water productivities of feed crops and dairy products along the dairy value chain in South Africa. The research contributes to filling the gap in knowledge regarding the economic water productivity along the dairy value chain in South Africa. We estimated economic water productivity for milk and important feed crops because evidence shows that a significant proportion of water usage in the dairy sector goes into feed production. This will be the first step towards an assessment of economic water productivities for feed crops and dairy products, particularly in Africa. The economic water productivity is the value of the marginal product of the agri-food product with respect to water. The economic productivity gives an indication of the income that is generated per cubic metre of water used.

Chapter 9 examines compensating welfare estimates of water footprint sustainability policy changes in South Africa. We estimate consumers' willingness to pay and compensating surplus estimates of water footprint sustainability policy changes in South Africa. The overall effect of introducing a new product or changes in product attributes on consumer welfare is examined. Consumer surplus in this context is related to changes in the price of environmentally sustainable food products and/or their attributes.

Chapter 10 evaluates productive water use benchmarks along the wheat-bread value chain in South Africa. Efficient and wise management of freshwater resources in South Africa has become critical because of the alarming freshwater scarceness. The situation requires a thorough examination of how water is utilised across various departments that use water. Hence, this chapter reports an examination of the water footprint and economic water productivities of the wheat-bread value chain. The assessment methodology of the Water Footprint Network was employed.

Chapter 11 provides the summary, conclusions and recommendations drawn from this study. Also included in this chapter are suggestions for future research and policy options that could be adopted by different stakeholders towards sustaining the environment in terms of efficient water usage and management.

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CHAPTER 2
LITERATURE REVIEW

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2.1 INTRODUCTION

Chapter 2 is a review of the literature pertaining to the theoretical framework, methods for water footprint accounting, related research that assesses the product water footprints of field and forage crops and derived products, the economic value of water in South Africa's agricultural sector, sustainability assessment, consumer awareness and willingness to pay for water footprint labelling, social and economic impacts of proposed changes in water use behaviour, and conclusions and implications for this research. Thus, this chapter is categorised into seven sections. The first section discusses the theoretical framework which outlines the water footprint concept, Life Cycle Assessment, and ISO 14046. Section Two outlines methods for water footprint accounting. Under this section, the consumptive water-use-based volumetric water footprint, the Life Cycle Analysis (LCA, by Pfister et al. 2009), the Life Cycle Analysis (LCA) approach proposed by Milà i Canals et al. (2008), and the hydrological water balance method will be discussed. Section three reviews related research studies assessing product water footprints of field and forage crops and derived products such as lucerne, irrigated pasture, milk, maize, broilers, and wheat and bread. The fourth section discusses the economic value of water in South Africa's agricultural sector. The following section discusses sustainability assessment with detailed emphasis on contextualising sustainability assessment, methods for sustainability assessment, and related research assessing sustainability of water footprints. Consumer awareness and willingness to pay for water footprint labels are discussed and presented in Section Six. Section Seven outlines the social and economic impacts of proposed changes in water use behaviour.

2.2 THEORETICAL FRAMEWORK

Conceptually, a water footprint is internationally rooted in two approaches. These are the Water Footprint Network methodology (Hoekstra et al., 2011) and Life Cycle Assessment (LCA) methodology. The next sub-section discusses the water footprint concept according to the Water Footprint Network methodology (Hoekstra et al., 2011).

2.2.1 The Water Footprint Concept according to the Water Footprint Network Methodology

The Water Footprint Network concept has gained prominence since its introduction in 2003 by Hoekstra. Later development by Hoekstra et al. (2011) described the water footprint as an all-inclusive indicator of freshwater usage and can be examined along with the traditional and restricted measures of water withdrawal. The overall goal of the water footprint concept is to investigate the sustainability of freshwater use, and this is attained by relating the water footprint to the freshwater availability (Hoekstra and Mekonnen, 2011; Hoekstra et al., 2012).

Hoekstra et al. (2011) classified water footprints into blue, green, and grey footprints. The blue water footprint is referred to as the volume of surface and groundwater consumed along a product’s life cycle. Consumptive water use refers to the loss of surface or groundwater from a catchment (Hoekstra et al., 2011). The losses can occur through incorporation into the product, evaporation, or when the water runs into a different catchment. The green water footprint is the rainwater that has evapotranspired through the vegetation and is incorporated into the product. The volume of freshwater needed to reduce the pollutants to ambient levels is referred to as the grey water footprint. Depending on the degree of pollution of water, a given quantity of freshwater is needed to assimilate the load of pollutants to acceptable standards.

The water footprint concept is multidimensional and considers all the water used according to the sources from which the water is extracted, and the volumes of freshwater necessary to assimilate polluted water to ambient levels. Thus, the water footprint concept reveals water consumption volumes by source, and polluted volumes by type of pollution (Hoekstra et al., 2011). Different types of water footprint assessments can be conducted to evaluate the impact of human behaviour on sustainable water use (Hoekstra et al., 2011). A water footprint can be defined in different forms, as follows:

- **Water footprint of a consumer or group of consumers**
  Hoekstra et al. (2011) defined the water footprint of a consumer or group of consumers as the total volume of water used for the production of goods and services used by those consumers. Both freshwater consumed and the amount of water polluted during the course of production are taken into account. When a group of consumers is considered, one simply sums the water footprints of the individual consumers. The water footprints of consumers are expressed as the volume of water per unit of time, or as the volume

of water per monetary unit obtained, by dividing the volume of water per unit of time by the income. Where a group of consumers is concerned, the water footprint can be expressed as the water volume per unit of time per capita. The water footprint of a consumer or group of consumers gives an understanding of the cumulative impact that these individuals have on water resources.

- **Water footprint of a geographically delineated area**
  This is defined as the total volume of water consumed and polluted within the boundaries of a delineated area. Typical areas include catchments and river basins, states, provinces, nations, or any other administrative spatial unit. The water footprint for a spatial unit is stated as the volume of water per unit of time. Calculating the water footprint for a geographically delineated area is usually part of a larger assessment of the sustainability of the water resources in the target area.

- **Water footprint of a business**
  The water footprint of a business refers to the sum of the water footprints of the business outputs. This business water footprint can then be further divided into the direct (operational) and indirect (supply chain) water footprints. This can also be defined as the total volume of water used, both directly and indirectly, in the business operations. The direct water footprint is the total volume of water used and polluted in a business's own operations, while the indirect water footprint is the total volume of water used and polluted in order to obtain the inputs required for the business's operations. A business's water footprint aims to assess a specific business's impact on water resources. Often, a business's water footprint is largely "imported" from elsewhere in the form of water-intensive inputs produced in other catchments.

- **Water footprint of a product**
  The water footprint of a product refers to the volume of freshwater used to produce the product and is evaluated along the complete value chain of the product. All the steps along the complete value chain of the specific product are considered. Product water footprints are often calculated to enable comparisons to be made between products, often on the basis of volume of water per caloric unit, with the aim of determining the sustainability of water resources.

This concept consists of four phases, namely (1) setting the scope of the study; (2) the water footprint accounting phase where the volumetric water footprint indicators of all the products in this value chain are determined; (3) water productivities assessment, quantifying the value of water; and lastly (4), response formulation where policy recommendations are made. Water footprint evaluation is also well grounded from the Life Cycle Assessment (LCA) perspective. The next sub-section discusses the concept of a water footprint according to the Life Cycle Assessment (LCA).

2.2.2 Life Cycle Assessment

The life cycle assessment (LCA) is extensively accepted and applied in environmental management as a tool for measuring various environmental impacts (Berger and Finkbeiner, 2010). Water footprint assessment in an LCA approach focuses on the environmental impacts associated with water use. Water footprint assessment in LCA does not consider the economic and social impacts. All stages of the life cycle of the product under investigation are considered, starting at raw material acquisition through to the disposal of the final product. An LCA assessment consists of four phases that are included to ensure the completeness of the assessment. These are:

1. Definition of the goal and scope of the assessment
2. Water footprint inventory analysis
3. Water footprint impact assessment
4. Interpretation of the results.

A water footprint assessment using an LCA approach can be done independently (stand-alone) or factored into a wider environmental assessment. In the LCA, the origins of water sources are not considered, as they are in the Water Footprint Network (WFN) approach. LCA does not directly account for green water use. However, Ridoutt and Pfister (2010) have argued that because the use of green water is directly related to the occupation of land, it is accounted for elsewhere in a complete LCA. Hence, Berger and Finkbeiner (2010) argue that green water is particularly essential in crops and livestock production, and as such, failing to account for it does not give an accurate measure of the true water used, particularly in the agricultural sector. Although the LCA accounts for blue water, the deterioration of water quality is accounted for through other impact assessments such as freshwater ecotoxicity or eutrophication (Jefferies et al., 2012).

2.2.3 ISO 14046

ISO 14046 serves as a guideline as to what to include in a comprehensive water footprint assessment. The aim of this International Standard is to ensure a form of consistency between the different methodologies. This was done by standardising the terminologies used in the calculation and reporting the various methods. According to ISO 14046, the term "water footprint" can only be quantified when a comprehensive impact assessment is undertaken. The ISO 14046 is based on the LCA approach and identifies potential environmental impacts that are associated with water use. It also observes changes in water quality and water use over time and across geographical dimensions (ISO/TC207, 2014).

ISO 14046:2014 does not recommend a particular methodology for the assessment of a water footprint, but it does serve as a guide as to what should be considered in the calculation of a complete water footprint assessment. ISO 14046 defines a water footprint as the quantification of the potential environmental impacts related to water, and is based on the LCA approach to environmental impact. A water footprint assessment conducted according to this international standard must be compliant with ISO 14044:2006 and should therefore include the four phases of a LCA. Although both the LCA and WFN approaches can be used to evaluate the water footprints of products in South Africa, the guidelines of the ISO 14046 must also be kept in mind in the reporting of the water footprint indicators of South Africa. The WFN approach is employed in this study for water footprint assessment because it gives comprehensive indicators of freshwater use, as it directly accounts for blue, green and grey water utilisation.

2.3 METHODS FOR WATER FOOTPRINT ACCOUNTING

The relevance of water sustainability and the crucial need to protect the restricted available freshwater have prompted various authors to come up with different water footprint calculation methods. The existing methods of assessing water footprint are described in the following sub-sections

2.3.1 Consumptive Water-Use-Based Volumetric Water Footprint

This method is recognised by the Water Footprint Network. It was originally developed by Hoekstra (2003) and endorsed by the Water Footprint Network (WFN). Under this method, the assessment of a water footprint is categorised into three distinct sources of the water, namely blue, green, and grey water. Figure 2.1 describes the components of a water footprint as described in terms of the consumptive water-use based volumetric water footprint method. A shown in Figure 2.1, the total water footprint is categorised into three aspects, with the aim of identifying the origin of the water. Surface and groundwater are clearly separated. Rainfall that does not become runoff but for degradation of water quality are distinctly separated. This implies that the water footprint concept takes into account the blue, green and grey components of a water footprint, as well as indirect water usage. As shown in Figure 2.1, the return flows are excluded from water footprint evaluations.

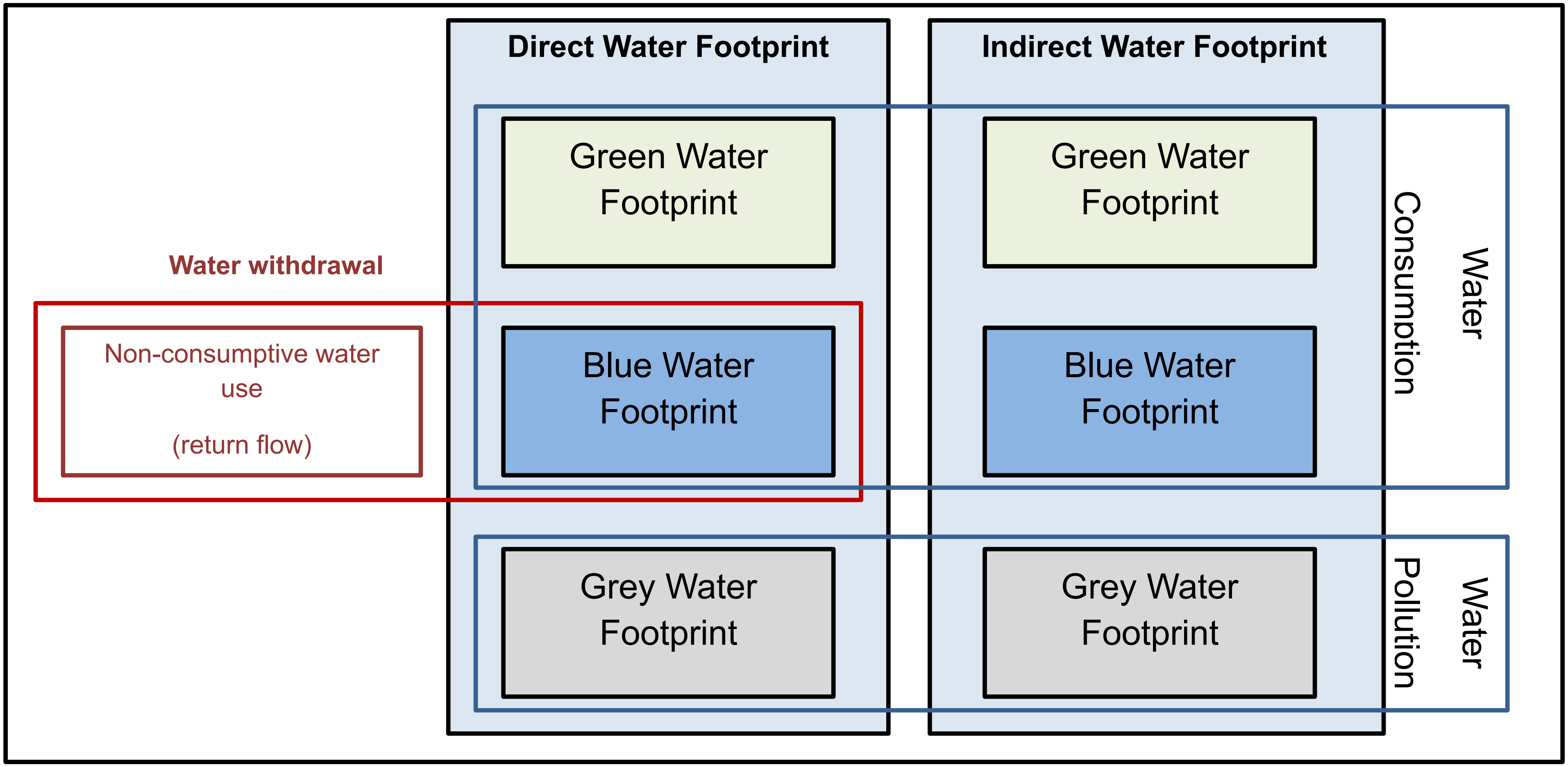

Figure 2.1: Components of a water footprint as described in a consumptive water-use-based volumetric water footprint method
Source: Hoekstra et al. (2011)

- **Blue water footprint**

This component of a water footprint comprises all the surface and groundwater utilised in a product's life cycle (Hoekstra et al., 2011). The blue water footprint is an indicator of fresh surface or groundwater consumed. Blue water consumptive uses include the quantity of water evaporated and the quantity that goes into the product, water lost to different catchments (including water transfers), and water abstracted during periods of limited supply and returned in times of excess supply. However, evaporation has been found to be the most significant component of blue water consumption, and hence consumptive use is often linked to evaporation.

However, the other components should not be excluded in assessing a blue water footprint (Hoekstra et al., 2011). It must be emphasised that the consumptive use does not suggest that the water disappears from the hydrological cycle; rather, it suggests that the water is not immediately available for alternative use. This is expressed empirically as:

$$WF_{proc,blue} = blue\ water\ evapotranspiration + blue\ water\ incorporation + loss\ return\ flow \qquad (2.1)$$

- **Green water footprint**

This consists of all the rainwater that is evapotranspired or goes into the product. It can also be described as rainwater kept in the soil and which is only available for vegetation transpiration. Hoekstra et al. (2011) defined this as the total amount of rainwater utilised in a production cycle. The green water footprint for agricultural and forestry production is very relevant. Empirically, it is expressed as:

$$WF_{proc,green} = green\ water\ evapotranspiration + green\ water\ incorporation \qquad (2.2)$$

In the context of agriculture, models that are suitable for estimating evapotranspiration of crops, based on soil, crop and climate data, can be used to assess green water consumption.

➢ **Grey water footprint**

This is defined as the amount of freshwater needed to reduce water pollutants to acceptable standards (Hoekstra et al., 2011). Thus, polluted water requires large quantities of freshwater to "dilute" loads of contaminants to acceptable standards. The volumetric-based grey water footprint does not include an indication of the extent of damage caused by the pollutants to the environment, but this is simply a method to include the amount of water required to reduce the pollution to acceptable norms. This is also expressed empirically as:

$$WF_{proc,grey} = \frac{L}{c_{max} - c_{nat}} \qquad (2.3)$$

The "*L*" in the calculation is the pollutant load (in mass/mass) that is discharged into the water body. This load is divided by the difference between the acceptable water quality standard for that pollutant (the maximum acceptable concentration c_{max} in mass/mass) and the natural concentration in the receiving water body, c_{nat} (in mass/mass).

The total water footprint is obtained by summing the different types of water footprints. This is expressed as:

$$WF_{\mathrm{Pr}oc} = WF_{proc,blue} + WF_{proc,green} + WF_{proc,grey} \qquad (2.4)$$

Two alternative approaches could be employed in examining the total water use along a product cycle. The two approaches are the chain-summation approach and the stepwise accumulative approach (Hoekstra et al., 2011). The first approach is employed in a production process with a single output. Such cases rarely exist in practice, where one can simply divide the total water usage by the output. The second approach is more general and is applicable to production processes that have more than one input and several outputs. The above discussions are highlighted in Figure 2.1.

2.3.2 Stress-Weighted Water Life Cycle Analysis (LCA) by Pfister et al. (2009)

This method was suggested by Pfister et al. (2009). The distinction between the LCA method and the consumptive volumetric-based method is that the LCA reveals the effect of water usage on a specific geographical area or region (van Der Laan et al., 2013). The basis for assessing the water footprint should be the stress-weighted water approach, as described in the LCA methodology (Pfister et al., 2009). However, the authors stated that much emphasis is placed on the quantities of water used, with little emphasis on water sources and the type of water use. The sources of water and the type of water use should be accounted for when using the LCA method to evaluate the water footprint, particularly at the inventory phase (Pfister et al., 2009).

In the LCA methodology, consumptive water use is defined to consist of all the freshwater withdrawals that go into different water catchments, to be incorporated into the products or evaporated. Changes in the quality of water that returns to the original water source are described as degradative use, according to Pfister et al. (2009). This methodology attributes much importance to consumptive use and virtual water. The virtual water includes blue and green water. A further review of the LCA approach by Pfister et al. (2009) shows that only a blue virtual water footprint is accounted for. The authors argued that green water does not add to environmental flows unless it becomes blue, and hence the LCA methodology does not directly include a green water footprint. Green water is linked to land use and is only available through the use of land.

The calculation of the water quantities used in a product cycle follows the virtual water database developed by Chapagain and Hoekstra (2004). After calculating the volume of water used, the Water Stress Index (WSI) is further estimated. The WSI examines whether the freshwater withdrawal surpasses the water body's replenishment capacity. The estimation of WSI is based on the water usage (WU) to water availability (WA) ratio (WTA), described by van Der Laan et al. (2013). The WaterGAP2 global model is also applied (Pfister et al., 2009). The WaterGAP2 global hydrological water availability model uses data from the period 1961 to 1990. Hence, the annual average water availability is used. The application of such dataset allows for annual estimations to be made and does not support short periods of severe water stresses. Hence, estimations of WTA are done using annual data only. A variation factor (VF) is usually included in the model to cater for monthly variations in precipitation. Pfister et al. (2009) highlighted the point that water catchment facilities (dams) decrease the change in water supply, and hence controlled catchments require a reduced variation factor (Pfister et al., 2009).

The WTAs in regulated and unregulated catchments are calculated as follows:

$$WTA_{\text{Regulated catchments}} = \sqrt{VF} \times \frac{WU}{WA} \tag{2.5}$$

$$WTA_{\text{Non-regulated catchments}} = VF \times \frac{WU}{WA} \tag{2.6}$$

$$VF = e + \sqrt{\ln(S_{month})^2 + \ln(S_{years})^2} \tag{2.7}$$

The variation factor is the overall measure of dispensation of the multiplicative standard deviation of the annual S_{Year} and monthly S_{Month} precipitation (Pfister et al., 2009). The WTA is employed in the estimation of WSI because the WSI is nonlinear in WTA. Hence, there is the need to adopt a logistic function. This helps in the attainment of continuous variables ranging between 0.01 and 1 (Pfister et al., 2009).

$$WSI = \frac{1}{1 + e^{-6.4WTA}(\frac{1}{0.01} - 1)} \tag{2.8}$$

The minimum value of WSI should be 0.01. The impact of water withdrawal at the minimum point will be marginal. The WSI value should not exceed one. A WSI value of 1 implies that there is extreme water stress (van Der Laan et al., 2013). The LCA approach does not directly account for grey water, as does the consumptive water-use-based volumetric water footprint approach described by Hoekstra et al. (2011). Water quality is indirectly included in other impact assessments, such as freshwater toxicity or eutrophication (Ridoutt and Pfister, 2010).

2.3.3 Life Cycle Analysis (LCA) Approach Proposed by Milà i Canals et al. (2008)

This methodology distinguishes Freshwater Ecosystem Impacts (FEI) from Freshwater Depletion (FD). This methodology uses several assumptions to arrive at the final impact estimates (Pfister et al., 2009). Under this methodology, the blue and green water entities are differentiated. The blue water under this methodology is defined as the total ground and surface water that can be abstracted. Water flows in a form of rain water or water in rivers, and groundwater reserves and water stocks are classified under this method. The authors assumed that various crops and natural vegetation have similar water requirements, and as such, they concluded that green water would not vary if crops were to be produced instead of natural vegetation. Green water is considered relevant under this methodology only when a blue water footprint is to be estimated. This implies that green water becomes irrelevant if blue water footprint calculations are not required (Milà i Canals et al., 2008). Understanding the LCA and ISO water footprint, a response to Hoekstra (2016). A critique on the water-scarcity weighted water footprint in LCA was presented by Pfister et al. (2017).

A distinction is made concerning non-evaporative and evaporative water uses. Milà i Canals et al. (2008) described water use as non-evaporative if the water used returns to the source where it originated from and can be used for other purposes. On the other hand, the water becomes evaporative if it is exhausted and not available for immediate use by other water users (Milà i Canals et al., 2008). The contribution from this methodology has to do with the addition of a land use variable, which is argued to have a significant effect on water availability. The authors explained that some farming systems impact significantly on rainwater availability. For instance, tilled lands dry faster than lands with vegetation cover do. Thus, land with vegetation cover can contain soil water for a longer period, compared with tilled land with no vegetation cover. This methodology accounts for the impact of land use in calculating a water footprint. The contribution of land use to a water footprint is calculated by deducting the water loss from a reference land use from the water loss from a specific plot or area of land under consideration (Milà i Canals et al., 2008). The Water Stress Indicator (WSI) used under this methodology is expressed as:

$$WSI = \frac{Water\ use}{Water\ Resource\ Available - Ecological\ Water\ Requirement} \tag{2.9}$$

The application of this formula gives detailed information regarding water availability for other purposes, since the water required by the ecological system is accounted for (Milà i Canals et al., 2008). The water loss attributable to land use is estimated and added to blue water use. The sum of these two water sources is multiplied by the Water Stress Indicator (WSI). The value obtained is used as a classification factor. The volume of depleted freshwater is estimated by the formula:

$$ADP_l = \frac{ER_l - RR_l}{(R_l^2)} \times \frac{R_{rs}^2}{(DR_{rs}^2)} \qquad (2.10)$$

where *l* is the relevant water resource, *rs* refers to the reference resource, ER_l is the resource's extraction rate, RR_l is the resource's regeneration rate, R_l is the resource's ultimate reserve, R_{rs} is the reference resource's ultimate reserve, and DR_{rs} is the reference resource's deaccumulation rate.

2.3.4 Hydrological Water Balance Method

This method builds upon the water balance method conceptualised by Hoekstra et al. (2011) and was described by Deurer et al. (2011). What is unique about this method is that it does not focus only on consumptive water, but also accounts for the water balance (van Der Laan et al., 2013). The description of the components of a water footprint follows Hoekstra et al. (2011). However, there is a slight difference in the estimation procedure (Deurer *et al*., 2011). Unlike Hoekstra et al. (2011), the estimated water footprints derived from the hydrological water balance method can be either positive or negative. Deurer et al. (2011) explained that in situations where the total blue water abstracted is higher than the water recharge is, either through return flows or through rainfall, then a positive water footprint is attained. On the other hand, if the water recharge through return flows and rainfall exceeds the blue water abstraction, then a negative water footprint is observed. Hence, a negative water footprint gives an indication of blue water sustainability (Deurer et al., 2011). The hydrological water balance method is specified empirically to include the amount of water that flows into a catchment, the amount that flows out, and storage variations (Deurer et al., 2011). Green water under the hydrological water balance method is specified as:

$$\Delta Green\ water = D^r + ET^r + R^r - RF \qquad (2.11)$$

where ET^r represents evapotranspiration during rainfall season, *RF* is the effective rainfall (rainfall – quantity of water intercepted by crops), D^r is the drainage under rain-fed conditions, and R^r is the runoff during rainfall. The blue water footprint, on the other hand, is expressed as:

$$\Delta Blue\ water = D^r + D^{ir} + R^r + R^{ir} - IR \tag{2.12}$$

where D^r denotes the drainage under rain-fed conditions, D^{ir} represents the difference between drainage under rain-fed and irrigated conditions, R^r denotes the runoff in rain-fed settings, R^{ir} represents the difference between runoff under rain-fed and irrigated conditions, and IR denotes the annual amount of water utilised for irrigation. The grey water footprint calculation follows the formula described by Hoekstra et al. (2011), as specified in Equation 2.3. The total water footprint is obtained by summing all the different components estimated (Herath et al., 2013).

2.3.5 Discussion of Methods

The above review shows that the methods of calculating a water footprint vary from one method to the other. As discussed, the consumptive water-use-based volumetric water footprint takes into consideration all the components of water used (blue, green, and grey), with clear distinctions made between the sources of water. The stress-weighted water LCA directly focuses on the blue water footprint, without accounting for a green water footprint, because the developers of this methodology believe that green water is inseparable from land use. The adapted LCA water footprint method, however, concentrates on green and blue water resources. Blue water under this methodology is categorised into groundwater, which is also referred to as fund, fossil groundwater, identified as stock and rivers or flows. The last method, the hydrological water balance, assesses blue, green, and grey water footprints, but on an annual basis and at local levels. This approach categorises the hydrological system into inflows, outflows and storage. Since the consumptive water-use-based volumetric water footprint takes into account, and clearly differentiates between, different water footprint components, this approach was employed to calculate the water footprint of the selected agricultural products in this research.

2.4 RELATED RESEARCH ASSESSING PRODUCT WATER FOOTPRINTS OF FIELD AND FORAGE CROPS AND DERIVED PRODUCTS

The assessments of water footprints of field and forage crops and derived products have received some attention in literature. In this section, we review some of the relevant papers that have assessed water footprints of field and forage crops such as lucerne, irrigated pasture, and wheat and maize used for the production of derived products like milk, broiler chicken and bread.

2.4.1 Water Footprint of Lucerne

The water footprint of lucerne has received little attention in recent literature. The existing literature is limited to that of Scheepers and Jordaan (2016) who assessed the blue and green water footprints of lucerne for milk production in South Africa. The authors found that it takes a volumetric water footprint indicator of 378 m^3 to produce a ton of lucerne. Of the total blue and green water footprint, 55% is the green water footprint and 45% is the blue water footprint. Thus, albeit in a major irrigation area of South Africa, the largest component of the total water requirement is met by effective rainfall. The assessment of sustainability of water use showed that the period when lucerne requires irrigation water furthermore corresponds to the period where the water scarcity index is smaller than 100%.

It was revealed that, although a substantial amount of freshwater is used, the water use for lucerne production at Vaalharts is environmentally sustainable (Scheepers and Jordaan, 2016). The blue water abstracted for lucerne production does not modify the natural run-off significantly, and the environmental flow requirement is met. Interestingly, although lucerne production is dependent on irrigation water, the green water footprint is the largest component of the total water footprint of lucerne production at Vaalharts. The producers prove to use rainfall effectively for the production of lucerne in the study area. By effectively using rainfall, the lucerne producers decrease the pressure on the scarce blue water resource. Especially in semi-arid and arid regions around the world, land management practices associated with improved water storage capacity of the soil may contribute significantly towards decreasing the demand for blue water, hence relieving the pressure on the scarce freshwater resource.

2.4.2 Water Footprint of Irrigated Pasture

The estimation of the water footprint for feed followed the method outlined in the work of Mekonnen and Hoekstra (2010). As indicated by Mekonnen and Hoekstra (2010), the feed ingredients for formulating feed ration in a country come from both domestic production and imported products. Therefore, the weighted average water footprint according to the relative volumes of domestic production and imports in the calculation of the water footprint of animal feed is adopted (Mekonnen and Hoekstra, 2010). After estimating the water footprint of the feed, it is worth noting that the composition and the volume of the feed need to be determined, given that feed consumption varies depending on breed of animal, the production system and the country. Total dry matter intake, feed conversion efficiency, and milk output per cow were recorded using electronic feed calculators. The irrigated pasture and feed crops considered include lucerne, cocksfoot, perennial ryegrass, tall fescue, white clover and kikuya as well as mixtures of these crops.

2.4.3 Water Footprint of Milk

While the Water Footprint Network and others have conducted and published water footprint assessments for a variety of different products, the focus of this discussion will be placed specifically on dairy-related research. Research studies exploring the water footprints of dairy products include those by Mekonnen and Hoekstra (2010), who carried out a global assessment of water footprints of dairy products; De Boer et al. (2012), who conducted a case study in the Netherlands; Ridoutt et al. (2010), who explored the water footprint of skimmed milk powder in Australia; and Murphy et al. (2013) and Manazza and Iglesias (2012) who explored the water footprints of dairy in Ireland and Argentina, respectively.

Mekonnen and Hoekstra (2010) used the WFN approach to estimate the water footprints of several animal products and compiled the estimated national averages for the products in many different countries. Their results are, therefore, not site-specific, but rather national averages. Among the product water footprints that were estimated, they distinguished between milk with a fat content of less than one per cent, milk with fat content greater than one per cent but not exceeding six per cent, and milk with more than six per cent fat content. For South Africa, they estimated that an average of 1 136 litres of water was required to produce 1 kilogram of milk (fat content 1-6%). Of the required 1 136 litres of water, 1 053 litres was green water, 42 litres was blue water, and the remaining 41 litres was grey water.

In the same study, Mekonnen and Hoekstra (2010) calculated the water footprint of Dutch dairy production, where their study was based on the average Dutch dairy farm. They estimated that the production of 1 kilogram of Dutch milk with a fat content of between one and six per cent required, on average, 544 litres of water. This water is made up of 477 litres of green water, 42 litres of blue water, and 25 litres of grey water.

A different Dutch study was undertaken by De Boer et al. (2012) in order to assess the environmental impacts associated with freshwater consumption of animal products, with a case study of dairy production in the Noord-Brabant province. They combined Life Cycle Analysis (LCA) with site-specific and irrigation-requirement modelling in order to assess the freshwater impact along the life cycle of milk production. They found that about 76% of the 66 litres of consumptive water used to produce 1 kg of fat-and-protein corrected milk was used for the irrigation of the feed crops. The remaining consumptive water use was for the production of concentrates (15%) and drinking and cleaning services (8%).

The results of De Boer et al. (2012) differ from the results obtained by Mekonnen and Hoekstra (2010) mainly because Mekonnen and Hoekstra (2010) calculated the water footprint for the average Dutch dairy producer, while De Boer et al. (2012) based their research on a site-specific case study that made significantly more use of intensive irrigation than the average Dutch dairy farm did. If a different case study concerning soil that was less drought sensitive, the 66 litres of blue water used was estimated to decrease to about 16 litres, compared with the 42 litres estimated by Mekonnen and Hoekstra (2010) and De Boer et al. (2012).

Ridoutt et al. (2010) used the Life Cycle Analysis (LCA) to calculate the water footprint of dairy production in the South Gippsland region of Victoria, Australia. This was the first comprehensive water footprint study of the dairy industry calculated with the LCA method. Their research involved a case study of skim milk powder. Based on the revised LCA method of Ridoutt and Pfister (2010), the green water was not included in the methodology because it is only accessible through the direct occupation of land and does not contribute to environmental flows until it becomes blue water. In the results, it was found that a litre of milk produced in South Gippsland used 14.1 litres of blue water, of which 83% was used on the farm for production. The remaining blue water was associated with the production of inputs used on the farm.

In Argentina, Manazza and Iglesias (2012) conducted a study on the water footprint of the milk agri-food chain. It is interesting to note that they chose to use an adapted version of the LCA method to calculate the water footprint, which is in contrast with the other studies of dairy value chains. Murphy *et al*. (2013) followed the literature defined by Hoekstra *et al.* (2011) to assess the water footprint of dairy production in Ireland. However, the focus of this study was solely on the dairy production, or from "cradle to farm gate". Their aim was therefore to only calculate the water used in the physical production of the milk, and not the complete dairy value chain (Murphy *et al*., 2013).

2.4.4 Water Footprint of Maize

Several WFA studies have been published by various authors, such as Ercin, Mekonnen and Hoekstra (2013), Mekonnen and Hoekstra, (2010), Sun *et al*. (2013), and others. This sub-section will identify what was done, how it was done, and the findings thereof. The purpose of this paper is to investigate the water footprint of maize and broiler as derived products. The water footprint of crop production is an inclusive indicator that can indicate water consumption types, volumes, and the effect on the environment (Sun *et al*., 2013). In their study, Sun *et al.* (2013) evaluated how climate change affected the crop water requirements and irrigation water requirements of maize production during the period 1978 to 2008. They investigated the extent to which the green, blue, and grey water footprints of maize production varied each year in response to climate change and the use of agricultural inputs. They also assessed the main factors that contributed to changes in the water footprint of maize production.

Sun *et al.* (2013) used the non-parametric Mann-Kendall test to evaluate climatic factors, and the volumetric water footprint approach to water footprinting. They used the correlation and path coefficient analysis to determine the relationship between the water footprint and its associated impact factors. They found that the crop water requirement increased by about 0.52 mm per annum, whereas the irrigation water requirement for maize tended to increase by about 2.86 mm per annum. These increases may be attributed to variations in climatic conditions, which exhibited an average trend of increasing temperatures and decreasing rainfall. The total water footprint and green water footprint exhibited decreasing trends, whereas the blue and grey water footprints showed increasing trends in response to the combined effect of climate variation and agricultural inputs. Sun *et al*. (2013) concluded that a decrease in effective precipitation would lead to a decrease in the green water footprint, and an increase in the blue water footprint. Furthermore, an increase in agricultural inputs such as chemical fertilisers would lead to an increase in the grey water footprint (Sun *et al*., 2013).

Mekonnen and Hoekstra (2014) found that the consumptive water use of maize (m^3.ton) varied across the globe, and they therefore divided the water use into percentiles. The consumptive water use of maize was 754 m^3.ton in the 50^{th} percentile, with a global average of 1 028 m^3.ton. According to Mekonnen and Hoekstra (2014), if the global green and blue water footprint were reduced to the 50^{th} percentile, there would be a 35% reduction in the consumptive water use. The grey water footprint of maize production in the 50^{th} percentile was 171 m^3.ton, with a global average of 194 m^3.ton. If the grey water footprint of all the countries in the world could be reduced to the 50^{th} percentile, there would be a 23% decline in water pollution (Mekonnen and Hoekstra, 2014). At the 50^{th} percentile, the reduction in water pollution translates to a 23% increase in water availability, worldwide (Mekonnen and Hoekstra, 2014). Mekonnen and Hoekstra (2014) concluded that the water footprint benchmark values may be used for comparison with the water footprint in a particular region or may be used as a reduction target. Given the considerable increase in water availability, the global benchmarks are attractive water footprint reduction targets for crop farmers.

Maize is used in the food industry as a sweetener to manufacture high-fructose maize syrups (HFMS) and to produce ethanol (Gerbens-Leenes and Hoekstra, 2009). About three-quarters of the ethanol produced worldwide is used as a fuel. The United States of America (USA) was the leading manufacturer of ethanol derived from maize in 2005 (Gerbens-Leenes and Hoekstra, 2009). According to the FAO (2008), ethanol production in the USA contributes about 43% to global bio-ethanol production. In 2019, the demand for maize in the USA for the purpose of producing ethanol is anticipated to increase to approximately 40% of total maize production (Gerbens-Leenes and Hoekstra, 2009). Producing ethanol by dry milling requires about 1 735 litres of water per ton of maize (Gerbens-Leenes and Hoekstra, 2009). In contrast, wet milling consumes about 1 921 litres per ton of maize (Gerbens-Leenes and Hoekstra, 2009). Hence, producing ethanol by dry milling rather than wet milling would save 186 litres of water per ton of maize.

About 95% of the ethanol produced globally is derived from crops such as maize (Gerbens-Leenes and Hoekstra, 2009). Maize is the second most-suitable crop for sugar and ethanol production in the world (Gerbens-Leenes and Hoekstra, 2009). The global average water footprint of HFMS 55 in particular is 1 125 m^3.ton, and for ethanol derived from maize it is 1 910 litre.litre (Gerbens-Leenes and Hoekstra, 2009). However, in the USA alone, maize has the lowest water footprint associated with producing sugar and ethanol (Gerbens-Leenes and Hoekstra, 2009). The average water footprint of HFMS 55 and ethanol derived from maize starch in the USA is 720 m^3.ton and 1 220 litre.litre, respectively. The maize products mentioned above primarily owe the degree of their water footprints to the maize water requirement and yields realised (Gerbens-Leenes and Hoekstra, 2009). Crop water requirement is a function of crop type, climate, and soil characteristics. Yields, on the other hand, have an inverse relationship with the water footprint (Gerbens-Leenes and Hoekstra, 2009). In other words, assuming that water use remains constant, increasing yields per hectare will effectively reduce the water footprint per ton of maize. In South Africa, the total water footprint of ethanol derived from maize is 4 264 litre.litre. It is comprised of 3 879 litres of green water, 79 litres of blue water, and 306 litres of grey water per litre of ethanol (Mekonnen and Hoekstra, 2010).

Maize production accounts for one of the highest green water footprints, the third largest blue water footprint, and the highest grey water footprint in Latin America and the Caribbean (Mekonnen *et al*., 2015). Despite its relatively low economic water productivity (EWP) of 0.10 US$/$m^3$ (Mekonnen *et al*., 2015), maize production accounts for a considerable share of freshwater consumption in Latin America and the Caribbean. Mekonnen *et al*. (2015) recommended the productive and efficient use of green water in rain-fed agriculture in order to increase production and minimise the demand for blue water resources, especially in water-scarce areas. They also recommended that there should be communication with small-scale farmers, river basin managers, and policymakers, as well as readily available water data at the river basin level. Regarding the grey water footprint, Mekonnen *et al*. (2015) suggested that fertiliser applications should be optimised and the discharge of untreated water from the domestic sector must be reduced in order to lower nutrient pollution. It is therefore important to devise methods for increasing the productivity of green water and lowering the grey water footprint and to establish a platform for river basin managers to communicate water data to policymakers and farmers.

Mekonnen and Hoekstra (2014) measured the water footprint of Kenya related to national production and consumption for the period 1996 to 2005, as well as the virtual water exports and imports of Kenya. Their aim was to evaluate the relationship between water consumption within Kenya and its international trade. Mekonnen and Hoekstra (2014) quantified the green, blue, and grey water footprints using the volumetric water footprint approach. The total water footprint of crop production in Kenya from 1996 to 2005 consisted of 97% green water, 1% blue water, and 2% grey water (Mekonnen and Hoekstra, 2014). Mekonnen and Hoekstra (2014) identified maize as the crop with the highest total water footprint related to crop production. Maize production accounted for 38% of the total water footprint (6 794 million m^3/year; 6 688 million m^3 green water, 11 million m^3 blue water, and 96 million m^3 grey water) related to crop production (Mekonnen and Hoekstra, 2014). Despite the high total water footprint of maize production, maize has a lower water footprint per tonne than various other crops do. The water footprint of maize per tonne is 2 746 m^3, of which 2 703 m^3.ton is green water, 4.4 m^3.ton is blue water, and 39 m^3.ton is grey water (Mekonnen and Hoekstra, 2014). Maize, coffee, and potato production account for more than 150 million m^3 of nitrogen fertiliser that leaches from crop fields.

According to Mekonnen and Hoekstra (2014), the EWP of maize production in Kenya is 0.09 US\$/m^3. Given the expected growth in the population from an estimated 9725 million in 2050 to 11 213 million in 2100 (United Nations (UN), 2015), as well as the changing consumption patterns, the blue water resources will drop from an estimated 316 m^3 per capita in 2050 to 192 m^3 per capita in 2100. This is quite low, considering that an adequate diet requires about 1 000 m^3/year per capita (Falkenmark et al., 2009).

In addition to the production of crops with a high EWP, Mekonnen and Hoekstra (2014) recommended that these crops must preferably be produced from green water. A large contribution to addressing water scarcity lies in the productive use of green water. Increasing maize yields per hectare will promote the productive use of green water by lowering the green water use per tonne of maize. Attention must also be paid to changes in the population size and consumption patterns in South Africa, over time, to estimate changes in blue water per capita. It will also be informative to quantify the extent to which maize production contributes to changes in blue water per capita.

Ercin, Mekonnen and Hoekstra (2013) examined the allocation of freshwater in France and analysed the extent to which production affected the country's state of water supply. They measured the volume of freshwater used in the production of products destined for export and the impact thereof. Ercin et al. (2013) investigated the degree to which France relies on virtual water imports, as well as the impact thereof on the exporting country. They followed the volumetric water footprint approach to quantify water use in France. Ercin et al. (2013) found that agricultural production made up 89% (80 Gm^3/year) of the total water footprint of production in France. Crop production accounted for 82% of the total water footprint of national production (Ercin et al., 2013). The water footprint of maize production was determined as 14% of the total water footprint of agricultural production (Ercin et al., 2013). Maize production accounted for the largest share of the blue and grey water footprints related to crop production. The blue water footprint of maize production accounted for 50% of the total blue water footprint of crop production, while the grey water footprint of maize production contributed 30% to the grey water footprint of crop production (Ercin et al., 2013). However, the green water footprint of maize production made up only 10% of the total green water footprint associated with crop production (Ercin et al., 2013). Thus, maize production accounts for the third largest share of the green water footprint of crop production in France.

France is a net importer of virtual water. Crop products constitute 69% of the virtual water exports (Ercin et al., 2013). The green water footprint of exported goods is 70%, the blue water footprint is 11%, and the grey water footprint is 18% (Ercin et al., 2013). Maize products make up 9% of the green water footprint of the goods exported to foreign nations, 17% of the blue water footprint, and 10% of the grey water footprint (Ercin et al., 2013). Maize production, among others, contributes considerably to the water scarcity experienced in various river basins at different times of the year (Ercin et al., 2013). This water scarcity has certain implications for the biodiversity in the vicinity of the river basins (UNEP, 2008). An identification of maize products whose water footprints contribute significantly to water scarcity could assist in devising effective methods to address the issue in the relevant river basins (Ercin et al., 2013). Linkages between products purchased by consumers and water scarcity in a relevant region are the basis on which Ercin et al. (2013) recommended that a consumer product policy should be part of a water policy.

In South Africa, the blue and grey water footprints of maize production must be compared with the blue and grey water footprints of other field crops. The contribution of maize production to the water scarcity of river basins must be quantified and assessed. Broilers are derived maize products and as such, their production should be assessed in terms of water use to ascertain the extent of their contribution to water scarcity. Consumer product policies will go a long way in communicating the degree of water scarcity to the final consumer.

The agricultural sector constituted 96% and crop production 92% of the total water footprint of agricultural production in this basin (Zeng *et al*., 2012). Maize production assumed an 11.1% share of the water footprint of crop production in the Heihe River Basin (Zeng *et al*., 2012). Maize thus had the second largest consumptive water footprint. Zeng *et al*. (2012) proposed optimising the crop planting patterns in order to ensure sustainable water use. Considering the contribution of green water to agricultural production, particularly crop production, which is the largest consumer of green water, Zeng *et al*. (2012) recognised the efficient use and management of green water resources as a prerequisite for improving the water management of a river basin and addressing food security.

2.4.5 Water Footprint of Broilers

Mekonnen and Hoekstra (2012) conducted a global assessment of the water footprint of farm animal products. They took into consideration differences in production systems, feed composition and countries. Their aim was to conduct an all-inclusive global assessment of the water footprints of farm animal products by determining the water footprint of farm animals and their derived animal products following a particular production system in a particular country for the period 1996 to 2005. They followed the volumetric water footprint approach. They found that the blue and grey water footprints associated with grazing systems are smaller than those resulting from industrial systems are. They suggest that it is more water efficient to use crop products as a calorie, fat or protein source rather than animal products. The study found that animal products in industrial systems have the largest blue and grey water footprints, compared with grazing and mixed systems. However, the water footprint of chicken products in industrial systems is not consistent with the general finding because they had the lowest blue and grey water footprints, compared with grazing and mixed systems.

Gerbens-Leenes et al. (2013) have examined the results of Mekonnen and Hoekstra (2012). Their objective was to identify the main contributing factors to the water footprint of meat. In their study, they distinguished between poultry, pork and beef, and between developed and developing countries, as well as different production systems, and took their differences into consideration. The study followed the volumetric water footprint approach. The study found the main contributing factors to be food conversion efficiency, feed composition (ratio of concentrates to roughages) and the origin of the feed. They found that the high feed conversion efficiency of poultry in industrial systems results in smaller green, blue and grey water footprints, compared with grazing systems in the United States, China, Brazil and the Netherlands. However, the mixed and industrial poultry systems in the United States and the Netherlands have similar green, blue and grey water footprints. Broilers were found to have the highest feed conversion efficiencies. This contributed to a low broiler water footprint. Nevertheless, the more concentrated broiler feed in all systems increased the blue and grey water footprints of poultry. In Brazil, relatively large green water footprints were observed for poultry, while a small total water footprint was seen in the Netherlands due to their efficient systems.

Ibidhi *et al.* (2017) analysed freshwater consumption and land use, as well as greenhouse gas emissions, for chicken meat production under different farming systems from 1996 to 2005. The chicken production followed the industrial system. The green, blue and grey water footprints of a chicken carcass were reported as 4535 litres/kg, 8.7 litres/kg and 200 litres/kg, respectively, with a total water footprint of 4746 litres/kg. It was found that the total water footprint of chicken meat is 2 to 4 times smaller than that for sheep meat. However, the grey water footprint component was larger for chickens than for sheep. The large part of the broiler and sheep water footprint was associated with the feed. Broiler feed was mainly imported; therefore, the broiler water footprint was largely outside of Tunisia. They concluded that the water, land and carbon footprints become smaller if the feed conversion efficiency is high and the feed is produced productively.

2.4.6 Water Footprint of Wheat

The amount of water used in the world is ultimately linked to final consumption by consumers. The water footprint of a product is the exact amount of water used to produce the product throughout its value chain. Wheat is grown on greater land areas than any other commercial crop is, making it one of the most widely cultivated cereal grains globally, and the second most produced cereal, followed by rice (Mekonnen and Hoekstra, 2010a).

The global water footprint in relation to the consumption of agricultural crops is given by 7 404 Gm^3.year. Wheat is accountable for 15 percent of this consumption (1 088 Gm^3.year), which is also the largest proportion for a single crop. Approximately 82 percent of this consumption is sourced from domestic production, excluding most African, South-East Asian, Central American and Caribbean countries, which rely strongly on external water resources for agricultural crop consumption (Mekonnen and Hoekstra, 2010a; 2010b). Mekonnen and Hoekstra (2010a) took a high resolution approach in estimating the water footprint of wheat, and found the global WF of wheat production of rain-fed and irrigated wheat as 1 805 m^3.ton on an average yield of 2.5 ton.ha, and 1 868 m^3.ton on an average yield of 3.3 ton.ha, respectively. The global average water footprint of wheat is 1 830 m^3.ton, at an average yield of 2.7 ton.ha. Blue water accounted for 50 percent of the total water used in irrigated wheat.

Mekonnen and Hoekstra (2010a; 2010b) realised that the average yield is directly proportional to water use and that the green water footprint generally has low opportunity costs, as compared with blue water. They then concluded that low yields in green water footprints should be increased in order to lower the footprint and address negative externalities in WFblue, as this will reduce the need for blue water usage. Mekonnen and Hoekstra (2010b) reported that the water footprint from irrigated agriculture is 30 percent higher than in rain-fed agriculture, even though the consumptive water use, which includes both green and blue water, is found to be the same, and the difference is attributable to evapotranspiration, as well as yields being higher in irrigated wheat.

Mekonnen and Hoekstra (2010a) concluded that the water footprint of a crop was largely dependent on agricultural management processes that the farmer can control, rather than the agro-climate under which the crop is grown. This can be done by implementing the ‘one drop per crop' approach, especially in unproductive green water evaporation. They went further to calculate the water footprint of the products produced by crops, and found wheat flour to have a water footprint of 1 849 m^3.ton (1 292 m^3.ton green, 347 m^3.ton blue, and 210 m^3.ton grey) and bread 1 608 m^3.ton (1 124 m^3.ton green, 301 m^3.ton blue, and 183 m^3.ton grey).

Chouchane, Hoekstra, Krol and Mekonnen (2015) conducted an assessment of the water footprint of Tunisia. They calculated the water footprints of crop production, grazing, animal water supply, industrial production, and domestic water supply. Due to the major contribution of crop production to the total water footprint of Tunisia, Chouchane *et al*. (2015) calculated the water footprints for total production of wheat per tonne. The water footprints of wheat produced in Tunisia were found to be 2 560 m^3.ton. Compared with the global average water footprints of wheat (1 830 m^3.ton) and barley (1 420 m^3.ton), Tunisia may have scope to decrease the respective water footprints.

In Iran, Ababaei and Etedali (2014) found the average water footprint of rain-fed wheat production to be 3 071 m^3.ton, which ranged from 1 595 m^3.ton to 4 906 m^3.ton. For irrigated wheat, the average water footprint was 3 188 m^3.ton and ranged from 2 249 m^3.ton to 5 056 m^3.ton. The variation in Iran's water footprint is high, and the necessary means should be taken to reduce it, and to also decrease the overall water footprint of wheat.

Ahmed and Ribbe (2011) explored the green and blue water footprints of rain-fed and irrigated crops in Sudan. Interestingly, they also considered the impact of different rain water harvesting techniques on the water footprints of the products. Among the irrigated crops, Ahmed and Ribbe (2011) considered wheat. The water footprint of the crop was found to be about 5 500 m^3.ton.

2.4.7 Water Footprint of Bread

Aldaya and Hoekstra (2010) used the water footprint network approach to calculate the water footprints of pasta and pizza in Italy. They found that 72 percent of durum wheat and bread wheat becomes semolina and bread flour, respectively, and that both constitute 88 percent of the total value of mill product, while the rest is attributed to bran and germ. To calculate the water footprint of flour, Aldaya and Hoekstra (2010) multiplied the WF_{wheat} by the value fraction divided by extraction rate (786×0.88/0.72) = 605 m^3.ton, further expressed as 154 m^3.ton green, 202 m^3.ton blue and 368 m^3.ton grey water. A similar process was followed for semolina (1 574×0.88/0.72) = 1 924 m^3.ton, further expressed as 914 m^3.ton green, 642 m^3.ton blue and 368 m^3.ton grey water.

Similar to Aldaya and Hoekstra (2010), calculated the water footprint required to produce 1 kg of bread in Hungary. He found the water footprint of wheat to be 1 267.5 m^3.ton and the Hungarian flour conversion rate to be 0.76 kg from 1 kg of wheat. Due to lack of data, the author estimated the value fraction of resulting flour, based on an Italian example as 0.88, meaning that 88 percent of total value of mill product is flour. The authors calculated the water footprint of flour by multiplying the water footprint of wheat by the value fraction, divided by the flour conversion rate (1 267.5×0.88/0.76) =1 468 m^3.ton, and further expressed this water as a combination of green, blue and grey water. She also concluded that there was no difference between the water footprint of flour and that of bread, due to a lack of regional share of bread production. Yet concluded that 1 014 litres of water is required for producing 1 kg of bread.

2.5 ECONOMIC VALUE OF WATER IN SOUTH AFRICA'S AGRICULTURAL SECTOR

2.5.1 Rationale for the Economic Valuation of Water Footprints

Agriculture consumes over 60% of the available freshwater supply in South Africa, with most of the water being used in irrigation activities (Thurlow *et al*., 2008). The situation is worsened because agriculture earns the lowest Gross Domestic Product (GDP) per million cubic metres of water, and creates the fewest jobs per million cubic metres of water (Nieuwoudt *et al*., 2004). Agriculture may thus be considered to be an inefficient user of fresh water in South Africa.

Irrigated agriculture, however, has a major role to play in the South African economy and is specifically mentioned in the National Development Plan as a focus area to contribute towards economic development in South Africa (NPC, 2011). The importance of agriculture is attributable to its economy-wide multiplier effects, its multi-sector linkages, its contribution to food security in general, and to the livelihoods of the rural poor in particular (Thurlow *et al*., 2008). It is crucial to ensure that freshwater is used in a sustainable manner, given the fact that agriculture is an inefficient user of freshwater, in the context of South Africa being considered a water-scarce country, together with the importance of irrigated agriculture to the South African economy,.

The National Water Act (Act No 36 of 1998) also recognises that the ultimate aim of water resource management is to achieve the sustainable use of water for the benefit of all users. Sustainable use of resources entails not only the sustainability from an environmental perspective, but also from an economic and social perspective. It is important to understand the socio-economic benefits and the environmental consequences of water use (Christen *et al*., 2007). Only if freshwater is used in a manner that is considered to be sustainable from an environmental, economic, and social perspective, can irrigated agriculture meet expectations in terms of its sustained contribution towards economic development in South Africa.

2.5.2 Contribution of Water to the Economy

The agricultural sector contributes ZAR 1.50 to the gross domestic product (GDP) per cubic metre of water that it consumes. It is followed by mining at ZAR 39.50, eco-tourism at ZAR 44.40, and the industrial sector at a staggering 157.40 ZAR/m^3 of water (Nieuwoudt *et al*., 2004). From an income perspective, the agricultural sector is clearly the most inefficient user of freshwater.

The agricultural sector generates far less employment per cubic metre of water use, as compared with the industrial sector. About 108 jobs are created in the agricultural sector per one million m^3 of water. This figure is extremely low when one considers the 4 269 jobs created in the industrial sector per one million m^3 of water. The mining sector, on the other hand, creates about 150 jobs per one million m^3 of water that it consumes (Nieuwoudt *et al*., 2004). Nevertheless, when one considers the employment created within the agricultural sector on the basis of “per value of agricultural products”, a different conclusion is reached. Agricultural output worth ZAR 1 million is associated with the creation of 24 jobs. This is a higher level of employment compared with the mining and manufacturing sectors that yield 10.9 and 9.0 jobs per ZAR 1 million worth of output, respectively (Nieuwoudt *et al*., 2004).

2.5.3 Contribution of Irrigation to Agricultural Production

Agriculture is the single largest user of water in South Africa and as the increase in population places greater demands on the water resources, agriculture will have to increase the efficiency with which it uses water (Nieuwoudt *et al*., 2004:). Although agriculture in South Africa uses up to 60% of the available water, only 12% of the total area of the country is considered to be arable, with as little as 3% being “truly fertile” (DWS, 2013).

South Africa irrigates 1.5% of the total landmass to produce 30% of the total crops produced (DWS, 2013). According to Backeberg and Reinders (2009), irrigated agriculture in South Africa uses roughly 40% of the exploitable runoff. Other estimates suggest that agricultural production uses more than 60% of the available water (DWS, 2013). With such a high proportion of the water being used by the agricultural sector, there is increasing pressure from government and other sectors on agriculture to use less water, while maintaining crop yields. This is not only a local phenomenon but also a global reality; more people compete for the same limited water resources and consequently water must be used with greater efficiency.

A cause for concern with the high water use in the agricultural sector is that agriculture’s direct contribution to the Gross Domestic Product (GDP) of South Africa is less than 3% (DAFF, 2014). The agricultural sector thus generates only a small share of income, while using the largest share of available water in South Africa. Therefore, it might be considered an inefficient allocation of the scarce freshwater resources to allocate it to irrigated agriculture (Nieuwoudt *et al*., 2004).

In addition to irrigated agriculture, water is also an important input for animal production. This is because animal production systems require vast quantities of feed, which is produced using water as an important input. The water usage for feed production is by far the greatest consumer of water along animal value chains, consuming in excess of 95% of all the water used along the value chain (Mekonnen and Hoekstra, 2010b; Hoekstra, 2012). The dairy industry is no different, and with intensive dairy production systems, good quality water is of crucial importance, given the relevance of the industry.

The dairy industry is relatively important in the greater context in that it contributes 14% to the gross value of animal production, and 7% of the gross value of agricultural production in South

Africa (DAFF, 2014). Therefore, the industry is of importance from an economic perspective, but its impact as an employer in the rural areas is of much more significance. According to an industry overview of the dairy industry in South Africa, this sector consists of about 4 000 milk producers who in turn provide employment to 60 000 farm workers. A further 40 000 people have indirect employment in the rest of the dairy value chain (DAFF, 2012). It is thus clear that the South African dairy industry is very important from a socio-economic perspective.

The dairy value chain is an elaborate chain, starting at feed production and ending with the processed dairy product on consumers' tables. Water is needed at all the stages along the value chain, with feed production using by far the greatest volume of water (De Boer *et al*., 2012). The fact that the dairy industry is using vast quantities of water in order to produce feed means that emphasis must be placed on the sustainable use of freshwater, from both an environmental and an economic perspective.

The role and significance of irrigated agriculture in the agricultural sector should not be assessed on the basis of its relatively low share of cultivated land, which in Tunisia amounts to 7% (Chouchane *et al*., 2013). At least 35% of the total production in Tunisia's agricultural sector may be attributed to irrigated agriculture. Furthermore, irrigated agriculture consumes more than 80% of the total water withdrawn in Tunisia (Chouchane *et al*., 2013). In South Africa, only 10% of maize production occurs under irrigation. However, irrigated maize yields 5.28 ton/ha to 6.10 ton/ha more than yields under rain-fed conditions. Therefore, irrigation contributes to higher crop output.

2.5.4 Economic Water Productivity of Crop Production

Economic water productivity (EWP) is the value realised per unit of water used (Chouchane *et al*., 2015). The economic productivity of water use is better defined once the water consumption of a particular crop is established. In this case, water use is expressed in terms of monetary unit/m^3, rather than tonne/m^3 or kg/ℓ (Hoekstra *et al*., 2011). EWP (ZAR/m^3) is the product of physical WP (kg/m^3) and crop value (ZAR/kg). Chouchane *et al*. (2015) found that the EWP in rain-fed agriculture (0.35 US\$/m^3) was higher than in irrigated agriculture (0.32 US\$/m^3). They also found that the economic land productivity (ELP) in irrigated agriculture was greater than in rain-fed agriculture.

In light of the above findings, they concluded that there was a direct relationship between irrigation and the ELP (ZAR/ha). Regarding EWP (ZAR/m^3), Chouchane *et al*. (2015) went on to state that one cannot raise the EWP (ZAR/m^3) by applying more irrigation. However, irrigation should be increased for crops with a high EWP and for which the difference between ELP in rain-fed and irrigated agriculture is high. This will allow one to benefit from the increase in EWP associated with such crops, as well as from the increase in ELP. This is a viable alternative where market conditions exist and crops with low EWP may be imported from other countries. Schyns and Hoekstra (2014) calculated the EWP for a variety of crops. They found that crops that accounted for the highest consumptive use of freshwater were associated with the lowest EWP, which ranged from 0.02 US$/$m^3$ for almonds to 0.08 US$/$m^3$ for wheat. Tomatoes, on the other hand, had an EWP that was 22 times higher than that of wheat. In semi-arid countries such as Morocco and South Africa, the productive use of freshwater must be a national priority. Hence, in addition to the factors that are considered in deciding which crops to produce (national strategy regarding food security and demand for crops), the EWP of a crop must also be taken into account.

In Africa, green water contributes more to crop production than blue water does. Morocco is a typical example, where 77% of its water footprint is green water (Schyns and Hoekstra, 2014). It is thus clear that the solution for lowering the blue water footprint lies in the productive use of green water. Rainwater harvesting is essential in ensuring blue water availability in times when there is no precipitation to meet the immediate needs of freshwater. This statement, however, becomes controversial when there is considerable evaporation of freshwater from reservoirs, which ultimately increases the blue water footprint of a particular production process. This is true for Morocco, where evaporation losses contribute 13% to the blue water footprint of the country (Schyns and Hoekstra, 2014).

2.5.5 Methods for Assessing Economic Water Productivity

After the water footprints are calculated, based on any of the methods discussed above, the economic water productivities can be estimated to give an indication of the income generated per unit of water use. In estimating the water productivities, a distinction should be made between crop yield from rainfall and that from irrigation (Chouchane et al., 2015). Once such distinction is made, water productivities can be discussed for different water components. Blue water productivity is defined as the yield attained due to irrigation, divided by the amount of blue water utilised. This is expressed as:

$$WP_{blue} = \frac{Yt_{blue}}{ET_{blue}} \tag{2.13}$$

where Yt_{blue} is the crop yield under irrigation, and ET_{blue} is the evapotranspiration of blue water. Green water productivity, on the other hand, can be defined as the crop yield obtained from rainfall only, without irrigation, divided by the total green water used by the crop (Hoekstra, 2013). This is specified as:

$$WP_{green} = \frac{Yt_{green}}{ET_{green}} \tag{2.14}$$

where Yt_{green} is the crop yield under rain-fed conditions only, and ET_{green} denotes evapotranspiration of green water for rain-fed conditions (without irrigation). It must be emphasised that this equation will not apply to crops grown under a winter rainfall climate or to winter crops grown in a summer rainfall region, as in both cases there probably would not be any rain-fed yield. Crop yields under rain-fed conditions only (Yt_{green}), according to Chouchane et al. (2015) and Doorenbos and Kassam (1979), can be calculated as:

$$\left(1 - \frac{Y_a}{Y_m}\right) = RF_y\left(1 - \frac{ET_a}{CWR}\right) \tag{2.15}$$

where RF_y denotes the yield response factor, the actual crop output per hectare is denoted by Y_a, and Y_m denotes maximum output attainable at the optimum water level. ET_a denotes the real crop evapotranspiration measured in millimetres per period, whereas CWR denotes the crop water requirement in millimetres per period.

2.5.6 Related Research Assessing Economic Water Productivity

Hoekstra (2014) emphasised that the economic or efficient use of water is one of the pillars of freshwater allocation. The three pillars of freshwater allocation are environmental sustainability, economic efficiency, and the socially equitable distribution of freshwater. One of the three pillars of freshwater allocation is economic efficiency, as highlighted by Hoekstra (2014). The estimation of economic water efficiency follows after the estimation of the total water footprint. This concept builds on or contributes to sustainability assessments which over the past few years have centred on blue, green and grey water footprint indicators only. This concept of underlying water productivities estimations is related to water footprints.

The calculation of the economic productivity of water begins with the estimation of physical water productivities. Physical water productivity is the ratio of the yield of the agricultural product to the amount of water used ('product per drop of water'). This is usually calculated for blue water withdrawal or for the summation of green and blue water footprints. Economic water productivity is stated as the product of the physical water productivity and the price of the agricultural product. The estimated value for the economic productivity of water provides an understanding of how much income is generated per m^3 of blue, green and grey water utilised. Very little research exists in recent literature regarding the evaluation of economic water productivities.

The existing literature is limited to the study of Chouchane et al. (2015) who assessed the economic water productivities for certain selected crops in Tunisia. The findings by the authors provide an indication of the income that was generated per cubic metre of green, blue, and grey water used in Tunisia. Specifically, Chouchane *et al.* (2015) found the economic water productivities of the selected crops in Tunisia to range from 0.03 US$/m^3 (olives) to 1.08 US$/m^3 (tomatoes). However, it must be emphasised that the authors did not include the costs incurred in producing this range of products. This implies that economic water productivity is not the same as profit, since costs of production are not factored into the analysis of economic water productivities.

In Cyprus, Zoumides et al. (2014) conducted an economic water productivity assessment for crop production. The main focus of the authors was on quantifying water utilisation and supply for crop production. However, the authors moved a step further to estimate blue and green economic water productivities. Total water productivities were first calculated for the selected crops, after which the value was multiplied by the product prices. The total productivities were then divided by the blue and green water footprints. The yields of crops were divided into rain-fed yield, and yields from both irrigation and rainfall. Once the crop yields from rain and irrigation were obtained, they are then divided by their respective footprint indicators. Green economic water productivity is calculated by dividing yield by rainfall only by the green water footprint, whereas the yield from irrigation is also divided by the blue water footprint to derive blue economic water productivities. The results are multiplied by the prices of each crop to ascertain the economic water productivities per cubic metre of water.

The findings reported by Zoumides et al. (2014) revealed that about 80% of agricultural gross value in Cyprus originates from irrigation farming, and out of this, only 39% comes from rain-fed agriculture. The remaining 61% is attained from blue water use or irrigation farming. The minimum blue water economic productivity in Cyprus was found to be 0.89 €/m^3, with a maximum of 1.15 €/m^3, from 1995 to 2009. The minimum green water economic productivity was found to be 0.22 €/m^3 and the maximum about 0.45 €/m^3 from 1995 to 2009. The above details indicate that blue water productivities are higher than green water productivities are in Cyprus. Such findings provide an indication of how productively Cyprus' blue and green water categories are being utilised.

Similarly, Central Asia has been assessed for its blue water economic productivities for the main fibre crop, cotton, and for wheat and rice cereal crops. The assessment was done by Aldaya, Munoz and Hoekstra in 2010. The authors found cotton to be the highest user of blue water, followed by rice and wheat, respectively. It was found that cotton has the highest blue water economic productivity, despite the high water footprint. This finding indicates that a high water footprint does not always mean that low water productivities will be observed in terms of economic water productivities. The economic productivities of cotton, rice and wheat were found to be 0.5 US$/m^3, 0.18 US$/m^3 and 0.07 US$/m^3, respectively.

Research on the economic productivities of water is very scanty for the semi-arid and arid regions of Southern Africa. The existing literature is limited to that of Munro et al. (2014) who assessed the citrus water footprint in the Sundays River Valley. The authors did not assess the total economic water productivity for citrus production, but rather water productivity at the production stage of citrus. This does not give an indication of water productivities along the entire citrus production value chain.

A sector-specific assessment of water use for irrigation farming and the forestry sector has been conducted by Crafford et al. (2004). The authors focused on the direct and indirect benefits associated with water utilisation for irrigation in the agricultural and forestry sector. This research was conducted for established forestry, sugarcane production under irrigation, and some subtropical fruits produced in the Crocodile River Catchment Area. The economic, social and environmental impacts were estimated for each of the production sectors mentioned above. The environmental aspect of this research was examined by using the LCA methodology. It was revealed that the minimum value added to a cubic metre of water was 1.8 ZAR/m^3, with a maximum of 2.6 ZAR/m^3, for established forest in terms of direct economic impact. For sugarcane and subtropical fruit, the authors found 1.3 ZAR/m^3 for sugarcane, while that for the subtropical fruit was found to range between 3.2 ZAR/m^3 and 8.7 ZAR/m^3. Indirectly, it was found that about 19.9 ZAR/m^3 to 32.1 ZAR/m^3 value is added to each cubic metre of water utilised in the forest sector, whereas about 9.9 ZAR/m^3 was found for sugarcane production, and the value for subtropical fruit was found to be between 3.2 ZAR/m^3 and 8.9 ZAR/m^3. Regarding the environmental aspect, the authors concentrated on water utilisation impacts in the various sectors on water quality and biodiversity, as well as the health effects of these production activities on humans (Crafford et al., 2004). These authors did not look at the actual water productivities, since their approach did not consider the estimations of water footprints from which economic productivities could be derived, given the yield and prices of products obtained from the irrigated sugarcane, subtropical fruit and forestry products.

The focus of water footprint research has traditionally been on the environmental impact of water use, while more recently, researchers have begun to also consider the economic and social aspects in water footprint assessments. Hoekstra (2014) considers sustainable (environmental), efficient (economic) and equitable (social) water use to be the “three pillars under wise freshwater allocation". Both efficient and equitable water uses are also specifically addressed in the Water Footprint Network approach for water footprint assessments (Hoekstra *et al*., 2011). However, the scope of economic and social analysis in reported water footprint assessments remains relatively small.

Lastly, Aldaya, Munoz and Hoekstra (2010) also calculated the economic blue water productivity of cotton, wheat and rice in Central Asia. The average water footprints of cotton, rice and wheat production in Central Asia were calculated to be 4 642 m^3.ton, 4 284 m^3.ton, and 2 652 m^3.ton, respectively. Interestingly, the economic blue water productivities for the three crops were about 0.5 US$/$m^3$, 0.18 US$/m^3 and 0.07 US$/$m^3$, respectively. Thus, the crops with the highest water footprints were also found to have the highest economic blue water productivity.

Within the South African context, very little research has been done to link water footprints with economic aspects of water use. Munro *et al*. (2014) calculated the water footprint of citrus along the Sundays River Valley and then calculated the economic productivity of the water used. This method is not an indicator of the value added to the water along the value chain, as it only considers the production-stage water use.

Although they did not actually calculate water footprints, Jordaan and Grové (2012) did consider water use along selected agri-food value chains. The aim was to explore marketing behaviour that would allow smallholder farmers to maximise their financial returns from having access to irrigation water. In order to achieve their objective, Jordaan and Grové (2012) calculated the value that was added to the water along the value chain of selected horticultural products (raisins, cabbages and carrots). The value that was added to the water, as it moved along the value chain towards the end consumer, was determined as the value that was added to the specific agri-food product at each node along the value chain. Interestingly, the amount of value that was added was calculated at each stage of value adding, and for different marketing channels. At the farm gate, the amount of value added was expressed as the gross margin (ZAR/m^3) per cubic metre of water. The gross margin is the difference between the income (ZAR/kg) of one kilogram of the crop and the variable costs (ZAR/kg) to produce one kilogram of the crop. Given that farmers received different prices when selling their products through different marketing channels, the value added also differed for the different marketing channels.

From the farm gate to the end consumer, the amount of value added was expressed as the difference in the value of the product once it leaves the specific node (i.e. the price at which the product is sold to the next agent along the value chain), and the value of the product when it arrived at the node (i.e. the price that was paid for the product). Again, this was done for each food product for the different marketing channels to ultimately provide information of which marketing channel is associated with the highest amount of value added to the water that was used to produce the product.

The results of Jordaan and Grové (2012) show that the value added (in 2012 prices) at the farm gate for raisins ranged between ZAR1.58/m^3 and ZAR1.94/m^3 for the different types of raisins considered. The highest total value added was ZAR8.66/m^3 for raisins that were used as ingredients in the bakery industry. At the farm gate, they found the value added to range between ZAR1.31/m^3 and ZAR2.08/m^3 for cabbages, and between ZAR3.63/m^3 and ZAR6.75/m^3 for carrots. At the point when cabbages and carrots reached the end consumer, the total value added for cabbages ranged between ZAR1.80/m^3 and ZAR5.56/m^3, and for carrots between ZAR4.93/m^3 and ZAR15.49/m^3. Thus, the marketing channel chosen had a major influence on the benefit that accrued from having access to irrigation water.

Although South Africa is a water-scarce country and the dairy industry uses a large quantity of the available freshwater, no study has yet evaluated the water use along the dairy value chain *per se*. Several researchers have calculated the economic productivity of water in other value chains, but again this has not yet been done for the dairy value chain. The approach and findings of Crafford *et al.* (2004) and Jordaan and Grové (2012) thus provide good insight that may guide the economic evaluation of the South African dairy value chain. The value-added approach used by Jordaan and Grové (2012) is useful and will be used in a similar fashion with the water footprint data at the various stages.

2.5.7 Summary of Review

The above discussions reveal that little has been done in terms of how economical South Africa's water use has been. Thus, the economic productivities of water in South Africa have not being thoroughly assessed in order to provide vital economic indications of water use, even though the country is water scarce. More importantly, the little research on value addition and economic water productivities has focused on crops only, with little or no emphasis being placed on the dairy value chain, and on the livestock industry in general. Hence, there is the need for an economic evaluation of water productivities in the dairy industry to be undertaken. In order to contribute to the assessment of economic water productivities, there is the need to discuss the methods that are used in estimating a water footprint and economic water productivities. Therefore, the next section provides detailed discussion on the methods applied in a water footprint and economic water productivities assessment.

According to Mekonnen and Hoekstra (2014), the demand for freshwater will increase in the next couple of years in response to the rising demand for food, fibre, and biofuel crops. Sustainable economic growth and development, energy production, and food security depend heavily on the availability of freshwater (KPMG and Small Enterprise Development Agency (SEDA), 2012). However, considering the degree of dependence of a nation's economy on freshwater resources, the economic value of water does not appropriately convey the value of water (KPMG and SEDA, 2012). As the demand for freshwater rises among the various sectors in an economy, at a particular point, the local freshwater reserves may be insufficient to satisfy the demand. This may compromise food security, as evident in the fluctuating global food prices (KPMG and SEDA, 2012). About 8% of South Africa's rainfall becomes runoff (KPMG and SEDA, 2012). About 17% of captured or stored freshwater is released unintentionally into the environment due to degraded infrastructure that does not have the capacity to hold water sufficiently (KPMG and SEDA, 2012). The increase in the demand for water can be accommodated by using freshwater resources in a sustainable manner. This sustainability may be achieved by increasing the productivity of water in the agricultural sector.

Freshwater is a valuable resource and it must be treated as such. In dealing with the issue of water, it is important for one to acknowledge the influence that one source of water has on the use of another. The productive use of green water will lower the pressure on blue water resources. It is also important for one to appreciate the differences in the water consumption of crops produced in different river basins owing to the different climatic conditions in each river basin. The phenomenon of climate change will thus introduce changes in the known water consumption of crops produced in various river basins. Furthermore, the productivity of one crop with respect to water use varies from another. This variation may be attributed to the characteristics of each crop. In deciding which crop to produce, the EWP of a crop must be considered. An increase in irrigation increases ELP (R/ha). Increasing the ELP for crops with a high EWP is an effective way of promoting freshwater productivity in irrigated agriculture. The productive use of water has the potential to lower costs and thus increase income.

From an income perspective, the agricultural sector is clearly the most inefficient user of freshwater. Regarding employment created by the sector, the benefits derived from water are in one view undesirable, while satisfactory in another. The agricultural sector yields insignificant jobs per unit of water use, relative to other sectors. However, when one considers the value of the agricultural product, the agricultural sector employs more workers than other sectors do. An agricultural product is a good that has a water footprint of its own. With an agricultural product, the total volume of water used, rather than per unit water consumed, becomes relevant. Hence, the focus shifts from water to the product itself. Thus, the employment associated with the product is the number of jobs created along the value chain of the product. It is this employment in agriculture that is said to be higher than in other economic sectors.

2.6 SUSTAINABILITY ASSESSMENT

2.6.1 Contextualising Sustainability Assessment

The context of the sustainability assessment is very dependent on the goals and scope set out in the first phase of the water footprint assessment. In this phase, the water footprint has to be viewed in a larger context. In essence, this phase is where it has to be determined whether the available resources can support the current extraction levels over the long term, without causing adverse effects for the environment. The water footprint calculated in the accounting phase is compared with available freshwater resources at the relevant place and time. Such an assessment may include several different dimensions, such as environmental, economic and social sustainability, and it may include both primary and secondary impacts (Hoekstra and Mekonnen, 2011).

It has to be kept in mind that the sustainability of a consumer or producer water footprint will depend on the geographic context of the products consumed. This is because one final product might comprise several process steps that might take place in various geographic locations. One such a process step might not necessarily result in water scarcity, but the cumulative effect of all the steps in a specific geographic area might well result in water shortages. When the water footprint of a process, product, producer or consumer contributes to an unsustainable situation in a given geographic context, this specific water footprint is also considered to be unsustainable.

When a product water footprint is considered, it is important to consider the sustainability of all the process step water footprints that make up the product water footprint. This then makes it possible to evaluate the sustainability of the product water footprint by dividing the water footprint into the different process steps and then looking at each of these step water footprints individually. By evaluating each of these process steps individually, it is then possible to distinguish between process steps that take place in different geographic areas or catchments and to then determine whether or not the unsustainable steps can be avoided by moving such steps to different catchments, or by eliminating the steps altogether.

It is important to evaluate the sustainability of a water footprint over a period of time because the water availability varies across seasons. Even if the total water footprint is sustainable, by adding the temporal dimension to the sustainability assessment, it is possible to identify those months in which the catchment is water stressed.

2.6.2 Methods for Sustainability Assessment

The sustainability assessment of water use is done after calculating the volumetric water footprint. This is done to ascertain whether water use in a catchment area for production is sustainable or not. The blue water footprint used in a given production system is regarded as unsustainable if the blue water footprint exceeds blue water availability in the catchment area. It must be emphasised that the blue water footprint and blue water availability are determined for the particular catchment area at definite time periods due to seasonal changes in water use and run-off. Gerbens-Leenes and Hoekstra (2012) expressed blue water availability (WA_{blue}) in the catchment 'z' for the period 't' as the difference between the natural run-off in the catchment (R_{nat}) and environmental flow requirement (EFR):

$$WA_{blue}[z,t] = R_{nat}[z,t] - EFR[z,t]\,(volume/time) \tag{2.16}$$

The environmental flow requirement (EFR) for a particular catchment area at a certain time period is not met when the blue water footprint surpasses the blue water availability in the catchment. The environmental flow requirement denotes the volume and timing of water flows needed to ensure freshwater ecosystems and human livelihoods. Failure to meet the environmental flow requirement indicates unsustainable water use. Gerbens-Leenes and Hoekstra (2012) further revealed that the blue water footprint sustainability assessment can be estimated by means of an index known as the blue water scarcity index. They expressed the blue water scarcity index (WSI_{blue}) as:

$$(WSI_{blue})[z,t] = \frac{\sum WF_{blue}[z,t]}{WA_{blue}[z,t]} \tag{2.17}$$

where $(WS_{blue})[z,t]$ is the blue water scarcity index for the catchment area for the time period. $\sum WF_{blue}[z,t]$ is the summation of the blue water footprints of all the blue water that was used in that catchment area for the time period. The blue water availability (WA_{blue}) is unsustainable if $(WS_{blue})[z,t]$ is greater than 1 for a particular catchment area for a specific time period (Gerbens-Leenes and Hoekstra, 2012). A catchment area where $(WS_{blue})[z,t]$ greater than 1 at a point in time is regarded a hotspot (Gerbens-Leenes and Hoekstra, 2012). Such catchment areas need intervention to ensure sustainability of freshwater use at the relevant time period.

2.6.3 Related Research Assessing Sustainability of Water Footprints

According to the methodology used by Hoekstra and Mekonnen (2011), the blue water availability was compared with the blue water footprint on a monthly basis to determine the blue water scarcity. Blue water scarcity is the water footprint divided by the water availability. The blue water availability was calculated by subtracting the environmental flow requirement from the natural runoff in the basin.

The blue water scarcity of the Orange River basin, in which Vaalharts is situated, was determined by Hoekstra and Mekonnen (2011). The blue water scarcity is calculated as the blue water footprint divided by the blue water availability of the basin on a monthly basis. Figure 2.2 below indicates the monthly blue water footprint (WF), the monthly blue water availability (WA), and the monthly blue water scarcity (WS). It is evident that from January to May, and in December, there is a water scarcity index (WS) of below 100%, since the blue water availability (WA) exceeds the blue water footprint (WF). During these months, there is low blue water scarcity, with sufficient water being available to satisfy the environmental flow requirements. However, in June and November, there is moderate blue water scarcity (100-150%). This causes slight modification of the runoff and hence the environmental flow requirements are not met.

In July, there exists significant blue water scarcity (150-200%), for which the runoff is significantly modified and does not meet the environmental flow requirements. August, September and October have water scarcity indices exceeding 300%. The blue water footprints exceed 40% of the natural runoff during these months; runoff is thus seriously modified and environmental flow requirements are not met. Therefore, it is clear that the Orange River Basin experiences low blue water scarcity during January, February, March, April, May and December. Of the feed crops used by the dairy farms for feeding cattle, corn is grown under irrigation between November and February, and sorghum is planted in December and harvested at the end of February.

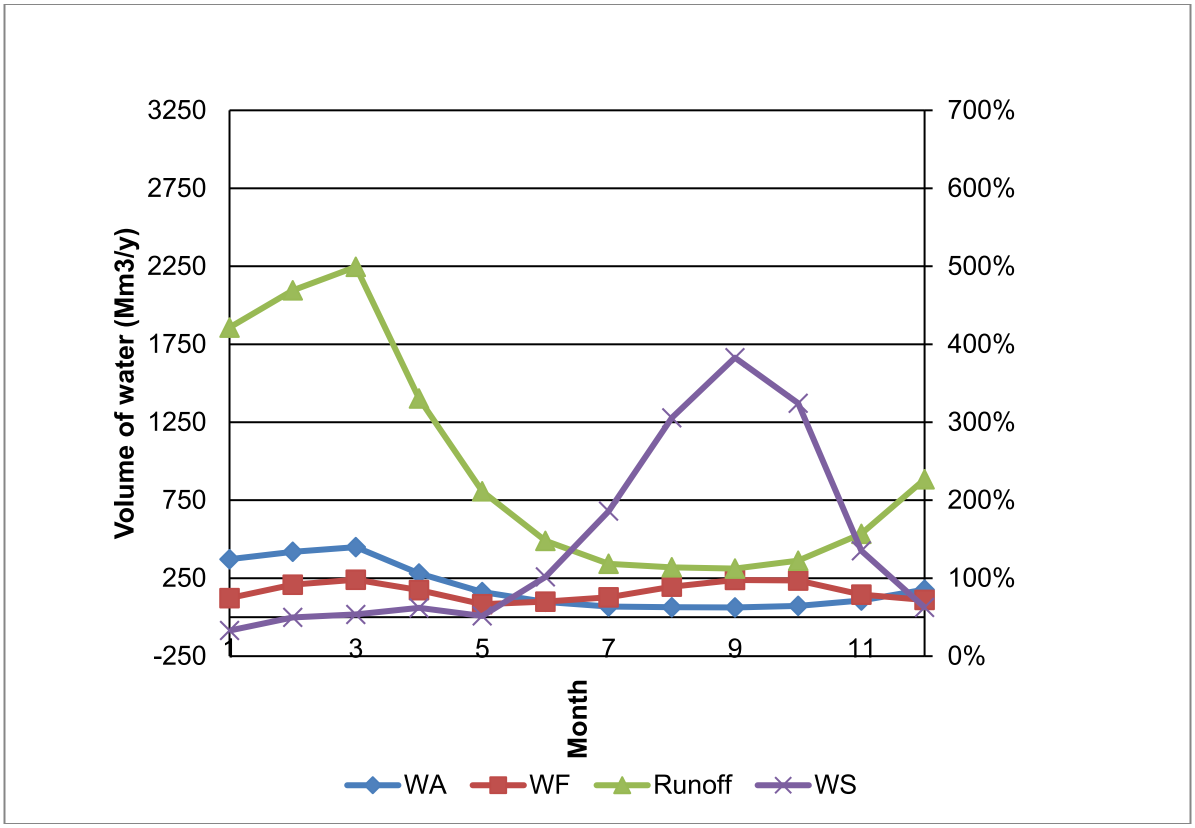

Figure 2.2: Monthly blue water scarcity of the Orange River Basin
Source: Hoekstra and Mekonnen (2011)

Hence, corn and sorghum production under irrigation in the greater Orange River Basin is considered sustainable since the production does not distort the natural runoff significantly and environmental flow requirements are met.

Lucerne production for feed has a larger freshwater requirement since it falls in the summer months (December to February) when evapotranspiration is high. Therefore, lucerne production for livestock feed at Vaalharts is considered to be sustainable (Owusu-Sekyere et al., 2016). Moderate blue water scarcity occurs in June and November, with significant blue water scarcity in July. Meanwhile, in August, September and October, there is severe water scarcity. The production of oats for silage takes place between June and October, depending on the planting date. June has moderate blue water scarcity, and significant blue water scarcity in occurs in July; while August, September and October experience severe water scarcity. Therefore, oats production under irrigation in the Orange River Basin is not sustainable from an environmental water flow requirement perspective and should, therefore, be reconsidered. More importantly, it is observed that the water scarcity index is greater than 100% in six of the twelve months of a year, which gives an indication that the Orange River Basin is a hot spot. The major cause for concern to water users and managers is the fact that a large water scarcity index occurs in 4 of the 12 months in a year. There are dams which regulate the basins.

2.7 CONSUMER AWARENESS AND WILLINGNESS TO PAY FOR WATER FOOTPRINT LABELLING

2.7.1 Consumers’ Awareness of Environmental Sustainability Attributes

Generally, producers are required to inform or update consumers on the constituents of their products that are offered for sale. This is because the consumer has the right to know about the product he or she is purchasing. The process of allowing the consumer to be aware of the product that he or she is buying is termed product awareness (Khurana, 2007). Consumer awareness in terms of marketing ensures that consumers are enabled to become knowledgeable about the different types of products, product qualities or characteristics, point of sales, product prices, and available sales promotion. The rationale behind the creation of consumer awareness started in England after the Second World War. More emphasis was placed on the right of consumers to be aware of the attributes or characteristics of food products in the United States of America in 1962, where consumer’s rights to information on products were formally declared. The declarations were initially made on four basic consumer rights, namely choice, information, safety, and awareness (Khurana, 2007). Keller (2003) has noted that product awareness could be formed through labels or brands, and that such information is of particular importance to consumers, since purchasing decisions often made with a short time and under time pressure. This implies that for a consumer to know the quality status of a product, the product label or brand awareness acts as a signal to consumers.

Recently, environmentalists and conservation scientists have proposed that food products should be labelled according to how much water is used to produce them, as well as information on the carbon thereby emitted to the earth's atmosphere (Grebitus et al., 2015; Van Oel and Hoekstra, 2012). The call for such footprint labels and information is attributable to the current water scarcity situation and global warming. Bougherara and Combris (2009) found that the impact of a product and its production process on the environment is an important factor which influences consumers' decisions to buy a product. The authors highlighted the point that the consumers' awareness of the impacts arising from the production of the product and the product itself is the main influencer of consumers' buying decisions.

Consumers' awareness of the quantity and source of water that goes into the growing, manufacturing and processing of food products, as well as concerns over GHG emissions, has resulted in water and carbon footprint sustainability assessments being made in recent years. The creation of awareness and the promotion of the concept of water and carbon footprints in the context of consumers' studies has placed focus on including items of sustainability information on product labels, with the goal of drawing the attention of consumers to how drastically we are draining our most precious resource, and to how we could sustain it for future generations.

Although the use of footprint label information is gaining prominence, there is no consensus on how best to measure and label footprint indicators on products so as to ensure that the public understands its full impact (Noga and Wolbring, 2013), as well as on the precise quantification of the footprint indicators or attribute changes on the welfare of consumers. Most people have no idea how much fresh water they are consuming, nor of the carbon emitted during the production of the products they are consuming. This suggests that producers and manufacturers could create awareness by adding water and carbon footprint labelling information to gain competitive advantage and earn a premium for their products.

The method for conveying water and carbon sustainability information to consumers is very relevant to sustainable product marketing. This is because global anxieties about climate variation and the wide-ranging standing of the environment have augmented the expectations of consumers that food products should have sustainability credentials, and these are expected to be verified by consumers in time to come, as awareness heightens. There are significant and increasing pressures in key export and local markets for disclosure to be made of information on GHG intensity, carbon footprints, and recently, the water footprints of products. Product labelling has been identified as a common method for communicating the product attributes to consumers that may influence their choices. The increased consumer consciousness and awareness of sustainable food products have created heterogeneity among consumers, globally (Bougherara and Combris, 2009). The various segments of consumers for sustainable food markets are influenced by both public and private motivations that are directed towards creating a sustainable environment.

Within the agri-food market, existing studies on carbon labelling of products are limited to those of Vandenbergh, Dietz and Stern (2011). The findings from these studies highlighted the role of carbon labelling in maintaining a green economy. A similar study was done in Germany by Grebitus et al. (2015) to assess consumers' stated preferences for carbon and water footprint labelled products. The findings from the authors revealed that an assessment of environmentally sustainable attributes provides an understanding of consumers' choices and identifies potential markets for environmentally sustainable food products. Insights from such findings indicate that awareness creation achieved through water and carbon footprint labelling will act as an effective instrument for changing consumers' behaviour and transforming markets. This, moreover, supports the interests in the growing realisation that creating awareness through label designs and information should be informed by research that focuses on the primary end-user – the consumer.

Presently, many international and domestic research studies into food product labels have, to date, established that the design of food labels or mode of creating awareness of a product is crucial in its success in the market. Meanwhile, existing products on the market today do not have environmental sustainability attributes. However, recent concerns over the environment and fresh water scarcity have prompted concerns for including key information that consumers seek to rely on in purchasing. Carbon and water footprint labelling can be very successful in driving market changes. This requires wider consumer education and retailer training to ensure that new labels are widely understood and used by consumers (Ottman, 2011).

It must be emphasised that the concept of consumers' awareness and use of product labelling to convey information about product quality is well well-known and rooted in economic theory (Nelson, 1970; Darby and Karni, 1973). The perfect information is usually attained through awareness creation through product labelling. The supply aspect of marketing sustainable products is very intricate. The motivations for businesses and producers to provide product labels with credence characteristics impact positively on consumers. Once these attributes are provided, it becomes a search characteristic. Producers with a profitability objective will only adopt sustainability labelling if the extra income attained exceeds the cost incurred in producing the labelling design (Cohen and Vandenbergh, 2012; Vandenbergh et al., 2011). The above discussions reveal that consumers' awareness has different implications for their preferences, willingness to pay, and product competitiveness. Hence, the next section discusses consumers' preferences and willingness to pay for environmentally sustainable characteristics.

2.7.2 Willingness to Pay for Water Footprint and Sustainability Attributes

Prior to considering the discussion of consumers' preferences for environmentally sustainable attributes or products, it is very important to explain the assumptions, rationale and relevance of studying consumers' preferences (Centre for International Economics (CIE), 2001). The CIE (2001) conceptually defined consumers' preferences as a bundle of propositions that centres on the choices of consumers that gives rise to diverse changes in consumers' pleasure, values, and utilities. The underlying rationale behind consumers' preferences is to attain the ideal choice. Preferences by individuals or segments of consumers provide the room for consumers to rate or rank different goods and services, based on their expected or revealed utilities.

It must be emphasised that consumers' preferences for products are not only reliant on their prices or the incomes of the consumers (Castello, 2003). This means that a consumer's ability to purchase a product does not reveal his or her choice. For instance, a consumer may have a preference for sustainable food products, but his or her income might only allow the purchase of conventional or unsustainable products. There are three important assumptions which are considered when analysing consumers' preferences. The first is completeness. This assumption applies when a consumer is indifferent between two products in terms of which one to choose. For instance, if a consumer is faced with beef and lamb, every consumer has his or her preference for one of the two meat choices. The assumption of completeness requires that the consumer should be able to weigh his options between beef and lamb.

The next assumption is known as transitivity (CIE, 2001). This assumption establishes a relationship between a set of products. For example, if a consumer prefers sustainable product A to sustainable product B, and also prefers sustainable product B to product C, the assumption requires the consumer to prefer sustainable product A to product C. The third assumption relating to a consumers' preference is centred on non-satiation. This assumption indicates that greater amounts of a product will continually be accepted, as long as it does not have negative implications on the consumer's capacity to consume new products.

In economic terms, the assessment of consumers' preferences or choices is very relevant because it establishes the strong relationships between product preferences and consumers' demand for such products. It helps to understand what consumers prefer and are willing to spend their incomes on. This in turn will help producers to determine consumers' demands and what characteristics of products to strive for in order to meet the demand of consumers. Once the consumers' preferences are revealed, the next step is to evaluate in monetary terms the amount that a consumer is willing to offer for an increase in utility or the amount that he or she is willing to accept for a reduction in utility. This estimation approach is referred as willingness to pay (WTP). Conceptually, willingness to pay is defined as the maximum amount that the consumer is willing to contribute to compensate for the increase in his or her utility following the introduction of new products or improvements in a product's attributes.

Based on this, the assessing of consumers' preferences for existing and new products has become an important task for researchers and practitioners in governmental, non-governmental and private organisations (Castelló, 2003). This is because entrepreneurs are concerned about what the preferences of people are, while marketing departments are interested in knowing which products consumers prefer and are willing to pay for, and generally, governments are keen to know what members of the public think about health, environment and welfare policies. This suggests that the assessment of consumers' preferences has diverse implications, such as in the design and implementation of social policies, testing the acceptance of newly introduced products on the market, and the demographic targeting of consumers based on preference categories.

Recent literature on consumers' preferences for food products in the agricultural sector has seen some changes in consumer and retailer demands, particularly in some niche markets for sustainable food products (Grebitus et al., 2015). The changes in consumers' choices and preferences are shifting towards environmentally sustainable agri-food products because of consumers' conscious awareness of the environmental effects associated with agricultural production and the fact that food production is the major user of the global limited water resources (van Oel and Hoekstra, 2012).

In New Zealand, Tait et al. (2011) revealed that consumers' concerns about variability in the climate and the state of their environment have influenced consumers' preferences for food products with sustainability attributes and characteristics that are visible to the consumers. The authors emphasised the point that the preferred medium for communicating sustainability attributes to consumers is through product labelling. The shift in preferences for sustainability attributes has resulted in increasing pressures on producers, exporters and companies to indicate their carbon footprint information on products. It was worth nothing that the way in which the sustainability information is conveyed to consumers is a critical issue of policy concerns in New Zealand. The trend in preferences for sustainability products and information has also created significant changes in most value chains in New Zealand's major industries.

Consumers' attitudes and preferences for environmentally sustainable attributes have been evaluated for Japan and the United Kingdom (UK) (Tait et al., 2011). It was found that the labelling of environmentally sustainable products is the common method used for passing information of sustainability attributes to consumers, and that this influences their choices for fruits. Interestingly, the authors found that the format of labelling the sustainable product plays a significant role in catering to consumers' preferences. However, the authors found variations in preferences for the different labelling formats and in how much consumers are willing to pay for the sustainability attributes. It must be emphasised that a discrete choice experimental survey was employed by the authors to assess the preferences for the sustainability attributes in Japan and the UK.

In Canada, consumers' preferences and choices regarding ground beef that was labelled with environmentally sustainable footprint information were assessed by Grebitus et al. (2013). The authors found that preferences for environmental footprint indicators hinge on the consumers' human values, besides traditional socio-economic characteristics. The authors concluded that certain human ethics have a predictive influence on choices and readiness to pay for products with environmentally sustainable footprint indicators or attributes. Additionally, consumers' behaviour towards environmentally sustainable attributes has been found to be linked to human attitudes towards environmental quality and the economic motivation for sustaining the environment (Grebitus et al., 2016). Similarly, Roeser (2012) studied consumers' preferences for footprint-labelled products from the viewpoint of emotional engagement by consumers, and found that consumers who are passionate about the changing climate have positive preferences and motivation to buy footprint-labelled products, all things being equal. This implies that preferences and willingness to pay for environmentally sustainable or footprint-labelled products are more related to the ethics, standards and attitudes of the individual consumers, and this differs from country to country.

Early research on preferences for environmentally friendly products by Kempton (1991) revealed that Americans prefer, and are ready to pay for, environmentally friendly goods and services, with the intention of sustaining the environment for future generations. On the other hand, Hersch and Viscusi (2006) related preferences for environmentally sustainable products to how risky the consumers see the implications of climate change over a period of time. It was found that individuals who are not in favour of environmental sustainability have their own personal interests and are not looking at environmental sustainability from a social welfare point of view. They are interested in the benefits that they will accumulate from the unsustainable environmental conditions for their own parochial interests. However, the authors opined that this attitude of the advocates of non-environmentally sustainable product declines with time. The authors further found that the age of consumers also has significant impact on preferences for environmentally sustainable products, and that younger people are more concerned about the future and are more willing to pay in order to sustain the environment for the future

In Germany, an interesting study on consumers' stated preferences for carbon and water footprint labelled potatoes was conducted by Grebitus et al. (2015). The authors applied choice experimental survey data in their research and found that heterogeneity in preferences exists for potatoes without carbon and water footprint labels. The authors found that accounting for the value systems of consumers significantly explains German consumers' preferences and choice of water and carbon footprint labelled products. However, it was revealed that the consumers' generalised trust and beliefs do not significantly influence consumers' preferences for footprint-labelled food products in Germany. Gulev (2012) and Grebitus et al. (2015) found that consumers with strong social orientation have higher preferences for potatoes labelled for lower footprints, compared with consumers with their own personal orientations. The authors concluded with a hypothesis that consumers with social orientation have a better congruency for footprint-labelled products that are more sustainable. Among the socio-demographic factors considered in their study, only the age of respondents was found to have significant standard deviation estimate, suggesting that the age of respondents plays a vital role in explaining consumers' choices for footprint-labelled food products in Germany. The policy implications that emanated from this research were that consumers' heterogeneity matters to some extent in terms of labelling food products with carbon and water footprint information.

The above discussions suggest that, for environmental sustainability policymakers to communicate effectively in terms of the merits and demerits of environmentally sustainable attributes through footprint labelling, it is very important to consider heterogeneity in preferences among consumers. They should consider identifying the various segments of consumers and designing labelling formats that will educate consumers about footprint indicators. It is clear from the discussions that most of the consumer studies on preferences and willingness to pay for footprint labelling and environmentally sustainable attributes are European based, with few or none from Africa, particularly South Africa. Although it has been found that heterogeneity in preferences exists for footprint labelling and environmentally sustainable attributes, this does not necessarily imply that the findings in Europe can be said to be in harmonisation with heterogeneity in African regions. Hence, there is a need to assess individual or class-specific choices and willingness to pay for footprint labelling and environmentally sustainable attributes in Africa, with heterogeneity of preferences in mind. In order to obtain efficient findings, as well as the identification of the various consumer segments which are interested in footprint labelling and environmentally sustainable attributes, there is the need to review existing methods of evaluating preferences and willingness to pay for product attributes. Therefore, the next section provides a detailed review of methods for estimating consumers' preferences and willingness to pay.

2.7.3 Empirical Literature on Use of Eco-Labels in the Decision-Making Process

According to McCluskey and Loureiro (2003), an eco-label is a visible logo on a product used to identify environmentally preferable products, based on an environmental-impact assessment of the product, as compared with other products in a similar category. McCluskey and Loureiro (2003) define the environmental-impact as an assessment that involves production processes, uses, and discarding of the product. Although eco-labels need acquiescence with certain environmental standards, they are still considered to be market-oriented for the reason that they do not involve direct government regulation (McCluskey and Loureiro, 2003). Researchers have done tremendous amounts of research on the ecological behaviour significance in the pre-purchasing decision-making process and the importance of eco-labels (Rex and Baumann, 2006; Gao and Schroeder, 2009; Thøgersen et al., 2010). The common finding in the research is the role that eco-labels play in guiding the consumers' choice. An eco-label is defined as a product label that contains a product's environmental claims, properties and features. Consumers, on a normal basis, rely on these product claims to inform their choices. The inclusion of product eco-labels should allow consumers to effortlessly and confidently understand the product environmental features and to further easily identify the best preforming product, based on the product's environmental features (Chamorro and Bañegil, 2006).

The consistent verdict in other studies is that a change in product labelling may lead to a change in consumers' perceptions and purchasing behaviour (Wessells et al., 1999; Kim et al., 1999; De Pelsmacker et al., 2005, Thøgersen et al., 2010). Consumers' willingness to pay for a perceived superior level of quality depends on the benefits they will receive from the product attributes (Janssen and Hamm, 2012). Consumers will demand environmentally sustainable products until the marginal benefits of the environmental attribute equal marginal cost, which in this instance would be the premium price. There are a number of studies that analyse how consumers perceive different attributes associated with consumer preferences and food quality (Schnettler et al., 2009; Janssen and Hamm, 2012; Owusu-Sekyere, 2014).

2.7.4 Methods of Eliciting Consumer Preference and Willingness to Pay

The recent literature measuring consumer preferences for products and services has been of uttermost importance for both academics and practitioners in both public and private settings (Castelló, 2003). Frequently, industrialists are interested in knowing and understating the perceptions of people or consumers. According to Owusu-Sekyere et al. (2014), marketing departments and government officials want to know consumers' preferences and thoughts of the general public with regard to public health and other issues. There are numerous methods described by scientific literature used to measure consumer preferences and willingness to pay for specific product attributes. Owusu-Sekyere et al. (2014) describe two prominent and widely used methods to be the stated preference and revealed preference methods. Stated preference methods are based on an individual's responses and preferences, when given a set of options to choose from (Loureiro et al., 2002). The stated preference method is simply defined by van Zyl (2011) as asking an individual questions, with the intention of eliciting their preferences regarding a specific product attribute, without requiring the participant to act accordingly. The latter method, the revealed preference method, makes use of actual consumer decisions to draw out consumer presences (Loureiro et al., 2002). According to Loureiro et al. (2002), revealed preferences are derived from using information of consumers' actual purchasing behaviour.

Individual preferences assessment may be used for different purposes, including setting social policies and evaluating the acceptance of a new product in the market, to mention but a few. Revealed or stated preference data can be used to source consumers' preferences. According to Castelló (2003), revealed preference data is used to estimate consumer valuation when data already exists, while stated preference is used when there is no past behavioural data. The stated preference techniques hold significant advantages when historical data that suites the objectives does not exist (Loureiro et al., 2002). A variety of stated preference techniques exists for eliciting consumers' preferences and to measure their willingness to pay for goods and services. The stated preference methods relations and classifications that are extensively used in eliciting consumers' preferences and willingness to pay for a product and or additional attributes of the product are shown in the illustration below (Castelló, 2003).

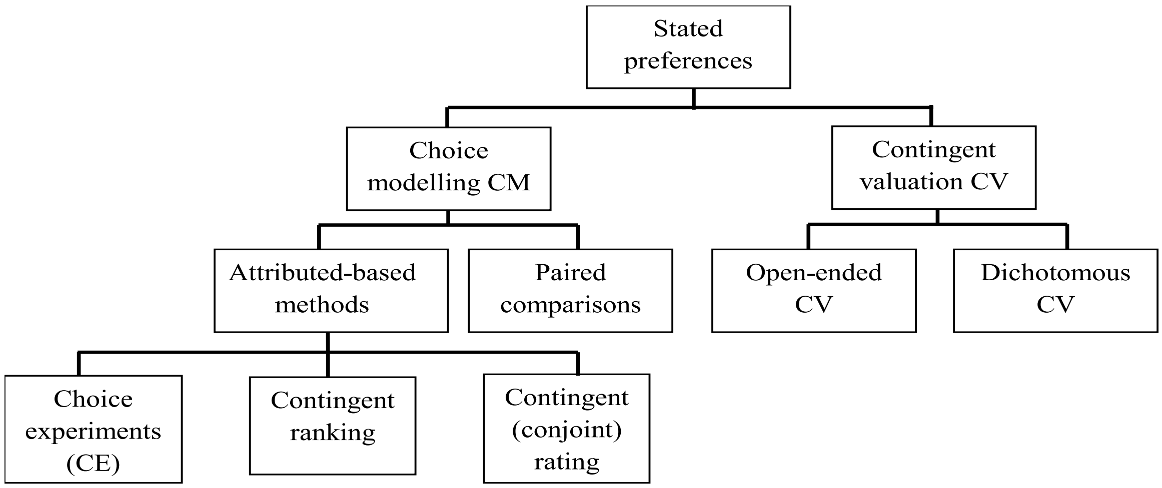

Figure 2.3: The family of stated preference methods
Source: (Castelló, 2003).

The above figure clearly shows the different methods that could be used in eliciting consumer willingness to pay, preferences and awareness. The stated preference method makes use of hypothetical scenarios to generate consumer preferences (). In this method, consumers (respondents) are given one or more hypothetical options and are asked to select the one option that best represents their preferences (Owusu-Sekyere, 2014). A number of economists and researchers have used these methods extensively to elicit details of consumer willing to pay and consumer preferences for organic food, food quality, country of origin, product labelling and numerous other product attributes (Janssen and Hamm, 2012; Castelló, 2003; Owusu-Sekyere, 2014; Loureiro and Umberger, 2003). According to Kimenju et al. (2006), Contingency Valuation methods have been mostly used in earlier consumer surveys to estimate consumers' willingness to pay for a new product or services. This method is based on a hypothetical market in a non-market that the researcher creates, allowing a respondent to operate in that market and records the result (Kimenju and Hugo, 2008).

Choice modelling methods are based on the theory that posits that consumers make choices based on preferences for different attributes of the product, and predicts consumers' choices by determining the comparative prominence of different product attributes in the consumer choice process (Kimenju and Hugo, 2008).The one common factor is that all these methods involve asking consumers questions. Contingency Valuation (CV) is able to estimate consumer preferences through an appropriately designed questionnaire approach (Castelló, 2003). In this approach, consumers are directly asked to express the maximum amount that they are willing to pay for a hypothetical change in the attributes of the product in question. The questions could be open ended (Open-ended CV) or Dichotomous (Dichotomous CV). According to Castelló (2003), open-ended CV is considered to be vulnerable to a range of biases, and the preference data derived from dichotomous CV is in a binary form, as respondents are limited to answering 'yes' or 'no'. Hanley et al. (2001) revealed that the choice results from the dichotomous CV method are larger than the results from open-ended CV are, thus there are significant limitations in estimating WTP values in both methods. To partly address the limitation to the open-ended CV and dichotomous CV researcher, Owusu-Sekyere (2014), Loureiro and Umberger (2007), Gao and Schroeder (2009) and Janssen and Hamm (2012) have made use of the choice modelling (CM) approach, which includes attributed-based methods such as choice experiment (CE), contingent ranking (CR) and contingent (conjoint) rating.

One major difference between contingent valuation (CV) and choice modelling (CM) is the fact that the latter explores and analyses a multiple of attributes simultaneously, as compared with the former, which only analyses one attribute of the product at a time (Castelló, 2003). Some advantages of multi-attribute valuation methods that solve the drawbacks of contingent valuation have been noted (Bateman et al., 2002; Castelló, 2003), as discussed in the remainder of this paragraph. The only way that a contingent valuation (CV) study can be used to estimate these attributes is to design different valuation scenarios for each attribute level, but this is very costly to achieve. Multi-attribute methods, however, provide a natural way to do this because they look at more than two alternatives. Since multi-attribute designs are based on the attribute theory of value, they are much easier to pool with cost models or hedonic price models than CV is. Furthermore, multi-attribute designs can reduce extreme multicollinearity problems because attribute levels are usually designed as orthogonal, and multi-attribute methods may avoid some of the response difficulties that appear in CV.

2.7.4.1 The Conjoint Analysis Method

The conjoint analysis, as a method, reveals an approximate structure of the consumer's preferences, given their overall evaluation of a set of alternatives with pre-specified levels of product attributes (Bateman et al., 2002). A conjoint analysis can be used to make inferences about consumer preferences and attitudes toward a specific product attribute.

2.7.4.2 The Choice Experiment Method

According to Lusk et al. (2003) and Olynk et al. (2010), the choice experiment method endorses an assessment of trade-offs between alternatives by replicating realistic buying situations, and allows the assessment of several attributes. In a choice experiment method, participants are given a set of different product alternatives to choose from. The choices that participants make can be used to determine the participants' willingness to pay for different product attributes (Gao and Schroeder, 2009). In simple terms, a choice experiment can be defined as a scene where consumers or respondents are asked to make a choice between different products with predefined attributes, with the intention of eliciting the consumers' stated preferences for the specified product attributes represented in the choice set. The choice experiment method is based on real buying situations and this is one advantage when compared with other WTP analysis methods (Janssen and Hamm, 2012).

The choice experiment method has been widely used in recent research studies that evaluate the trade-offs between product attributes. Gao and Schroeder (2009) make use of the choice experiment method to analyse the effect of additional quality attributes on consumers' willingness to pay for food labels. In the study, two sets of beef steak (beef-strip steak) are used in the choice experiment to compose the alternatives. The first set of attributes was used to test consumers' willingness to pay where the eco-label was included on the product, and the second set was to test the effects of additional information, but which excluded the eco-label.

Gracia et al. (2008) conducted a research study and made use of the choice experiment method to determine willingness to pay for food products carrying organic and 'food miles' labels. Gracia et al. (2008) estimated the error component random parameter with correlated errors to measure the effect of the labels on consumers' utility and willingness to pay.

Michaud et al. (2012) conducted a study to assess consumer willingness to pay for non-food agricultural products. Their paper investigated consumers' willingness to pay a price premium for two environmental attributes of roses: the eco-label (production processes of the roses) and the carbon footprint (greenhouse gas emissions). To elicit individual preferences for different attributes of roses, Michaud et al. (2012) made use of a technique combining discrete choice questions and economic incentives. A major supposition of a discrete choice modelling is the assumption that consumers associate each alternative in choice set with a utility level, and choose the option that provides them with the greatest utility (Lusk et al., 2001).

Janssen and Hamm (2012) conducted research to analyse consumer willingness to pay for different organic certification logos, and the choice experiment was conducted with the use of two different products: organic apples and eggs. The data was analysed with random parameter models (Janssen and Hamm, 2012). In Bosworth, an experiment with ice cream with different labels was conducted, and the data derived from the choice experiment was analysed by using a random utility model to determine willingness to pay for private labels, national brands, and local designations at retail level.

In all the above-mentioned studies, the price of the product was included in addition to the different product attributes levels. A conclusion can thus be made that the price, which is equivalent and consistent with the current real retail price of the product, must be included in addition to the different product attributes. The studies use either discrete choice or an attribute-based model that might be a mixed logit, binary, and/or multinomial logit model to evaluate consumer preferences, as reiterated by Lusk et al. (2001) and Michaud et al. (2012). Attribute-based techniques are multidimensional, which means that several product attribute levels can be simultaneously altered, and thus may elicit a more confident indication of consumers' preferences than contingent valuation methods can (Owusu-Sekyere, 2014).

2.7.5 Strengths and Weaknesses of Stated Preference Methods

Stated Preference Methods have strengths and limitations, and according to Kimenju and Hugo (2008), one of the strengths is that they are relatively easy control and thus are not as costly in nature as the stated preference methods are. These authors suggested that one of the reasons for this might be that only hypothetical situations and product attributes are presented. In stated preference methods, the researcher can create a hypothetical scenario of a market, which is the main strength of the stated preference method (Lusk et al., 2001). Stated preference methods are also characterised by being relatively flexible, as compared with revealed stated preference methods, in that they are able to deal with a wide spectrum of variables within a particular experimental design.

The major limitation or weakness of stated preference methods is that, because of the hypothetical nature of the questionnaire or the scenario, no actual behaviour is observed, which may result in the participants' responses not corresponding precisely with their actual preferences (Lusk et al., 2001; Loureiro et al., 2002).

2.8 SOCIAL AND ECONOMIC IMPACTS OF PROPOSED CHANGES IN WATER USE BEHAVIOUR

2.8.1 Contextualising Social and Economic Analysis of Changed Water Use Behaviour

Water has traditionally been considered as one of the most important natural resources in terms of contribution to the development of civilisations. The importance of water lies in the fact that it satisfies a broad group of needs, both in its role as a necessary good upon which public health and life itself depend, and in its role as a basic input in most agricultural and industrial production processes (Roibas et al., 2007). Changing demographic and climatic factors will have the effect that periods of water shortages can be expected to reappear in the future. These factors include population growth, urbanisation, migration, industrialisation, food and energy security policies, legislation and management, and macro-economic processes such as trade globalisation and changing consumption patterns (such as increases in the consumption of meat and use of technological devices that have increased water consumption). This, in turn, will give rise to the need for policies that limit consumption and will change consumers' behaviours towards water use (Connor et al., 2015).

The increase in population and urbanisation threatens resource allocation, sustainable intensification of agriculture, food security, and environmental sustainability (FAO, 2009). With the world's population projected to reach over 9 billion by 2050, governments, stakeholders, development partners, practitioners and organisations are interested in the development and implementation of agricultural and water-related polices that will yield positive impacts in terms of saving resources (water) and changing the behaviour of water users. As populations keep increasing, greater amounts of food and livestock feed will need to be produced in the future and more water applied to this purpose. Irrigated agriculture will have to claim large quantities of water to produce the food required to feed the world. The main source of food for the population of the world is agriculture (Leenthech, 2016).

In particular, one of the most serious causes of water shortage in many regions, including South Africa, is drought, and when this cyclical phenomenon reoccurs, the entities responsible for water supply often impose water cuts and restrictions in order to match the available supply with demand. The water restrictions have already been applied in some provinces of South Africa. Generally, water shortages give rise to the need for water rationing, while the authorities frequently resort to water supply cuts. The effects of policies aimed at limiting water consumption have been the subject of several studies, including those of Woo (1994) and Renwick and Archibald (1998), which quantify the welfare losses associated with various alternative rationing systems in household consumption. Under a price rise, consumers are free to consume whenever they wish. A supply cut, on the other hand, reduces the availability of the resource to consumers. This generates a distortion in demand behaviour because consumers cannot freely choose the timing of their consumption, which in turn implies that consumer utility is affected (Roibas *et al*., 2007). South Africa, a leader in agribusiness on the continent, has a well-established agri-food sector that is facing increasing pressure from climate variability that affects production (Pereira and Ruysenaar, 2012). South Africa is not different from other countries, and recently various provinces in South Africa have had to cut water usage (water restriction) by 15%, and the agricultural sector would have to reduce water use by 50%.

2.8.2 Methods for Assessing Social and Economic Impact

2.8.2.1 A CGE Model

To evaluate the impact of different policy is driven scenarios of water on grain sub-sector (maize and wheat) was applied a modified International Food Policy Research Institute (IFPR) economy-wide computable general equilibrium (CGE) model. A CGE model is evaluated economy-wide, because it, in a sense, includes all sectors. Such models have gained increasingly wide acknowledgment in terms of policy evaluation. This model permits a systematic analysis to be made of external price shocks and shifts in other exogenous variables, while tracking the effects of such changes on various actors in the economy. It is possible to distinguish the implications of various policies and external price regimes with respect to their effects on several variables of interest: macroeconomic variables, sectoral output, employment, household income, and welfare (Nielson, 2002; Bahta et al., 2014).

The underpinning database to be used for the model is a social accounting matrix (SAM) of the base year 2009, developed in 2014 by the International Food Policy Research Institute (IFPRI) (2014). The model is initially set up to replicate the base year SAM by appropriately calibrating the parameters of the model (see Addendum 'A' for a mathematical summary for the standard CGE model (Lofgren et al., 2002)). Most of the parameters of the model can be, and are, calibrated from the SAM; however, the Armington elasticities are obtained from Gibson for some agricultural and non-agricultural products and for selected agricultural products (Gibson, 2003; Ogundeji et al. 2010)

2.8.2.2 Social Accounting Matrix (SAM)

A social accounting matrix (SAM) provides a comprehensive and consistent description of the transactions taking place in an economy in a given year; between production sectors, factors, households, government institutions and the rest of the world. Each macro-account in the SAM is represented by a column and a row, with columns tracking expenditures and rows tracking incomes. The SAM follows the principles of double-entry accounting. This has two implications: (1) any purchase, expenditure or financial outlay by one account is the sale, income or financial inflow to one or more other accounts, and (2) for each account, total income must be equal to total expenditure (Nielsen, 2002).

The original SAM provided a detailed representation of the South African economy with 49 activities and 85 commodities, where labour was disaggregated by education level, and households by per-capita expenditure deciles (Rob and Thurlow, 2013). However, adjustments were made for the sectors Non-ferrous metals, General machinery, and Aircrafts. The three sectors showed higher exports than gross output figures, which implied negative domestic supply of domestic produce. This episode indicated re-export of imported goods because the economy exported more than the produced gross output. The three export figures were netted and their respective import figures were lowered by equivalent values.

The South African SAM does not include specific accounting for the grain sector (maize and wheat). The grain sector ("Maize and Wheat") was included in the "Agriculture" account. In order to conduct an analysis, it was separated from the aggregated 'Agricultural' account. The grain sector was disaggregated using a different source of data: for the share of gross output to total agricultural output, the Department of Agriculture, Forestry and Fisheries source data were used (DAFF, 2014). The share of maize and wheat gross output (gross value of output) in 2009 were 11.51% and Wheat 2.43% to total agricultural output, respectively. The share of export and import to total agricultural export and import used information from ITC (International Trade Centre) (2014) and NAMC (2014). The shares of maize and wheat exports in 2009 were 8.18% and 0.50% to total agricultural exports, respectively, and the shares of maize and wheat imports in 2009 were 0.51% and 6.58% to total agricultural imports, respectively. Furthermore, the maize and wheat sectors were disaggregated into irrigated and non-irrigated farming, based on the Statistics South Africa report (2012) that in 2009, about 19% of maize production was irrigated and 30% of wheat production was irrigated. Information on import tariffs and household expenditure was obtained from ITC and Income and Expenditure (IES), respectively (Statistics South Africa, 2015).

As a result of all the data discrepancies, the SAM was unbalanced, and the cross-entropy method was used to balance the SAM (Robinson et al., 2000; Lee and Su, 2014). Balancing a SAM using the cross-entropy (CE) method has become a standard procedure in most SAM-based modelling.

Robinson, Cattaneo, and El-Said have explained that the CE method is built on information theory, as developed by Shannon (1948) and brought into economics by Theil (1967).

2.8.2.3 The SWIP – E (Soil Water Irrigation Planning – Energy) model

The SWIP – E (Soil Water Irrigation Planning – Energy) model (Venter, 2015) was used to calculate the effect of water restrictions on the crop yield, the area planted, and the gross margin of maize and wheat. The SWIP – E programming model is based on the SAPWAT optimisation (SAPWAT – OPT) model (Grové, 2008) that optimises a daily soil water budget for a single crop. The SAPWAT – OPT model was further developed to optimise water use for a crop rotation system. Detailed electricity cost calculations are included in the model to facilitate electricity management in an irrigated way.

Production income, yield, area and irrigation dependant costs are based on the calculation procedure recommended in Venter (2015). Production income is a function of yield and area planted for each crop and the price of the crop. Production income is calculated by multiplying the crop yield with the crop price and area planted. The calculation of yield dependent costs is based on a cost reduction method (Grové, 1997). Area-dependent costs include all input costs which will change the area planted. Irrigation dependent costs (IDC) include electricity costs, labour costs, repair and maintenance costs, and water costs of the irrigation system. Total electricity costs depend on the type of electricity tariff.

All tariff options include a fixed cost and a variable cost. Fixed costs have to be paid every month, irrespective of whether electricity was used or not, while variable costs have to be paid for actual electricity consumption. Variable electricity costs are a function of management (hours pumped), electricity tariffs, and irrigation system design (kW). The calculation procedures for labour and repair and maintenance costs are based on formulas proposed by Meiring (1989). Water charges are a function of the irrigation water applied, the area planted, and the water tariff charged by the water user association.

2.9 CONCLUSIONS

The review of the water footprint and economic water productivity of products reveals that water footprint assessments are gaining prominence and have become a major issue of policy concern to governments, organisations, policymakers, water users, and water managers. This is because water is a scarce resource and a large proportion of the world's population faces difficulties in getting fresh water. It is concluded that food production is the major user of freshwater resources. South Africa is among the most arid countries in the world, and agriculture is the highest user of the available water resources. Water footprint assessments have received some attention in South Africa, but the economic aspects of water footprints have received little attention. Few researchers have linked the economic aspects of water to water footprint indicators South Africa.

The existing knowledge is insufficient to effectively guide South African policy and decision makers, water users and managers in formulating appropriate policies to guide freshwater use, and for water users to be economically efficient in water use. The review of the concepts of water footprints reveals that the Global Water Footprint Standard of the Water Footprint Network, described by Hoekstra et al. (2011), gives an all-inclusive indicator of freshwater use, relative to the Life Cycle Assessment (LCA).

The estimation of economic water efficiency builds upon the estimation of a total water footprint. The estimation of economic water productivities follows certain steps; the first stage involves the estimation of physical water productivities, and finally the economic water productivities are estimated. Research on the economic productivities of water is very scanty from the viewpoint of the semi-arid and arid regions of Southern Africa. Hence, there is the need for an assessment of economic water productivities to be undertaken. Available methods for estimating water footprints include the consumptive water-use-based volumetric water footprint, stress-weighted water Life Cycle Assessment (LCA), adapted LCA water footprint methodology, and the hydrological water balance method. The consumptive water-use-based volumetric water footprint, as accepted by the Water Footprint Network, accounts for blue, green, and grey water footprints, with clear distinctions being made between the sources of water, and hence will be used in this study.

The review of consumers' preferences, WTP, and welfare effects of water footprint sustainability information shows that it is very relevant to know how environmentally sustainable attributes and information will change consumers, producers, and sustainability behaviour, as well as the welfare implications of their changed behaviour. Despite the relevance of understanding consumers' preferences, willingness to pay, and welfare effects, the review of literature has revealed that existing research on environmental sustainability assessments has ignored South Africa. Hence, the present knowledge is inadequate to understand how South African consumers would react to changes in water footprint sustainability attributes and policy changes. The review further shows that consumers' awareness of water footprint information plays a significant role in shaping consumers' behaviour. It is also concluded that heterogeneity in preferences exists among consumers for sustainable product attributes, and as such, sustainability studies should adopt methods that account for heterogeneous preferences.

The review of the methods used for assessing consumers' preferences and WTP for product attributes emanates from McFadden's standard statistical framework and Lancaster's characteristic methodology for explaining consumer behaviour and choices. The methods for assessing consumers' preferences and WTP for sustainability attributes can be categorised into revealed and stated preferences approaches. The stated preference approach will be used in this study because no data currently exists on preferences and WTP for water and carbon footprint sustainability attributes in South Africa. The review of the methods for estimating consumers' preferences and welfare estimates reveals that a choice experiment is appropriate when dealing with multiple sustainability attributes or policy changes. Hence, in this study, the choice experiment was used to assess preferences and welfare estimates arising from consumers' choice of water and carbon footprint sustainability attributes.

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CHAPTER 3
CASE STUDY OF MILK AND IRRIGATED PASTURES

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Summary

The main objective of this case study was to assess the water footprint of milk and irrigated pasture, which is then used as an important feed input for the production of milk in order to get an understanding of the volume of freshwater that is needed to provide consumers with pasteurised milk. The financial value that was added to the water that was used to produce milk was also explored in order to get an understanding of how the value of the water increases along the milk value chain, from the feed producers to the end consumer. Lucerne production was explored in detail, using in situ data from a secondary source, while the water usage of the other crops was estimated with the use of several formulae. The results show that the water footprint indicator of lucerne production at Vaalharts was 456.6 m^3.ton. Of this, 206.9 m^3.ton^{-1} of water originates from effective rainfall (green water footprint), 171.3 m^3.ton^{-1} from surface and groundwater (blue water footprint), and the remaining 78.4 m^3.ton^{-1} of water was used to assimilate the salts leached during production to acceptable levels (grey water footprint). Milk production in the South African case study uses more water than the global average and slightly less than the country average estimate for South Africa, but remains environmentally sustainable nonetheless. Importantly, water is not simply used as an input for producing milk, but value is added to the water along the milk value chain. Evaluating the value added along the value chain found that the total value added depends greatly on the volume of the container in which the processed milk is sold. The processing facility in the case study produced milk in two container sizes, one litre and three litres. It was found that by packaging the processed milk in a bottle with a capacity of one litre, a total value of 12.11 ZAR per kilogram of milk (4% fat, 3.3% protein) was added. In contrast, milk packaged in three litre containers only added 9.04 ZAR of value per kilogram. The value added per cubic metre of water once the processed milk reaches the final consumer was evaluated for the two different product volumes. Despite using the same volume of water during production, the value chain of the

smaller container added 11.81 ZAR per cubic metre of water, as opposed to the 8.82 ZAR added to the water along the value chain of the three litre containers. A substantial amount of value was added along the value chain of milk. The findings on pastures have provided different pasture combinations with their dry matter yield and water usage for different seasons and production systems. The findings reveal that the yield and water usage for sole pasture crops and mixed pastures varies from season to season. Blue water usage dominates in the pasture production, and green water usage is minimal.

3.1 BACKGROUND AND MOTIVATION

In 1896, William Jennings Bryan wrote: "Burn down your cities and leave the farms, and your cities will spring up again as if by magic; but destroy the farms and the grass will grow in the streets of every city in the country." The role of commercial agriculture in a modern society cannot be over-emphasised and therefore we need to keep on improving this sector. South Africa is water scarce and ranked as the 30th driest country in the world (Department of Water Affairs (DWA), 2013). The agricultural sector is crucial for the food security of not only South Africa, but also the neighbouring countries and the broader Sub-Saharan Africa (Department of Agriculture, Forestry and Fisheries (DAFF), 2011). Rapid population growth and increasing variability in rainfall has led to tighter water supply in many parts of South Africa where the water demand often exceeds the supply (DWA, 2012).

Agriculture is the single largest user of water in South Africa, and as the increase in population places greater demands on the water resources, agriculture will have to increase the efficiency with which it uses water (Nieuwoudt *et al*., 2004). Although agriculture in South Africa uses up to 60% of the available water, only 12% of the total area of the country is considered to be arable, with as little as 3% being "truly fertile" (DWA, 2013). South Africa irrigates 1.5% of the total landmass to produce 30% of the total crops produced (DWA, 2013). According to Backeberg and Reinders (2009), irrigated agriculture in South Africa uses roughly 40% of the exploitable runoff. Other estimates suggest that agricultural production uses more than 60% of the available water (DWA, 2013). With such a high proportion of the water being used by the agricultural sector, there is increasing pressure from government and other sectors being placed on agriculture to use less water, while maintaining crop yields. This is not only a local phenomenon but also a global reality; more people compete for the same limited water resources, and consequently water must be used with greater efficiency.

A cause for concern with the high water use in the agricultural sector is that agriculture's direct contribution to the Gross Domestic Product (GDP) of South Africa is less than 3% (DAFF, 2014). The agricultural sector thus generates only a small share of income, while using the largest share of available water in South Africa. Therefore, it might be considered an inefficient allocation of the scarce freshwater resources to allocate it to irrigated agriculture (Nieuwoudt *et al*., 2004). In addition to irrigated agriculture, water is also an important input for animal production. This is because animal production systems require vast quantities of feed, which is produced using water as an important input. The water usage for feed production is by far the greatest consumer of water along animal value chains; consuming in excess of 95% of all the water used along the value chain (Mekonnen and Hoekstra, 2010b; Hoekstra, 2012). The dairy industry is no different and with intensive dairy production systems, good quality water is of crucial importance, given the relevance of the industry.

The dairy industry is relatively important in the greater context in that it contributes 14% to the gross value of animal production, and 7% of the gross value of agricultural production in South Africa (DAFF, 2014). Therefore, the industry is of importance from an economic perspective, but its impact as an employer in the rural areas is of much more significance. According to an industry overview of the dairy industry in South Africa, this sector consists of about 4 000 milk producers, who in turn provide employment to 60 000 farm workers. A further 40 000 people have indirect employment in the rest of the dairy value chain (DAFF, 2012). It is thus clear that the South African dairy industry is very important from a socio-economic perspective.

The dairy value chain is an elaborate chain, starting at the feed production and ending with the processed dairy product on consumers' tables. Water is needed at all the stages along the value chain, with feed production using by far the greatest volume of water (De Boer *et al*., 2012). The fact that the dairy industry is using vast quantities of water in order to produce feed means that emphasis must be placed on the sustainable use of freshwater, from both an environmental and economic perspective.

Water footprints are emerging as an important sustainability indicator in the agriculture and food sectors (Ridoutt *et al*., 2010). The water footprint is a relatively new concept, with good prospects for contributing towards the efficient use of freshwater. Where a product is considered, the water footprint is the volume of freshwater used to produce the product, and is measured along the complete value chain of the product, from the inputs up until the end product reaches the consumer (Hoekstra *et al*., 2011).

Deurer *et al.* (2011) highlight the point that the focus has traditionally been on reducing agriculture's impact on freshwater through the technical aspects of irrigation and drainage. Furthermore, water footprints could possibly be used as a tool to address water issues through regional trade policies and consumer attitudes. Van Der Laan *et al.* (2013) envisaged that the water footprint could be useful to the agri-food sector in that it could guide and inform policy formulation and integrated resources management at national level, Furthermore, it could lead to improved understanding of water-related risks, which could then assist with water management at regional level, while the water use information could help to identify opportunities to reduce the water consumption at the local level.

The aim of the case study is to contribute to the limited body of knowledge by assessing the water footprint of lucerne (*Medicago sativa*) produced under irrigation and used as important feedstuff in the production of milk in South Africa. The complete value chain of milk produced in the Free State province of South Africa will be evaluated to obtain the water footprint of milk production. The final value of the water that was originally allocated towards the production of lucerne will also be explored. Ultimately, this will be the first step towards establishing benchmarks for the economically and environmentally sustainable use of freshwater in the lucerne-dairy value chain. The aim of the study will be achieved through the following sub-objectives.

Sub-Objective 1: Assess the water footprint of lucerne produced under irrigation and used as an important feedstuff in the dairy value chain in order to determine the water use efficiency of the South African lucerne-dairy industry, in comparison with other dairy production areas. The focus will specifically be on milk produced and processed in central South Africa.

Sub-Objective 2: Quantify the value of the water by the time it reaches the end consumer in order to see how much value is added to the water along the lucerne-dairy value chain.

The value of the water will be calculated by expressing the value added along the value chain in terms of ZAR/m^3 of water used.

3.2 DATA AND METHOD

In this section, the water footprint methodology that best suits the goals and scope of this study are elaborated. From the literature considered in Chapter 2, it was determined that the Water Footprint Network's approach is best aligned with the goals and scope of this study. Therefore, in this chapter, the application of the method is explained. Once the total water footprint methodology is explained, the method used to quantify the value of the water, once it reaches the end consumer, will be expanded upon. The data for the calculations is also explained, together with the management of the data to enable the calculation of the water footprints and the value added to the water.

3.2.1 Data

The scope of this study covers a case study of the lucerne-dairy value chain, with a focus on milk, from raw to processed, and sold at retail level. Secondary data on water usage for the production of lucerne as a fodder crop was obtained from van Rensburg *et al.* (2012) who, among other things, explored the management of salinity on lucerne crops. Once the lucerne hay is produced, it becomes an important input for dairy production, and the link between the lucerne and dairy value chains is made. Therefore, water data for a commercial dairy farm and a dairy processor is needed. This data was collected through questionnaires and interviews held with the managers of the various divisions at the case study agribusiness. The business consists of both a commercial dairy and a processing plant where the milk is processed and bottled.

3.2.1.1 Study area

The measurements taken by Van Rensburg *et al.* (2012) that are of relevance for this study were noted on farms within the Vaalharts Irrigation Scheme. This irrigation scheme is situated between the Vaal River and the Harts River in the Northern Cape, and falls within the Lower Vaal Water Management Area (WMA). Figure 3.1 is a layout of the Vaalharts Irrigation Scheme. The Vaal River is the main supplier of water to the Vaalharts Irrigation Scheme, with the Warrenton Weir just upstream of Warrenton diverting water into the Vaalharts main canal. This main canal in turn supplies the North, West, Taung and Klipdam-Barkley canals that convey the water to Vaalharts, Barkley-West, Spitskop and Taung sections. The total licensed areas for irrigation in the sections are 29 181, 2 555, 1 663 and 6 424ha, respectively. In order to convey the irrigation water to the licensed areas, the system comprises 1 176 km of concrete-lined canals, together with 314 km of additional concrete-lined drainage canals, used to convey storm-water and subsurface drainage water out of the irrigation scheme through to the Harts River (Van Rensburg *et al*., 2012).

The Vaalharts area is essentially bordered by two plateaus on the east and west sides of the Harts River Valley (Erasmus and Gombar, 1976) and the valley slopes towards the south. The low gradient of the Harts River, with no incising by the river itself, means that very little topographical changes can be observed within the valley (Erasmus and Gombar, 1976). The general surface flow pattern tends to be towards the Harts River (Van Rensburg *et al*., 2012).

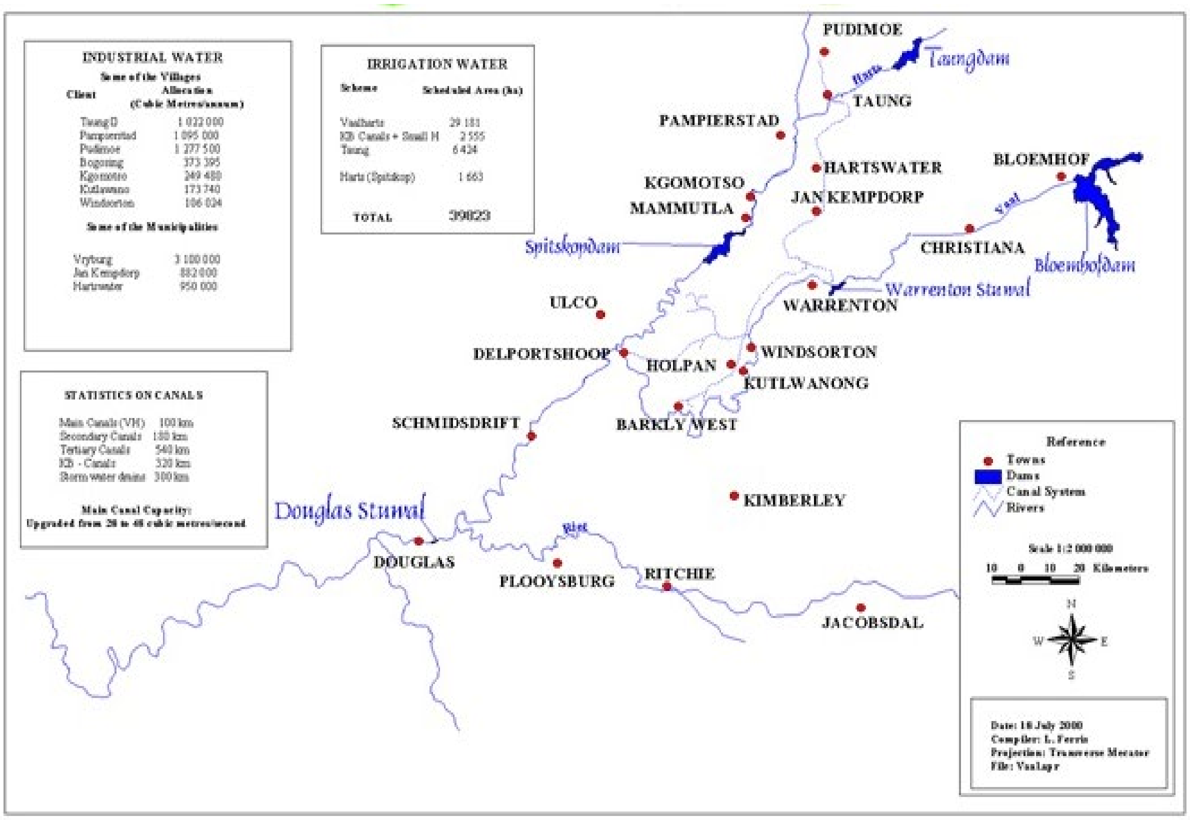

Figure 3.1: Layout of the Vaalharts irrigation scheme
Source: Anon, 2014

The Vaalharts Irrigation Scheme falls within a summer rainfall area, with thunder showers are responsible for the majority of the rain during the summer months. Between November and April, the long-term rainfall for the area is normally more than 40 mm per month, with a mean of 59 mm. The long-term maximum temperature between November and March for Vaalharts is 31°C, while the minimum temperatures vary between 14 and 17°C. During the winter months, the maximum temperature is around 20°C, with the mean minimum temperature just above 0°C.

Water Quality

A major focus of the study by Van Rensburg *et al.* (2012) was on the quality of the water used for irrigation in the Vaalharts Irrigation Scheme, among others. They used data provided by the Department of Water Affairs and Forestry to calculate the mean long-term electrical conductivity (EC) and sodium absorption ratio (SAR) of the dams and river water for the period 1970-2006.

The measuring stations where the water quality was measured are indicated in Figure 3.2, along with the long-term electrical conductivity of the water at those stations shown in red. Van Rensburg *et al.* (2012) found that the SAR of all the measuring stations within the irrigation scheme remained below 10, and consequently the scheme represents a low-sodium hazard (S1).

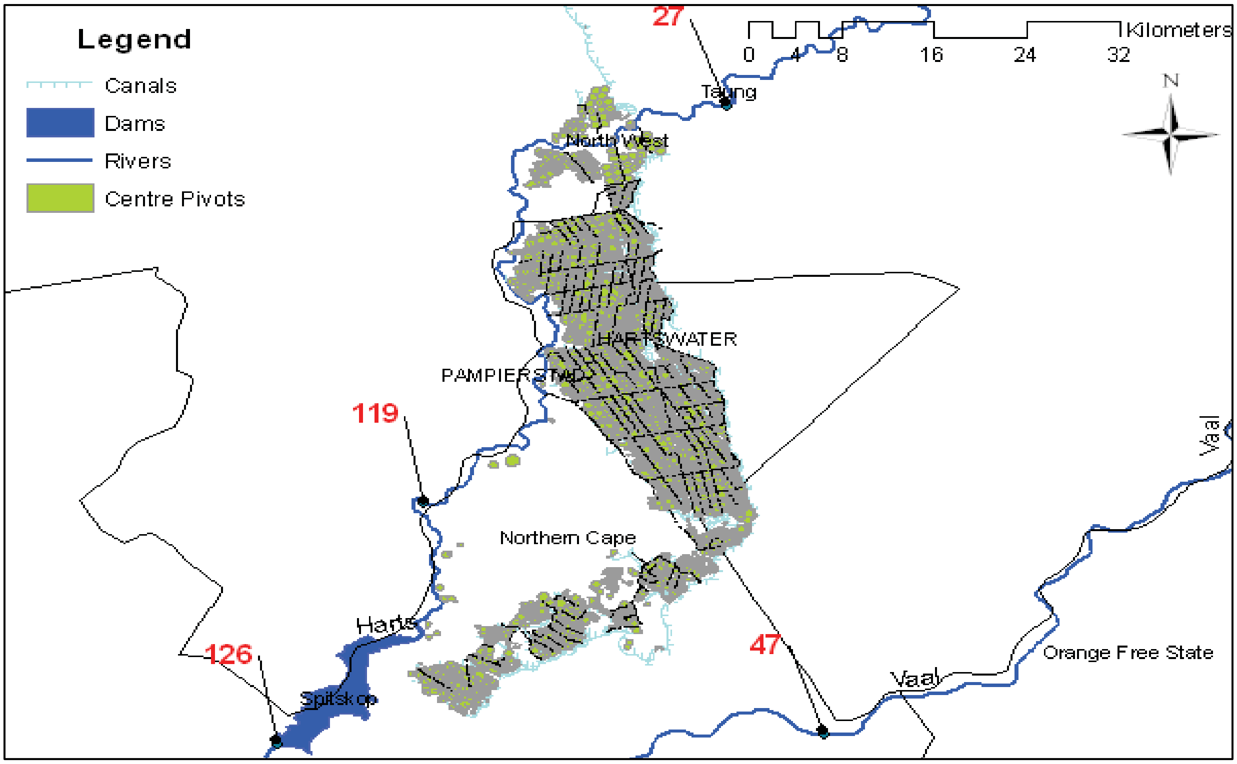

Figure 3.2: Mean long-term electrical conductivity (mSm-1) of dams and rivers at the Vaalharts Irrigation Scheme for the period 1970-2006
Source: Van Rensburg *et al*., 2012

In order to see how the irrigation practices at Vaalharts contributed to the deterioration of the water quality, Van Rensburg *et al.* (2012) determined that fairly good quality irrigation water (C2), with a mean long-term EC of 4 mS m^{-1}, is received from the Vaalharts Barrage. The addition of the salt load of the drainage water from the scheme changes the mean long-term EC of the Harts River from 27 mSm^{-1} at Taung Dam to 119 mSm^{-1} at Espagsdrif, ending with a mean long-term EC of 126 mSm^{-1} at Spitskop Dam. It is therefore concluded that the water leaving the scheme can be classified as C3 water, and poses a high-salinity hazard (Van Rensburg *et al*., 2012). This deterioration of irrigation water has an impact on the water footprint of lucerne in that it greatly increases the grey water footprint.

Layout of measuring points

The fact that the land used for irrigation was not homogeneous meant that several measuring sites had to be selected in order to get an accurate representation of the irrigation scheme. Thus, no irrigated field is similar, and each of the measuring points was seen as a unique opportunity to obtain information on water and salt management practices carried out by farmers at Vaalharts. Measuring points were therefore selected to include a variety of bio-physical conditions at root-zone scale so as to cover differing irrigation water qualities, soil types, crops, irrigation systems and soils that are artificially drained. This also allowed for the incorporation of different managers. Figure 3.3 shows the geographical positions of the measuring stations at the Vaalharts scheme.

Measuring points with dimensions of 4 m x 4 m were set up in a crop field. In fields with artificial drainage systems, two measuring points were established, one on the drainage line and the other some distance away, depending on the line spacing and type of drainage system. Two neutron access tubes (2 000 mm), one piezometer (perforated 63 mm PVC tubes and 3 000 mm deep) and a rain gauge were installed at each measuring point. Measurements at these measuring points were conducted over four seasons (two winters and two summers) from July 2007 to June 2009 (Van Rensburg *et al*., 2012).

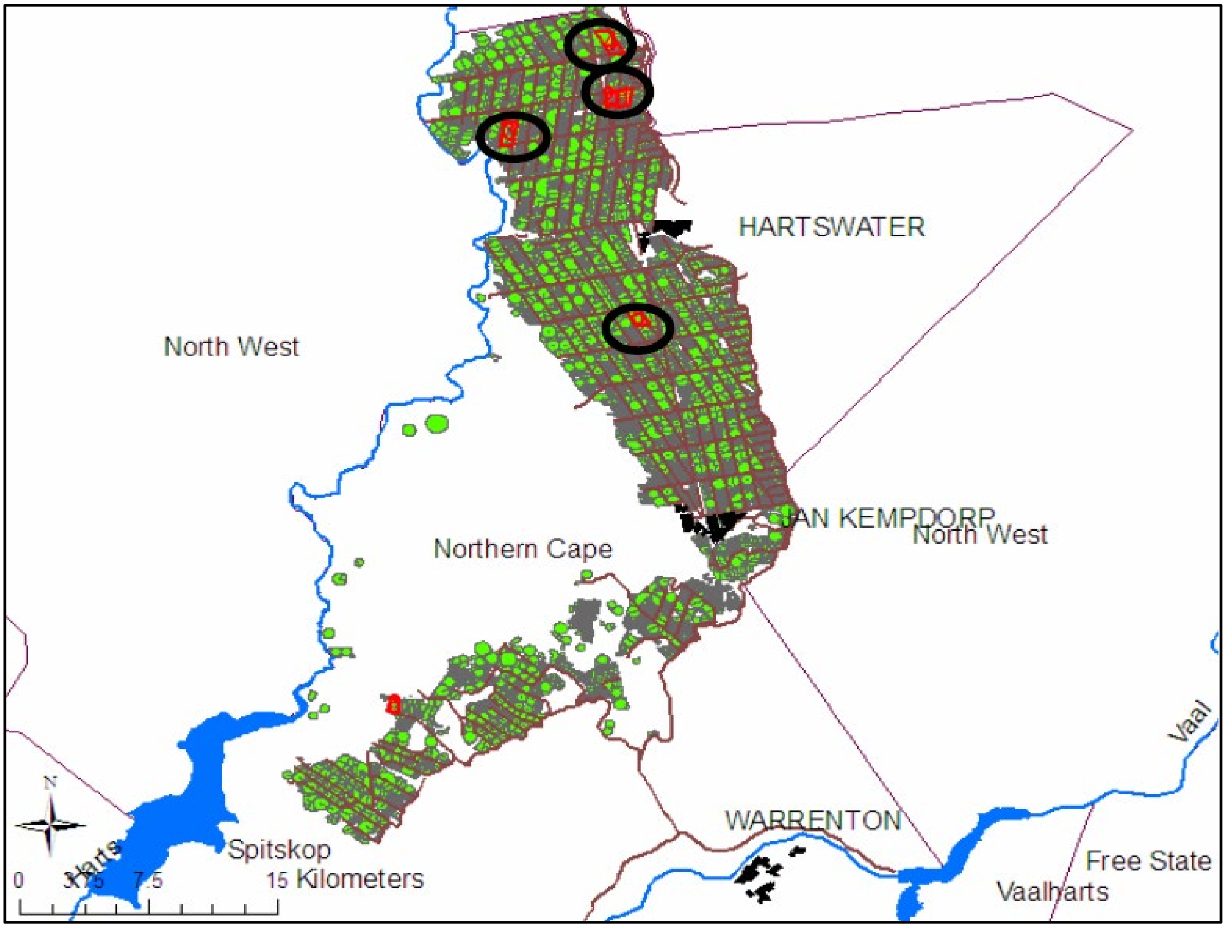

Figure 3.3: Geographical position of the measuring points at the Vaalharts irrigation scheme
Source: Barnard *et al*., 2012

3.2.1.2 Water use data on feed production

Van Rensburg *et al*. (2012) measured the data on a weekly basis at every experimental area or measuring point. These weekly measurements enumerated rainfall, irrigation, soil water content, water table depth, and drainage from artificial drainage systems, if any, as well as electrical conductivity (EC) of the irrigation water, water table and drainage water. The rainfall and irrigation was measured with rain gauges placed on the surface of the soil, with a 6 m^2 cleared area provided around each rain gauge to prevent interference from the crop. Soil water content was measured with a calibrated neutron probe. The depth of the water table was measured manually by using an electronic device, while the volume of drainage water flowing from the artificial drainage systems was measured with a bucket and converted to L min^{-1}.

In order to measure the electrical conductivity of the irrigation water, water table and drainage water, a calibrated handheld Ecoscan (Con6) Electrical Conductivity Meter was used. Water was manually collected with a bailer from the piezometers and with 100 ml bottles from the rain gauge and drainage system. The principle of conservation of mass, where any change in water or salt of a given volume or depth of soil must be equal to the difference between water or salt added and lost from the same volume, was used to calculate the soil water and salt balances. It is thus crucial to define the boundaries of the relevant system. The soil depth is of relevance for root-zone induced salinity, and in the system under consideration, the soil depth was taken as 2 000 mm, since this is the potential root zone of the majority of agricultural crops. Figure 3.4 below is a conceptual illustration of the soil and salt water balances. The root zone was then taken as the depth to the restrictive layer, in the cases where such restrictive layers were present.

Changes in irrigation, rainfall, soil water content, and drainage from artificial drainage systems were all measured, of which the latter mentioned also apply to the change in salt content of the soil, and salts added through rainfall and irrigation, as well as salts removed through the artificial drainage system. The net amount of salt applied through fertilisation (SF,) was calculated as the difference between salt applied through fertilisers and salt removed by the crop. Van Rensburg *et al.* (2012) assumed that 50% of the total salt addition through fertilisation was removed by the crop. This amount is equal to approximately 3-5% of the seed yield, which was determined from seed yield measurements of Ca, K, Mg, Na, P and N at the various measuring points.

The linear relationship between the amount of fertiliser applied (kg.ha^{-1}) and the change in electrical conductivity of a 300 mm soil layer was used to obtain the total salt addition through fertilisation. This relationship was determined from fertiliser solutions with different concentrations, the electrical conductivity of which was measured. Van Rensburg *et al.* (2012) prepared the different fertiliser solutions to represent a range of different types of fertilisers and applications by farmers at Vaalharts. Furthermore, it was assumed that all the fertilisers were applied to a 300 mm soil layer and the soil water content was near the upper limit of available water for the plant. SWAMP (Soil Water Management Program) was used to estimate the evaporation from bare and converted surfaces, transpiration, water and salt transport through water table uptake, and the movement of water and salt from the top of the soil downward through percolation into the water table.

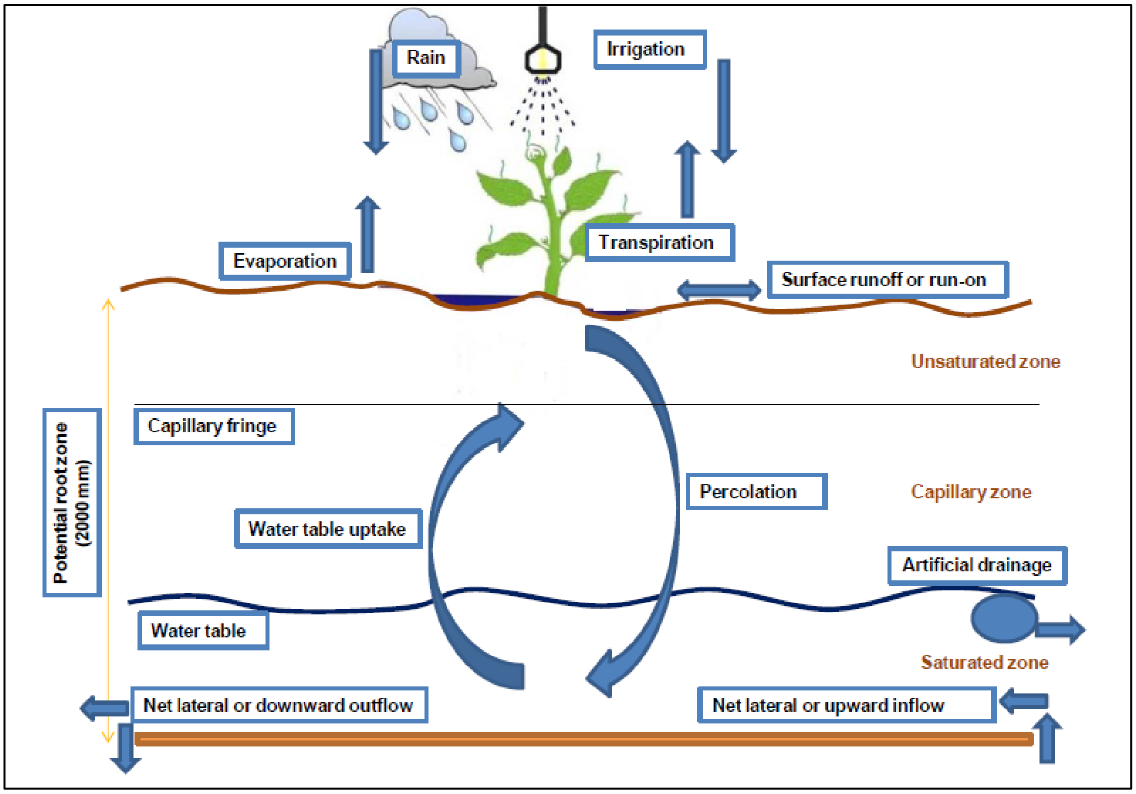

Figure 3.4: Conceptual illustration of the soil water and salt balance for a potential root zone of 2 000 mm of an irrigation field
Source: Van Rensburg *et al*. (2012)

Mekonnen and Hoekstra (2010b) and Hoekstra (2012) found that animal feed was by far the greatest contributor to the total water footprint of animals. Therefore, a great deal of effort was spent on the accurate calculation of the water used to produce the feed for the lactating cows. The National Research Council (2001) lists several different methods to determine the dry matter intake (DMI) of lactating dairy cows and explains how the methods have evolved since the 1970s. Several DMI prediction models have been developed to include environmental, dietary and animal factors. The methods suggested by (among others) Holter and Urban (1992), Holter *et al*. (1996) and McGilliard *et al.* (1997) have been widely published and used in the industry, yet it is often difficult to have all the parameters available for a given animal type at specific environmental conditions.

The fact that the farm under consideration has a modern feed calculating system with electronic recordkeeping of the lactating cows' feed means accurate data on the feed composition and the quantities fed is available. This data was aggregated to the whole dairy and average values were used in further calculations without any need to estimate the DMI and the FCE. From this electronic feed calculator, one can clearly see the quantities of the various inputs in the feed ration, the moisture content and DM, and nutritional values of the inputs and the complete ration, as well as the average DMI across all the lactating cows. In the case study, it was found that feed ration consists of six main ingredients. The ingredients of the feed ration and the proportions in the final feed mix are summarised in Table 3.1.

Table 3.1: Composition of the feed ration, the moisture and DMI, together with the production yields of the input products

Product	Actual kg	Kg DM	%	Ton.ha^{-1}	Moisture %	DM Yield
Lucerne	4.8	4.22	17.53	35.2	12	30.95
Oats Silage	3.4	1.05	4.38	37.0	69	11.47
Sorghum Silage	8.6	2.58	10.71	55.0	70	16.50
Maize Silage	13.9	3.89	16.16	70.0	72	19.60
Yellow Maize meal	8.5	7.48	31.05	6.1	12	5.37
High Protein Concentrate	5.4	4.86	20.17	6.0	10	5.40
Dairy Feed Total	44.6	24.09	100	-	-	-

The water usage for lucerne production was explained in the first half of this chapter and therefore the focus in this section will be on the water usage for silage, maize meal and high protein concentrate production. No *in situ* water usage data is available for silage or for high protein concentrate production. The yields of the crops and the moisture content of the yields are available. These groups of data were used as inputs for estimating the water use to produce the various products. This was done by using the equation suggested by Bennie *et al*. (1998) to estimate the total seasonal water requirement of the crop. The following parameters are required for this equation:

- Y_a = Actual total DM yield (kg.ha)
- Y_m = Maximum DM yield (kg.ha)
- ET_a = Actual total evapotranspiration (mm)
- ET_m = Maximum total evapotranspiration (mm)
- β = Slope of the (1-Y_a/ Y_m) vs (1-ET_a/ ET_m) relationship

The actual total evapotranspiration (mm) is then estimated as follows:

$$ET_a = ET_m - \left[ET_m . \left(1 - (Y_a/Y_m)\right)/\beta\right] \tag{3.1}$$

In order to account for the silages, a harvest index (HI) is required to convert the total dry matter production into grain yield and residue yield because the equation requires the dry matter yield, excluding the grain. The harvest indices, together with the other maximum parameters given by Bennie *et al*. (1998), were used for the estimations. No data was available for oats, so the values for wheat were used in the estimation. The maize cultivars have improved significantly since the publication by Bennie *et al*. (1998), resulting in much higher harvest indices. Therefore, it was decided to use an average HI of 0.55 for maize, as this is the average HI that Howell *et al*. (1998) calculated for modern maize hybrids.

Once the actual total evapotranspiration (ET_a) was determined, the rainfall during the growing period of the respective crops was used as the green water. The average rainfall data of a measuring station at De Brug (29.18502 S; 25.9756 N) was used in the calculations. It was assumed that all the rain measured by the measuring station was effective rainfall, meaning that all the rain became green water. Hoekstra *et al.* (2011) explains that the blue water footprint of a growing crop is the minimum of the crop water requirement and the effective irrigation. In the case study, it is assumed that the farmer over irrigated, but for the blue water footprint the over irrigation is not considered. This then means that the blue water is the difference between the ET_a and the effective rainfall.

The over irrigation was not taken into consideration for the calculation of the blue water, but it is accounted for in the grey water footprint. In order to estimate the grey water footprint for the various crops, the leaching requirement approach of Ayers and Westcot (1985) was used to estimate the total volume of water required to keep the salt content of the soil below the salinity threshold of the crops (EC_e). This method is for stable-state situations and applies for long-term salt control, but it does not take rainfall into account. Maize is the crop in the feed production system which is most susceptible to saline soils. The farm makes use of a crop rotation system with maize, sorghum and oats, and the soil therefore has to be below the maximum salt level for maize, which is given as 170 $mS.m^{-1}$ by Ayers and Westcot (1985). Thus, the EC_e of maize was used for all the crops, as the soil cannot in any event exceed this level, as it will decrease long-term maize yields.

Ayers and Westcot (1985) suggest a method that makes use of the electrical conductivity of the irrigation water (EC_w) and the salinity threshold of the crop (EC_e) to estimate the leaching requirement (LR). The method is as follows:

$$LR = \frac{EC_w}{5(EC_e) - EC_w} \tag{3.2}$$

Once the leaching requirement is estimated, the actual amount of water (AW) required to supply both the ET_a and leaching is determined as follows:

$$AW = \frac{ET}{1 - LR} \tag{3.3}$$

The amount of water determined from this method will be greater than the ET_a is, and the difference between AW and ET_a will be the grey water. For the maize produced under dry-land conditions, it was not possible to determine the grey water without physical measurements, so the grey water listed by Mekonnen and Hoekstra (2010a) for the Free State province of South Africa was used. Soy cake and sunflower cake, which make up the high protein concentrate, are not produced on the farm, and therefore the blue, green, and grey water was taken as that listed by Mekonnen and Hoekstra (2010a) for the country average of South Africa.

Water usage: Pastoral grazing

Some uncertainties arise in the calculation of the water usage to produce the natural rangeland on which all the non-lactating animals are kept. Great discrepancies arise from the literature with regard to the DMI of dry cows and growing heifers on pastoral rangelands. The NRC (2001) support this perception and emphasise that most research studies of growing heifers were based on sample sizes of fewer than 40 animals, with a limited weight range.

Live body weights (BW) of the cattle on pastoral grazing are required, as the animals consume natural vegetation in relation to their BW. No weight data is available for the individual heifers in the case study; they are simply grouped together by age. Bowling and Putnam (1943) compiled an extensive list of the average body weights and shoulder heights of Ayrshire cattle. The data was reported for every month of animal age, from birth to 108 months. The average BW of the animals over the age groups corresponding to the ages of those in the case study will be used as representative weights of the animals.

The DMI reported by Stalker *et al*. (2012) for the various cattle groups are used for the DMI of the non-lactating cattle in the case study. It was decided to use this DMI as a guideline because the animals in that study were fed grass hay similar in nutritional value to the natural vegetation on the case study farm. Before the actual DMI can be calculated, the average body weights (BW) of the animal groups had to be determined. The detailed data of Bowling and Putnam (1943) was used to estimate the average BW of the animals in the various animal categories.

Once the DMI of the animals on natural vegetation was determined, the water required to produce one ton of DM was obtained from Mekonnen and Hoekstra (2010a). They reported that 385 m^3 of water was required to produce one ton of DM from natural vegetation in South Africa. The pastoral rangeland is only rain fed, meaning that the 385 m^3 per ton contributes to the total green water footprint.

Drinking water of the cattle

The amount of water a cow drinks depends on her size, milk yield, quantity of dry matter consumed, the temperature, and relative humidity. Other factors are the moisture content of the feed, quality and availability of the water, and the composition of the diet (DAEA, 2006). The assumption is made that all the drinking water available to the cattle on the case study farm is clean and palatable.

Several different equations have been developed to determine the free water intake (FWI) of dairy cows (National Research Council, 2001). These different methods make provision for various factors that influence the water intake of the lactating cows. The most applicable method for estimating the water intake of the lactating cows is the equation suggested by Little and Shaw (1978). After applying multiple regression analysis to the water intake data for lactating cows, they found that:

$$FWI = 12.3 + \left(2.15 \times DMI, (kg.day)\right) + \left(0.73 \times milk\ yield, (kg.day)\right) \tag{3.4}$$

After the FWI is calculated, the total water intake (TWI) can be calculated by adding the FWI to the water ingested along with the feed (NRC, 2001).

No *in situ* data was available for the non-lactating animals in the case study, and therefore drinking water requirements as prescribed by Ensminger *et al*. (1990) were used as a guideline for the water that the cattle drank. The daily drinking water requirements of the various groups of animals on the case study dairy farm were based on requirement guidelines as suggested by Ensminger *et al*. (1990) (See also DAEA, 2006; DWAF, 1996b; Ensminger *et al*., 1990). It is then assumed that on this farm, a dry cow and a bull drink 45 litres and 50 litres of water per day, respectively. Depending on the ages of the heifers, it was assumed that they drink between 15 litres and 42 litres per day. It must be noted that these drinking water requirements are based on annual averages and that water excreted through urine and faeces was not taken into account.

3.2.1.3 Water used to produce milk

A complete dairy production system is made up of cows in lactation, dry cows, replacement heifers, calves, and bulls. The percentages of these different animal groups as part of the whole herd differ, along with managerial objectives and other factors (Milk SA, 2014). In the case study where the data for the calculations was collected, the dairy is currently in an expanding stage. This means that the percentage of heifers in relation to the total herd is relatively high. Of the complete herd of 2 133 Ayrshire cattle, 825 cows are in various stages of lactation, 399 are dry cows, 886 are heifers at various ages, with 23 bulls completing the total. The lactating cows in the production system concerned were on a zero-grazing system and fed a ration with the required nutritive value, while the remainder of the herd was kept in a pastoral system on natural vegetation.

In the case study, the agribusiness is both a milk producer and dairy processor. The processing plant is adjacent to the dairy parlour, meaning that the milk is simply pumped from the parlour to the processing plant. The processing plant, however, processed more milk than the dairy produced at the time of the research, and the agribusiness bought milk from a nearby farm. The grey water from processing will therefore be estimated for the total amount of milk processed and then expressed in terms of cubic metre per kilogram of milk processed. This grey water will then be added to the grey water of dairy production. Besides the economic benefits of having the milk production close to the processing facility, the water usage is also more efficient. Water used for cleaning and sanitation in the processing plant is reused for cleaning the floors of the parlour. Freshwater used for the cleaning and sanitation of the milking apparatus also becomes part of the effluent. This water then moves to an effluent pond before it is used for irrigation.

No measurement data was available for the volume of effluent, but the volumes of freshwater used for the original cleaning were available. These volumes were then added together to obtain the volume of effluent. Evaporation of the water was not taken into account. A sample of the freshwater and the effluent was analysed in order to obtain the salt content thereof. It was decided to estimate the grey water of the effluent based on the total dissolvable salt content thereof because the grey water of the crops was also estimated, based on the salts that leached. The method of Hoekstra *et al.* (2011), as applied by Chapagain (2014), was used to determine the grey water of the effluent. The maximum acceptable concentration of salts was taken as 150 $mS.m^{-1}$ as this level of salinity will result in a 90% relative yield for moderately salt-sensitive crops (DWAF, 1996a).

3.2.1.4 Data for assessing economic water productivity

Value added along the value chain of milk was determined with the use of an equation. Let V_c denote value added along the value chain c, V_{ic} refers to the value added at process step i of value chain c. PS_{ic} and PP_{ic} represent the selling price and purchase price at process i of value chain c, respectively. Total value added along the value chain of milk was then calculated as the sum of the value added at each process step. This calculation is represented by the following calculation:

$$V_c = \sum_i V_{ic} \tag{3.5}$$

where V_{ic} (value added at process step i of value chain c) is defined as:

$$V_{ic} = PS_{ic} - PP_{ic} \tag{3.6}$$

At the first process step (raw milk production), the directly allocatable cost of producing the raw milk was taken as the purchase price. The gross margin (selling price minus the directly allocatable costs) then represents the value added to the inputs by producing milk. Raw milk produced at the case study dairy farm is not sold to a producer since the agribusiness also process the milk. However, capacity of the processing plant exceeds the production capacity of the dairy, and consequently raw milk is procured from other farmers. The price paid for this milk varied according to the quality of the milk and the transport distance, so the average price was used as the selling price of the dairy producer and the purchase price of the processor. Processed milk was contracted for delivery to a premium retail group. At the time the case study was conducted, the processing plant only produced milk packaged in bottles, with capacities of one litre and three litres. The selling price to the retail group was provided by the agribusiness, while the retail price was obtained from visiting a retail outlet where the milk was sold.

3.2.2 Methods

After evaluating the different water footprint accounting methods, it was decided that the consumptive water-use-based volumetric water footprint method of Water Footprint Network (WFN) best fits the scope of this study. The methodology in this chapter and the calculations in the following chapter are therefore based on the guidelines of the WFN approach. Hoekstra *et al.* (2011) provide a conceptual framework for a complete water footprint assessment. According to this framework, a water footprint assessment consists of four distinct phases which add more transparency to the methodology and help stakeholders to understand the process. The first phase involves setting the scope and goals of the assessment. In phase two, data is collected and the actual calculations are done to calculate the volumetric water footprint indicator.

The third phase involves a sustainability assessment in which the water footprint assessment is evaluated from an environmental, social, and economic perspective. The four phases conclude with the final fourth phase, being the formulation of response options and strategies for improving the sustainability of the water footprint.

3.2.2.1 Setting goals and scope of water footprint of lucerne and milk production

With any study, the purpose of the study must be stated at the outset before any further steps can be taken. A water footprint assessment is no different, and one must clearly indicate what the purpose of the study is because this has a great impact on the execution of the assessment. The focus of this water footprint assessment is on the calculation of the water footprint indicator and sustainability thereof. The response formulation phase is thus not included. Firstly, it needs to be stated what type of water footprint is of interest, as this will dictate which methodology to follow in the study. The goal of the study will determine which entity the water footprint will be completed for. Therefore, if the aim of the study is to understand the water usage along a specific supply chain, the water footprint of a particular product or business will be most useful.

Some of the more common entities for which water footprints are conducted include process steps, products, consumer groups, markets, and geographically delineated areas. Once one has determined the specific entity around which the water footprint will be conducted, several further questions will have to be answered. These questions, for purposes of this study, included examining:

- Blue, green, and/or grey water: It was decided to conduct a thorough water footprint assessment and therefore all the components of the water footprint will be accounted for. Generally, blue water is scarcer than green water is and has greater opportunity costs, and therefore the focus has traditionally been only on blue water accounting. However, the argument is that the supply of green water is also limited and therefore it would make sense to include green water in water accounting. The grey water of the considered entity might have a significant effect on water pollution, and will therefore also be included in the water accounting.

- Truncation of the supply chain: All types of footprints face a truncation issue, where one needs to determine where along the supply chain to truncate the analysis. With water footprinting, there is no generally accepted guidelines for what to include in the study, but Hoekstra *et al.* (2011) suggest the inclusion of all water usages that contribute “significantly” to the overall water footprint. It is common practice not to include the water footprint of labour, as this could lead to a never-ending cycle of accounting, as well as the problem of double counting. In South Africa, the use of biofuels and hydropower is fairly limited, especially in the agricultural sector, and therefore these will also be excluded from the study.

- Data period: Fluctuations in water supply and availability within and across years is a reality, and consequently the water footprint will also vary with the time chosen. Thus, it is important to state clearly whether one is calculating the water footprint in a specific year, an average over several years, or for a number of years.

- Direct or indirect water footprint: Although the focus has traditionally been on the direct water usage, the indirect water usage is often much larger. The recommendation of Hoekstra *et al.* (2011) is therefore to include both the direct and the indirect water footprints.

The data for this study is based on a case study of an agribusiness that produces and processes milk. The business produces the majority of the feed for the dairy feed ration on the farm, but does have a procurement strategy in place to acquire lucerne and high protein concentrate.

In order to achieve the aims and objectives of this research, it would be sensible to include all the components of the water footprint and to include all the water uses along the lucerne-dairy value chain. The major steps in the value chain of the case study is illustrated in Figure 3.5 and include feed production; milk production; milk processing; and finally the retailing of the milk. After the aims and objectives have been defined, the next step is to calculate the volumetric water footprint indicator.

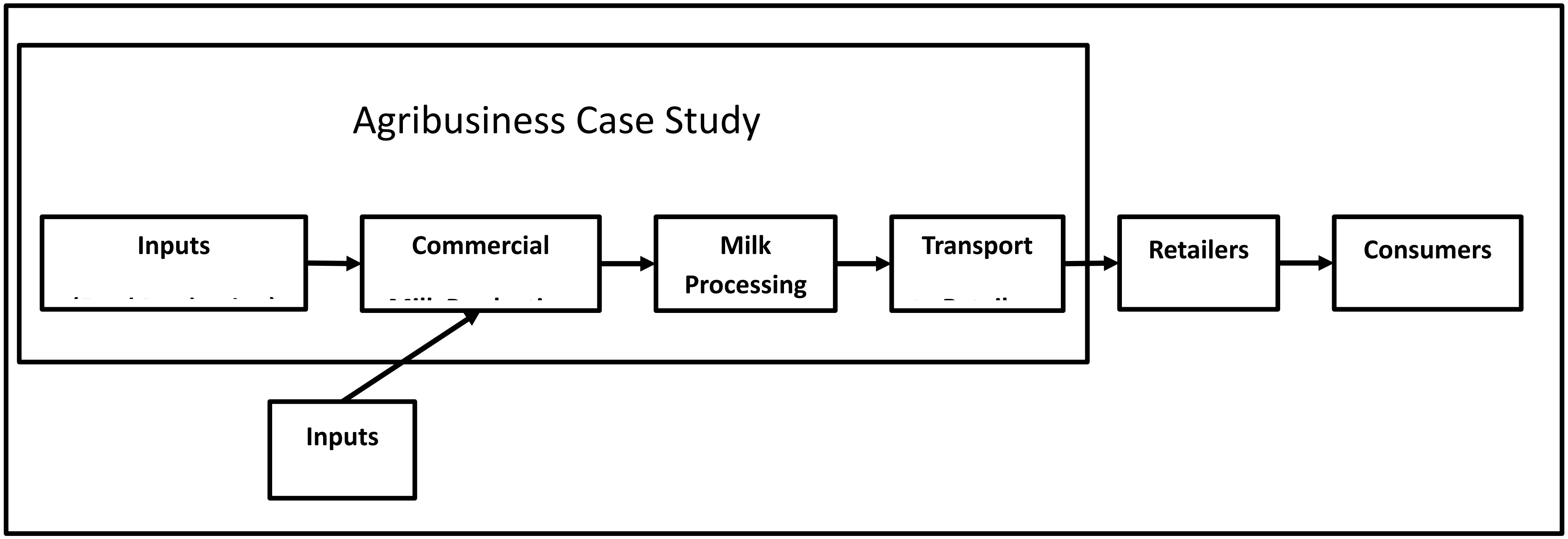

Figure 3.5: Schematic illustration of the lucerne dairy value chain in the case study

3.2.2.2 Volumetric water footprint of milk production at farm and milk processing levels

Water footprint accounting is the second phase of the water footprint assessment, as suggested by Hoekstra *et al*. (2011). Water footprint accounting is concerned with the actual calculation of the volumetric water footprint indicator, after the goals and scope of the study have been identified. For the purpose of this study, the product water footprint is the most applicable, and therefore most of the calculations and methods will be based on the product water footprint, using the method prescribed by Hoekstra *et al*. (2011). The lucerne-dairy value chain will comprise a crop water footprint for the lucerne production and a product water footprint for the dairy production. The dairy water footprint will be calculated for milk, and not a variety of products. These water footprints will then be added together to obtain the water footprint of the whole value chain.

Whenever the water footprint of a product has to be calculated, the production process of the product will first have to be conceptualised. The production process of a product will be broken down into several process steps in order to simplify the calculation of all the water used. The chain-summation approach is the simpler one of the two alternatives, but can only be used in a production process with only one output. Such cases rarely exist in practice, where one can simply divide the total water usage by the production quantity. The lucerne production process can be analysed using this model because the lucerne hay is the only output of the production process.

- *Chain-summation approach:* Only production systems with a single output can be analysed with this method, and because the processor in the case study only produces milk, this approach will be sufficient for the accounting of the value chain. The various process steps, as outlined in Figure 3.5, are considered individually before the water footprints of these process steps are added together in order to obtain the total water footprint.

Once the lucerne-dairy value chain is broken down into the individual processes, a distinction must be made between the different types of water used during production.

The water footprint of a growing crop is the sum of the process water footprints of the different sources of water. Hoekstra *et al.* (2011) explain the water footprint of the process of growing a crop (WF_{proc}) as:

$$WF_{proc} = WF_{proc,blue} + WF_{proc,green} + WF_{proc,grey} \tag{3.7}$$

where the blue water footprint ($WF_{proc,blue}$,m^3/ton) is calculated as the blue component in crop water use (CWU_{blue},m^3/ha), divided by the crop yield (Y,ton/ha). The calculation of the green water footprint (WF_{green},m^3/ton) is calculated in a similar fashion:

$$WF_{proc,blue} = \frac{CWU_{blue}}{Y} \tag{3.8}$$

$$WF_{proc,green} = \frac{CWU_{green}}{Y} \tag{3.9}$$

Calculating the grey water footprint ($WF_{proc,grey}$,m^3/ton) of a growing crop is done by taking the chemical application rate for the field per hectare (AR,kg/ha) and multiplying it by the leaching-run-off fraction (α). Once the multiplication is done, the product is divided by the difference between the maximum acceptable concentration (c_{max},kg/m^3) and the natural concentration of the pollutant considered (c_{nat},kg/m^3). Finally, the result is divided by the crop yield (Y,ton/ha) in order to get the water footprint per ton of crop produced.

$$WF_{proc,grey} = \frac{(\alpha \times AR)/(c_{max} - c_{nat})}{Y} \tag{3.10}$$

Blue and green crop water use (CWU,m^3/ha) is the sum of the daily evapotranspiration (ET,mm/day) over the complete growing period of the crop:

$$CWU_{blue} = 10 \times \sum_{d=1}^{lgp} ET_{blue} \tag{3.11}$$

$$CWU_{green} = 10 \times \sum_{d=1}^{lgp} ET_{green} \tag{3.12}$$

ET_{blue} and ET_{green} represent the blue and green water evapotranspiration, respectively. The water depths are converted from millimetres to volumes per area or m^3/ha by using the factor 10. Summation is done over the complete length of the growing period (*lgp*) from day one to harvest (Hoekstra *et al*., 2011).

According to Hoekstra *et al.* (2011), the "blue" crop water footprint refers to the total amount of irrigated water that evaporated from the field over the total length of the crop's growing period, while the "green" crop water footprint is the total volume of rainwater that evaporated from the field during the same period.

Animal product water footprints are also made up of different process water footprints. These processes are made up of the direct water footprint related to the service water and the water that the live animals drink, while the indirect water footprint is the water footprint of the feed. Mekonnen and Hoekstra (2010a) have expressed the water footprint of a dairy cow as follows:

$$WF_{dairy} = WF_{feed} + WF_{drink} + WF_{service} \tag{3.13}$$

where WF_{dairy} is the water footprint of a dairy cow in the considered geographic region and production system. The feed, drinking water and service water footprint is given by WF_{feed}, WF_{drink}, $WF_{service}$, respectively. The service water refers to the water used to wash the animal, clean the farmyard, and all other water used in order to maintain the production environment (Mekonnen and Hoekstra, 2010a).

Animal water footprints are usually expressed in terms of m^3/animal/year, but these can also be summed over the entire lifespan of the animal and then given in m^3/animal. Where the water footprint of animals that only provide their products after they have been slaughtered are calculated, it is sensible to calculate the water footprint for the entire lifespan of the animal, as it will be the footprint used to calculate the various product water footprints (meat, leather). The water footprints of dairy cattle and layer chickens are usually calculated per annum (averaged over their lifetime), as these can then easily be related to annual production or even per unit (litre of milk) water footprint (Mekonnen and Hoekstra 2010a).

Animal feed water footprints take into consideration not only the water used in the production of the various feed ingredients, but also the water used to mix the feed ration. The total water footprint of the feed component is therefore the sum of the water footprint of the feed ingredients and the water used in the mixing process. Mekonnen and Hoekstra (2012) express the water footprint of the feed as follows:

$$WF_{feed} = \frac{\sum_{p=1}^{n}\left(Feed[p] \times WF^*_{prod}[p]\right) + WF_{mixing}}{Pop^*} \tag{3.14}$$

The *Feed[p]* represents the annual amount of the feed ingredient *p* that is consumed by the dairy cow and is expressed in terms of ton/year. Furthermore, the water footprint of the feed ingredient *p* is given by $WF^*_{prod}[p]$ (m^3.ton) and WF_{mixing} is the volume of water used to mix the feed and is expressed in terms of m^3.animal.year. The Pop^* is the number of lactating dairy cows in the considered dairy production system in a year.

Water footprints of feed ingredients must be added together in order to get the total feed ingredient water footprint. Quite often, the complete animal feed ration is made up of products produced both domestically and in a foreign country. Therefore, Mekonnen and Hoekstra (2012) calculate the water footprint of the animal feed as the weighted average of the relative volumes of the domestic production and imported products. Thus:

$$WF^*_{prod}[p] = \frac{P[p] \times WF_{prod}[p] + \sum_{n_e}\left(T_i[n_e,p] \times WF_{prod}[n_e,p]\right)}{P[p] + \sum_{n_e} T_i[n_e,p]} \tag{3.15}$$

where the production quantity of feed product *p* in a country is given by *P[p]* (ton/y). $T_i[n_e,p]$ represents the imported quantity of the feed *p* from the exporting country n_e (ton/y), while $WF_{prod}[p]$ is the water footprint of the feed product *p* produced in the considered country (m^3.ton). $WF_{prod}[n_e,p]$ is the water footprint of the imported feed *p* as in the exporting nation n_e (m^3.ton).

After the water footprint of the feed itself is calculated, the composition and the volume of the feed needs to be determined. Feed consumption varies with the type of animal, the production system, and the country that the animal is in. Therefore, these factors need to be accounted for when the total feed per production system is calculated. Before one can calculate the total feed consumed, the feed conversion efficiencies need to be estimated. The feed conversion efficiencies (FCE) represent the amount of feed consumed per unit of animal product produced (kg of feed in dry mass/kg of product). It can then be deduced that the lower the FCE is, the more efficient a feed converter the animal is. The FCE for ruminants is then calculated as:

$$FCE = \frac{FI}{PO} \tag{3.16}$$

where *PO* is the product output per head (kg product/y/animal) and *FI* is the feed intake per head (kg dry mass/y/animal). In the case of dairy production, the amount of dry matter feed intake is divided by the milk produced per cow to obtain the FCE. Once the FCE and product output have been calculated, one can continue to calculate the total feed per production system for dairy cows as follows:

$$Feed = FCE \times PO \tag{3.17}$$

in which *Feed* is the total amount of feed consumed by the dairy cows in the considered production system (ton/y). The *FCE* is the feed consumption efficiency of the dairy cows, while *PO* is the total amount of milk produced by the dairy cows in the production system under consideration (ton/y). However, to calculate the total feed consumed, one first has to estimate the total animal production.

Milk production differs from meat production in the sense that the producing animal can continue to produce the products and does not have to be slaughtered to make the products available. For milk production, P_{milk} represents the total annual milk production in the production system (ton/y) and *MY* is the milk yield per dairy cow in the production system (ton/dairy cow). *DC* is the number of dairy cows in the production system.

$$P_{milk} = MY \times DC \tag{3.18}$$

3.2.2.3 Total water footprint of milk produced from lucerne

Once the blue water footprint for lucerne and milk production is calculated, the blue water used for cleaning and sanitation in the processing plant must be added to the calculated blue water footprint in order to obtain the total blue water footprint of the lucerne-milk value chain in the specific case study. It is assumed that the volume of water used at retail level for cleaning is negligible in relation to the complete value chain, and will therefore not be included in this study.

The final blue water footprint is then an indicator of the total amount of surface and ground water that evaporated along the lucerne-milk value chain, or that was incorporated into the final product. No green water is used in the processing and retailing of dairy products, so the green water used for the feed production, including the natural vegetation for pastoral grazing, is the total green water footprint of the lucerne-milk value chain in the considered case study. The final calculated green water footprint is an indicator of the total amount of rainwater that was evapotranspired by the crop and incorporated into the crop along the lucerne-milk value chain.

A detailed calculation was used to determine the grey water footprint of lucerne production, but grey water also arises from other stages along the value chain. Grey water from the production of the feed ration of the lactating cows was estimated as a leaching requirement to maintain the good productive potential of the soil. No blue water originated from the processing plant, as the fresh water that was used for cleaning the facility was recycled and later used for cleaning the cattle runs and the floor of the dairy parlour. The dairy processing water thus becomes grey water in the effluent pond and was accounted for according to the grey water methodology. The grey water emanating from the faeces and urine of the lactating cows was estimated with the use of an effluent sample analysis, and the volume measured as the flow into the effluent pond. From the analysis, the electrical conductivity (EC) of the effluent pond was taken and multiplied by the total volume of the effluent, and the salts originating from the abstracted water were then subtracted to obtain the total salts added to the effluent at the facility. The volume of water required to assimilate this load to below the acceptable norm is then the grey water for processing the milk.

3.2.2.4 Assessing the sustainability of the water footprint

The scope of the sustainability assessment is very dependent on the goals and scope set out in the first phase of the water footprint assessment. In this phase, the water footprint has to be viewed in a larger context. In essence, this phase is where it has to be determined whether the available resources can support the current extraction levels over the long term, without causing adverse effects for the environment. The water footprint calculated in the accounting phase is compared with available freshwater resources at the relevant place and time. Such an assessment may include several different dimensions, such as environmental, economic and social sustainability, and it may include both primary and secondary impacts (Hoekstra and Mekonnen, 2011).

It has to be kept in mind that the sustainability of a consumer or producer water footprint will depend on the geographic context of the products consumed. This is because one final product might comprise several process steps that might take place in various geographic locations. One such a process step might not necessarily result in water scarcity, but the cumulative effect of all the steps in a specific geographic area might well result in water shortages. When the water footprint of a process, product, producer or consumer contributes to an unsustainable situation in a given geographic context, this specific water footprint is also considered to be unsustainable.

When a product water footprint is considered, it is important to consider the sustainability of all the process step water footprints that make up the product water footprint. This then makes it possible to evaluate the sustainability of the product water footprint by dividing the water footprint into the different process steps and then looking at each of these step water footprints individually. By evaluating each of these process steps individually, it is then possible to distinguish between process steps that take place in different geographic areas or catchments, and to then determine whether or not the unsustainable steps can be avoided by moving such steps to different catchments, or by eliminating the steps altogether.

It is important to evaluate the sustainability of a water footprint over a period of time because the water availability varies across seasons. Even if the total water footprint is sustainable, by adding the temporal dimension to the sustainability assessment, it is possible to identify in which months the catchment is water stressed.

Evaluating the sustainability of the South African lucerne-dairy value chain will be done in a spatio-temporal dimension, according to the monthly blue water scarcity method suggested by Hoekstra and Mekonnen (2011). It is not yet viable to determine the equitable allocation of the water in the river basin under consideration, but the calculation of the lucerne-dairy water footprint will contribute towards determining water footprint benchmarks for water-intensive products.

3.2.2.5 Quantifying the value of water

Although Jordaan and Grové (2012) did not calculate the water footprint of raisins *per se*, their approach to determine the value added to the water along the complete value chain is compatible with the water footprint concept. The value added to the water was therefore calculated in a similar fashion as that done by Jordaan and Grové (2012). Value is added as the product moves through the stages of the value chain, as explained in Chapter 2, and is expressed in terms of ZAR/m^3 at each stage. This was achieved by taking the value added at each stage and dividing it by the volume of water used at the specific stage.

Value added on the dairy farm was calculated by dividing the gross margin per kilogram of milk by the volume of water used to produce a kilogram of milk. Gross margin was calculated by subtracting the directly allocable costs per kilogram of milk from the total revenue generated from selling one kilogram of milk. Once the milk is pumped from the dairy to the processing plant, the value added to the water was used instead of the gross margin, owing to the unwillingness of the role players to make information regarding their cost structures available. In this sense, value added is the difference between the selling price per kilogram of milk and the price paid per kilogram when the milk was bought (before value was added). Value thus includes operating profit, taxes and other expenses (Crafford *et al*., 2004).

The value added to the water at each stage was also explored in order to get a better understanding of where the most value was added to the water. At the final stage (retail), the sum of the value added to the water is the true value of the water used in the production of the milk.

3.3 RESULTS

3.3.1 Water Footprint of the Lucerne-Milk Value Chain

3.3.1.1 Water footprint of lucerne

For the purpose of this study, it was decided to make use of actual measurements, instead of estimations from water use models, to determine the water footprint of lucerne. Table 3.2 sets out a summary of the aggregated biophysical data collected at the measuring sites over the course of the measuring period. The average cuttings of 7.75 and the 30 594 kg.ha^{-1} yield, as indicated in Table 3.2, are discussed in the methods section concerning lucerne biomass measurement. As the data was collected over a complete growing season, the data at the measuring sites was aggregated in order to obtain average values for all the measuring points over the course of the measuring period. Therefore, the green and the blue crop water footprints will both not be calculated by summing the daily evapotranspiration, but by simply using the average values over the data collection period.

Table 3.2: Biophysical data of the measuring sites at Vaalharts

	Cuttings	**Yield (kg ha^{-1})**	**Silt-plus-clay (%)**	**θs (mm mm^{-1})**	**Soil Depth (mm)**	**W (mm)**	**T (mm)**
Average	**7.75**	30594	23	0.38	2075	793	1089

3.3.1.1.1 Blue and Green Water Footprint of lucerne production

According to Hoekstra *et al.* (2011), the blue water footprint of a growing crop is the minimum of the crop water requirement and the effective irrigation. Hoekstra *et al.* (2011) continue to explain that the irrigation requirement (IR) is the difference between the crop water requirement and the effective rainfall. Therefore, one has to compare the IR (524 mm) in Table 3.3 with the effective irrigation of 602 mm. The IR of 524 mm is smaller than the effective irrigation, and therefore the blue water footprint of producing lucerne in Vaalharts is 524 mm per year.

Table 3.3: Summary of water use data at the measuring points at Vaalharts

	ET crop (mm)	R (mm)	I (mm)	IR (mm)	R+I (mm)
Average	1157	633	605	524	1238

In order to convert the water footprint into a spatio-temporal dimension, the 524 mm is converted to 5 240 $m^3.ha^{-1}$ which is the blue CWU (crop water use). This conversion of the unit in which the water footprint is expressed is also indicated in Table 3.4. Most often, water footprints are expressed in terms of water per unit of production, and therefore it is more sensible to express the blue water footprint in terms of m^3 per ton of output. The blue CWU must thus be divided by the yield per hectare. Table 3.4 shows a blue water footprint of 171.28 $m^3.ton^{-1}$ for the production of lucerne at Vaalharts.

Table 3.4: Summary of the blue- and green water footprint of producing lucerne in Vaalharts

ET crop	ET Green	ET Blue	CWU	CWU Green	CWU Blue	Yield	WF	WF Green	WF Blue
	mm/period			m^3/ha		ton/ha		m^3/ton	
1157	**633**	**524**	**11570**	**6330**	**5240**	**31**	**378**	**207**	**171**

Similar to the blue water footprint, the green water footprint will also be calculated using aggregated data collected over a complete growing season of lucerne at Vaalharts. Again, the method supplied by Chapagain (2014) was used to calculate the green water footprint. He suggests that the green water footprint is the minimum between the effective rainfall and the crop water requirement. Considering the data from Table 3.4, the effective rainfall of 633 mm is far smaller than the crop water requirement of 1 157 mm. The green water footprint of producing lucerne is therefore 633 mm. This ET_{Green} is then converted to m^3.ha to get the water footprint of one hectare, which is 6 330 m^{3}·ha. Table 3.4 above shows that in order to relate the water footprint to the biomass production of lucerne, the CWU_{Green} must be divided by the average yield over the growing period. The green water footprint to produce lucerne in Vaalharts is then 206.9 m^3.ton.

3.3.1.1.2 *Grey Water Footprint of lucerne production*

In the literature review chapter, it was explained that polluted water requires vast quantities of fresh water to assimilate the load of pollutants to acceptable standards. This volume of freshwater needed to reduce the pollutants to ambient levels is considered to be the grey water footprint. The volumetric-based grey water footprint does not include an indicator of the severity of the environmental damage of the pollution, but it is simply a method to include the volume of water required to reduce the pollution to acceptable norms.

The historic data collected at the measuring points in Vaalharts was used to calculate the grey water footprint of lucerne. The Electrical Conductivity (EC) of the soil was measured at the beginning, middle and end of the season, at the various measuring points. This, together with the complete salts balance of the soil body, was used to calculate the actual grey water footprint of lucerne production at Vaalharts. The collected data has a fairly low variance across the various measuring points, and therefore the average values of the measuring points will be used. Table 3.5 then represent the average values of the salts balance for producing lucerne at Vaalharts.

Table 3.5: Summary of the Salts Balance and EC of the soil at the end of the production season at the Vaalharts measuring points

EC_e (mS m^{-1})	**ΔS_{Soil} (kg ha^{-1})**	**S_R (kg ha^{-1})**	**S_I (kg ha^{-1})**	**$\pm S_D$ (kg ha^{-1})**	**S_{Pre} (kg ha^{-1})**
252.25	**-1278**	**95**	**2662**	**-3486**	**-549**

In order to calculate the grey water footprint of producing lucerne at Vaalharts, the total salts drained per hectare was taken as the load (L). This value was taken, rather than calculating the load through the application and leaching fraction of the fertiliser, because the drained total dissolvable salts already account for the fertiliser leaching and deterioration in irrigation water quality. The load was therefore taken as 3 486 kg.ha.

The c_{max} of the system was taken as the EC_e of the soil at the end of the production season, rather than the salinity threshold of lucerne, in order to get the “true” grey water footprint. It is considered to be the “true” grey water footprint because it reflects the actual occurrences in the soil balance.

This measured EC_e was 252.25 mS.m^{-1}, but in order to get the total dissolvable salts (TDS) in terms of kg.l^{-1}, the EC was multiplied by a conversion factor of (7.5 x 10^{-6}) (DWAF, 1996). According to Hoekstra *et al.* (2011), c_{nat} is the natural concentration in the receiving water body, therefore the EC of the irrigation water was taken as the c_{nat}. As with the c_{max}, the c_{nat} of 58.4 mS.m^{-1} was converted to kg.l^{-1} before the calculation of the grey water footprint could be done. Using the formula suggested by Hoekstra *et al.* (2011), the grey water footprint was calculated in terms of litres per hectare and has to be converted to m^3 per hectare before it can be divided by the yield per hectare to get the final value in terms of cubic metres per ton of biomass production.

$$WF_{grey,Lucerne} = \frac{L}{c_{max} - c_{nat}} \tag{3.19}$$

$$WF_{grey,Lucerne} = \frac{3486 kg.ha^{-1}}{193.8 \times (7.5 \times 10^{-6}) kg.l^{-1}} \tag{3.20}$$

$WF_{grey,Lucerne}$ = 2397557.20 l.ha

= 2397.56 m^3.ha^1

= **78.37 m^3.ton**

The resultant grey water footprint is 78.37 m^3 per ton (DM) of lucerne biomass produced in Vaalharts.

3.3.1.1.3 Lucerne Water Footprint

The complete water footprint of the process of growing lucerne is calculated according the method suggested by Hoekstra *et al.* (2011).

$$WF_{proc} = WF_{proc,blue} + WF_{proc,green} + WF_{proc,grey} \tag{3.21}$$

After all the individual components of the water footprint are calculated, the values are added together to obtain the final water footprint of lucerne in terms of m^3 per ton of biomass production.

Table 3.6 summarises all the individual components of the lucerne water footprint. It is clear from Table 3.6 that adding the blue, green, and grey water footprints together results in a lucerne water footprint indicator of 457 m^3.ton. Of this water, 207 m^3.ton originates from effective rainfall, 171 m^3.ton from surface and groundwater, and the remaining 78 m^3.ton was used to assimilate the salts leached during production to acceptable levels.

Table 3.6: Summary of lucerne water footprint at Vaalharts

ET_{Crop}	**ET_{Green}**	**ET_{Blue}**	**CWU**	**CWU_{Green}**	**CWU_{Blue}**	**WF_{Grey}**	**Yield**
	mm/period				m^3/ha		ton/ha
1157	633	524	11572	6330	5242	3282	32
$WF_{Lucerne}$ (m^3/ton)		**WF_{Green} (m^3/ton)**		**WF_{Blue}**	**WF_{Grey} (m^3/ton)**		
457		207		171	78		

It must be noted that this lucerne water footprint considers only the in-field water use of producing lucerne and does not account for water usage in the supply chain. Furthermore, the evaporation of water during transport (via canals and diversions) and storage (from dams and reservoirs) is also not considered in the calculation of the water footprint.

3.3.1.2 Water footprint of milk production

The average dairy cow in the case study consumed 24.09 kg of dry matter per day and produced a daily average of 25 litres of milk. The fat content of the milk averages at about 4 per cent, while the protein content is about 3.3 per cent, relating to a milk density factor of 1.033. One litre of milk then weighs 1.033 kg. Converting the unit of the milk from litres to kilograms is required to enable the comparison of the results of this study with international studies.

3.3.1.2.1 Water usage: Feed production

The calculation of the water used to produce the feed for the lactating cows was done by using the equation suggested by Bennie *et al*. (1998). By using this equation, the total seasonal water requirement of the crop was estimated. A summary of the parameters required for the estimation of this equation is set out in Table 3.7. The parameters in the calculation are: Y_a is the actual total DM yield (kg.ha); Y_m represents the maximum DM yield ($kg.ha^{-1}$); ET_a is the actual total evapotranspiration (mm); ET_m is the maximum total evapotranspiration (mm); and β is the slope of the ($1-Y_a/Y_m$) vs ($1-ET_a/ET_m$) relationship (Bennie *et al*., 1998).

The actual total evapotranspiration (mm) (ET_a) is then estimated as follows:

$$ET_a = ET_m - \left[ET_m.\left(1-(Y_a/Y_m)\right)/\beta\right] \tag{3.22}$$

This equation by Bennie *et al*. (1998) was used to estimate the ET_a of oats, sorghum, maize silage and maize harvested for grain. Table 3.7 gives the values for the various parameters and lists the ET_a of the crops estimated by using the above-mentioned equation. Once the total water usage of the feed crops, apart from lucerne, was estimated, the water usage had to be divided into blue, green, and grey water. The maize milled for maize meal was produced under dry-land conditions and therefore all the water used originates from rainfall, meaning that all of the water is green water.

The production of oats, sorghum and maize for silage was under irrigation, but no accurate measurements of the irrigated water were available. However, planting and harvesting dates were well documented, enabling a comparison to be made of the crop water requirements with rainfall data in order to distinguish between blue and green water.

Table 3.7: Summary of the parameters for the equation by Bennie et al. (1998), together with the ETa estimated with the equation

Product	DM	HI	Gr	Resi	Y_m	Y_a	ß	ET_m	ET_a		
Units	ton	-	kg	kg	kg	kg	-	mm	mm	m^3	**m^3/ton**
Oats Silage	11.5	0.4	3277	8193	14000	8193	1.3	684	459	4590	**400**
Sorghum Silage	16.5	0.5	5121	11379	17150	11379	1.5	636	488	4880	**296**
Maize Silage	19.6	0.6	6955	12645	25300	12645	1.4	958	616	6160	**314**
Maize meal	5.4	0.6	5368	9760	25300	9760	1.4	958	538	5380	**1002**
HPC	5.4	-	-	-	-	-	-	-	-	-	**1801**
Soy	-	0.5	2.7	-	-	-	-	-	-	-	**2357**
Sun	-	0.5	2.7	-	-	-	-	-	-	-	**1244**

The grey water of the oats, sorghum and maize was estimated using the leaching requirement method of Ayers and Westcot (1985). For maize, oats and sorghum, the EC_e of maize was used because maize has the lowest salt tolerance, and these crops are planted in a rotational system. The grey water of oats was calculated as follows:

$$LR = \frac{EC_w}{5(EC_e)-EC_w} = \frac{57.6}{5(170)-57.6} = 0.07 \tag{3.23}$$

The leaching rate was then used to determine the actual water needed to leach the soil to below the crop tolerance levels:

$$AW = \frac{ET_a}{1-LR} = \frac{458.825}{1-0.072691} = 494.79mm \tag{3.24}$$

After the actual water required to fulfil the requirements of ET_a and leaching was determined, the difference between AW and ET_a was taken as the grey water per hectare. It was found that the grey water for oats was 359.67 m^3, which in turn amounts to 31.36 m^3 per ton of DM. The calculations were replicated for the other crops and it was found that the grey water was 23.20 m^3.ton and 24.63 m^3.ton for sorghum and maize, respectively. Maize produced in the Free State province of South Africa has a grey water footprint of 87.00 m^3.ton, according to Mekonnen and Hoekstra (2010a). The same dataset of Mekonnen and Hoekstra (2010a) was used to obtain the country average values for soy cake and sunflower cake. According to this list, it takes 2 272 m^3 of green water, 73 m^3 of blue water, and 12 m^3 of grey water to produce one ton of soy oilcake in South Africa. It also states that the production of sunflower oilcake in South Africa uses 1 162 m^3 of green water, 29 m^3 of blue water, and 53 m^3 of grey water. This data was used in Table 3.7 to determine the water footprint of the high protein concentrate, as the concentrate is made up of equal parts of sunflower and soy oilcake.

After the water footprints all the individual feed ingredients were determined, they were placed in a table to aid the calculation of the total daily dairy feed water footprint. Table 3.8 contains the quantities of all the feed ingredients and the proportions of all the ingredients in the final feed for the lactating cows. Each cow was fed 24 kg of DM every day, with 825 cows being in lactation. The proportion of every ingredient of the 24 kg was multiplied by the 825 cows to obtain the volume of each ingredient that was consumed on a daily basis.

Table 3.8: Summary of the water to produce feed for the lactating cows per day

Product	kg DM	%	Herd Total	Ton	m^3/Ton	m^3/day	Blue	Green	Grey
Lucerne	4.2	17.5	3485	3.5	457	1591	597	721	273
Oats Silage	1.1	4.4	870	0.9	431	375	284	64	27
Sorghum Silage	2.6	10.7	2129	2.1	319	679	335	295	49
Maize Silage	3.9	16.2	3211	3.2	339	1088	518	491	79
Yellow Maize meal	7.5	31.1	6171	6.2	1089	6718	0	6181	537
HPC	4.9	20.2	4010	4	1801	7219	205	6884	130
Soy	-	-	-	-	-	4725	146	4555	24
Sun	-	-	-	-	-	2494	58	2330	106
Dairy Feed Total	24	100	19874	20	-	**17671**	1939	14636	1096

After the herd total for each ingredient was determined, it was multiplied by the water footprint of each ingredient and expressed in terms of cubic metres per day for the total water footprint, and the blue, green, and grey water footprints. It is clear from Table 3.8 that in order to produce 21 306 kg of milk from 825 lactating cows, 17 671 m^3 of water was used to produce only the feed. The total feed water footprint of 17 671 m^3 per day relates to 0.83 m^3 per kilogram of milk produced. This figure of 0.83 m^3.kg only considers the feed consumed by the lactating cows, and not the complete herd of cattle. The water for the feed of the non-lactating animals is explained in the following section.

3.3.1.2.2 Water usage: pastoral grazing

Mekonnen and Hoekstra (2010a) reported that 385 m^3 of water was required to produce one ton of DM of natural vegetation, under rain-fed conditions, all of which contributes to the total green water footprint. The DMI guidelines of Stalker *et al*. (2012), together with the average body weights set out by Bowling and Putnam (1943), were used to determine the total feed consumption, as indicated in Table 3.9.

Table 3.9 indicates how the daily DMIs of all the non-lactating animals were determined. The total DMI was then multiplied by the 385 m^3 reported by Mekonnen and Hoekstra (2010a) in order to calculate the water footprint for the pastoral rangeland. From Table 3.9, it can be seen that the combined total water requirement for all the free range animals is 3 735 m^3 per day, all of which contributes to the total green water footprint.

Table 3.9: Summary of the daily feed intake and water required for the production thereof, for the non-lactating animals on the case study farm

		Live Weight		DMI			**m^3/day**
		Kilogram	% of BW	kg	Total	ton	385 m^3/ton
Number of dry cows	**399**	544	2.4%	13	5147	5.2	1982
Number of heifers	**886**	-	-	-	-	-	-
0-6 months	220	62	1.5%	1	205	0.2	79
6-12 months	206	171	2.1%	4	741	0.7	285
12-18 months	238	260	2.2%	6	1328	1.3	512
18-24 months	156	332	2.2%	7	1141	1.1	439
24+ months	66	479	2.3%	11	728	0.7	280
Number of bulls	**23**	590	3%	18	407	0.4	157
						9.7	**3735**

3.3.1.2.3 Drinking water of the cattle

Little and Shaw (1978) suggest a method to estimate the drinking water of lactating cows as follows:

Total Water intake = *12.3 + (2.15 x DMI, (kg.day)) + (0.73 x milk yield, kg.day)) + (feed intake – DMI, (kg))*

= *12.3 + (2.15 x 24.09) + (0.73 x 25.825) + (44.6 – 24.09)*

= *103 litre/cow/day.*

The guidelines suggested by Ensminger *et al*. (1990) were used to estimate the volume of drinking water for the non-lactating animals on the case study dairy farm (DAEA, 2006; DWAF, 1996b; Ensminger *et al*., 1990). The assumption was made, based on the guidelines of Ensminger *et al*. (1990), that on the case study farm, a dry cow and a bull drink 45 litres and 50 litres of water per day, respectively. Depending on the ages of the heifers, it was assumed that they drink between 15 litres and 42 litres per day. The total drinking water of the complete herd is summarised in Table 3.10. From Table 3.10, the amount of water per animal in the various animal groups and the total drinking water of the specific group, as well as the total of the herd, can be seen. The total drinking water of the herd, as indicated in Table 3.10, was 127 972 litres, or 127.97 m^3, per day, which contributes to the total blue water footprint of milk production.

Table 3.10: Summary of total daily drinking water by the complete cattle herd on the case study farm

		Water use		
		l/animal/day	**Total/day**	
Total herd size	2133	-	-	85351
Number of cows in lactation	825	103	-	-
Average Daily production per cow (kg)	26	-	-	-
Number of dry cows	399	45	-	17955
Number of heifers	886	-	-	23516
0-6 months	220	15	3300	-
6-12 months	206	22	4532	-
12-18 months	238	30	7140	-
18-24 months	156	37	5772	-
24+ months	66	42	2772	-
Number of bulls	23	50		1150
	-	-		127972

3.3.1.3 Water footprint of milk processing

All the freshwater used for the cleaning and sanitation of the processing facility is reused to clean the excrement of the dairy cows off the floors of the dairy parlour. It is assumed that all this water becomes effluent (no evaporation is considered). Table 3.11 summarises the use of freshwater in the processing plant. The totals in the second last row represent the volume of water used for each clean-up. The plant was cleaned twice a day and therefore the total volume of water is double the volume used at each clean-up.

Table 3.11: Summary of the volume of freshwater used for cleaning the processing plant and dairy parlour

Cleaning and sanitation	**(m^3)**
Inline Pasturators	3
Cream Tank	1
Milk Tanks	15
Intake	1
Fillers	3
Floors	3
Milking Apparatus	5
Other uses	5
Total	36
Twice Daily	72

Using the above-mentioned values in the formula of Hoekstra *et al.* (2011), gives the following:

$$WF_{grey,Processing} = \frac{Effluent \times C_{effl} - Abstraction \times C_{Abst}}{c_{max} - c_{nat}} \quad (3.25)$$

$$WF_{grey,Processing} = \frac{194.1225 kg.l^{-1}}{50 \times (7.5 \times 10^{-6}) kg.l^{-1}} \quad (3.26)$$

Following the equation through gives the volume of grey water that originates from the effluent on a daily basis. This grey water is used to process, on average, 36 155 kg of milk every day.

$WF_{grey,Processing}$ = 517 660 Litres per day

= 518 m^3 per day

= **0.014 $m^3.kg^{-1}$ milk processed**

It is thus clear that the agribusiness in the case study requires 0.014 m^3 of water per kilogram of milk processed to assimilate the effluent to the acceptable norm.

3.3.1.4 Total water footprint of milk produced from lucerne-fed dairy cows

After the water footprints of all the different components of the lucerne-milk value chain were determined, they were added together to obtain the complete water footprint. Table 3.12 summarises the water footprint according to the different types of water.

Table 3.12: Lucerne-milk water footprint

	Blue	Green	Grey	Total
Drinking Water:				
Lactating cows	85	-	-	85
Non-lactating animals	42.62	-	-	42.62
Feed Production Water:				
Lactating cows	1939	14636	1096	17671
Non-lactating animals	-	3734	-	3734
Total Daily Water Usage (m^3)	2067	18370	1096	**21533**
Daily Milk Production			**21305.6** kg	
m^3/kg	**0.10**	**0.86**	**0.05**	**1.01**
Processing Water:				
Processing (**m^3/day**)			518	518
Daily Milk Processing			**36155** kg	
Total Daily Processing Water (m^3/kg)	**0**	**0**	**0**	**0**
Total water Footprint (m^3/kg)	0.10	0.86	0.07	1.04
Total water Footprint (litre/kg)	**97**	**862**	**66**	**1025**

It is clear from the bottom row of Table 3.12 that in the case study value chain, 1 025 litres of water was used to produce one kilogram of milk with an average fat content of four per cent and a protein content of 3.3 per cent. The 1 025 litres per kilogram compares well with the global average of 1 020 litres per kilogram for milk production estimated by Mekonnen and Hoekstra (2010b). The weighted average water footprint for producing milk with a fat content between one and six per cent in South Africa was estimated to be 1 136 litres per kilogram (Mekonnen and Hoekstra 2010b). This is somewhat higher than what was found in this case study and can be attributed to a much larger green water footprint than was calculated in the case study. The total water footprint per kilogram of milk is made up of 97 litres of blue water, 862 litres of green water, and 66 litres of grey water. Figure 3.6 shows the contributions of blue, green, and grey water to the total water footprint indicator. Green water is clearly by far the greatest contributor towards the total water footprint indicator.

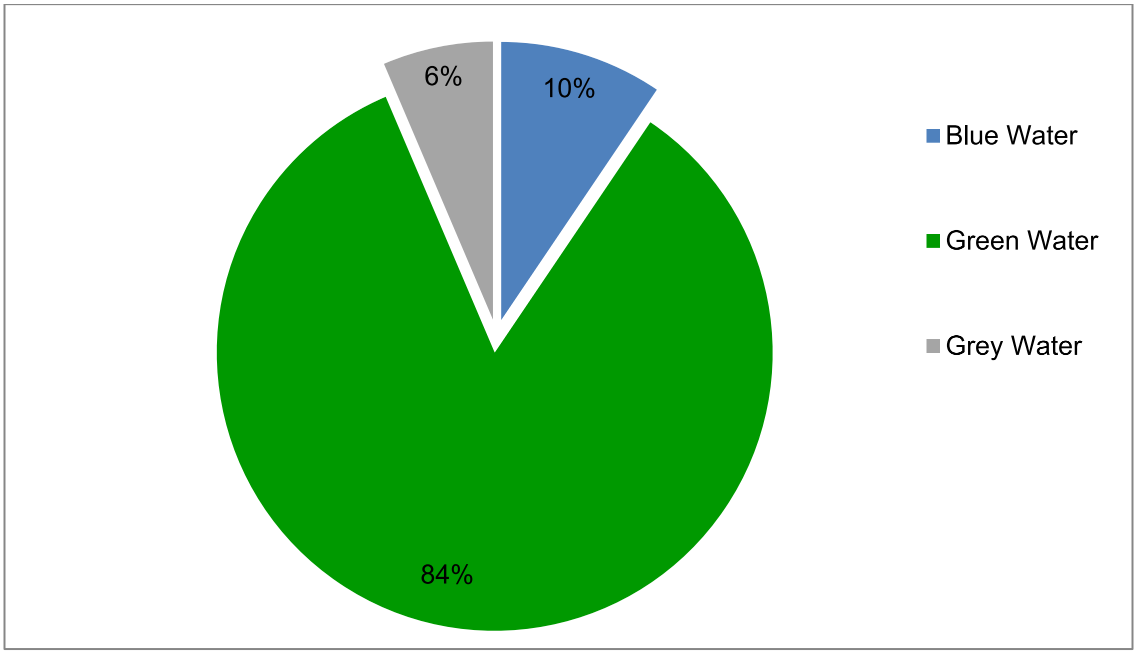

Figure 3.6: Composition of the dairy water footprint in the case study

Source: Own calculations

Interestingly, the component that contributed the greatest to the total dairy water footprint indicator is the feed for the 825 lactating cows. From Figure 3.7, it is evident that the water used to produce the feed for the lactating cows is by far the greatest contributor, attracting 81% of the total water usage.

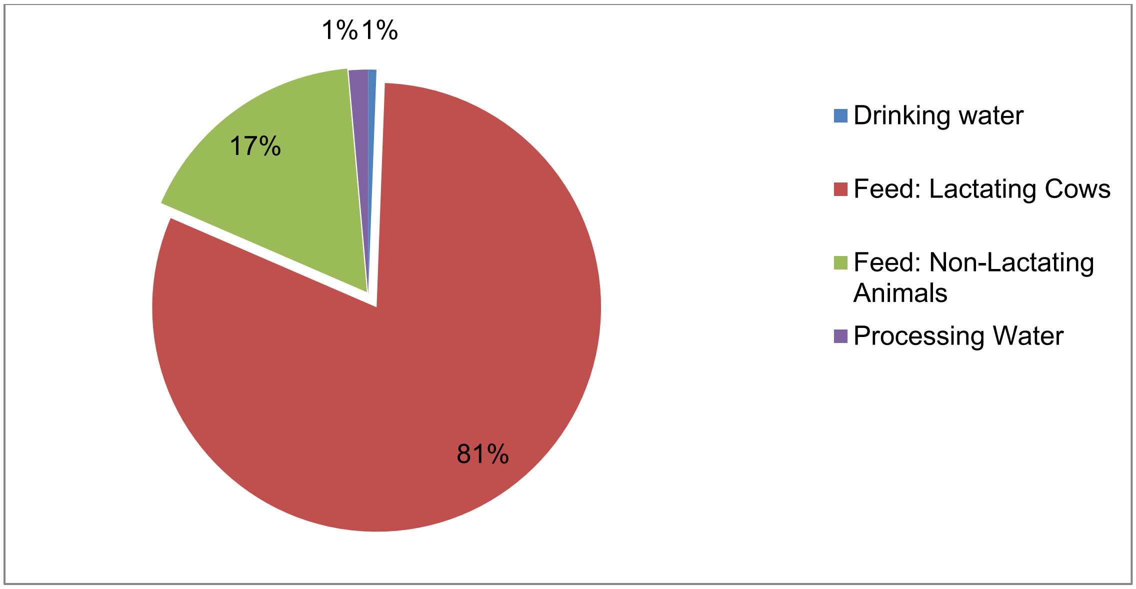

Figure 3.7: Contribution of the various components to the total dairy water footprint
Source: Own calculation

It is also clear from Figure 3.7 that water used for processing is only marginal and that 98% of the water usage is taken up in the production of feed for the total herd of cattle (lactating cows, dry cows, heifers and bulls). This is consistent with the findings of Mekonnen and Hoekstra (2010b) and Hoekstra (2012) who also calculated that about 98% of the water footprints of animal products relates to water used for feed production.

3.3.2 Sustainability Assessment

The blue water scarcity of the Orange River Basin, in which Vaalharts and the dairy farm falls, was determined from the methodology and data of Hoekstra and Mekonnen (2011). The blue water scarcity is calculated as the blue water footprint divided by the blue water availability of the basin on a monthly basis. Figure 3.8 0indicates the monthly blue water footprint (WF), the monthly blue water availability (WA) and the monthly blue water scarcity (WS). It is clear from 0 that from January to May, and in December, the blue water availability (WA) exceeds the blue water footprint (WF), resulting in a water scarcity index (WS) of below 100%. During these months, there is low blue water scarcity with sufficient water available to satisfy the environmental flow requirements. June and November experience moderate blue water scarcity (100-150%), meaning that the runoff is slightly modified and the environmental flow requirements are not net. July experiences significant blue water scarcity (150-200%); the runoff is significantly modified and does not meet the environmental flow requirements. August, September and October have water scarcity indices exceeding 300%. The blue water footprints exceed 40% of the natural runoff during these months; runoff is thus seriously modified and environmental flow requirements are not met.

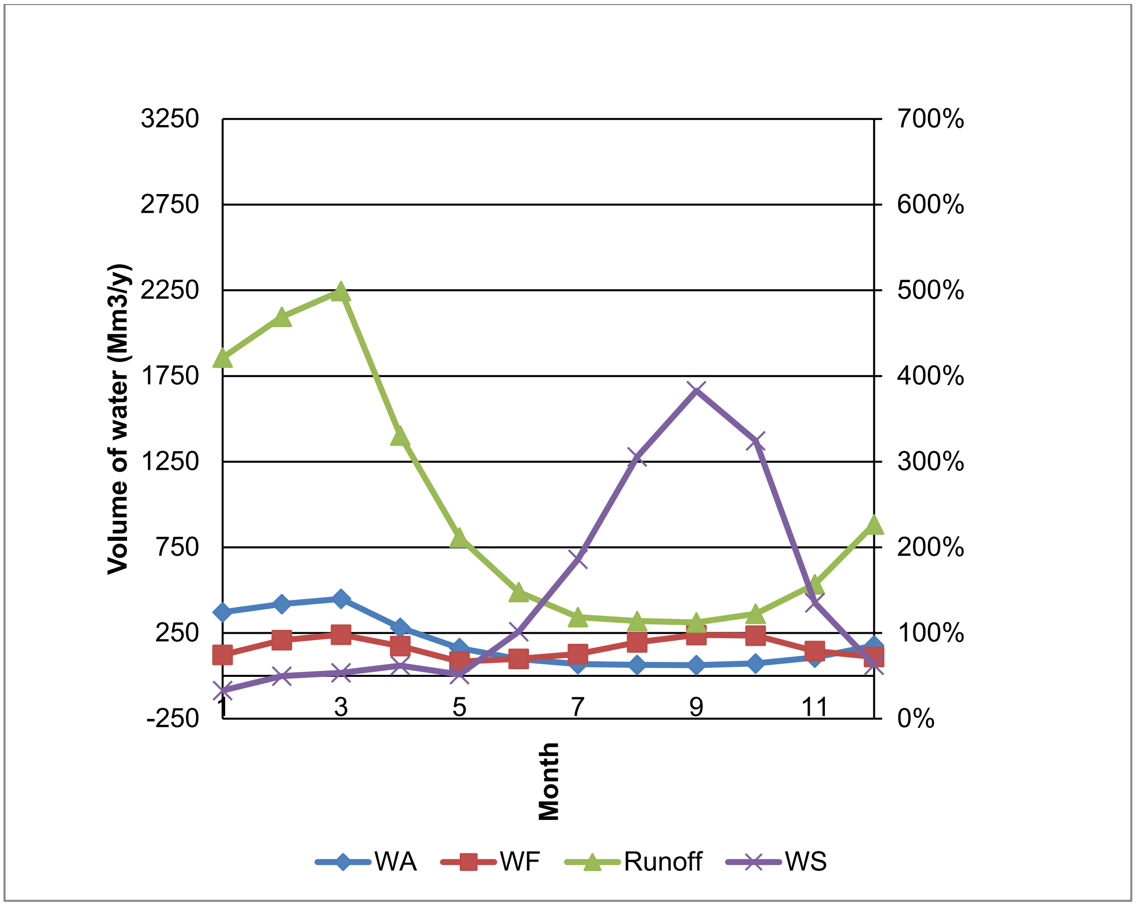

Figure 3.8: Monthly blue water scarcity of the Orange River Basin
Source: Hoekstra and Mekonnen 2011

It is thus clear that the Orange River Basin experiences low blue water scarcity during January, February, March, April, May and December; moderate blue water scarcity in June and November; and significant blue water scarcity in July; while August, September and October experience severe water scarcity.

All of the feed crops, apart from oats, used at the dairy require the majority of water usage from November to February. The growing period of maize produced under irrigation is between November and February, while sorghum is planted in December and harvested at the end of February. Although lucerne is a perennial crop, the ET_a was significantly higher during the warmer months of November, December, January and February. Apart for November that has moderate blue water scarcity, the main production months of December, January and February have low blue water scarcity. The production of lucerne, maize and sorghum under irrigation in the greater Orange River Basin is sustainable in the sense that the production thereof does not distort the natural runoff significantly and environmental flow requirements are met.

The production of oats for silage takes place between June and October, depending on the planting date. June has moderate blue water scarcity; significant blue water scarcity occurs in July; while August, September and October experience severe water scarcity. Oats production under irrigation in the Orange River Basin is not sustainable from an environmental water flow requirement perspective and should, therefore, be reconsidered.

3.3.3 Value Added to Water

All the values in this section are expressed in ZAR. The total value added (per kilogram of milk) along the value chain of milk was determined as follows:

$$V_c = \sum_i V_{ic}$$

where V_i (value added at process step *i* of value chain *c*) is defined as:

$$V_{ic} = PS_{ic} - PP_{ic}$$

The parameters of the equation are as follows:

V_c	=	Value added along value chain *c*
V_{ic}	=	Value added at process step *i* of value chain *c*
PS_{ic}	=	Selling price at process step *i* of value chain *c*
PP_{ic}	=	Purchase price at process step *i* of value chain *c*

Unlike the other stages along the value chain, milk production does not have a purchase price, so the directly allocatable costs per litre of milk produced were used as the purchase price. In the case study, these costs were provided by the farmer and amount to ZAR3.23 per litre of milk produced. The gross margin is then used as a proxy for the value added at farm level. Although the price that the processor paid for raw milk varied with the quality of the milk and the distance it had to be transported, the average price paid for milk with 3.3 per cent protein and four per cent fat was ZAR 4.75. Since the processing facility had two output products that have distinctly different values, the values added from processing to retail also differ. Therefore, the values added to the two product categories were explored individually.

The one-litre bottles were sold to the retailer at ZAR 10.40 per unit, while ZAR 25.90 was the price the processor received for a three-litre bottle of processed milk. At retail level, the milk was sold at ZAR 14.95 for a one-litre unit and ZAR 35.95 for a three-litre bottle. Figure 3.9 summarises the distribution of value along the value chain of producing milk and packaging it in one-litre bottles. From the results of the equations explained in the beginning of this section, it was found that by packaging the processed milk in a bottle with a capacity of one litre, a total value of ZAR 11.72 was added per litre of milk. To see how much value is added per kilogram, the value per litre is multiplied with the weight of one litre of milk, which was explained earlier to be 1.033 kilogram. The value added per kilogram of milk (4% fat, 3.3% protein) is then ZAR 12.11.

It is clear from Figure 3.9 that the greatest value is added to the milk during processing where ZAR 5.65 is added per litre. Retailers added a further ZAR 4.55 per litre, with farmers adding only ZAR 1.52 per litre of milk. Exploring the value added along the value chain of the milk packaged in three-litre bottles shows that only ZAR 8.75 of value was added per litre, in comparison with the R11.72 added to the smaller containers. Figure 3.9 indicates the distribution of value along the value chain of processed milk packaged in bottles with a capacity of three litres is again concentrated between the processor and the retailer. The dairy farmer receives the same price for the raw milk, regardless of the value added to the milk further along the value chain, so the value added to the milk by the farmer is again ZAR 1.52 per litre. Converting the value added per litre of milk to value added per kilogram reveals that the three-litre containers only add value of ZAR 9.04, while the one-litre bottles add ZAR 12.11 per kilogram of milk.

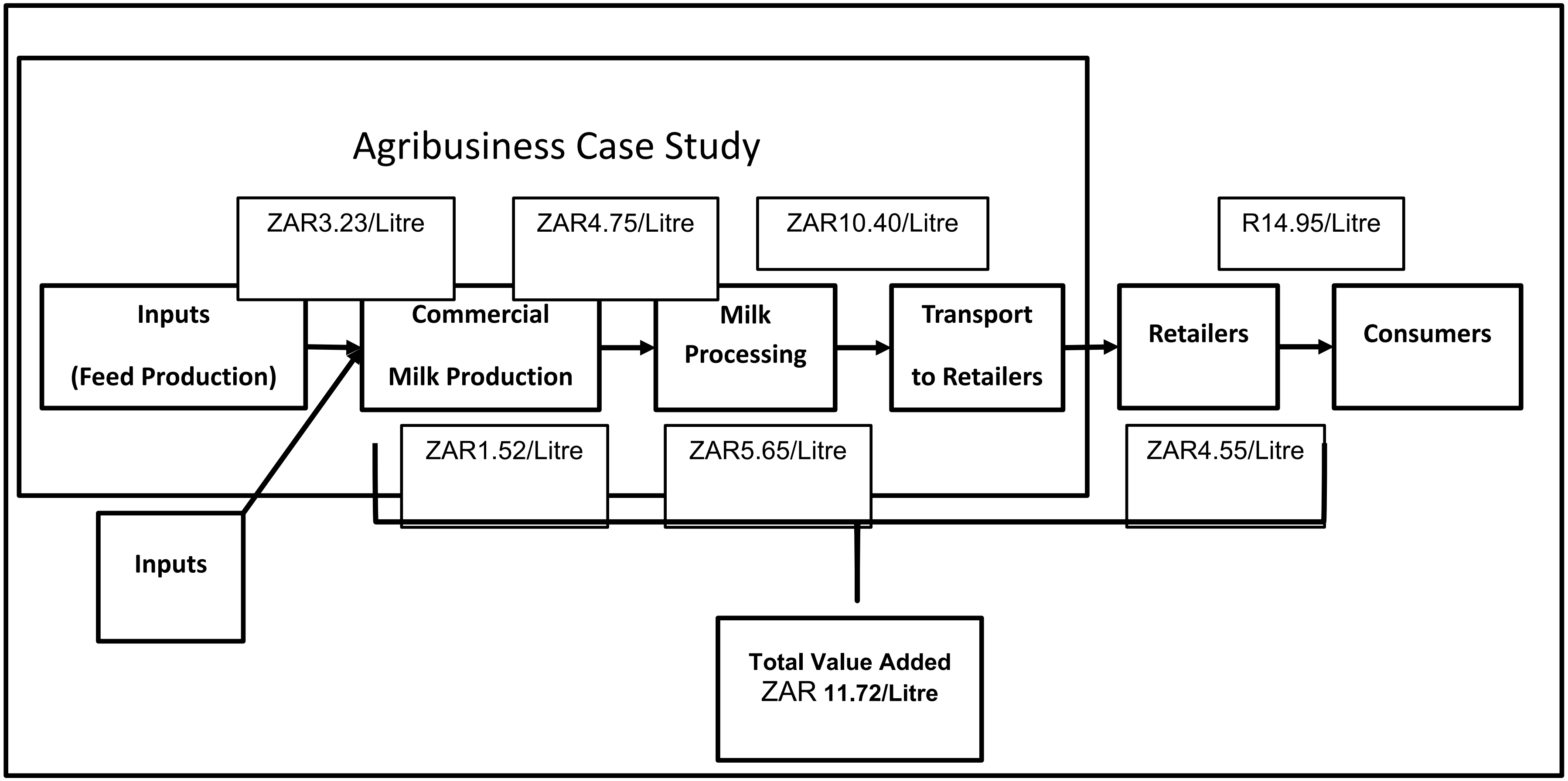

Figure 3.9: Distribution of value added (in 2014 prices) to milk produced in the Free State and sold in one litre bottles
Source: Authors' calculations

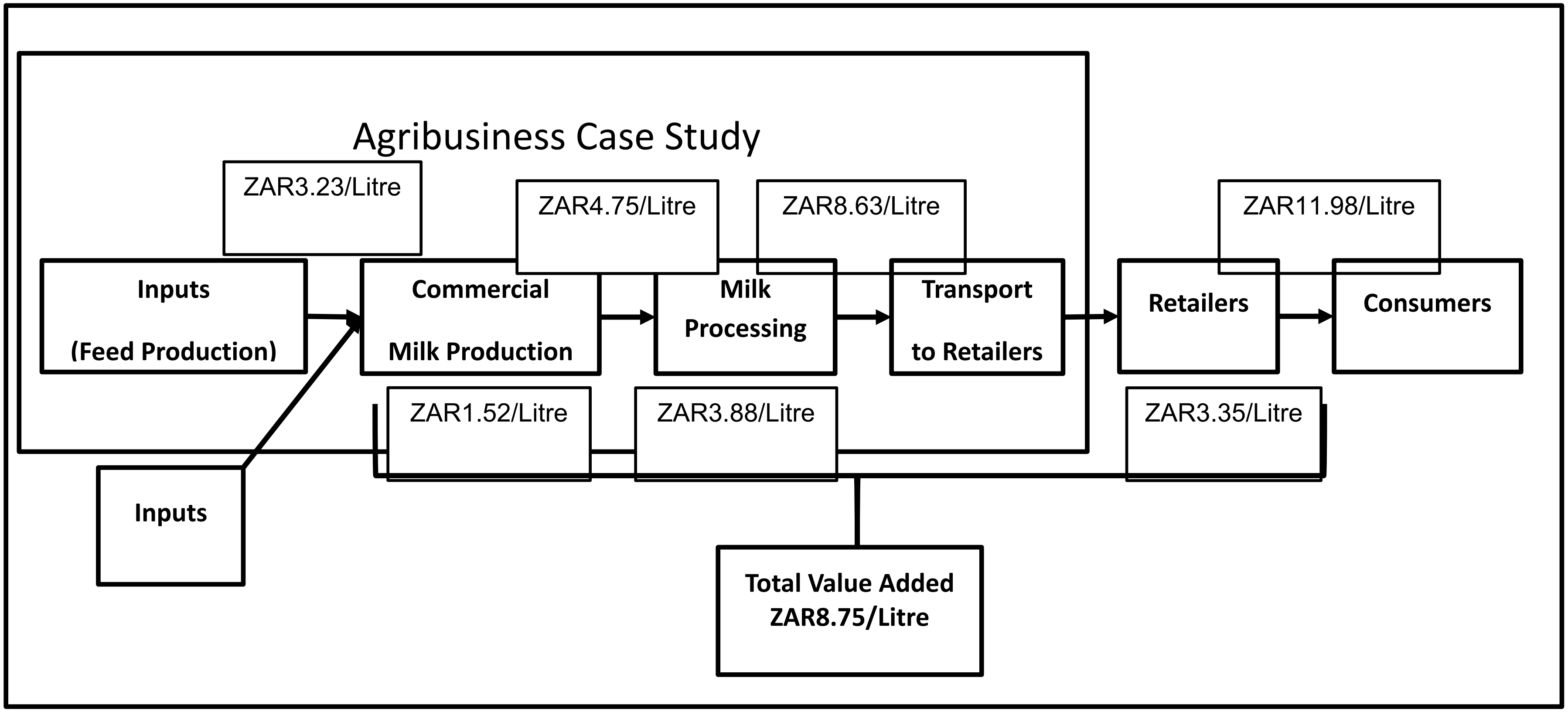

Figure 3.10: Distribution of value added (in 2014 prices) to milk produced in the Free State and sold in bottles with a capacity of three litres
Source: Authors' calculations

The value-added approach neglects the costs incurred, and only considers the value added. It is clear from both Figure 3.9 and Figure 3.10 that the greatest value is added to the milk when it is bottled in smaller containers, rather than in larger containers.

The same volume of water is used to produce one litre of milk, regardless of the container in which it is packaged. Value added from processing to retail varied with the different packaging sizes, resulting in significantly different total value added. Table 3.13 lists the value added at the nodes along the value chain of milk. The total value added to the milk is then divided by the water footprint calculated earlier to obtain the value added per cubic metre of water, once the processed milk reaches the final consumer.

Table 3.13: Value added (in 2014 prices) to the milk as it moves along the value chain from the primary producer to the final consumer

Parameters	**1 Litre**	**3 Litre**	Unit
Dairy Value Added	1.57	1.57	ZAR/kg
Processing Value Added	5.84	4.01	ZAR/kg
Retail Value Added	4.70	3.46	ZAR/kg
Total Value Added	12.11	9.04	ZAR/kg
Water Used for Production	1.03		m^3/kg
Value Added to the Water	**11.81**	**8.82**	**ZAR/m^3**

Milk sold in the one-litre bottles added the greatest value per litre of milk (thus, also per kilogram), while the same quantity of water was used in the production thereof. It therefore makes sense that the value chain of milk packaged in bottles with a volume of one litre add significantly more value to the water than the larger container's value chain does. Table 3.13 above confirms that the smaller container's value chain adds ZAR 11.81 per cubic metre of water used during production, as opposed to the ZAR 8.82 added to the water along the value chain of the three-litre bottles.

In excess of 98% of the all the water used to deliver the milk to the final consumer was used on the farm, but only 13% (17% for the 3 L bottle) of the total value was added to the water on the farm. This heavily skewed distribution of water used and value added emphasises the importance of focusing on the farm level to optimise the water used and value added to the water in the production of milk.

3.4 WATER FOOTPRINT OF IRRIGATED PASTURE

This section presents the water footprint estimates of irrigated pasture crops, such as cocksfoot, perennial ryegrass, tall fescue, lucerne, white clover and kikuyu, and various mixtures of these crops. The water footprint estimates were estimated for different seasons (winter, autumn, summer and spring) and for different production systems. Table 3.14 presents the pasture yields and water use for forage crops during spring (August-October). The results show that for the mono-cropping system for the spring season, white clover and lucerne produced the highest yield estimates of 2338 and 2104 kilograms of dry matter, respectively. This is followed by perennial ryegrass. Cocksfoot had the lowest yield. Regarding water footprints, the results show that for all the pasture crops, blue water usage was higher than green water. The blue water footprint ranges from 442 m^3.ton to 889 m^3.ton, whereas the green water footprint ranges from 50 m^3/ton to 292 m^3/ton. Cocksfoot and kikuyu have the highest total water footprint among all the pasture crops grown solely. White clover and perennial ryegrass have the lowest water total footprint estimates. It is worth noting that this assessment did not consider grey water footprint estimation.

Regarding the mixed system for spring season, we found that the combination of tall fescue and white clover produced the highest yield in terms of kilograms of dry matter per ton. This is followed by the combinations of tall fescue, cocksfoot and white clover, and kikuyu, annual ryegrass and white clover, respectively. The combination of tall fescue, cocksfoot and lucerne produced the lowest yield. Under this system, we found that the blue water usage was still higher than that of the green water was. Specifically, the combination of kikuyu, annual ryegrass and lucerne had the highest water footprint estimates, followed by the tall fescue, cocksfoot and lucerne combination.

The pasture combinations with low water footprints are those of tall fescue and white clover, followed by tall fescue with cocksfoot and white clover, and kikuyu with annual ryegrass and white clover, respectively. For both seasons and for the different pasture crops, the ET_0 was found to be 114 mm. The total water footprints for the different pasture combinations range from 440 m^3.ton to 846 m^3.ton. The estimates show that the blue water footprints range from 390 m^3/ton to 756 m^3/ton, whereas those of the green water range from 49 m^3.ton to 136 m^3.ton.

Table 3.14: Pasture yields and water use for sole crop and mixed pasture crops during spring (August-October)

System	Forage type	Total Yield (kg DM/ha)	Total Blue Water Use (mm)	ET_0 (mm)	Effective Rainfall (mm)	Blue WFP (m^3.ton)	Green WFP (m^3.ton)	Total WFP (m^3.ton)
Mono	Cocksfoot	1157	99	114	15	889	141	1030
Mono	Perennial ryegrass	2032	102	114	12	525	58	583
Mono	Tall fescue	1744	96	114	18	567	103	670
Mono	Lucerne	2104	93	114	21	497	108	605
Mono	White clover	2338	102	114	12	442	50	492
Mono	Kikuyu	1519	73	114	40	480	292	772
Mixed	Tall fescue/White clover	2976	111	114	13	390	49	440
Mixed	Kikuyu/Annual ryegrass/Lucerne	1390	99	114	14	730	116	846
Mixed	Kikuyu/Annual ryegrass/White clover	2343	102	114	12	444	53	497
Mixed	Tall fescue/Cocksfoot/White clover	2467	107	114	8	438	36	474
Mixed	Lucerne/Kikuyu	1941	96	114	22	511	135	646
Mixed	Tall fescue/Lucerne	1932	105	114	10	566	75	641
Mixed	Tall fescue/Cocksfoot/Lucerne	1352	102	114	12	756	87	843

For the summer season, we present the pasture yields and water use for forage crops in Table 3.15. The results indicate that for the sole cropping pastures, lucerne, white clover and tall fescue produce the highest dry matter yields, and therefore recorded the lowest water footprint estimates accordingly. For both seasons and for the different pasture crops, the ET_0 was found to be 167 mm. The total water footprint for the sole cropping pastures ranges from 607 m^3.ton to 1490 m^3.ton. The blue water footprint ranges from 472 m^3.ton to 1024 m^3.ton. The results further indicate that kikuyu has the highest total and blue water footprints among all the sole pasture crops by cocksfoot. This is not surprising, given that kikuyu has lower yields during the summer. Lucerne has the lowest blue and total water footprint estimates, and this is consistent with the higher yields of lucerne during the summer season.

For the mixed system, tall fescue/lucerne and lucerne/kikuyu produced the highest yields, respectively. This is followed by tall fescue/white clover. In terms of water footprint, the results indicate that tall fescue/lucerne, lucerne/kikuyu and tall fescue/white clover had the lowest water footprint estimates, respectively. The blue water footprints for the different combinations range from 419 m^3.ton to 578 m^3.ton. Kikuyu/annual ryegrass/white clover has the highest total water footprint, followed by kikuyu/annual ryegrass/lucerne. On average, the water footprint estimates for the sole cropping pastures are higher than those for the mixed pastures.

The total water footprints for the different pasture combinations range from 532 m^3.ton to 775 m^3.ton. It is worth noting that the blue water footprint estimates are higher than the green water footprint values. This suggests that more irrigation water is used in pasture production, relative to rainfall.

Table 3.15: Pasture yields and water use for sole crop and mixed pasture crops during summer (November)

System	Forage type	Total Yield (kg DM/ha)	Total Blue Water Use (mm)	ET_0 (mm)	Effective Rainfall (mm)	Blue WFP (m^3.ton)	Green WFP (m^3.ton)	Total WFP (m^3.ton)
Mono	Cocksfoot	1390	132	167	35	980	258	1238
Mono	Perennial ryegrass	1803	126	167	41	753	256	1009
Mono	Tall fescue	2132	124	167	43	583	201	784
Mono	Lucerne	2928	129	167	38	472	135	607
Mono	White clover	2375	130	167	37	567	172	739
Mono	Kikuyu	1810	121	167	46	1024	466	1490
Mixed	Tall fescue/Cocksfoot/Lucerne	2888	129	167	38	463	138	601
Mixed	Tall fescue/White clover	3004	135	167	32	466	116	583
Mixed	Kikuyu/Annual ryegrass/Lucerne	2393	125	167	42	544	200	744
Mixed	Kikuyu/Annual ryegrass/White clover	2414	124	167	43	578	197	775
Mixed	Tall fescue/Cocksfoot/White clover	2571	137	167	30	578	137	715
Mixed	Lucerne/Kikuyu	3219	125	167	42	427	140	566
Mixed	Tall fescue/Lucerne	3617	133	167	34	419	114	532

Table 3.16 presents the pasture yields and water use for forage crops during the winter (May-July) season. The results show that for the mono-cropped pastures for the winter season, tall fescue and perennial ryegrass yielded the highest dry matter of 1757 and 1534 kilograms, respectively. This is followed by white clover, with a total dry matter yield of 1526 kilograms. Lucerne had the lowest yield. Regarding water footprints, the results show that for all the pasture crops, blue water usage was higher than green water during the winter season. Blue water footprints range from 449 m^3.ton to 768 m^3.ton, whereas green water footprints range from 51 m^3.ton to 122 m^3.ton for the winter season. Cocksfoot and perennial ryegrass have the highest total water footprint among all the pasture crops grown solely. Tall fescue and lucerne had the lowest water total footprint estimates. It is worth noting that this assessment did not consider grey water footprint estimation.

For the mixed system during the winter season, we found that the combinations of kikuyu/annual ryegrass/white clover and tall fescue/cocksfoot/white clover produced the highest yields in terms of kilograms of dry matter per ton. This is followed by the combinations of lucerne/kikuyu, and tall fescue/white clover, respectively. The combination of tall fescue/lucerne produced the lowest yield. Under this system, we found that blue water usage was still higher than green water. Specifically, the combination of tall fescue/cocksfoot/lucerne and tall fescue/white clover had the highest total water footprint estimates, followed by the tall fescue/lucerne combination. Lucerne/kikuyu had the lowest total water footprint, while the next combination with a low water footprint was kikuyu/annual ryegrass/white clover.

For both seasons and for the different pasture crops, the ET_0 was found to range from 58 mm to 84 mm. The total water footprint for the different pasture combinations ranges from 420 m^3/ton to 758 m^3/ton. The estimates show that the blue water footprint ranges from 334 m^3.ton to 651 m^3.ton, whereas that of the green water ranges from 31 m^3.ton to 143 m^3.ton for the different pasture combinations.

The pasture yields and water use for forage crops during the autumn (March-April) season are presented in Table 3.17. The results show that among the mono-cropped pastures for the autumn season, lucerne and kikuyu yielded the highest dry matter, respectively. These are followed by white clover, with total dry matter yield of 1817 kilograms, while tall fescue had the lowest yield. Regarding water footprints, the results show that for all the pasture crops grown solely, blue water usage was higher than green water was during the autumn season. The blue water footprint ranges from 271 m^3.ton to 579 m^3.ton, whereas the green water footprint ranges from 112 m^3.ton to 309 m^3.ton for the autumn season.

Table 3.16: Pasture yields and water use for sole crop and mixed pasture crops during winter (May-July)

System	Forage type	Total Yield (kg DM/ha)	Total Blue Water Use (mm)	ET_0 (mm)	Effective Rainfall (mm)	Blue WFP (m^3.ton)	Green WFP (m^3.ton)	Total WFP (m^3.ton)
Mono	Cocksfoot	1409	95	82	14	768	119	887
Mono	Perennial ryegrass	1534	95	82	13	641	90	731
Mono	Tall fescue	1757	72	64	10	449	63	512
Mono	Lucerne	1403	70	76	6	547	51	598
Mono	White clover	1526	66	84	19	580	122	702
Mixed	Tall fescue/Cocksfoot/Lucerne	1346	75	65	12	651	107	758
Mixed	Tall fescue/White clover	1637	85	65	21	571	143	714
Mixed	Kikuyu/Annual ryegrass/Lucerne	1581	71	66	7	548	54	603
Mixed	Kikuyu/Annual ryegrass/White clover	1821	66	66	6	427	31	458
Mixed	Tall fescue/Cocksfoot/White clover	1699	79	60	19	470	112	583
Mixed	Lucerne/Kikuyu	1662	53	58	14	334	86	420
Mixed	Tall fescue/Lucerne	1174	53	58	6	617	72	689

Table 3.17: Pasture yields and water use for sole crop and mixed pasture crops during autumn (March-April)

System	Forage type	Total Yield (kg DM/ha)	Total Blue Water Use (mm)	ET_0 (mm)	Effective Rainfall (mm)	Blue WFP (m^3.ton)	Green WFP (m^3.ton)	Total WFP (m^3.ton)
Mono	Tall fescue	1433	76	97	21	579	144	723
Mono	Lucerne	2811	71	119	48	271	195	465
Mono	White clover	1817	97	119	22	552	112	664
Mono	Kikuyu	2188	61	119	58	323	309	632
Mixed	Tall fescue/Cocksfoot/Lucerne	3316	71	97	26	217	81	299
Mixed	Tall fescue/White clover	1872	99	97	10	565	60	626
Mixed	Kikuyu/Annual ryegrass/Lucerne	2650	78	97	19	297	74	370
Mixed	Kikuyu/Annual ryegrass/White clover	1948	87	97	10	455	51	506
Mixed	Lucerne/Kikuyu	3177	63	119	56	202	178	379
Mixed	Tall fescue/Lucerne	3114	68	97	29	217	98	315

Tall fescue and white clover have the highest total water footprints among all the pasture crops grown solely. Lucerne and kikuyu had the lowest total water footprint estimates. It is worth noting that this assessment for this season did not consider a grey water footprint estimation.

For the mixed system during the autumn season, we found that the combinations of tall fescue/cocksfoot/Lucerne, lucerne/kikuyu and tall fescue/lucerne produced the highest yields in terms of kilograms of dry matter per ton, respectively. The combination of tall fescue/white clover produced the lowest dry matter yield. Under this system, we found that the blue water usage was still higher than that for green water in the autumn season. Specifically, the combinations of tall fescue/white clover and kikuyu/annual ryegrass/white clover had the highest total water footprint estimates, followed by the lucerne/kikuyu combination. Tall fescue/cocksfoot/lucerne had the lowest total water footprint, and the next combination with a low water footprint was tall fescue/lucerne. The total water footprints for the different pasture combinations range from 299 m^3.ton to 626 m^3.ton. The estimates show that the blue water footprint ranges from 202 m^3.ton to 565 m^3.ton, whereas that of the green water footprint ranges from 51 m^3.ton to 178 m^3.ton for the different pasture combinations.

3.5 DISCUSSION

The finding that 1 025 litres of water was used to produce one kilogram of milk with a fat content of four per cent and 3.3 per cent protein is consistent with the global average reported by Mekonnen and Hoekstra (2010b), who reported a total water footprint of 1 020 litres of water to produce one kilogram of milk. They estimated that in South Africa, 1 136 litres of water were required for the production of one litre of milk, which is somewhat higher than the finding in the case study. Global averages and country water footprint estimates provide valuable insight into the use of freshwater, but it is clear that local studies are even more important to reflect the true impacts on freshwater resources.

The results also show that 98% of the water used relates to the production of feed for the animals. Again, this finding corresponds with the findings of Mekonnen and Hoekstra (2010b) and Hoekstra (2012) who determined that about 98% of all the water used was for feed production. With such a high portion of the total water being used for the production of feed, on-farm improvements in production efficiencies are most likely to bring about reductions in the total water footprint.

When assessing the sustainability of the water footprint, the blue water footprints in the Orange River Basin severely exceed the availability of blue water during August, September and October. During these months, the water scarcity indices exceed 300%, resulting in inefficient water flows to meet the environmental requirements. From December to May, there is low blue water scarcity, while the remaining months experience moderate to significant blue water scarcity. The production of lucerne, maize and sorghum under irrigation in the Orange River Basin is sustainable from an environmental water flow requirement perspective because the majority of the water required for production is needed in the warmer months with low blue water scarcity. Oats production is, however, not as sustainable, because it is produced during the cooler months when blue water availability is very low. These months experience moderate to severe water shortages, with insufficient water to fulfil the environmental water flow requirements. Oats production in the Orange River Basin should, therefore, be reconsidered.

Despite using 1 024.965 litres of water to produce one kilogram of milk, the milk value chain in the case study does not significantly disrupt the natural runoff and remains environmentally sustainable. The water used in the production of milk is used to create a product that consumers demand, and in the process, value is added to the water allocated to the production of milk. By adding value to the scarce resource, progress is made towards ensuring environmental sustainability, resource efficiency, and social equity. Value added to the milk differed notably, depending on the packaging volume of the processed milk. The results showed that if the milk was bottled in a container with a capacity of one litre, the total value added to the milk was ZAR3.06 per kilogram more than when it was bottled in a container with a three-litre capacity. Despite using in excess of 98% of the total water for milk production at farm level, only between 13% and 17% of the value (depending on the packaging volume) was added on the farm level.

The total value added to the water used to produce one kilogram of milk (4% fat; 3.3% protein) and sold in one-litre bottles amounted to ZAR 12.11. This relates to ZAR 11.81 per cubic metre of water used. In contrast, milk sold in bottles with a capacity of three litres only added a total of ZAR 9.04 per kilogram of milk and ZAR 8.82 per cubic metre of water used. The results of this study show that allocating scarce freshwater to agriculture, and more specifically to milk production, is not only sustainable from an environmental flow requirement perspective, but also adds significant value to the water through using the water for the production of milk.

The findings on pastures have provided details of different pasture combinations with their dry matter yields and water usage for different seasons and production systems. The findings reveal that the yield and water usage for sole pasture crops and mixed pastures vary from season to season. Blue water usage dominates in the pasture production, and green water usage is minimal. For each season, the same pasture crops have different water footprints and dry matter yields, and as such, the study suggests that there should be a careful review of the different pasture crops and studies done to ascertain which ones will be efficient in terms of dry matter yield and water usage.

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CHAPTER 4

CASE STUDY OF BROILERS PRODUCED FROM MAIZE

Authors

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Summary

The aim of this case study was to assess the water footprint of maize and broilers as derived from irrigated maize production in the form of a case study carried out in the Bloemfontein area. This aim was attained by firstly quantifying the volumetric water footprint indicators for the production of maize and broilers as derived from maize production. Thereafter, a sustainability assessment was conducted, followed by the formulation of response strategies to inform the sustainable use of freshwater. The method of the Water Footprint Network (WFN) was identified as suitable to achieve the aim and objectives of this study. The method consists of the scope of the study, water footprint accounting, sustainability assessment, and response formulation. Maize water use data were obtained from secondary data from field experiments at the Orange-Riet Irrigation Scheme. Water use data for farm-level broiler production were obtained from a broiler-producing company. Process data were obtained from a broiler-processing company, which happened to be the same firm that produces broilers on site. At a yield level of 14.3 ton.ha, the total maize water footprint was determined as 584.2 m^3.ton. This comprises a green water footprint of 186.9 m^3.ton, a blue water footprint of 275.6 m^3.ton, and a grey water footprint of 121.7 m^3.ton. The total broiler water footprint was determined as 1 474.6 m^3.ton of chicken meat produced. The water footprint of farm-level broiler production, excluding feed, is equivalent to 38.8 m^3.ton, while the water footprint associated with broiler feed was 1 430.3 m^3.ton. The slaughtering and the processing of the broiler chickens used 2.7 m^3.ton each. The economic water productivity (EWP) was found to be higher for fresh chickens than for frozen chickens. Chicken portions had a higher associated EWP than whole chickens did. Maize and broiler production were found to be sustainable from December to May. It is recommended that maize production in the Orange-Riet Irrigation Scheme should commence from December, rather than October. Irrigation should be postponed to the later hours of the day. Optimum in-row spacing should be implemented to provide sufficient covering of the ground surface to avoid evaporation losses from the soil.

4.1 BACKGROUND AND MOTIVATION

Water is a scarce resource, globally, and thus the sustainable use of water is important to ensure that water demand in the agricultural, industrial, and domestic sectors is met. Globally, the agricultural sector consumes about 75% of freshwater resources, the industrial sector accounts for about 20%, and the domestic sector uses about 5% of global freshwater resources (United Nations Environment Programme (UNEP), 2008). According to Mekonnen and Hoekstra (2014), the demand for freshwater resources will increase in the next couple of years in response to the rising demand for food, fibre, and biofuel crops. This increase in the demand for freshwater resources may be attributed to the rise in the global population, which is expected to increase by 2.3 billion people between 2009 and 2050 (Food and Agriculture Organization (FAO), 2009). This will not only place pressure on the agricultural sector to increase output, which will be accompanied by an increase in water use in the sector, but it will also increase the demand for freshwater resources in the industrial and domestic sectors.

South Africa is a water-scarce country, with a total surface area of about 1.2 million km² of land, of which 12% is suitable for the purposes of crop production. Water availability is a major limiting factor for crop production (Baloyi *et al.*, 2012; World Water Council, 2004), despite the allocation of 60% of South Africa's water resources to agricultural irrigation (Department of Water Affairs (DWA), 2013). In South Africa, about 1.3 million hectares (ha) of land is under irrigation (Bezuidenhout, 2013). Irrigated agriculture accounts for 30% of South Africa's crop production. With only 1.5% of land under irrigation, agricultural irrigation is not only a large consumer of freshwater, but also a method of achieving food security (DWA, 2013). Irrigated agriculture contributes to the growth of the agricultural sector and thus to economic growth. It contributes to poverty reduction in various ways, such as by increasing the productivity, employment, and incomes of farms operating under irrigation (Hasnip et al., 1999). Of the irrigated crops in South Africa, maize is the most important crop. Broiler consumption accounts for 60% of total meat consumption in South Africa (United States Department of Agriculture (USDA), 2015). The increasing demand for water from the agricultural, industrial, and domestic sectors will give rise to competition for water resources among the three sectors of the economy. It is thus necessary to inform water users and policymakers on sustainable water use management in South Africa to ensure the efficient and sustainable use of freshwater resources in the largest water-consuming sector, the agricultural sector, as a means to minimise the implications that will be incurred in response to inadequate freshwater supplies.

Given that maize is an important crop and that broiler consumption is relatively high in South Africa, attention should be given to the water use for maize and broiler production. One method that can be used to ensure efficient and sustainable use of freshwater within the agricultural sector is to conduct a water footprint assessment (WFA). The WFA can contribute to ensuring that the objective of the National Water Act of 1998 (No. 36 of 1998) is met, namely "to ensure that South Africa's water resources are protected, used, developed, conserved, managed, and controlled in a sustainable and equitable manner, for the benefit of all persons". A water footprint is the volume of freshwater used (directly and indirectly) to produce a product or service. If lowered whilst yields per hectare are maintained or increased, it can ensure the sustainable use of freshwater and thus increase the productivity of freshwater within the agricultural sector (Mekonnen and Hoekstra 2014).

One can distinguish between three different types of water footprints, namely blue, green, and grey water footprints. Collectively, they represent the total water footprint. The blue water footprint is an indicator of the total volume of surface water (i.e. rivers, aquifers, dams, and harvested rainwater) and groundwater (i.e. renewable groundwater and fossil groundwater) consumed in the production of a commodity, product, or service. In the case of crops, water consumption refers to the blue water that is evaporated, incorporated into the crop, lost to another catchment area, or returned to the same catchment area in a different period. Thus, the blue water footprint is a measure of how much of the available surface water and groundwater is consumed during production (Hoekstra *et al*., 2011). The green water footprint is an indicator of the total volume of rainfall that does not form part of runoff or groundwater, but is stored in the soil, or remains temporarily on top of the soil or vegetation. This water is then evapotranspired by plants. The part of the green water that remains above the soil or vegetation may be evaporated and lost to a different catchment area, or may return to the same catchment area in a different period (Hoekstra *et al*., 2011). The grey water footprint is the total volume of freshwater needed to dilute the substances that pollute water and return the water to ambient water quality standards (Hoekstra *et al*., 2011). These three types of water footprints are the backbone of a WFA.

A WFA is a science-based method to explore sustainable water use. It has been applied widely to assess the water footprint of nations, consumers, producers, regions, and so on. Although the fundamental goal of a WFA is to ensure the sustainable use of freshwater and avoid water losses where necessary, there are limited, if any, alternative uses for green water other than being consumed by natural vegetation or cultivated crops. However, blue water that is conserved may be redistributed among the agricultural, industrial, and domestic sectors. It may also be reserved to meet environmental flow requirements (EFRs). Hence, alternative uses exist for conserved blue water (World Water Council, 2004).

Despite wide applications internationally, WFAs in South Africa have not been applied to a great extent. Only five studies have been published in South Africa on WFAs. SABMiller published the first, while Pegasys Consulting (2010) published the second. These were followed by three publications in 2015 by Pahlow et al. (2015), Munro *et al*. (2015), and Scheepers (2015). Globally, the water footprints of grain products have been quantified. The water footprint of maize production, in particular, has been calculated using the consumptive water-use-based volumetric water footprint approach, hereafter referred to as the volumetric water footprint approach (Mekonnen and Hoekstra, 2013; Mekonnen and Hoekstra, 2014; Schyns and Hoekstra, 2014). The water footprint of animal production, particularly that of broilers, has also been widely determined using the WFN approach (Mekonnen and Hoekstra, 2012; Gerbens-Leenes et al., 2011).

Pahlow et al. (2015) conducted a national WFA in South Africa, following the approach presented by Hoekstra *et al.* (2011). Their study identified crop production as a major activity in terms of water consumption, accounting for about 75% of the total water footprint of national production. Of the different crops, maize was found to be one of the major consumers of the water resource. The degree of water pollution associated with nitrogen and phosphorous fertilisation was reported as being unsustainable for all South African river basins. In the context of ample international applications and limited local use, there is a lack of scientific water footprint information to effectively guide water use in South Africa's maize and poultry industries. Considering the importance of the maize industry, seen in its role as a staple food for South Africans, a WFA of maize and broiler production is critical to ensure sustainable water use in the value chain.

To the authors' knowledge, very little has been done in South Africa on the water footprint of maize and derived maize products. Thus, no information is available to inform water users on the production of maize and derived maize products in South Africa. The aim of this study was to assess the water footprint of maize and broilers as a derived product from irrigated maize production in the form of a case study carried out in the Bloemfontein area. This was done to inform water users, water managers, and policymakers regarding the sustainable use of water for the production of irrigated maize for broiler feed, and ultimately broilers for human consumption.

The aim of the study was formulated around the following objectives:

Objective 1: Quantify the volumetric water footprints associated with the production of maize and broilers as derived maize products.

Objective 2: Assess the sustainability of the green, blue, and grey water footprints of maize, as well as derived maize products, in a particular catchment at a certain time from an environmental, social, and economic perspective.

Objective 3: Formulate response strategies to inform sustainable use of freshwater.

4.2 DATA AND METHOD

4.2.1 Data

4.2.1.1 Background information on data

This study analyses the water footprint of the maize-broiler value chain, with a focus on broiler chickens. The study considers production from farm level to processor, right through to retail level. Secondary data on the water requirements for maize production were obtained from Van Rensburg *et al.* (2012). The general objective of Van Rensburg *et al.* (2012) was to formulate methods for controlling irrigation-induced salinity on the farms located in the Orange-Riet and Vaalharts irrigation schemes. However, for the purposes of this study, only the Orange-Riet Irrigation Scheme will be considered.

Maize is the major input used as feed in the production of broiler chickens. Therefore, data on the water requirements for maize production at farm level are essential. Data on water used during the processing of maize to produce chicken feed are also necessary. Thus, water use data for a commercial poultry farm and poultry processor have a considerable contribution towards this study. These data were acquired from a chicken-processing facility by means of questionnaires and interviews conducted with senior management. Data on rainfall, irrigation, soil water content, water table depth, drainage from artificial drainage systems (where applicable), electrical conductivity of irrigation water, water table and drainage, and fertiliser application were taken from Van Rensburg et al. (2012).

The annual mean maximum temperature in the scheme is 25.58°C. The mean maximum temperature for each of the summer months (October to February) is greater than the mean maximum temperature per annum is. As autumn sets in, the temperatures begin to fall gradually. The mean minimum temperature in the scheme is 8.5°C per annum. The mean minimum temperature for each winter month (May to July) is less than the mean minimum temperature in the scheme per annum is. As spring sets in, the temperatures begin to rise. The total mean evaporative demand in the scheme is 1 741 mm. The mean evaporative demand for the summer months is about 965 mm. This is 55.43% of the total evaporative demand. As autumn approaches, the mean evaporative demand declines. The mean evaporative demand for the winter months is about 251 mm. This is 14.42% of the total mean evaporative demand. As spring approaches, the mean evaporative demand increases. The total mean rainfall in the scheme is 397 mm, while the mean rainfall for the summer months is about 239 mm (60.2%).

Table 4.1 is a guideline for determining the leaching-runoff fraction of nitrogen. It distinguishes between environmental factors and agricultural practice. The environmental factors consist of atmospheric nitrogen deposition, soil texture, and natural drainage, as well as precipitation. The agricultural practice comprises nitrogen fixation, application rate, plant uptake, and management practice. In determining the leaching-runoff fraction, a weight is assigned to each factor. The weights ranged from 5 to 15. Natural drainage and plant uptake received the lowest weights. Soil texture and precipitation were assigned the highest weights.

The maize season, at measuring points or18 and or20, commenced in October and ended in May 2008. This was a period of eight months. Rainfall over this period was 361 mm. Both N-deposition from the atmosphere and N-fixation are unknown, therefore they are each assigned a score of 0.5, as suggested by Franke *et al.* (2013). The soil is clayey with no drainage system, hence the soils are poorly drained. Nitrogen fertilisation was applied at 217 kg/ha. The management practice was good because a yield of 13.32 t.ha^{-1} was achieved in the area. At this yield level, the Fertilizer Society of South Africa (FSSA, 2007) has suggested that 199.8 kg N/ha is taken up by the crop.

The first maize season, at measuring points or4 and or5, commenced in December 2007 and ended in July 2008 the following year. This was a period of eight months. Rainfall over this period was 262 mm. Both N-deposition from the atmosphere and N-fixation are unknown, therefore they are each assigned a score of 0.5 as suggested by Franke *et al.* (2013). The soil is sandy with no drainage system at the fields in the vicinity of measuring point or5. Nevertheless, lands that were covered by measuring point or4 had a drainage system, hence the soils are moderately to imperfectly drained. Nitrogen fertilisation was applied at 215 kg/ha.

Table 4.1: The score of each factor and the associated weight for the case of nitrogen at measuring points or18, or20, or4 and or5

Category	**Factor**		**Score (s_i)**		**Weight (w_i)**	
			or18 and or20	or4 and or5	or18 and or20	or4 and or5
Environmental factors	Atmospheric input	N-deposition (g $N.m^{-2}.yr^{-1}$)	0.5	0.5	10	10
	Soil	Texture (relevant for leaching)	0	1	15	15
		Texture (relevant for runoff)	0	1	10	10
		Natural drainage (relevant for leaching)	0	0.33	10	10
		Natural drainage (relevant for runoff)	1	0.67	5	5
	Climate	Precipitation (mm)	0	0	15	15
Agricultural practice	N-fixation (kg/ha)		0.5	0.5	10	10
	Application rate		217	215	10	10
	Plant uptake		359.7	413.8	5	5
	Management practice		0.3	0.3	10	10

Source: Van Rensburg *et al*. (2012)

The management practice was good because a yield of 15.3 tons.ha was achieved in the area. At this yield level, the FSSA (2007) has suggested that 413.8 kg N.ha^{-1} is taken up by the crop.

Figure 4.1 illustrates an industrial production system that is followed by the broiler farm studied in this research study. The broiler farm is located in the eastern Free State. The broilers are relatively less mobile, they are bred to grow at a higher rate, and they are slaughtered at an earlier age. Their feed ration comprises maize, full-fat soya, soya oilcake, and sunflower oilcake.

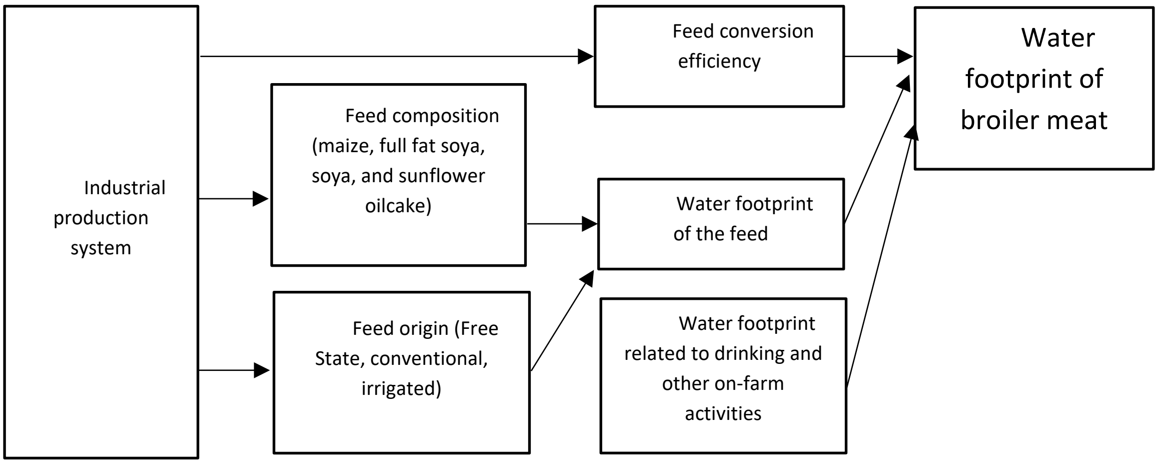

Figure 4.1: Factors influencing the water footprint of chicken meat
Source: Gerbens-Leenes *et al.* (2013)

The broiler diet is divided into pre-starter, starter, grower, finisher, and post-finisher compounds. Maize accounts for the highest percentage in all phases of their diet, followed by soya oilcake and sunflower oilcake. The feed is produced locally, using conventional practices, mainly under irrigation conditions. Ultimately, the FCE, the water footprint of the feed, the water footprint associated with drinking, and other on-farm activities yield the water footprint of chicken meat.

4.2.1.2 Study area

The research area is the Orange-Riet Irrigation Scheme. A large area of the Orange-Riet Irrigation Scheme is located in the Free State within the confines of the Orange River and the Riet River, and extends marginally into the Northern Cape (Van Rensburg *et al.*, 2012). The

Orange-Riet Irrigation Scheme is managed within the Riet/Modder and Vanderkloof sub-areas of the Upper Orange Water Management Area (Van Rensburg *et al.*, 2012).

The Orange-Riet Transfer Scheme is in the Free State province. It allows for the flow of freshwater from the Vanderkloof Dam through the Orange-Riet Canal and into the Riet River catchment. Figure 4.2 is a graphic illustration of the position of the Orange-Riet Irrigation Scheme in South Africa. It is evident from Figure 4.2 that the scheme is primarily located in the Free State province.

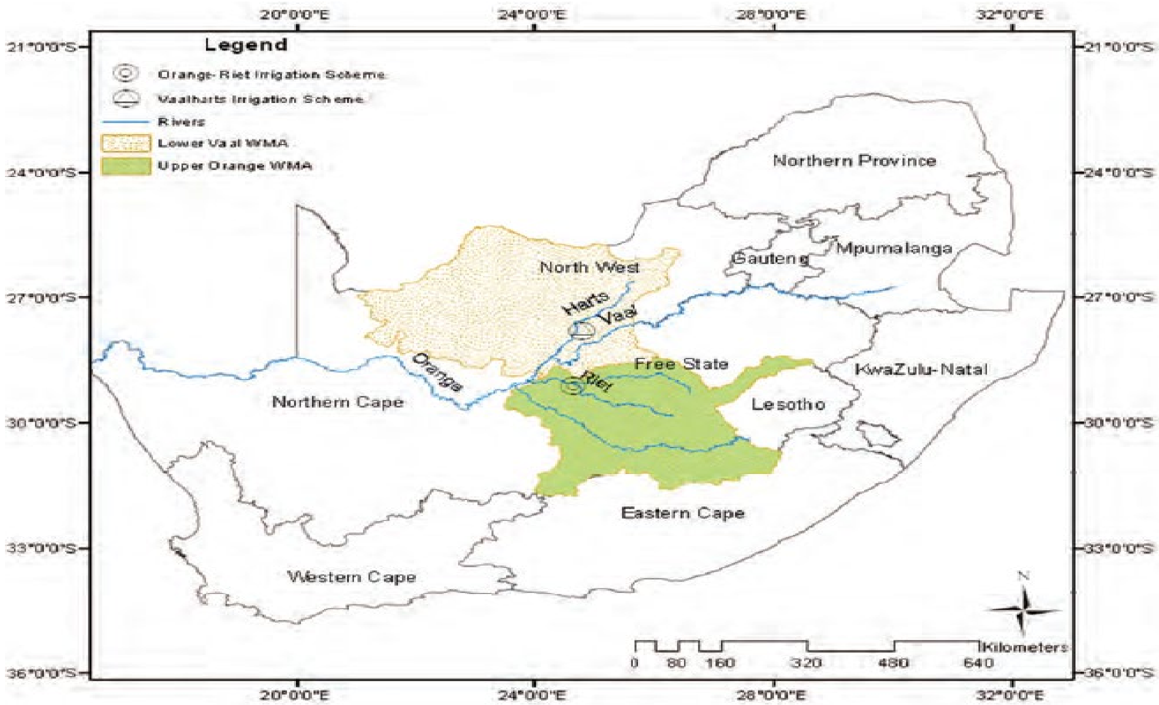

Figure 4.2: Geographic position of the Orange-Riet irrigation scheme in South Africa
Source: Van Rensburg *et al.* (2012)

Figure 4.3 provides a more detailed description of the Orange-Riet Irrigation Scheme. The Vanderkloof Dam serves as a source of water for the Orange-Riet Irrigation Scheme (Van Rensburg *et al.*, 2012). As freshwater flows from the Vanderkloof Dam along the Orange-Riet canal section, about 3 970 ha are irrigated. In the Riet River Settlement section, 8 045 ha are irrigated, and 637 ha are irrigated in the Scholtzburg section of the Orange-Riet Irrigation Scheme (Van Rensburg *et al.*, 2012). Excess and drainage water from the settlement section flow into the Riet River, which in turn flows across the Ritchie and Lower Riet sections of the

Orange-Riet Irrigation Scheme, where 97 ha and 3 938 ha are irrigated, respectively (Ninham Shand, 2004).

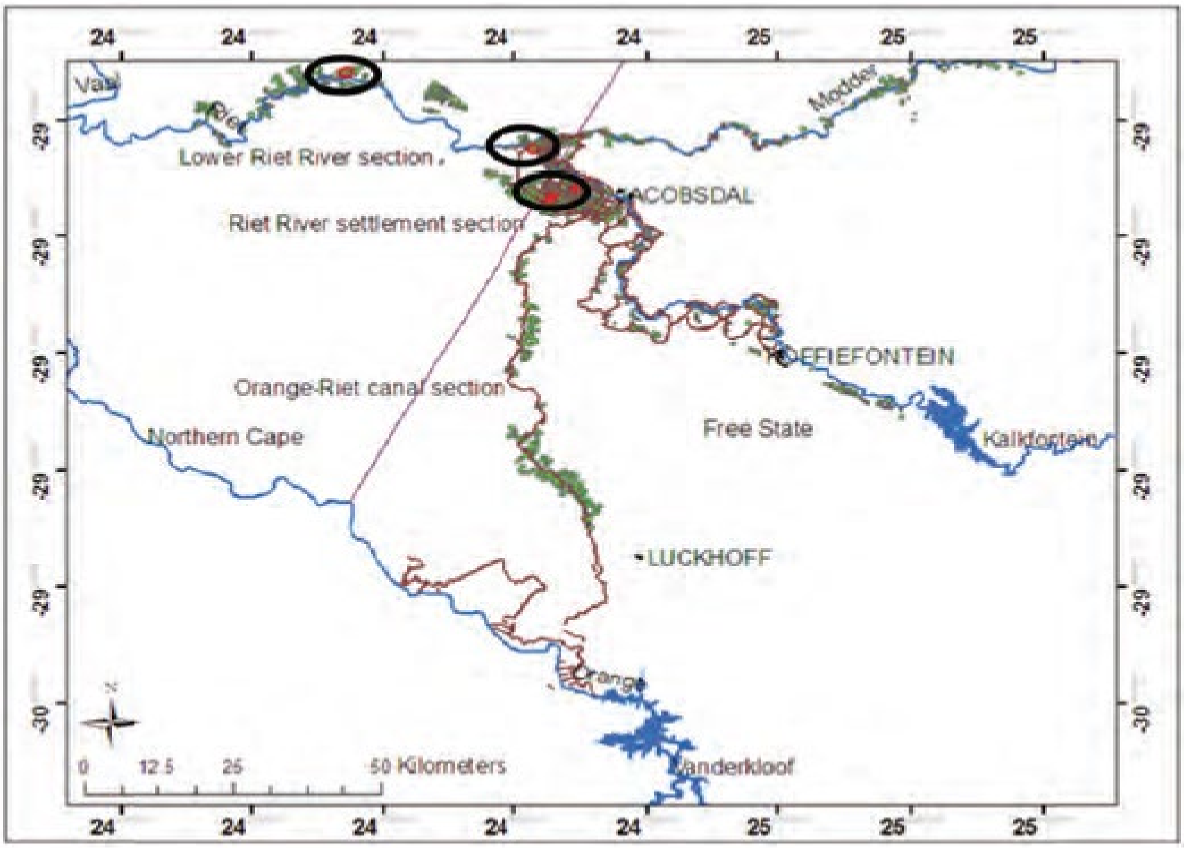

Figure 4.3: Graphical description of the Orange-Riet Irrigation Scheme
Source: Van Rensburg *et al.* (2012)

Figure 4.4 indicates the geographic location of measuring points or18 and or20. They are both located in the valley bottom of a farm located in the Lower Riet River section of the Orange-Riet Irrigation Scheme. These measuring points are situated on a 42-ha centre pivot irrigation scheme. The soil form in this area is Valsrivier Aliwal (Soil Classification Working Group, 1991). The Valsrivier Aliwal soil form comprises various horizons with unique characteristics of its own. At a depth of 0 mm to 300 mm from the soil surface lies the dark-brown Orthic A with 41% clay. It is followed by a dark-brown B1 horizon with 43% clay which extends to 900 mm. The dark-brown B2 consists of 46% clay and is situated at a depth of 900 mm to 1 200 mm, directly beneath the B1 horizon.

An unspecified C horizon concludes the profile. It reaches depths beyond 1 500 mm and consists of 50% clay. A strong, coarse, angular, and blocky structure with clay cutans, slickensides, and lime concretions are marked features of the profile. The B2 and C horizons are characterised by blue, black, brown, red, and white mottles. The centre pivots in the vicinity of measuring points or18 and or20 have a uniformity coefficient, distribution uniformity, application efficiency, and system efficiencies of 93%, 92%, 97%, and 88%, respectively. It is on this basis that Van Rensburg *et al.* (2012) declared that the irrigation systems are in good condition. A drainage system has been constructed in the area to address water logging. The drainage water is released into a storage dam, where it is mixed with water from the Lower Riet River and reused to irrigate crops at the measuring sites.

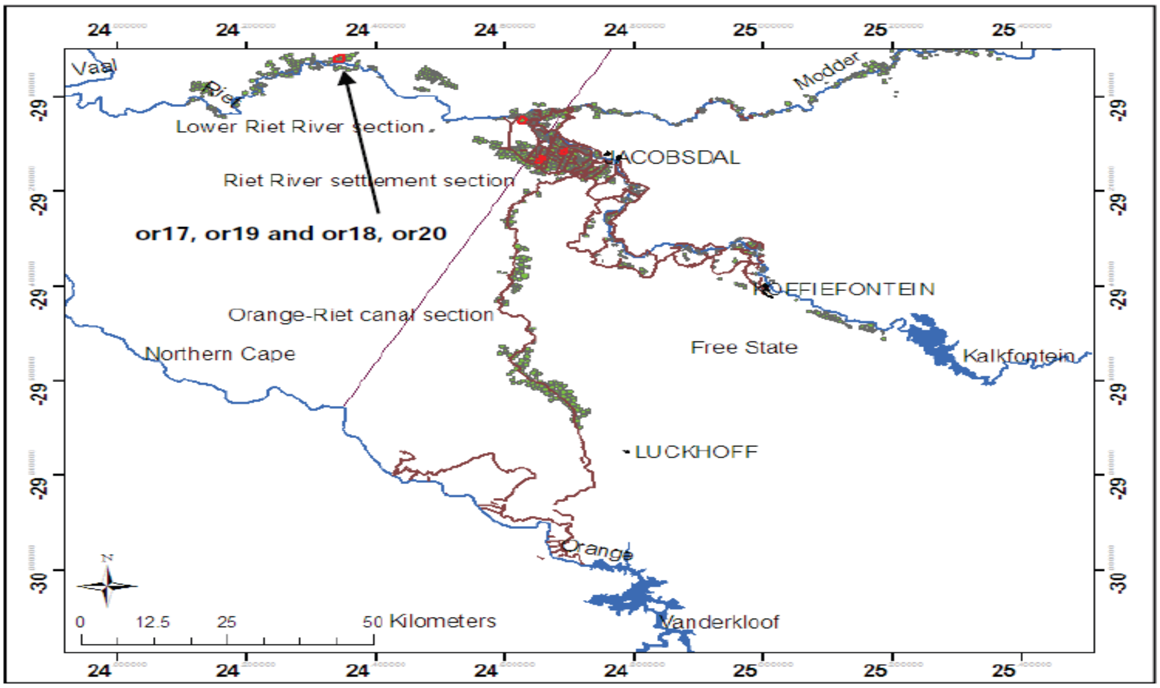

Figure 4.4: Geographic position of measuring points or18 and or20 within the Lower Riet section of the Orange-Riet Irrigation Scheme
Source: Van Rensburg et al. (2012

The A, B1, B2, and C horizons have an apedal massive structure. The A and B1 horizons are grouped in the fine sandy textural class. In contrast, the B2 and C horizons are grouped into the fine loamy sand class. The measuring points or4 and or5 have an internal drainage system, which comprises a single lateral installed at a depth of 1 800 mm in the centre of the field. The measuring points or4 and or5 are positioned on a 30-ha centre pivot in the settlement section of the Orange-Riet Irrigation Scheme. These two measuring points occupy a soil classified as the Hutton soil from of the Ventersdorp family (Soil Classification Working Group, 1991). The profile is characterised by four diagnostic horizons, namely Orthic A with 4% clay (0 mm to 300 mm), red apedal B1 with 8% clay (300 mm to 600 mm), red apedal B2 with 10% clay (600 mm to 1500 mm), and an unspecified C with 10% clay (+1 500 mm) (Van Rensburg *et al.*, 2012).

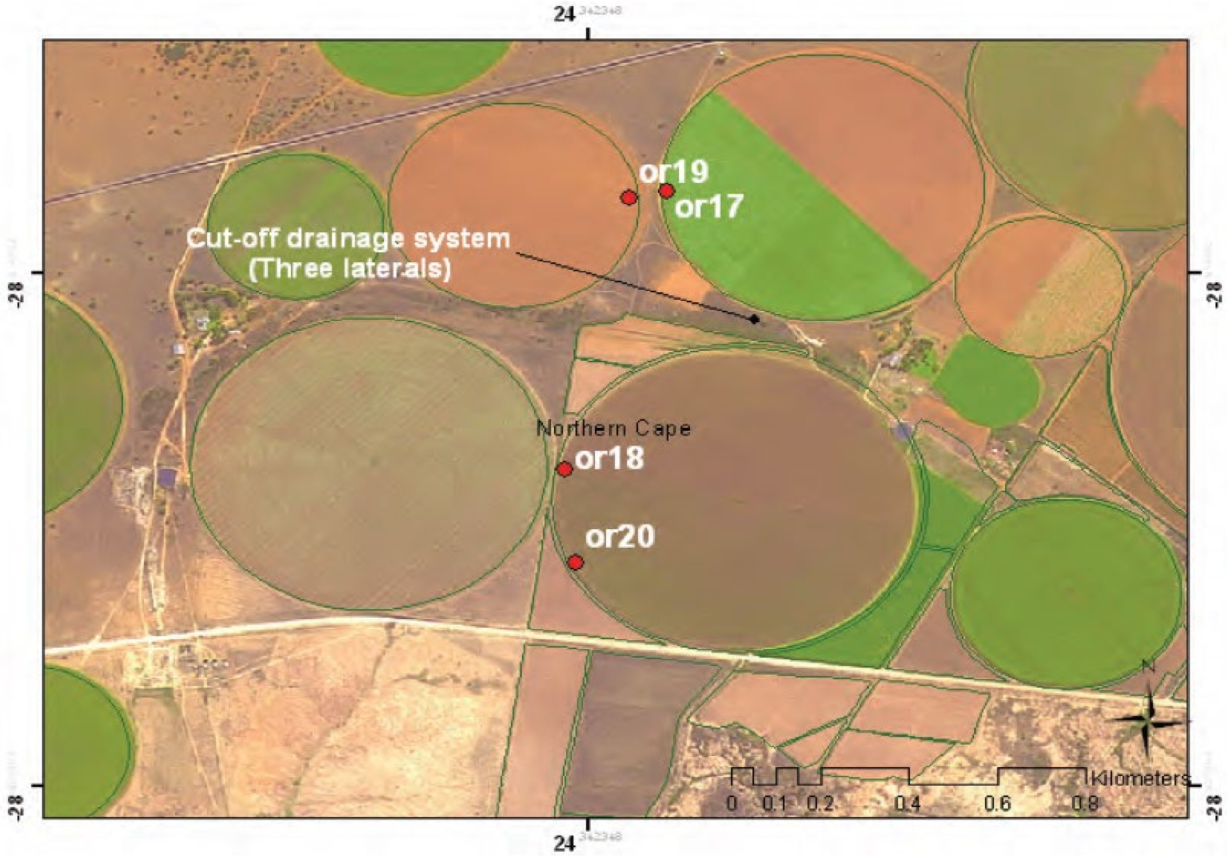

Figure 4.5: Position of measuring points or18 and or20 on the irrigated fields of the Valsrivier Aliwal soil form in the Lower Riet section of the Orange-Riet Irrigation Scheme
Source: Van Rensburg *et al.* (2012)

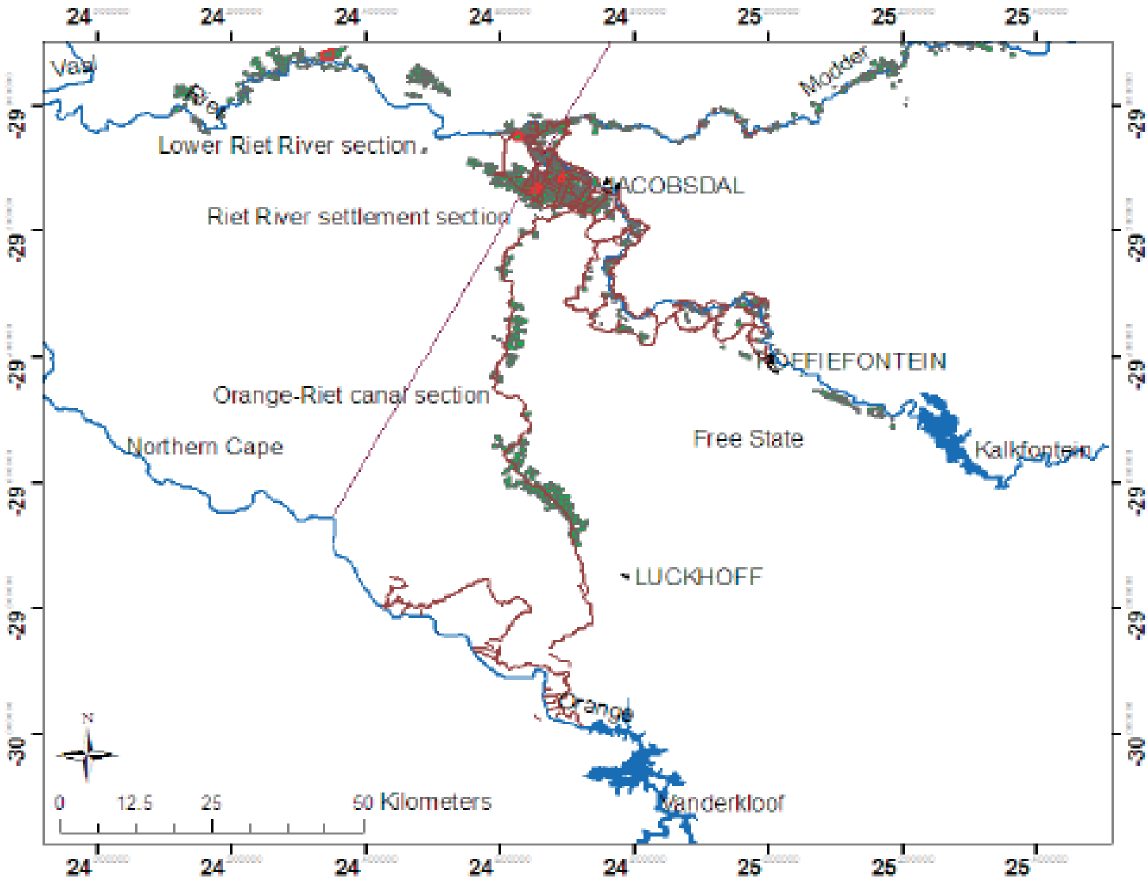

Figure 4.6: Geographical position of measuring points or4 and or5 at the Riet River settlement section of the Orange-Riet irrigation Scheme
Source: Van Rensburg *et al.* (2012)

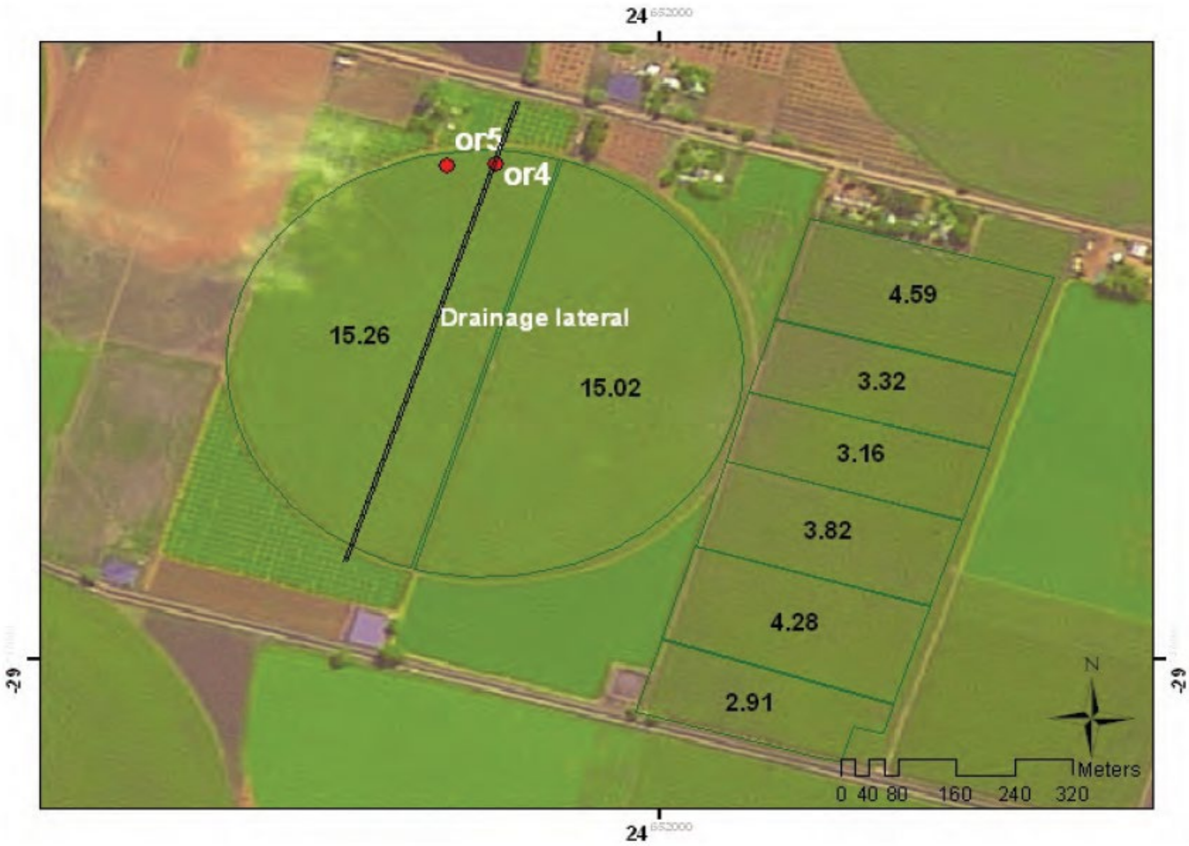

Figure 4.7: Location of measuring points or4 and or5 on the irrigated fields at the Riet River settlement section of the Orange-Riet Irrigation Scheme
Source: Van Rensburg *et al.* (2012)

4.2.1.3 Farm-level water use for broiler production

Water usage for feed production

According to Hoekstra (2014), the largest share of the water footprint of animal products is attributed to the production of animal feed. Mekonnen and Hoekstra (2010) found that animal feed production accounts for 98% of the water footprint of animal products. Nevertheless, the feed composition has a marked impact on the contribution of animal feed to the total water footprint of animal products. Feed concentrates have a larger water footprint than roughages (grass, crop residues, and fodder crops) (Gerbens-Leenes and Hoekstra, 2011). In fact, Hoekstra (2014) found that the water footprint of concentrates is five times greater than that of roughages. Thus, animal feed with a higher proportion of concentrates contributes to a larger water footprint of animal products than feed with a higher proportion of roughages does. It is thus critical to quantify the water footprint of chicken feed.

Table 4.2 is a summary of the total water footprint of a tonne of soya and sunflower oilcake production in South Africa's Free State province. It was derived from Mekonnen and Hoekstra (2010). The green water footprint is the largest component in the water footprint of soya and sunflower oilcake. It makes up 98.4% of the total water footprint per tonne of soya oilcake produced, and 96% of the total water footprint per tonne of sunflower oilcake produced. The consumptive water footprint is greater than the grey water footprint in both cases. The consumptive water footprint of soya oilcake is more than double the consumptive water footprint of sunflower oilcake. Nevertheless, the grey water footprint of sunflower oilcake is four times greater than the grey water footprint of soya oilcake.

Table 4.2: Water footprint of soya and sunflower oilcake

Broiler Feed	WF	WFgreen	WFblue	WFgrey
		m^3.ton		
Soya oilcake	2434	2396	29	9
Sunflower oilcake	1199	1152	10	37

Source: Mekonnen and Hoekstra (2010)

Drinking water of chickens

The drinking water of chickens is discussed here. The volume of water a chicken drinks depends on several factors. Kratzer *et al.* (1994) identified environmental temperature, relative humidity, diet composition, rate of growth or egg production, and the efficiency of kidney absorption of water as being factors that influence the freshwater intake of a chicken. Kratzer *et al.* (1994) quantified the water consumption of a broiler chicken at an environmental temperature of 21°C. According to Kratzer *et al.* (1994), the volume of freshwater a broiler chicken drinks increases by 7% for every 1°C in temperature above 21°C. One can conclude that as the chicken gets older, the volume of water that it drinks, on average, per week increases. For a broiler chicken, the increase is variable until the chicken is four weeks old. From five weeks old, the broiler chicken maintains a more constant increase in water intake per week.

Williams et al. (2013) investigated the water consumption of broiler chickens. The objective was to establish whether or not there is a variation in the volume of water broiler chickens drink over time. The broiler chickens for the periods 1991 (Period 1), 2000 to 2001 (Period 2), and 2010 to 2011 (Period 3) were housed in four commercial broiler houses at the University of Arkansas Applied Broiler Research Farm. During Periods 1, 2, and 3, each house was allocated an average of 18 800, 20 600, and 20 590 chicks respectively. The numbers of chicks per 0.09 m^2 were 0.85, 0.78, and 0.78 in Periods 1, 2, and 3, respectively. An in-house water meter for poultry water lines was used to capture the volume of water the chickens drank per day. This was done for each house. Digital scales on feed bins were used to measure how much feed the chickens ate each day, and this was also done for each broiler house.

Service water of chicken

The broiler farm produces 101 465 broilers per day. Each broiler weighs 0.00185 tonnes. Therefore, the farm produces 187.71 tonnes of broilers per day. The farm reported that they use 2800 m^3 of water per broiler house per year, and has 950 broiler houses in total. Therefore, the volume of water used at the broiler farm for the purposes of drinking, cleaning, and service water was determined as 38.82 m^3 per tonne of broilers produced, as shown below:

$$
\begin{aligned}
BWF_{FARM} &= \frac{(2800m^3\ per\ year \times 950\ broiler\ houses)/365\ days}{101465\ broilers\ per\ day \times \left(1.85kg\ per\ broiler/1000\right)} \\
BWF_{FARM} &= \frac{7287.67\ m^3\ per\ day}{187.71\ tons\ per\ day} \\
BWF_{FARM} &= 38.82\ m^3
\end{aligned}
\tag{4.1}
$$

4.2.1.4 Processing-level water usage

The broiler abattoir uses 0.01 m^3 of water per bird to slaughter and process a chicken. It is assumed that the slaughtering and the processing of broilers each accounts for 50% of the volume of water used at the abattoir. Each chicken is slaughtered at 0.00185 tonnes. The abattoir slaughters 286.75 tonnes per day. Therefore, the volume of water used to slaughter a tonne of broilers at the abattoir is 2.70 m^3. The processing of a tonne of broilers uses 3.76 m^3 of water. This includes service water. It is determined as follows:

$$
\begin{aligned}
BWF_{ABATTOIR(SLAUGHTERING)} &= \frac{(0.01m^3\ per\ broiler/2) \times (155000\ broilers)}{0.00185\ tonnes \times 155000\ broilers} \\
BWF_{ABATTOIR(SLAUGHTERING)} &= \frac{775m^3}{286.75\ ton} \\
BWF_{ABATTOIR(SLAUGHTERING)} &= 2.70m^3.ton
\end{aligned}
\tag{4.2}
$$

$$BWF_{ABATTOIR(PROCESSING)} = \frac{(0.01m^3 \ per\, broiler / 2) \times (155000\, broilers)}{0.00133\, tonnes \times 155000\, broilers}$$

$$BWF_{ABATTOIR(PROCESSING)} = \frac{775m^3}{206.15\, ton} \tag{4.3}$$

$$BWF_{ABATTOIR(PROCESSING)} = 3.76m^3.ton$$

4.2.2 Methods

The volumetric water footprint approach has been identified as the method of choice to use for the purposes of this study. This approach comprises four phases that explicitly guide the procedure for conducting a WFA. The first phase involves setting the goals and scope of the study. Phase 2 comprises water footprint accounting. This is followed by a water footprint sustainability assessment in Phase 3, and finally, a response formulation in Phase 4.

4.2.2.1 Stage 1: Formulating Goals and Scope

Each WFA study has a unique purpose. This purpose will, in turn, demand attention to various aspects that will inevitably make up the scope of the study. Hence, one must first identify the goal of a WFA. Once the goal has been established, the foundation upon which the scope will emerge will be set.

The data for this study were acquired from experiments documented by van Rensburg *et al.* (2012), as well as from a broiler-producing company. The broiler company procures its feed elsewhere, but produces and processes their broilers on-site. For the purposes of this study, all the components of the water footprint will be considered for maize production, but only the blue water footprint will be considered for broiler production and processing. The processes that account for a considerable share of the water footprint in the value chain are identified as feed production and broiler production and processing. Both the direct and indirect water footprints will be considered because the water footprint of the feed is an indirect water footprint of the broiler-producing firm.

Accounting for both the direct and indirect water footprints will achieve the aim of the study. In analysing the sustainability of the maize-broiler value chain, only the blue water footprint will be considered. It will be assessed based on the water availability in the Orange River Basin. The study will only focus on the environmental aspect of sustainability. The study intends to inform maize and broiler producers and processors, as well as policymakers, about the environmental impacts of using water to produce maize and broilers at a certain time of the year. Producers and processors are anticipated to respond by taking the recommendations of this study into consideration as they perform their activities. Policymakers are expected to consider the findings of this study as they amend or draft policies.

4.2.2.2 Stage 2: Water Footprint Accounting

Blue Water Footprint (volume/time)

$$WF_{proc,blue} = Blue\,Water\ Evaporation + Blue\,Water\ Incorporation + Lost\ \mathrm{Re}turn\ Flow \quad ..[4.4]$$

The blue water footprint of the process of growing a crop is expressed as the volume of water consumption per unit of time. However, when divided by the yield, the units change to the volume of water consumed per tonne. It is important to note that the water footprint of a consumer, producer, or a particular area is always expressed in terms of the volume of water consumed per unit of time, since there is no "yield" to be realised in such cases. Time may be expressed per day, month, or year, depending on the study.

'Blue Water Evaporation' comprises the water that may be used through evapotranspiration, evaporate during storage (e.g. artificial water reservoirs, dams, and harvested rainwater), transport (e.g. open canals), processing (e.g. evaporation of heated water that is not recollected), and collection and disposal (e.g. from drainage canals and from wastewater treatment plants). 'Blue Water Incorporation' is the volume of blue water that is incorporated into the crop or product. 'Lost Return Flow' is the part of the return flow that is not available for reuse within the same catchment within the same period of withdrawal, either because it is returned to another catchment (or discharged into the sea) or because it is returned in another period of time.

Green Water Footprint (volume/time)

$$WF_{proc,\,green} = Green\,Water\ Evaporation + Green\,Water\ Incorporation \qquad [4.5]$$

'Green Water Evaporation' refers to the evaporation of rainwater stored in soil or temporarily positioned on the surface of soil or vegetation. 'Green Water Incorporation' refers to the absorption of freshwater derived from the top soil or soil surface into the crop.

Grey Water Footprint (volume/time)

$$WF_{proc,\,grey} = \frac{L}{c_{\max} - c_{nat}} \quad [volume\,/\,time] \qquad [4.6]$$

The pollutant load (*L*) is the mass of the substance that is released into a water body at a particular time. The maximum concentration (c_{max}) refers to the highest level of the pollutant load that is considered acceptable in a given water body, while the natural concentration (c_{nat}) is the mass of the substance present in a water body in the absence of human influence, interference, or activity.

4.2.2.2.1 Volumetric water footprint of water footprint of maize

The total water footprint (WF_{proc}) of the process of growing a crop is calculated as follows:

$$WF_{proc} = WF_{proc,\,green} + WF_{proc,\,blue} + WF_{proc,\,grey} \quad [m^3\,/\,ton] \qquad [4.7]$$

Hence, WF_{proc} is the sum of the green, blue, and grey water footprints of the process of growing a crop. The green water footprint ($WF_{proc,\,green}$) of the process of growing a crop is calculated as follows:

$$WF_{proc,\,green} = \frac{CWU_{green}\,(m^3\,/\,ha)}{Y\,[ton\,/\,ha]} \quad [m^3\,/\,ton] \qquad [4.8]$$

Hence, $WF_{proc,\ green}$ is the green crop water use (CWU_{green}), measured in m^3/ha, divided by the yield (Y) measured in tonne/ha.

$$CWU_{green} = 10 \times \sum_{d=1}^{1gp} ET_{green} \quad [m^3 / ha] \qquad [4.9]$$

ET_{green} is the evapotranspiration of green water. Factor 10 is a standard used to convert water depths in millimetres into water volumes per land surface in m^3/ha. The equation d = 1 illustrates that green water evapotranspiration is calculated from the “first day of planting”. The factor 1gp represents the day of harvest, thus it entails measuring evapotranspiration for the entire length of the crop-growing period in days. Hence, the CWU_{green} is the sum of the evapotranspiration experienced by the crop over the growing period, from planting to harvest.

The blue water footprint of the process of growing a crop is calculated as follows:

$$WF_{proc,\,blue} = \frac{CWU_{blue}}{Y} \quad [m^3 / ton] \qquad [4.10]$$

Hence, $WF_{proc,\ blue}$ is the blue crop water use (CWU_{blue}), measured in m^3/ha, divided by the yield (Y) measured in tonne/ha (Hoekstra *et al*., 2011).

$$CWU_{blue} = 10 \times \sum_{d=1}^{1gp} ET_{blue} \quad [m^3 / ha] \qquad [4.11]$$

ET_{blue} is blue water evapotranspiration. The CWU_{blue} works on the same basis as the CWU_{green}. The only difference is that ET_{blue} is used instead of ET_{green} (Hoekstra *et al*., 2011). The grey water footprint ($WF_{proc,\ grey}$) of the process of growing a crop is calculated as follows:

$$WF_{proc,\,grey} = \frac{L}{(C_{\max} - C_{nat})} = \frac{(\propto \times AR)}{(C_{\max} - C_{nat})} \left(volume / time\right) \qquad [4.12]$$

$$WF_{proc,\,grey} = \frac{(\propto \times AR) / (C_{\max} - C_{nat})}{Y} \quad \left(m^3 / ton\right) \qquad [4.13]$$

AR is the chemical application rate to the field per ha (kg/ha). $\propto$ represents the leaching-runoff fraction. C_{max} is the maximum acceptable concentration of the pollutant (kg/m^3). C_{nat} is the natural concentration for the pollutant considered (kg/m^3). *Y* represents crop yield (tonne/ha).

The $WF_{proc,\ grey}$ calculates the volume of solution that is leached into the soil. It then divides it by the increase in the chemical concentration of the water source into which the chemicals (e.g. salts) were deposited. This quotient is then further divided by the yield to determine the $WF_{proc,\ grey}$ in m^3/tonne. Note that the pollutants are mainly fertilisers, pesticides, insecticides, and herbicides. Subtracting C_{nat} from C_{max} indicates the amount of pollutant that has been applied. It is important to note with regard to the grey water footprint that one only considers the pollutant that accounts for the largest contribution to the grey water footprint (Hoekstra *et al*., 2011).

4.2.2.2.2 Volumetric water footprint of water footprint of broiler chicken (product)

The water footprint of an animal product comprises a direct water footprint and an indirect water footprint (Mekonnen and Hoekstra, 2010). The direct water footprint is associated with drinking water and service water used (Mekonnen and Hoekstra, 2010). The indirect water footprint is the water that is linked to the feed (Mekonnen and Hoekstra, 2010). According to Mekonnen and Hoekstra (2010), the water footprint of an animal product may be expressed as follows:

$$WF_{chicken} = WF_{feed} + WF_{drink} + WF_{service} \qquad [m^3/year/chicken] \text{ or } [m^3/chicken] \qquad [4.14]$$

$WF_{chicken}$ is the total water footprint associated with the production of a tonne of chicken meat. WF_{feed} is the total water footprint associated with producing chicken feed. WF_{drink} is the water that the chickens drink during their production and is associated with a blue water footprint. $WF_{service}$ is the water used to create and sustain a hygienic environment suitable for chicken production. $WF_{service}$ has a blue and a grey water footprint. It is more appropriate to express the water footprint of broiler chickens in terms of m^3/chicken (Mekonnen and Hoekstra, 2010). However, the water footprint of layer chickens is best described as m^3/year/chicken (Mekonnen and Hoekstra, 2010). The component of the water footprint of a chicken that is associated with chicken feed is calculated as follows:

$$WF_{feed} = \frac{\sum_{p=1}^{n}(Feed[p] \times WF^{*}_{prod}[p]) + WF_{mixing}}{Pop*} \qquad [4.15]$$

Feed [*p*] represents the yearly quantity of the feed ingredient *p* that is consumed by a chicken, and is expressed in terms of tonne/year. $WF^*_{prod}[p]$ is the water footprint of the feed ingredient *p*, which is expressed in terms of m^3/tonne. WF_{mixing} is the water footprint of mixing the chicken feed and is expressed in terms of m^3/year/chicken. *Pop** is the number of slaughtered broiler chickens per year. The water footprint of the feed ingredient *p* may be calculated as follows:

$$WF^{*}_{prod}[p] = \frac{P[p] \times WF_{prod}[p] + \sum_{n_e} T_i[n_e, p] \times WF_{prod}[n_e, p]}{P[p] + \sum_{n_e} T_i[n_e, p]} \qquad [4.16]$$

P [*p*] is the quantity of the feed product produced in a country per year and it is expressed in terms of tonne/year. $T_i[n_e,p]$ is the amount of feed product *p* that is imported from an exporting nation n_e and it is expressed in terms of tonne/year. $WF_{prod}[p]$ is the water footprint of the feed product *p* when it is produced in the nation under review and it is expressed in terms of m^3/tonne. $WF_{prod}[n_{e,p}]$ is the water footprint of the feed product *p* when it is produced in the exporting nation n_e and it is expressed in terms of m^3/tonne.

The amount and composition of feed consumed is a function of animal type and the production system, as well as the country in which production takes place. The differences in climatic and agricultural practices between different countries make the water footprint of feed crops different from one country to another. The total feed consumed by a certain animal following a production system in a country may be calculated as follows:

$$Feed = FCE \times P \qquad [4.17]$$

Feed represents the total quantity of an animal's feed intake (tonne/year). *FCE* is the feed conversion efficiency of the animal (kg dry mass of feed/kg of product). *P* is the total quantity of product produced by an animal, for instance meat produced by broiler chickens or the total quantity of eggs produced by layer chickens. The term "feed conversion efficiency" is used to describe the quantity of feed an animal must consume to produce a unit product (Mekonnen and Hoekstra, 2010). Low FCE suggests that an animal is an efficient user of feed.

4.2.2.2.3 Total water footprint of broilers produced using maize feed

The blue water footprint of the maize-broiler value chain will comprise the blue water footprint of farm-level irrigated maize and chicken production. At the processor level, the blue water footprint will include those of processing maize into chicken feed and of processing broiler chickens into final products for consumers, as well as the blue water utilised for cleaning and sanitation at the processing plants. Green water in the maize-broiler value chain only plays a role during farm-level maize production; thus, the green water footprint will only be calculated for maize production. There is no green water use at farm-level broiler chicken production, neither is green water used during the processing of chickens.

4.2.2.3 Stage 3: Water Footprint Sustainability Assessment

The water footprint in a catchment is considered to be environmentally sustainable if the environmental freshwater requirements are satisfied and the degree of water pollution is below the waste assimilation capacity. If, however, the water footprint in a catchment is environmentally unsustainable, an environmental hotspot will develop. The hotspot can be quantified by determining the green water scarcity, the blue water scarcity, and/or the extent of water pollution. An environmental hotspot occurs when the green water scarcity, the blue water scarcity, and/or the extent of water pollution are beyond 100%. Regarding the blue water footprint, one must assess whether there is a reduction in blue water in response to the water footprint, such that the reduction goes beyond a certain environmental threshold. The green, blue, or grey water footprints can have a direct influence on the occurrence of environmental hotspots. The blue water footprint will be explored in the following discussion.

Environmental sustainability of the blue water footprint

The aggregate blue water footprint in a particular catchment is equal to the sum of all the blue water footprints of the processes that occur in the catchment. When the blue water footprint at a certain time in a particular catchment is greater than the blue water availability at that time and in that catchment, a hotspot will develop during that time and in that catchment area. The blue water availability (WA_{blue}) in a catchment x in period t may be calculated as follows:

$$WA_{blue}[x,t] = R_{nat}[x,t] - EFR[x,t] \qquad [volume/time] \qquad [4.18]$$

WA_{blue} is the blue water availability, R_{nat} is the natural runoff, and EFR is the environmental flow requirement. According to the above equation, the total blue water availability in catchment x during period t is equal to the natural runoff minus the EFR. In the case where the blue water footprint is greater than the blue water availability, the surplus freshwater is derived from environmental freshwater flows, thus rendering the blue water footprint unsustainable. The EFRs are estimated based on the volume and timing of freshwater flows necessary to support freshwater and estuarine ecosystems and human livelihoods that depend on these ecosystems. Figure 4.8 demonstrates the relationship between the blue water footprint and availability, as well as the EFRs.

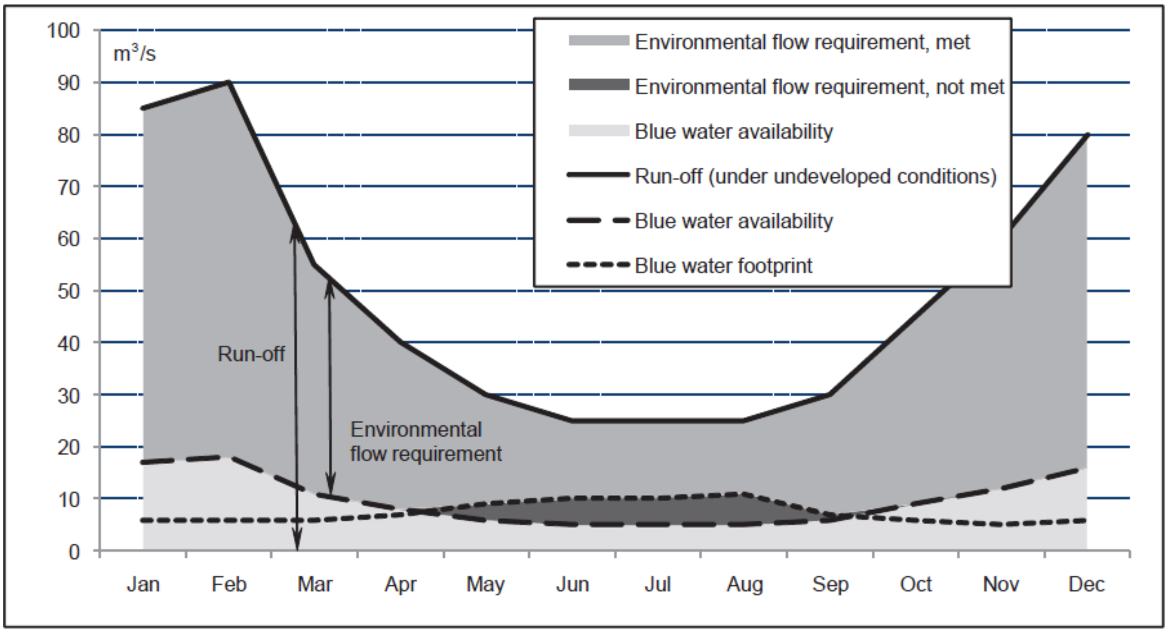

Figure 4.8: Example of annual blue water footprint versus blue water availability
Source: Hoekstra *et al.* (2011)

It is important to note that the total blue water available is equal to the blue water remaining from the runoff after the EFR has been satisfied. According to Figure 4.8, from January to mid-April and during the second half of September to December, the blue water footprint is sustainable. However, from May towards the end of September, the blue water footprint is unsustainable. The blue water footprint is not sustainable in the latter period because a fraction of the blue water intended for the purpose of meeting the EFR is redirected for another use.

Environmental flow requirements (EFRs) are determined by subtracting the natural runoff from the blue water availability. The natural runoff is the sum of the actual runoff and the blue water footprint within the catchment. There are two criteria for assessing the environmental sustainability of the blue water footprint in a catchment or river basin. Firstly, in any given month, the blue water footprint may not be sustainable from an environmental point of view if the blue water footprint within the catchment is greater than the blue water availability. Such a situation compromises the EFRs, as freshwater or runoff that is meant to satisfy the EFRs is utilised for a different purpose. Secondly, one may examine the implications on groundwater reserves and the volume of freshwater in lakes in a catchment that arise in response to the blue water footprint. The blue water scarcity (WS_{blue}) in a catchment x in period t may be calculated as follows:

$$WS_{blue}[x,t] = \frac{\sum WF_{blue}[x,t]}{WA_{blue}[x,t]} \quad [-] \qquad [4.19]$$

WS_{blue} is the blue water scarcity, WF_{blue} is the aggregate blue water footprint, and WA_{blue} is the blue water availability. According to the above equation, the blue water scarcity in a catchment x in period t is equal to the quotient of the sum of the blue water footprints to the blue water availability in catchment x in period t. The blue water footprint is a physical concept in that it measures the difference between the utilised and available freshwater resources. It is also an environmental concept because it takes the EFRs into consideration.

4.3 RESULTS AND DISCUSSIONS

This chapter expresses and discusses the calculations of the green, blue, and grey water footprints at each stage of the maize-broiler value chain. The total water footprint of a tonne of chicken meat is then established by summing the water footprint components at each stage of the value chain accordingly. This is followed by a calculation of the economic waEWP of chicken.

4.3.1 Water Footprint of Maize-Broiler Value Chain

4.3.1.1 Water footprint of maize

The water footprint of maize production describes the total freshwater use per unit of maize produced. Total freshwater refers to the sum of the volume of rainfall and irrigation water consumed during the growth of the maize. It also includes water reservoirs, whose quality is degraded by chemicals applied during the course of maize production. One site where the water footprint of maize production was measured consisted of measuring points OR18 and OR20 and another site consisted of measuring points OR4 and OR5. Both sites are located in the Orange-Riet Irrigation Scheme. Measuring points OR18 and OR20 are discussed in the next section.

Table 4.3 describes the biophysical data at measuring points or18 and or20. The yield of maize was obtained from Van Rensburg *et al*. (2012). The soil form at the measuring points is a Valsrivier soil form with a Silt-plus-clay percentage, a mean volumetric soil water content, and soil depth of 65.67%, 0.33 mm.mm^{-1}, and 2 000 mm respectively. Maize evapotranspiration for the production period was 507 mm.

Table 4.3: Biophysical data of measuring points or18 and or20

Average	Yield (kg.ha)	Silt-clay (%)	θs (mm.mm^{-1})	Soil Depth (mm)	ΔW (mm)	ET (mm)
	13322	65.7	0.33	2000	31	507

Source: Van Rensburg *et al*. (2012)

Blue and green water footprint at measuring points or18 and or20

Table 4.4 illustrates the levels of water use at measuring points or18 and or20. The evapotranspiration of maize produced at the measuring points was 589 mm. The rainfall in the area for the period of maize production was 199 mm. Despite an irrigation requirement of 390 mm, the farmers irrigated the maize fields with 496 mm. About 31 mm of the excess irrigation water was stored in the soil, while 75 mm was lost from the potential root zone through upward or downward drainage. The rainfall and irrigation together totalled 695 mm for the maize production period. It can be deduced from Table 4.4 that the maize farmers in the vicinity of measuring points at Orange-Riet Irrigation Scheme over-irrigated by 106 mm.

Table 4.4: Summary of water use data at the measuring points or18 and or20 at Orange-Riet Irrigation Scheme

	ET crop (mm)	R (mm)	I (mm)	IR (mm)	R+I (mm)
Average	589	199	496	390	695

Source: Van Rensburg *et al*. (2012)

Table 4.5 is a summary of the consumptive water uses at measuring points or18 and or20. It shows the green and blue water footprints of maize production to be 149.4 m^3.ton and 292.8 m^3.ton, respectively. The consumptive water footprint of maize production amounts to 442.13 m^3.ton.

Table 4.5: Summary of the green and blue water footprints of producing maize in the Orange Riet Irrigation Scheme at measuring points or18 and or20

ET crop	ET green	ET blue	CWU	CWU green	CWU blue	Yield	WF	WF green	WF blue
	mm/period			m^3.ha		Ton.ha		m^3.ton	
589	199	390	5890	1990	3900	13.32	442	150	293

Source: Van Rensburg *et al*. (2012)

Grey water footprint or18 and or20

Table 4.6 is a summary of the leaching-runoff fractions and application levels of nitrogen at measuring points or18 and or20. The leaching-runoff fraction of nitrogen at measuring points or18 and or20 is estimated at 7.4%. Van Rensburg *et al*. (2012) reported the nitrogen application in the area at 217 kg.ha.

Table 4.6: Variables necessary for estimating the pollutant load for nitrogen at measuring points or18 and or20

Nutrient	Pollutant load	
N	α	Application (kg/ha)
	7.4%	217

Source: Van Rensburg *et al*. (2012)

Table 4.7 describes the grey water footprint at measuring points or18 and or20. The grey water footprint per ha was found to be 1 244 m^3.ha. At a yield of 13.3 ton.ha, the grey water footprint was found to be 93.4 m^3.ton.

Table 4.7: Summary of the grey water footprint at or18 and or20

GWF_N	Yield	GWF_N
m^3·ha	Ton.ha	m^3·ton
1244	13.3	93.4

Source: Van Rensburg *et al*. (2012)

The maize yield at measuring points or18 and or20 was 13.3 ton.ha. At this yield level, the blue water footprint was found to be the highest, at 292.8 m^3/ton. It was followed by a green water footprint of 149.4 m^3·ton. The grey water footprint was by far the lowest, at 93.4 m^3.ton. As a result, the distribution of water footprint components indicated that the blue water footprint made up the majority of the total water footprint, while the grey water footprint was the lowest. The blue water footprint made up 54.7% of the total water footprint. It was followed by the green and grey water footprints, which made up 27.9% and 17.4% of the total water footprint, respectively.

Blue and green water footprint at measuring points OR4 AND OR5

Table 4.8 describes the biophysical data at measuring points or4 and or5. The yield of maize was obtained from Van Rensburg *et al*. (2012). The soil form at the measuring points is a Hutton soil with a Silt-clay percentage, mean volumetric soil water content, and soil depth of 11%, 0.4 $mm.mm^{-1}$, and 2 000 mm respectively. Maize evapotranspiration for the production period was 693 mm.

Table 4.8: Biophysical data of measuring points or4 and or5 at Orange-Riet Irrigation Scheme

	Yield	Silt-clay	θs	Soil Depth	∆W	ET
Average	(kg.ha)	(%)	($mm.mm^{-1}$)	(mm)	(mm)	(mm)
	15325	11	0.4	2000	45	693

Source: Van Rensburg *et al*. (2012)

Table 4.9 indicates that the evapotranspiration of maize produced in the vicinity of measuring points or4 and or5 was 740 mm. The rainfall in the area for the period of maize production was 262 mm. Despite an irrigation requirement of 478 mm, the farmers irrigated the maize fields with 344 mm, which is 134 mm less than the actual irrigation requirement. The build-up of a water table over time made up for the under-irrigation because it supplemented the irrigation. The rainfall and irrigation together totalled 606 mm for the maize production period. Table 4.9 shows that the maize farmers in the vicinity of measuring points or4 and or5 at

Orange-Riet Irrigation scheme under-irrigated by 134 mm. However, the maize was not under water stress due to a water table that had risen to high levels over time.

Table 4.9: Summary of water use data at the measuring points or4 and or5 at the Orange-Riet Irrigation Scheme in season 1

	ET crop (mm)	R (mm)	I (mm)	IR (mm)	R+I (mm)
Average	740	262	344	478	606

Source: Van Rensburg *et al*. (2012)

Table 4.10 shows that, at a yield level of 15.3 ton.ha, the green and blue water footprints of maize production are 171 m^3.ton and 258 m^3.ton, respectively. The consumptive water footprint of maize production is 395 m^3.ton. There is under-irrigation of approximately 87 m^3 for each ton of maize produced. Since Van Rensburg *et al*. (2012) indicated that this water was evapotranspirated by the crop, the researcher assumed that this water was stored in the soil as groundwater and thus formed part of the blue water footprint. Hence, the true blue water footprint is 258 m^3.ton. This makes it the highest water footprint component, accounting for 40.83% of the total water footprint per tonne of maize production.

Table 4.10: Summary of the green and blue water footprints of producing maize in the Orange-Riet Irrigation Scheme at measuring points or4 and or5 in season 1

ET crop	ET green	ET blue	CWU	CWU green	CWU blue	Yield	WF	WF green	WF blue
	mm/period			m^3.ha		Ton.ha		m^3/ton	
740	262	344	7400	2620	3440	15.3	430	171	258

Source: Van Rensburg *et al*. (2012)

Grey water footprint or4 and or5

Table 4.11 is a summary of the leaching-runoff fractions and application levels of nitrogen at measuring points or4 and or5. The leaching-runoff fraction of nitrogen was estimated at 13.8%. Nitrogen application was reported at 215 kg.ha. These values are necessary for determining the pollutant load of nitrogen.

Table 4.11: Variables necessary for estimating the pollutant load for nitrogen and phosphorous at measuring points or4 and or5

Nutrient	Pollutant load	
N	α	Application
	13.8 2%	215 kg/ha

Source: Van Rensburg *et al*. (2012)

Table 4.12 describes the grey water footprint at measuring points or4 and or5. The grey water footprint per ha was found to be 1 244 m^3.ha. At a yield of 13.3 tonne/ha, the grey water footprint was found to be 93.4 m^3.ton.

Table 4.12: Summary of the grey water footprint at or4 and or5

GWF_N	Yield	GWF_N
m^3.ha	Ton.ha	m^3.ton
2299.4	15.3	150

Source: Van Rensburg *et al*. (2012)

The maize yield at measuring points or4 and or5 was 15.3 ton.ha. At this yield level, the blue water footprint was found to be the highest, at 258.4 m^3.ton. It was followed by a green water footprint of 171 m^3.ton. The grey water footprint was the lowest, at 150 m^3.ton. Hence, the distribution of water footprint components showed that the blue water footprint made up the majority of the total water footprint, while the grey water footprint was the lowest. The blue water footprint made up 35.5% of the total water footprint. It was followed by the green and grey water footprints, which made up 27% and 24% of the total water footprint, respectively. However, about 14% of the consumptive water footprint of each tonne of maize produced is not accounted for.

The total water footprint of maize production or18, or20, or4, and or5

Table 4.13 is a summary of the total water footprint of maize production in the Orange-Riet Irrigation Scheme. The average yield between the two sites is 14.3 ton.ha. The total water footprint of maize production in the Orange-Riet Irrigation Scheme is taken as the average of the water footprint at measuring points or18 and or20, and or4 and or5. The mean water footprint of maize production is therefore 584 m^3.ton. The consumptive water footprint amounts to 463 m^3.ton, while the grey water footprint associated with nitrogen fertilisation is 122 m^3.ton. The blue water footprint makes up 47% of the total water footprint of maize production in the Orange-Riet Irrigation Scheme. It is followed by the green water footprint, which accounts for 32% of the total water footprint. Grey water contributes 21% to the total water footprint.

Table 4.13: The total water footprint at Orange-Riet Irrigation Scheme

	WF_{maize}	WF_{green}	WF_{blue}	WF_{grey}	Yield
Mean			m^3.ton		ton.ha
	584	187	276	122	14.3

Source: Van Rensburg *et al*. (2012)

4.3.2 Water Footprint of Broiler Production

The water footprint of broiler production describes the total volume of freshwater used to produce a ton of chicken meat. The farm uses about 7 287.67 m^3 of water to produce 101 465 broilers a day. At a broiler final weight of 1.85 kg, the broiler farm's blue water footprint amounted to 38.8 m^3.ton. The abattoir uses 775 m^3 of water to slaughter 155 000 broilers a day. At a broiler weight of 1.85 kg, the abattoir's blue water footprint of slaughtering a tonne of broilers is 2.7 m^3.ton. The abattoir uses 775 m^3 of water to process 155 000 broiler carcasses per day. At a carcass weight of 1.33 kg, the blue water footprint for processing the broiler carcass was 3.8 m^3.ton. Blue water is the main source of freshwater for broiler production.

Table 4.14 is a summary of the volume of water used to produce a tonne of chicken meat. It distinguishes between the volume of water used at the farm, abattoir, and processing plant. Water use is the highest at the farm. The water footprint of maize production has been estimated at 584.2 m^3.ton. The broiler farm uses 1.04 tons of maize, 0.29 tons of soya oilcake, and 0.10 tons of sunflower oilcake to produce one tonne of broilers. Therefore, the water footprint associated with the broiler feed per tonne of broilers produced is equivalent to the product of the maize, soya oilcake, and sunflower oilcake water footprint per tonne and the tonnes of maize, soya oilcake, and sunflower oilcake consumed by a tonne of broilers, respectively. Hence, the feed water footprint of a tonne of broilers is 1 430.3 m^3. The abattoir and processing plant have a smaller water footprint. The total volume of water used to produce one tonne of chicken is the sum of the volume of water used on the broiler farm, abattoir, and processing plant, as well as the water footprint associated with the maize feed.

In total, water used along the three segments of the broiler value chain amounts to 1475.6 m^3 per tonne of chicken produced. Water that has been used at the broiler farm, abattoir, and processing plant is released into the nearby veld. This water forms part of the grey water footprint of chicken production. About 97% of the water footprint of a tonne of chicken meat is attributed to broiler feed. This is well in line with the findings of Mekonnen and Hoekstra (2010), who established that animal feed accounts for 98% of the water footprint of animal products.

Table 4.14: Total water footprint per tonne of broilers produced, slaughtered, and processed

m^3 per ton	Farm		Abattoir	Processing plant	Total
	Excluding feed	Broiler feed	Broilers	Carcasses	
	38.8	1430.3			
	1469.2		2.7	3.8	1475.6

The total water footprint associated with the production of a tonne of chicken meat is made up of a green, a blue, and a grey component. The green water footprint is 1 001.66 m^3.ton of chicken meat produced. This is 67.9% of the total water footprint of a ton of chicken. The blue and grey water footprints are 341.3 m^3 and 132.7 m^3 per ton of chicken produced, respectively. The blue water footprint makes up 23.1%, and the grey water footprint contributes 9%, of the total water footprint of chicken production. The green water footprint makes up more than half of the total water footprint.

4.3.3 Economic Water Productivity

Economic water productivity (EWP) is the economic value obtained per unit of water utilised (Chouchane *et al.*, 2015). Table 4.15 is a description of the average retail prices of chicken meat for 2015, depending on whether it is whole chicken or chicken portions, and whether they are fresh or frozen. For the period of 2015, the average retail prices of fresh whole chicken, fresh chicken portions, and frozen chicken portions were R39 560, R51 210, and R28 980 per ton, respectively. To produce a ton of chicken meat, about 1 475.6 m^3 of water is used.

Table 4.15 Average chicken retail prices

Chicken	Retail price		EWP
	ZAR/kg	ZAR/ton	ZAR/m^3
Whole chicken: fresh	40	39560	26.8
Chicken portions: fresh	51	51210	34.7
Chicken portions: frozen	29	28980	19.7

Source: South African Poultry Association (2016)

The EWP of producing a ton of fresh, whole chicken meat is ZAR26.8. When producing a ton of fresh chicken portions, the EWP is approximately ZAR34.7. The production of a ton of frozen chicken portions has EWP of ZAR19.7. Thus, greater EWP is derived from producing fresh chicken portions than frozen chicken portions.

4.3.4 Sustainability Assessment

The Orange-Riet Irrigation Scheme falls in the Orange River Basin. Figure 4.1 is a graphical representation of the blue water scarcity of the Orange River Basin. Low blue water scarcity is a condition where water availability exceeds water usage, such that the ratio of the water footprint to water availability is less than 1 or 100%. This ratio is known as the water scarcity index. As the water footprint increases relative to the water availability, until such a point where it is equal to water availability, a water scarcity index of 100% is reached. An increase in water usage beyond this point would render the blue water scarcity index moderate. Moderate blue water scarcity ranges from 100% to 150%. Further demand for freshwater above a scarcity level of 150% but below 200% is in a significant phase. Severe blue water scarcity indices are reached at scarcity levels exceeding 200%.

The monthly magnitudes of water availability (WA), water footprint (WF), and water scarcity (WS) in the basin are depicted in Figure 4.1. The water footprint exceeds the water availability from June to November, resulting in water scarcity during this period. The water scarcity during this time reaches moderate to severe levels, such that water use during this period is considered unsustainable. Nevertheless, the degree of unsustainability in the Orange River Basin from June to November varies from moderate to severe. June marks the beginning of a moderate blue water scarcity. It becomes significant in July, and severe from August to September. As October approaches, the blue water scarcity drops down to moderate levels and maintains those levels until the end of November. Low levels of blue water scarcity are reported from December to May. Nevertheless, the monthly blue water data provided by Hoekstra and Mekonnen (2011) did not take into account the water in dams and inter-basin water transfers. Therefore, their study underestimated the blue water availability in the Orange River Basin and was not a true reflection of the basin's water endowment throughout the year.

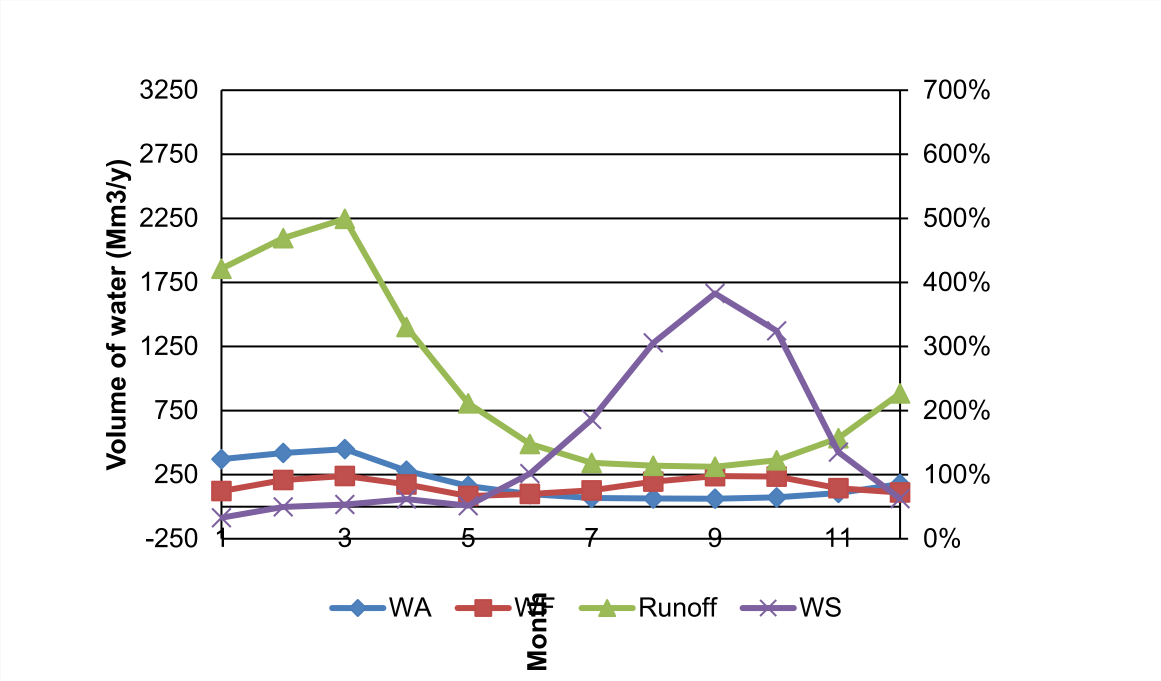

Figure 4.9: Monthly blue water scarcity of the Orange River basin
Source: Hoekstra and Mekonnen (2011)

Maize production at measuring points or18 and or20 commenced in October, and harvesting was done in May. At measuring points or4 and or5, maize was planted in December and harvested in July. Thus, maize production is moderately unsustainable during June, October, and November, and is significantly unsustainable in July. The maize water requirement increases gradually from planting, and diminishes as it reaches its physiological maturity stage. Hence, considerable maize water requirement occurs during a period of low blue water scarcity. Ultimately, maize, soybean, and sunflower are summer crops and are largely produced during the summer months when blue water scarcity is low. Chicken production occurs throughout the year. Given that 97% of the water footprint of broiler production is attributed to feed, broiler production may be considered to be sustainable.

4.4 DISCUSSION

This case study was concerned with the implications of broiler production on freshwater availability. It evaluated the sustainability of maize production in the Orange-Riet Irrigation Scheme and chicken meat produced by a broiler company located in the Free State. It does not necessarily claim to represent South Africa's entire broiler industry, as there are differences in the production systems that various companies use. The conclusions that arise from the analysis of the results of this study are set out below.

According to the DWA (2013), South Africa's water usage comprises 77% surface water, 9% groundwater, and 14% reuse of return flows. South Africa's annual surface water supplies are estimated at 49 billion m^3. Given the annual fluctuations in surface water availability, the country can only guarantee the availability of 10.24 billion m^3 of surface water each year. This is a concerning issue because about 9.5 billion m^3 of water is needed to meet the freshwater demand of the total ecological reserve. Nevertheless, groundwater availability is estimated at 5 billion m^3 per year, with an annual consumption of 2 billion m^3. This limited volume of freshwater has to be distributed such that it does not fall short of the country's registered water usage, currently reported at 15 to 16 billion m^3 per year. More than 60% of the total water consumption is attributed to agricultural irrigation. Despite its high level of water consumption, irrigated agriculture has an important role to play in promoting food security. As such, maize is an important ingredient in broiler feed. It forms 60% of broilers' diet and the broiler industry thus relies heavily on maize. Such reliance on the product of a water-intensive industry, particularly irrigated agriculture, in a semi-arid South Africa, warrants the use of tools to investigate the sustainability of maize production. The WFA is a reliable indicator for assessing the sustainability with which freshwater is used for broiler production in South Africa.

There is an abundant and increasing use of WFAs in the world. However, South Africa falls behind in that respect, as seen in its limited local applications of WFAs. To the authors' knowledge, there has been no assessment of the water footprint of the South African maize-broiler value chain, thus there is a lack of scientific water footprint information to effectively guide water use in the South African maize and broiler industries.

This study aimed to assess the water footprint of the South African broiler industry in terms of a derived product of maize that is used as feed for broiler chickens. First, the volumetric water footprint indicator was calculated for the maize-broiler value chain. Thereafter, the degree of sustainability was determined. Lastly, the EWP was assessed to gain insight into the economic returns that were generated from using freshwater in the maize-broiler value chain.

The results showed that, in both sites of the study area, the blue water footprint of maize production is greater than the green water footprint of maize production is. The blue water footprint accounted for most of the consumptive water footprint. Even in the total water footprint, which is meant to be representative of the whole scheme, the blue water footprint accounts for almost 60% of the consumptive use of freshwater, and more than double the grey water footprint. This suggests that there is great reliance on blue water in the Orange-Riet Irrigation Scheme. The grey water footprint associated with nitrogen fertilisation accounts for about 17% of the water footprint at measuring points or18 and or20, and approximately 24% of the water footprint at measuring points or4 and or5. The total grey water footprint (GWF_N) makes up 21% of the total water footprint in the Orange-Riet Irrigation Scheme; thus, the grey water footprint accounts for a significant share of the total water footprint of maize production in the scheme. This suggests that there is great potential for lowering the total water footprint by reducing the total grey water footprint. Hence, special attention must be paid to addressing blue water consumption, as well as minimising the leaching and runoff of nitrogen into blue water.

Despite the large blue water footprint of maize production in the Orange-Riet Irrigation scheme and the 60% share of maize in broiler feed, the results show that the green water footprint accounts for 67.88% of the total water footprint of producing a tonne of chicken meat. The blue and grey water footprints account for 23.13% and 9%, respectively. Soybean and sunflower oilcake have a much higher green water footprint, compared with their blue water footprint. This has caused the green water footprint of producing a ton of chicken meat to be higher than the blue water footprint. Therefore, the water footprint of soybean and sunflower oilcake have had a greater impact in “shaping” the green, blue, and grey water footprints of the water footprint of producing a tonne of chicken meat. Therefore, the significance of broiler feed ingredients in the water footprint of broilers does not only lie in their share of the feed, but also in how large their individual water footprints are.

The water footprint of chicken production varies from the farm to abattoir, to the processing plant. About 97% of the farm-level water footprint of broiler production per tonne of broilers is attributed to broiler feed. This entails that other uses of water on the farm account for less than 3% of the water footprint of on-farm broiler production. The slaughtering of broilers makes up 0.18% of the volume of water used to produce a tonne of chicken, while processing contributes 0.25%. Together, the slaughtering and processing of chickens account for 0.43% of the total water footprint of producing a tonne of chicken.

The irrigation and nitrogen fertilisation of maize for broiler feed account for the greatest share of the water footprint of producing a tonne of chicken meat. Farmers in the Orange-Riet Irrigation Scheme typically plant maize in December when the blue water scarcity index of the Orange River Basin is low. As mentioned in the previous chapter, the monthly blue water data provided by Hoekstra and Mekonnen (2011) did not take into account the water in dams and inter-basin water transfers. Therefore, farmers in the scheme may be regarded as operating in a sustainable manner.

The economic value derived per unit of water used depends on the type of chicken product produced. Chicken meat sold fresh yields higher economic returns per unit of freshwater than frozen chicken meat does. In terms of fresh chicken, a tonne of chicken portions yields greater economic returns per unit of water consumed than a tonne of whole chicken does. Therefore, the EWP is higher for chicken portions that are sold fresh. South Africa's water resources are limited. Irrigation puts pressure on freshwater but ensures an adequate supply of broiler feed. Nevertheless, production is sustainable. To increase the economic productivity of water, value must be added to broilers through processing. Despite maize production extending past the end of the maize marketing year, farmers generally do not irrigate maize in June and July. These two months form part of the harvesting season. Nevertheless, farmers in the region normally plant maize in December, when water use in the Orange River Basin is sustainable. The sustainability of broiler production largely depends on the sustainability of maize production. Broiler production is thus found to be sustainable because maize production is sustainable.

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CHAPTER 5
CASE STUDY OF BREAD PRODUCED FROM WHEAT

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Summary

The main objective of this research is to assess the water footprint of wheat in South Africa, being an important input in the wheat-bread value chain. The water footprints of flour and that of bread are also calculated in order to determine the total water footprint of bread along the wheat-bread value chain in South Africa. Water productivities at each stage of production within the wheat-bread value chain are also determined. The study was conducted as a case study of the Vaalharts region. Farm-level data was obtained from van Rensburg et al. (2012). A commercial processor with both a mill and bakery was used for the processing level of the value chain. The total water footprint of wheat in Vaalharts is 61 percent lower than that of the global average, which depicts a certain level of efficiency in the Vaalharts. Approximately 79 percent of the water footprint of wheat was derived from absorbed surface and ground water (irrigated water), which shows a high dependency on surface and ground water for wheat production in the Vaalharts region. Effective rainfall attributed only 21 percent of the total water footprint, which leaves room for possible increased usage. At the processing stage, 86 percent of the total water footprint in the processing stage of bread along the wheat-bread value chain is from the bakery, and only 14 percent from the mill process. It is concluded that the amount of water used at farm level is the largest contributor to the total water footprint of bread along the wheat-bread value chain (99.95 percent), while processing is only accountable for 0.06 percent. For economic productivities, greater income is generated per cubic metre of water used from wheat than from any other product along the wheat-bread value chain, due to the high contribution of wheat in this value chain – a conclusion that is easily understood. Value added to water encompasses the value added to the product throughout its value chain (in monetary terms), multiplied by the water footprint of the product "at different nodes of production" throughout the product value chain. Total value added to water from the water footprint assessment of the wheat-bread value chain is ZAR 11.4 per kilogram. About 65 percent of this value is from the processing level and only 35 percent from the farm level. This means that higher income is received per cubic metre of water used in the processing level of

the wheat-bread value chain. A result is similar to the value added per cubic metre of water footprint of bread along the wheat-bread value chain.

5.1 BACKGROUND AND MOTIVATION

Approximately 70 percent of the world is covered with water, but only 2.5 percent of the coverage is freshwater, mostly imbedded in glaciers, ice caps or at great depths underground (Gleick, 1998). Freshwater is a renewable resource, but when considering its availability in terms of unit per time per region, the reality of the limitations of this resource cannot be ignored (Jefferies, Munoz, Hodges, King, Aldaya, Ercin, Canals and Hoekstra, 2012).

South Africa is the 30th driest country in the world (Department of Water Affairs (DWA), 2013). Located in a predominantly semi-arid part of the world, South Africa receives an average rainfall of 450 mm per annum, which is approximately half that of the global average, 860 mm per annum (Department of Environmental Affairs (DEA), 2008). The agricultural sector is the largest user of freshwater in South Africa (Department of Agriculture Forestry and Fisheries (DAFF), 2014). This sector accounts for 60 percent for freshwater use, while about 40 percent of exploitable runoff is used for irrigated agriculture (Backeberg and Reinders, 2009). Field and forage crops are the largest users of freshwater (Ray et al., 2013). Considering the close relation of these crops to food security and eradication of poverty, it is realised that water availability is not only a limiting factor in agricultural production, but also a key contributor to rural socio-economic development (Hoekstra et al., 2012; World Wide Fund, 2013).

The agricultural sector contributes less than 3 percent to South Africa's gross domestic product (DAFF, 2012). Looking at water as an economic good, this contribution does not coincide with the allocation and use of freshwater resources in South Africa (DWA, 2013). The large use of freshwater in agriculture is inefficient and ineffective in sustaining socio-economic development (DWA, 2012). This enhances the need for innovative water management systems that incorporate the use of freshwater resources in a sustainable, economic and social aspect as does the water footprint assessment method.

The concept of a "water footprint", as introduced by Hoekstra (2003), is an indicator of direct and indirect appropriations of freshwater resources, which ultimately account for the total volume of freshwater that is used to produce a product, as measured along its full supply chain

(Hoekstra *et al.,* 2011). This assessment takes a consumptive perspective to freshwater and links production to final consumption by consumers (Bulsink, Hoekstra, and Booij, 2009). The components of a water footprint are specified graphically and temporally (Aldaya et al., 2010). This assessment consists of blue, green and grey water footprints (Bulsink *et al.,* 2009). The blue water footprint refers to the volume of surface and groundwater consumed or evaporated as a result of the production of a good along the supply chain of that product (Aldaya and Hoekstra, 2010), as well as losses that occur when water returns to a different catchment area. The green water footprint refers to the rain water consumed, evapotranspired and incorporated into a crop (Chapagain and Orr, 2009). The grey water footprint of a product refers to the volume of freshwater that is required to assimilate the load of pollutants, based on existing ambient water quality standards (Mekonnen and Hoekstra, 2011). As such, the grey water footprint is the volume of freshwater required to reduce pollutants to ambient levels, and it therefore considers the impact of water pollution.

Agriculture is the largest freshwater user, accounting for 99 percent of the global consumptive, green plus blue water footprint (Hoekstra and Mekonnen, 2012). Global freshwater withdrawals have increased nearly sevenfold in the past century, and with growing populations, coupled with changing diet preferences, water withdrawals are expected to continue to increase, and South Africa is no exception (Orlowsky et al., 2014). Hoekstra and Chapagain (2008) have shown that visualising the amount of water used in producing products can further increase understanding the global character of freshwater, a concept that is explored in a water footprint assessment.

Internationally, water footprint assessment is emerging as an important sustainability indicator in the agricultural sector, as well as in the agricultural food processing industry (Ruini et al., 2013). Ruini *et al.* (2013) conducted a water footprint assessment of Barilla pasta production, based on the life cycle assessment approach. In Italy, Aldaya and Hoekstra (2010) conducted a water footprint assessment according to the water footprint assessment manual of Hoekstra *et al.* (2011) on Italian wheat and bread. Similarly, Sundberg (2012), Cao et al. (2014) and Mekonnen and Hoekstra (2014) conducted a water footprint assessments of wheat and bread in Sweden, Hungary, China and Tunisia, where different production states were calculated and national averages taken. Mekonnen and Hoekstra, (2010c) conducted a water footprint assessment of wheat globally, and from this assessment, a benchmark for irrigated and rain-fed wheat was established.

The water footprint assessments reported above focused only on the environmental impacts of water, and not on the economic aspects thereof. Although he did not conduct a water footprint of wheat in South Africa, Scheepers (2015) calculated the water footprint assessment of a lucerne-dairy value chain, where he linked the economic valuation of water to the Global Water Footprint Assessment approach in order to determine where along the respective value chain the most value was added to water.

Water footprint assessments have been accepted internationally and are widely used as a tool to assess the sustainable use of water. In the South African wheat industry, the use thereof is limited, as there is no scientific information on water footprints available to inform sustainable water use behaviour. Considering the importance of this industry in the South African economy, a water footprint assessment would effectively guide policymakers in formulating appropriate strategies to guide freshwater use and assist irrigation farmers' water use behaviour to becoming more sustainable.

The main objective of this study is to explore the water footprint of wheat along the wheat-bread value chain in South Africa, and to conduct a water productivity assessment in order to quantify the value added to water long the wheat-bread value chain. The aim is to inform water management authorities and policymakers of the appropriate strategies and sustainability targets along the selected value chain. The two sub-objectives used to achieve the main objective are:

To determine the volumetric water footprint of wheat and bread, as derived wheat products, along the wheat-bread value chain.

To quantify the value of water along the wheat-bread value chain in order to identify areas along the chain where most attention is required. This was expressed in South African rands (ZAR) per cubic metre of water.

5.2 DATA AND METHOD

5.2.1 Data

5.2.1.1 Study area

South Africa has 19 catchment-based water management areas (only two are operational), that are equipped with agencies that manage water resources by coordinating water-related activities within their jurisdiction (DWA, 2008; Mukheibir, 2005; van Rensburg *et al*., 2012). Irrigated water within the respective CWMAs is managed by Water User Associations (WUA) which regulate the daily supply of irrigated water to farms and also the channels used to convey water to the various farms. Lastly, the farmer manages the on-farm irrigation, where efficiency is crucial to the entire system.

For the purpose of this study, the Orange-Riet and Vaalharts Irrigation Schemes are managed by the CWMA of the upper Orange and lower Vaal, as well as the WUA of the Orange-Riet and Vaalharts region. These schemes are spread across the Free State, as well as parts of the Northern Cape (van Rensburg *et al*., 2012). Figure 5.1 sets out a layout of the Vaalharts Irrigation Scheme.

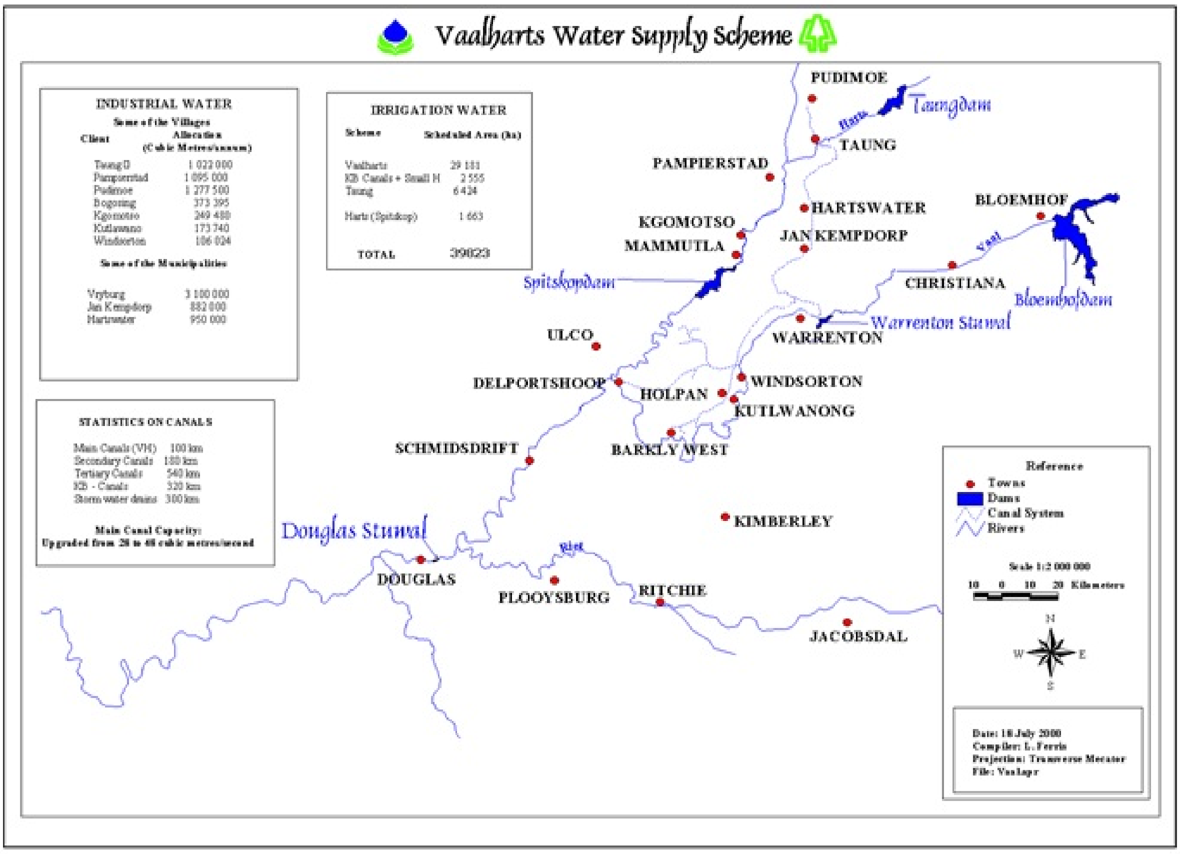

Figure 5.1: Layout of the Vaalharts irrigation scheme
Source: Van Rensburg et al. (2012)

The Vaal River (the largest tributary of the Orange River) is the main supplier of water to the Vaalharts Irrigation Scheme, with the Warrenton Weir just upstream of Warrenton diverting water into the Vaalharts main canal. This main canal in turn supplies the North, West, Taung and Klipdam-Barkley canals that convey water to the Vaalharts, Barkley-West, Spitskop and Taung sections. The total licensed areas for irrigation in the sections measure 29 181, 2 555, 1 663 and 6 424ha, respectively. In order to convey the irrigation water to the licensed areas, the system comprises 1 176 km of concrete-lined canals, together with 314 km of additional concrete-lined drainage canals to convey storm-water and subsurface drainage water out of the irrigation scheme through to the Harts River (van Rensburg *et al*., 2012; Muller and van Niekerk, 2016). The Vaalharts area is essentially bordered by two plateaus on the east and west sides of the Harts River Valley (Erasmus and Gombar, 1976), and the valley slopes towards the south. The low gradient of the Harts River, with no incising by the river itself, means that very little topographical changes can be observed within the valley. The general surface flow pattern tends to be towards the Harts River (van Rensburg *et al*., 2012).

The Vaalharts Irrigation Scheme falls within a summer rainfall area, with thunder showers being responsible for the majority of the rain during the summer months. Between November and April, the long-term rainfall for the area is normally more than 40 mm per month, with a mean of 59 mm. The long-term maximum temperature between November and March for Vaalharts is 31°C, while the minimum temperatures vary between 14 and 17°C. During the winter months, the maximum temperature is around 20°C, with the mean minimum temperature being just above 0°C (van Rensburg *et al*., 2012).

5.2.1.2 Wheat-bread value chain

The South African wheat industry is highly concentrated (DAFF, 2012). Four large millers have 87 percent of the market power and most are vertically integrated, which contributes to managing risks along this supply chain (NAMC, 2015). On-farm wheat production employs about 28 000 people across the country, while the milling industry employs around 3 800 people, with further skilled job opportunities being provided throughout the value chain (DAFF, 2012). Figure 5.2 sets out a flow diagram of the wheat market value chain, which starts off with research in biotechnology and ends with consumers.

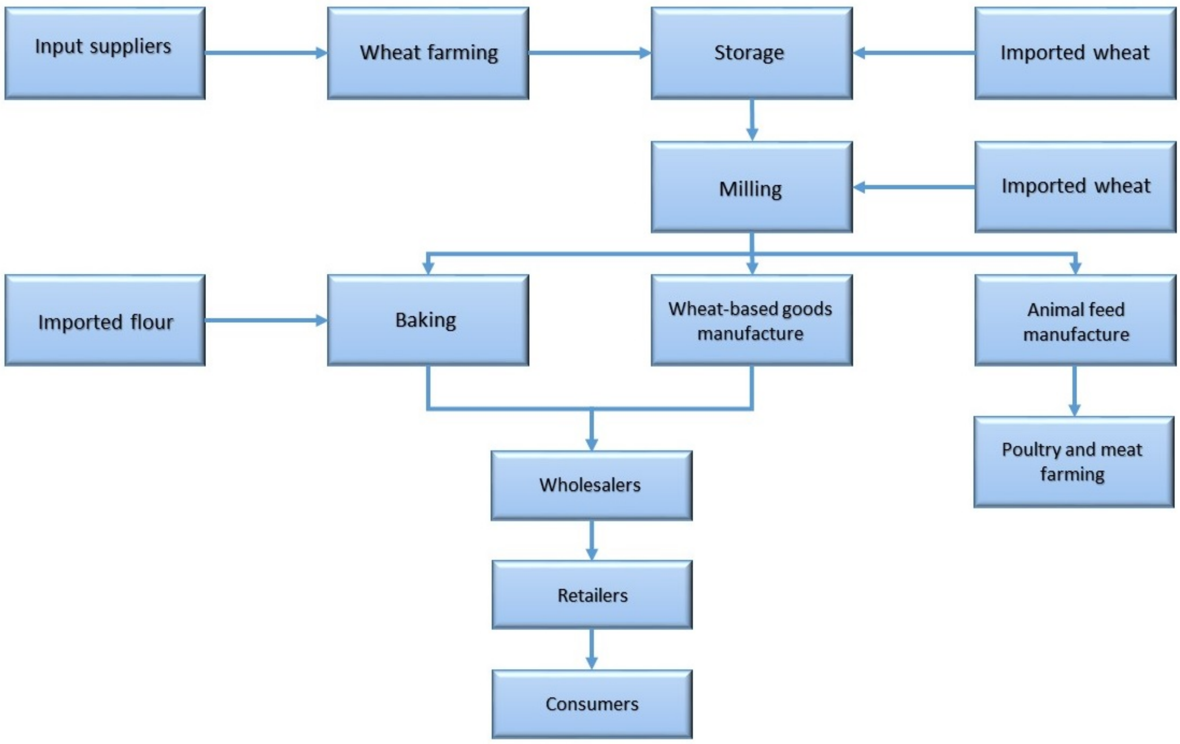

Figure 5.2: Wheat market value chain
Source: DAFF (2015)

The wheat market value chain (Figure 5.2) begins with research in biotechnology, where seed quality, climate predictions, soil quality, and consumer needs are realised. This process is followed by the actions provided by input suppliers of seed, fertiliser, truckers, etc. In order to carry out the planting process, co-operatives are put together in this phase, where inputs are shared and distributed in the different groups. Once the crop is harvested, it is stored according to different grades, with a small portion being exported or stored, until the desired selling price for the remainder of the crop is reached. Milling consists of four main processes:

1. *Sorting*, where wheat is passed through a cleaning process to remove coarse impurities and is stored according to qualities determined by protein content and gluten quality of wheat.
2. *Cleaning*, where impurities are removed and grain is sorted in different sized grinders.
3. *Tempering/Conditioning*, during which stage the wheat is soaked in water to make it softer in order to remove the outer bran coating, and it is in this step where the moisture content of the wheat is increased to about 12 percent.

4. *Gritting and milling*, where flour is created by the removal of bran and grinding of endosperm to make flour, which is then enriched or fortified.

From the milling stage, the produce is moved to bakeries, wheat-based goods manufacturers or animal feed manufacturers. Approximately 60 percent of the wheat flour (the rest is bran and meal) is used to produce bread, with the remaining percentage representing wheat-based products such as cereal and biscuits, and with a small portion being sold to animal manufacturers for animal feed.

Freshwater resources are said to have a global character, where we see exported commodities increasing local water use and scarcity, and imported water-intense commodities easing the pressure on local water resources and water security (Hoekstra, 2011; Mekonnen and Hoekstra, 2010a). To further explore this concept, it is important to quantify the amount of water used in the production of agricultural products, as well as the extent to which water use is sustainable.

5.2.1.3 Water-use data on wheat production

Secondary data on water usage for the production of wheat was obtained from Van Rensburg et al. (2012) who, among other things, explored the management of salinity on field crops, including wheat.

Wheat data was gathered in an experimental manner over a period of 3 years. The area of the experimental site was 70 m by 35 m, which was irrigated by means of a drip irrigation system. In the centre of this site, 30 round plastic containers (1.8 m diameter and 1.8 m deep) were arranged in two parallel rows of 15 each, with their rims 5 cm above the bordering soil surface. A 10 cm layer of rock was placed in the base of each container and covered with a plastic mesh. The one row of containers was filled with a homogenous yellow sandy soil, and the other with a red sandy loam soil to the same level as the soil in the surrounding field. An underground access chamber (1.8 m wide, 2 m deep and 30 m long), allowed access to the inner walls of the containers. On the access chamber side, an opening at the bottom of each container was connected to a manometer and a bucket that was used to recharge and regulate the height of the water table treatments. Each container was also equipped with two neutron probe access tubes (Ehlers et al., 2003).

It was decided to make use of actual measurements through a lysimeter trial, instead of estimations from water use models, to determine the water footprint of wheat. The experiment consists of 5 treatments, replicated 3 times and an average taken to represent each sample. The cultivars used were selected from those that are widely used through all the central parts of the South Africa. Above-ground biomass was harvested when crops were dry by cutting it just above the soil surface (Ehlers *et al.,* 2012). For the purpose of this study, only one of the five treatments was selected to represent the water footprint of wheat in the Vaalharts region.

5.2.1.4 Water used to produce bread and assessing economic water productivity

The scope of this study covers a case study of the water footprint of bread along the wheat-bread value chain. Once the wheat is produced, it becomes a vital input for bread production, and the link between the wheat and bread value chains is made. Therefore, water data for a commercial mill and bakery (processor) is needed. This data was collected through a questionnaire submitted to the managers of one of the leading wheat processing agri-businesses in South Africa.

Data used in this study was obtained from one of the leading processing companies in South Africa, with an average of 5 mills and 15 bakeries, nationwide. The company maintained an excellent record-keeping system, which guarantees the authenticity of the expected results. The data acquired is of a single production year and was acquired with the use of a questionnaire (compiled in a clear and easy to understand manner) to obtain the necessary information in order to conduct a water footprint assessment of the processing stage within the wheat-bread value chain. The questionnaire in Appendix 3.1 made it possible to calculate the water footprint of flour and bread in order to determine where the largest contribution to the water footprint lies along the value chain. There was no differentiation made between the different types of water. Therefore, this data is a representation of the total water used in the processing stage. From literature, we expect that the water footprint contribution from the processing stage to contribute less than 1% to the overall water footprint of bread along the wheat-bread value chain. These footprints are later compared with the value added to water, and the necessary conclusions are made.

5.2.2 Methods

After evaluating the different water footprint accounting methods referred to in Chapter 2, it was decided that the consumptive water-use-based volumetric water footprint method of the Water Footprint Network (WFN) best fits the scope of this study. The methodology in this chapter, and the calculations referred to in Chapter 4, are based on the guidelines of the Water Footprint Assessment Manual (Hoekstra *et al.,* 2011).

According to this framework, a water footprint assessment consists of four phases. The first phase involves setting the scope and goals of the assessment. The second phase is the water footprint accounting, where the volumetric water footprint indicator is calculated throughout the value chain. The third phase is a sustainability assessment in which the water footprint assessment is evaluated from an environmental, social, and economic perspective, and the fourth phase is the response formulation, where policy recommendations are made.

5.2.2.1 Volumetric water footprint of wheat production

The primary product evaluated in this assessment is wheat, and the water footprint of wheat will be calculated by following the Water Footprint Network Approach by Hoekstra *et al.* (2011), similar to Mekonnen and Hoekstra (2010a); Aldaya and Hoekstra (2010); Ahmed and Ribbe (2011); Sundberg (2012); Chouchane *et al*. (2013); and Ababaei and Etedali (2014). The water footprint of the growing crop, wheat, is the sum of the process water footprints of the different sources of water. Hoekstra *et al.* (2011) explain the water footprint of the process of growing a crop as:

$$WF_{wheat} = WF_{wheat,blue} + WF_{wheat,green} + WF_{wheat,grey} \quad [volume/mass] \tag{5.1}$$

where $WF_{wheat,\mathrm{blue}}$ is the blue crop water footprint, which refers to the total amount of surface and ground water that evaporates and is incorporated into the product and does not become runoff, from the field over the total length of the crop's growing period, and $\mathrm{WF}_{\mathrm{wheat,green}}$ refers to the total rain water that evaporates and is incorporated into the product, and does not become runoff. $\mathrm{WF}_{\mathrm{prod,grey}}$ is the total amount of water required to remove pollutants and return water to its ambient form.

The total amount of irrigated (ground or surface) water that has evapotranspired over the total length of the crop's growing period, $WF_{wheat,blue}$ ($m^3.ton^{-1}$), is calculated as the blue component in crop water use, CWU_{blue} ($m^3.ha^{-1}$), divided by the crop yield ($ton.ha^{-1}$). Similarly, the total volume of rainwater that has evapotranspired from the field during the same period, $WF_{wheat,green}$ ($m^3.ton^{-1}$), is calculated in a similar fashion.

$$WF_{prod,blue} = \frac{CWU_{blue}}{Y} \qquad [volume/mass] \tag{5.2}$$

$$WF_{prod,green} = \frac{CWU_{green}}{Y} \qquad [volume/mass] \tag{5.3}$$

Blue and green crop water use *CWU* ($m^3.ha^{-1}$) is the sum of the daily evapotranspiration (*ET*,mm/day) over the complete growing period of the crop:

$$CWU_{blue} = 10 \times \sum_{d=1}^{lgp} ET_{blue} \qquad [volume/area] \tag{5.4}$$

$$CWU_{green} = 10 \times \sum_{d=1}^{lgp} ET_{green} \qquad [volume/area] \tag{5.5}$$

ET_{blue} and ET_{green} represent the blue and green water evapotranspiration, respectively. The water depths are converted from millimetres to volumes per area, or $m^3.ha^{-1}$, by using the factor 10. Summation is done over the complete length of the growing period (*lgp*), from day one to harvest (Hoekstra *et al.,* 2011).

5.2.2.2 Volumetric water footprint of bread production

The water footprint of flour and bread was calculated following the logic of Sundberg (2012) who used the Water Footprint Network approach to conduct a water footprint assessment of winter wheat, as well as derived wheat products, along their respective value chains. Also referred to was the study by Ruini *et al.* (2013), who may not have used the Water Footprint Assessment Approach, but rather the LCA, to conduct a water footprint assessment of pasta along the wheat-pasta value chain. As affirmed in Chapter 2, Sundberg (2012) and Ruini *et al.* (2013) focused on calculating the water footprint of derived wheat products along the respective supply chain by calculating the water used in each production node and dividing it by the quantity of product produced at that node. After this, these footprints are then added to get the final water footprint of the end product along that supply chain In order to highlight the importance of the direct and indirect water use of a given product.

Mill

For the total water footprint of flour, the volume of water used in the mill to produce the flour is quantified and divided by the quantity of flour produced:

$$WF_{flour,mill} = \frac{total\ volume\ of\ water\ in\ mill\ (m^3)}{quantity\ of\ flour\ milled\ (ton)} \quad (5.6)$$

Bakery

Similar to the water footprint of flour, the total water footprint of bread is the volume of water used in the bakery divided by the quantity of flour produced:

$$WF_{bread,bakery} = \frac{total\ volume\ of\ waterin\ backery\ (m^3)}{quantity\ of\ flour\ milled\ (ton)} \quad (5.7)$$

5.2.2.3 Total water footprint of bread produced from wheat

The final blue water footprint is an indicator of the total amount of surface and ground water that has evaporated along the wheat-bread value chain, or that was incorporated into the final product. This is the one type of water that is realised both in crop production and at the processing level of the respective value chains, and is expected to be the largest contributor to the total water footprint realised at the end of this assessment. The case study is conducted on irrigated winter wheat, planted in a summer rainfall region, so it is expected that the green water footprint will be quite low, considering that no green water is used in the processing stage of the assessment. The final calculated green water footprint is an indicator of the total amount of rainwater that was evapotranspired by the crop and incorporated into the crop along the wheat-bread value chain.

The total water footprint of bread along the wheat-bread value chain is realised by adding the respective water footprints along this value chain, and is given as follows:

$$WF_{bread} = WF_{wheat} + WF_{flour,mill} + WF_{bread,bakery} \quad volume/mass \tag{5.8}$$

5.2.2.4 Economic water productivity

The value added to water along the wheat-bread value chain was calculated in terms of economic water productivity (EWP). The EWP was calculated at each node of production in order to determine which of processed steps along the value chain contributes the most, and least, economic water productivity. The steps followed in calculating economic water productivity are as follows.

1. The *physical water productivity* (m^3.kg) of each product along the wheat-bread value chain was calculated. This was done by taking the yield at each production node and dividing it by the respective crop water use in the case of wheat, and total water used in the case of flour and bread. These values are given in m^3.ton and therefore will be converted to m^3.kg by dividing the values by 1000.

2. *Value added* along the value chain (in ZAR.kg). Once the physical water productivity for each production node is known, the value added at each node can be calculated. This is done by following the logic of Jordaan and Grové (2012) and Scheepers (2015). Value added will be calculated using the following equation.

$$V_{ic} = \sum_i Vic \tag{5.9}$$

where V_i represents the value added at process step i of value chain c and is derived as:

$$V_{ic} = PS_{ic} - PP_{ic} \tag{5.10}$$

The parameters of the equation are as follows:

- V_c = Value added along value chain c
- V_{ic} = Value added at process step i of value chain c
- PS_{ic} = Selling price at process step i of value chain c
- PP_{ic} = Purchase price at process step i of value chain c

where the purchase price of each product at the beginning of the production node, as well the selling price at the end of each node, should be known. Due to the fact that wheat has no direct purchase price, the gross production value (in ZAR.ha), divided by the yield (in ton.ha), will be used as the value added at farm level. In the case of flour, the value added was sourced from industry sources and will be taken as the price of flour per ton. The cost and sale prices of bread is known.

3. Once the value added at each production node is known, the *Economic water productivity* (EWP) can be determined by multiplying the physical water productivity by the respective value added. EWP will be represented in ZAR.kg.

This assessment allows for the comparison of water usage and economic productivity of the water along the wheat-bread value chain. In order to calculate the economic water productivity along the wheat-bread value chain, data was sourced from Chapter Three of 'The Wheat-Bread Value Chain', in a general report of the Food Price Monitoring Committee (2003), led by the National Development Agency and the Department of Forestry and Fisheries.

Included in that report was data for the average wheat to brown and white bread supply chain for the period February 2000 to December 2002, where all the production costs and income made at each node of production, as well as when the products moved to the next node, were included. The values were adjusted to 2016 prices by using the 2016 CPI. This data was only used for flour-bread along the value chain. In the case of wheat, this study used the producer price framework for irrigation wheat for the 2016/2017 production year recorded by GrainSA. That report includes all the production costs and income received for wheat produced in the Northern Cape, at different yields.

5.3 RESULTS

In the first section, the volumetric water footprints of wheat, flour and bread along the wheat-bread value chain are reported. This is accomplished by first calculating the green and blue water footprints for each product throughout the value chain. Once completed, the total water footprint of bread along the wheat-bread value chain was established. The second section is the economic water productivity, where the value added to water in each production stage as the product moves along the value chain was determined. This chapter is concluded with a discussion on the findings, as well as the impacts, this has on South Africa's freshwater resources.

5.3.1 Water Footprint of Wheat-Bread Value Chain

5.3.1.1 Water footprint of wheat production

Table 5.1 sets out a summary of wheat production estimates recorded at the Vaalharts Irrigation Scheme. The wheat yield per hectare was found to be 9 010 kg. The cumulative ET was 869 mm, effective rainfall 183 mm, surface water 286.33 mm, and ground water 423.67 mm. Most often, water footprints are expressed in terms of water per unit of production, and therefore it is more sensible to express the blue water footprint in terms of m^3 per ton of output. In order to convert the water footprint into a spatio-temporal dimension, ET was converted to cubic metres per hectare, which is an indication of the blue crop water use (CWU_{blue}). The blue CWU must thus be divided by the yield expressed in tonnes per hectare to obtain the blue water footprint.

Similar to the blue water footprint, the same method employed by Aldaya and Hoekstra (2010) was used to calculate the green water footprint of wheat.

Table 5.1: Summary of wheat data at the measuring points, Vaalharts irrigation scheme

CROP	**YIELD** *(kg.ha)*	**DM** *(kg.ha)*	**TOTAL BIOMASS** *(kg.ha)*	**CUM. ET** *(mm)*	**R** *(mm)*	**WUE** *(mm)*	**I+R** *(mm)*	**I** *(mm)*	**WT** *(mm)*
wheat	9010	13995	23005	869	183	10.4	469	286	424

(Source; Ehlers *et al.,* 2003)

In Table 5.2, the water utilisation in wheat production is set out. The effective rainfall (R) is ET_{green}. The blue water used was classified according to its various sources. The blue water used from the surface ($ET_{blue}S$) was 286 mm, and the blue water used from the ground ($ET_{blue}G$) was 424 mm. The CWU_{green} and CWU_{blue} were given by multiplying the relevant ET by 1 000. For example, (183×1 000) = 1 830, which is CWU_{green} for all the treatments. The CWU_{blue} was 6860 m^3.ha. This implies that the amount of blue water utilised is substantially higher than the green water used. The green water footprint WF_{green} of producing wheat is therefore 203.1 m^3.ton, and this is achieved by dividing CWU_{green} by the yield in (m^3.ha). The total blue water footprint was estimated to be 788.01 $m^3.ton^{-1}$.

Table 5.2: Wheat Water Utilisation at Vaalharts Irrigation Scheme

CROP	**ET crop** *(mm)*	**ET green** *(mm)*	**ET Blue Surface** *(mm)*	**ET blue Ground** *(mm)*	**CWU** *(m^3)*	**CWU** green *(m^3.ha)*	**CWU blue** *(m^3.ha)*
Wheat	869	183	286	424	8690	1830	6860

(Source; Ehlers *et al.*, 2003)

Table 5.3: Blue and Green water footprints of wheat, Vaalharts irrigation scheme

Yield *(ton.ha)*	**WF green** *(m^3.ton)*	**WF_{blue} surface** *(m^3.ton)*	**WF_{blue} ground** *(m^3.ton)*	**Total WF** *(m^3.ton)*
9.01	203	318	470	991

Therefore, the total water footprint of wheat, WF_{wheat}, is given as follows:

$$WF_{wheat} = WF_{wheat,blue} + WF_{wheat,green} \tag{5.11}$$

$$WF_{prod} = WF_{blue(surface+ground)} + WF_{,green} \tag{5.12}$$

$$WF_{wheat} = 788.01 + 203.12$$

$$WF_{wheat} = 991m^3.ton \qquad volume/ton$$

The total water footprint of wheat is calculated to be 991 m^3.ton, as indicated in Table 4.3. The blue water footprint accounts for the largest portion of the total water footprint. It is worth noting that the blue water utilised from the ground is higher than the blue water utilised from the surface. These results indicate that water tables, influenced by over-irrigation over the years, are capable of contributing almost 50 percent of a crop's ET. This is achieved by under-irrigating the crop and also maximising the use of rain water. Mekonnen and Hoekstra (2010a) estimated the global water footprint of wheat, and concluded that the global average WF_{wheat} is 1 623 m^3.ton (1 277 m^3.ton green and 344 m^3.ton), and that of this total, blue water accounts for 50 percent of the total water used in irrigated wheat. Comparing this result to that of Mekonnen and Hoekstra (2010a), it is evident that the water footprint of wheat in the Vaalharts Irrigation Scheme in South Africa is lower than that of the world average.

Figure 5.3 reflects the total water footprint of wheat in the Vaalharts region. Blue water contributes 79 percent of the footprint (29 percent higher than the world average). Although 47 percent of this contribution is from water tables, it does not dispute the high use of ground and surface water resources. The green water footprint accounts for 21 percent of the water use, which could be fair, considering the current drought and the fact that the case study site is in a summer rainfall area and that wheat is planted in winter.

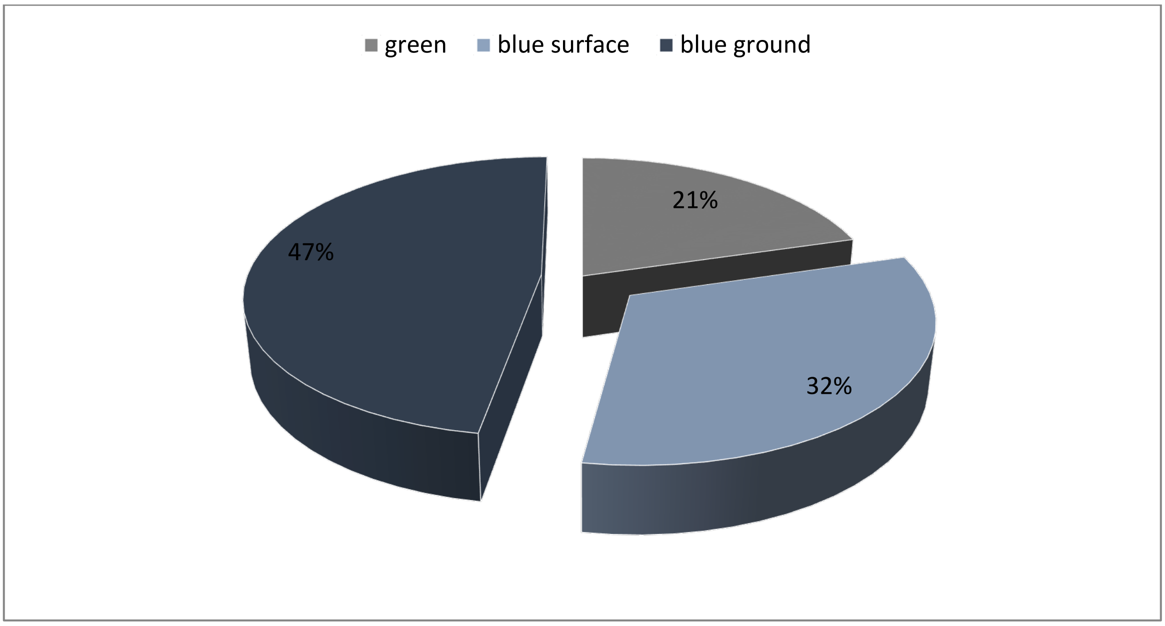

Figure 5.3: Total water footprint of wheat
Source, own calculations

5.3.1.2 Water footprint of bread

Data used in this study was obtained from a leading mill and bakery in South Africa, with an excellent record-keeping system. The data is of a single production year. Table 5.4 presents the water use at the processing stage of the wheat-bread value chain, which represents a combination of both brown and white bread. A total of 767 545 tons of wheat was milled in the processing plant. A ton of wheat had an extraction rate of 82 percent. This results in 632 348 tonnes of flour. This rate is higher than that reported by Aldaya and Hoekstra (2011) for Italy, by Mekonnen and Hoekstra (2011) for the global average and for Hungary, and by Sundberg (2012) for Sweden, but who did not differentiate between white and brown bread. This extraction rate is similar to the findings of NAMC (2009) for the flour extraction rate from wheat at a national level. Water use amounted to 46 053 m^3 per annum.

This volume includes the total water used in processing and cleaning. The water footprint of a product or process is expressed as the volume of water used in the product divided by the product yield (Hoekstra, 2011).To get the water footprint of flour, we divide the total annual water used in the mill for flour by the annual flour production (46 053 m^3 ÷ 63 234 tons) = 0.073 m^3.ton. When looking at bread production, 249 217 tons of flour is used in 15 bakeries per year (which is less than 40 percent of the total flour milled), with the rest of the flour being sold to other bakeries and end consumers. About 552 039 728 loaves of bread are produced each year by the processer considered in this study, and this includes both 600g and 700 g loaves, with a weighted average of 688 grams per loaf. Multiplying the loaves with the weighted average, and dividing this by a million, results in a figure of 379 803 tons of bread being produced per year.

Table 5.4: Water use at the processing stage of the wheat-bread value chain (mill and bakery)

Parameter	Unit	Quantity
	Milling stage	
Quantity of wheat	Ton	767 545
Volume of water used	m^3	46 053
Quantity of flour	Ton	632 348
Water footprint	m^3.ton	0.073
	Bakery stage	
Quantity of bread produced	Ton	379 803.33
Volume of water used	m^3	174 452
Water footprint	m^3.ton	0.459
Total water footprint processing	m^3.ton	0.532

Similar to flour, the total annual water use in the bakery for purpose of making bread was divided by the annual bread production (174 452 m^3 ÷ 379 803.33 tons) = 0.459 m^3.ton. The total water footprint of the processing stage is given by (0.073 + 0.459) = 0.532 m^3.ton. Approximately 1 percent of the mentioned water is used for other purposes and ends up in the municipality waste water systems.

5.3.1.3 Total water footprint of bread produced from wheat

Table 5.5 gives a clearer view of the green and blue water used at each production node, as well as of the total water used. Blue water had the highest contribution to the value chain, at 227 660.81 m^3 (99.2 percent), while green water contributed 1 830 m^3 (0.80 percent). This confirms that blue water resources play a crucial role in the wheat-bread value chain.

Table 5.5: Summary of the water footprint of bread along the wheat-bread value chain in South Africa

Parameter	Green Water	Blue water	Total
Volume of Water used (m^3)	1830	6860	8690
Yield (ton)	9	9	
WF ($m^3.ton$)	203	788.01	991
Volume of water used (m^3)	-	46053	46053
Quantity of flour produced (ton)	632348	632348	632348
WF of flour	-	0.07	0.07
Volume of water used (m^3)	-	174452	174452
Quantity of bread produced (ton)	379803.33	379803	3798033
WF of bread ($m^3.ton$)	-	0.459	0.46
Total WF of bread (m^3.*ton*)	191	745	992

The total volume of water used throughout this value chain, in m^3, is given by (8 985.81 + 46 053 + 174 452) = 229 490.81 m^3. The contribution to the total volume of water used, in ascending order, is as follows: crop production, milling and baking, with percentages of 4,20 and 76, respectively. If the analysis is interpreted at this point, it seems as if the most water is used at the last node of this value chain, which is not true. Therefore, we cannot express water use on its own, but with the respective yields of that production. By doing so, we get the water footprint of the respective processes and the effect that they have on water resources. Therefore, the water footprint of bread along the wheat-bread value chain is as follows:

$$WF_{bread} = WF_{wheat} + WF_{flour,mill} + WF_{bread,bakery}$$

$$WF_{bread} = 991m^3.ton \quad + \; 0.073\, m^3.ton \quad + 0.459\, m^3.ton$$

$$WF_{bread} = 991.84\, m^3.ton \qquad [volume/ton]$$

According to Table 5.5, the water footprint of bread along the wheat-bread value chain was 991.84 m^3.ton, of which, 991.12 m^3.ton was wheat and 0.532 m^3.ton processing, which is in accordance with the findings of Sundberg (2012). Crop production level contributes 99.95 percent to the water footprint of bread along the respective value chain, while processing (mill and bakery) contributes only 0.5 percent. Mekonnen and Hoekstra (2011) compiled the water footprint benchmark for wheat and derived wheat products, where the water footprint of wheat was used as a basis to calculate the water footprint of derived wheat products, based on product and value fractions of 79 percent and 80 percent, respectively, for flour. They also concluded that 1 kg of flour was equal to 1.15 kg of bread. The water footprint of wheat is given by 1 623 m^3.ton, and the water footprint of wheat flour is 1 639 m^3.ton (1 292 m^3.ton green and 347 m^3.ton blue), while that of bread is given by 1 425 m^3.ton (1 124 m^3.ton green and 301 m^3.ton blue). It is important to note that the authors' assessment was of a single product, and was not calculated along the wheat-bread value chain.

5.3.2 Economic Water Productivity

The economic contribution of water is expressed in terms of economic water productivity. This process consists of three steps:

1. Physical water productivity
2. Value added
3. Economic water productivity.

Table 5.6 represents the physical water productivity of wheat, flour and bread along the wheat-bread value chain. Physical water productivity is usually expressed in kg/m^3. The yield for the products was multiplied by 1000 to change it from tonnes to kilograms. From Table 5.6, it is seen that wheat (grain) has the highest water productivity of 1.037 kg/m^3, followed by bread with 0.022 kg/m^3. Flour has the lowest water productivity of 0.014 kg/m^3.

Table 5.6: Physical water productivity of wheat, flour and bread along the wheat-bread value chain

Parameters	Wheat	Flour	Bread
	Physical Water Productivity		
Yield	9 ton.ha	632 348 ton	379 803 ton
Total water use	8690 m^3.ha	46 053 m^3	17 447 m^3
Physical water productivity	1.04	0.01	0.02

The second step in determining the economic water productivity is calculating the value added to water at each stage of production. For wheat, the gross production value (in ZAR.ha) divided by the yield (ton.ha) is taken as the value added to water, which value is given as 4 001.55 ZAR.ton. Value added is usually expressed in rand per kg. This means that the value added to wheat is therefore given as 4.0 ZAR/kg. In the case of flour, no direct cost of buying was found. The selling price is taken as the value added, and this value is given as 5 700 ZAR/ton. Converted to ZAR/kg, this is amount is given as 5.7 ZAR/kg, and is taken as the value added at this production stage. The cost of bead is 6.56 ZAR/kg, and the selling price given as 8.29 ZAR/kg, and by deducting the purchase cost from the selling price, the value added is calculated as 1.73 ZAR/kg. Table 5.7 illustrates the calculation for the economic water productivity of wheat, flour and bread along the wheat-bread value chain.

Table 5.7: The economic water productivity of wheat, flour and bread along the wheat-bread value chain

Parameters	**Wheat**	**Flour**	**Bread**
	Economic water productivity		
Physical Water Productivity	1.037 kg/m^3	0.01 kg/m^3	0.02 kg/m^3
Value Added	4.0 ZAR/kg^{-1}	5.7 ZAR/kg	1.73 ZAR/kg
Economic Water Productivity	4.18 ZAR/m^3	0.079 ZAR/m^3	0.04 ZAR/m^3

Average exchange rate for December 2016: US$1 = ZAR14.62

From Table 5.7, it is seen that wheat has the highest economic water productivity, of 4.18 ZAR.m^3, followed by flour and then bread, at 0.08 ZAR/m^3 and 0.04 ZAR/m^3, respectively. Table 5.8 sets out a summary of the value added at the different stages of production, divided by the respective total water footprints at each stage. From Table 5.8, it is seen that the total value added by the water footprint of bread along the wheat-bread value chain is

11.52 ZAR/m^3. The water footprint of wheat has the lowest value added to water along the wheat-bread value chain.

Table 5.8: Summary of the value added to water for bread production along the wheat-bread value chain

Production nodes	Value added	Units
	Farm level	
Wheat	4	ZAR/kg
	Processing	
Mill$_{Flour}$ and Bakery$_{bread}$	7.43	ZAR/kg
Total value added	11.43	ZAR/kg
Water footprint of bread along the value chain is given by	$\mathbf{991.84}\ \boldsymbol{m^3.ton}$	
Therefore WF$_{bread}$ = 0.99 m^3/kg		
Production nodes	*Value added*	*Units*
	Farm level	
Wheat	4	ZAR/m^3
	Production level	
Mill$_{Flour}$ and Bakery$_{bread}$	7.49	ZAR/m^3
Total value added to water along the wheat-bread value chain	11.52	ZAR/m^3

Average exchange rate for December 2016: US$1 = ZAR14.62

5.4 DISCUSSION

The water footprint of wheat in the Vaalharts region was estimated to be 991 m^3.ton. This value is about 61 percent lower than that of the world average (1 623 m^3.ton), as well as the global average of irrigated wheat (1 8605 m^3.ton). According to Mekonnen and Hoekstra (2010a; 2010b), a water footprint is largely determined by overall yields. This low footprint could be attributable to the high yields attained by wheat producers in the Vaalharts region, being 9.0 m^3.ton.This indicates that South African wheat producers are effective in their production processes. Blue water accounts for 80 percent of the footprint found in this study. Globally, blue water use in irrigated wheat contributes 50 percent of the footprint, which raises a red flag of possible overexploitation of ground and surface water resources in the Vaalharts region. Given the current blue water scarcity conditions in South Africa, the high blue water usage should be a major concern for water users along the wheat value chain.

The South African wheat-to-flour extraction rate is higher than those of Italy, Hungary and Sweden. This means that wheat loss in South Africa (process of converting wheat to flour) is closer to the mill fraction of flour (88 percent) stipulated by the FAO (Aldaya and Hoekstra, 2010). This could result in less wheat being used in the mill to achieve the same yields. Wheat is accountable for 99.95 percent of the water footprint of bread along the wheat-bread value chain, while processing is only accountable for 0.56 percent. This highlights the importance of not only effective, but also efficient, water use in the production stages of crops. The water used at the farm level has the highest impact on sustainability, efficiency and effectiveness of water use for the entire value chain. Processors should therefore be aware of the water footprint of their raw materials because this volume accounts for more than 99 percent of the water footprint of the products they produce. The water footprint of bread is 58 percent lower than that of the global average. When only considering the volumetric water footprint, this means that in South Africa, bread is produced with effective and efficient use of freshwater resources.

When looking at water productivities, about 97 percent of the economic water productivity of the wheat-bread value chain is from wheat, while only 0.12 ZAR.m^3 is from the processing stage. However, when looking at the value added to water by the water bread along the wheat-bread value chain, the water footprint of wheat adds the lowest value to the value chain (35 percent), while the water footprint of the processor adds 75 percent value to the value chain (7.49 ZAR.m^3). The incorporation of the water footprints of bread production inputs, such as yeast, sugar, salt and eggs, would give a more holistic assessment and would potentially increase the water footprint of bread along this value chain, as well as value added at the processing stage.

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CHAPTER 6

CONSUMER AWARENESS AND WILLINGNESS TO PAY FOR WATER FOOTPRINT INFORMATION

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Summary

The research aim is to investigate the possibility of creating a niche market for beef products that are produced sustainably. This is achieved by examining consumer preferences and consumers' Willingness to Pay (WTP) a premium for beef products that contain labels of their environmental sustainability claims, in particularly focusing on water footprint information labelled on the products. Choice experimental survey data was collected from 201 beef consumers in the Gauteng province of South Africa. The present study has examined consumers' stated preferences for water footprint sustainability attributes. Discrete choice experimental data and a random parameter logit model were employed in the study. The study found that there are heterogeneous preferences for water footprint sustainability attributes. The heterogeneity in preferences for water footprint sustainability attributes are significantly related to an individual's age, gender, income, and education, as well as awareness of water scarcity. The findings suggest that, to communicate potential benefits and costs of water usage effectively, policymakers and interested groups should identify different heterogeneous consumer segments, and assess potentially simpler or more direct awareness or labelling methods that signal ecological sustainability as a new water scarcity and carbon emission campaign strategy.

6.1 BACKGROUND AND MOTIVATION

Globally, freshwater resources are becoming scarcer due to an increase in human population and subsequent increase in water appropriation and deterioration of water quality. Water is said to be a scarce natural resource, although three-quarters of the earth's surface is covered in water. Shiklomanov and Rodda (2003, cited by Hoekstra and Mekonnen, 2011) stated that approximately 97% of water on the earth is salt water and only about 2.5% of the global stock is fresh water, of which more than two-thirds is iced water. This means that about 1% of fresh water is available for human consumption. The impact of human consumption on the global water resources can be mapped with the concept of the 'water footprint', a concept introduced by Hoekstra and Hung (2002).

The water footprint concept helps with gaining an understanding of the enormous volumes of water required to support the human population – in particular for food production (Hoekstra, 2011). Hoekstra and Hung (2002) define a water footprint as the total volume of freshwater that is used in the production of goods and services consumed by the inhabitants of the particular nation. This is a fresh water use indicator, which reveals direct and indirect uses of water by a consumer or a producer (Hoekstra and Hung, 2002). It can be considered as an overall fresh water use index, in addition to the traditional simplified abstraction rates (Chapagain et al., 2005). It is a multidimensional index, which shows the water appropriation measure or volume of freshwater used during the production, measured along the entire supply chain of a product (Hoekstra and Hung, 2002). Neubauer (2011) points out that the revealing of the hidden water use of products can help in the understanding of the global nature of fresh water and to quantify the effects of the consumption and trade of water resources in food production.

According to Gerbens-Leenes et al. (2013), food accounts for a fairly large portion of the total usage of natural resources, in particular, fresh water. Agriculture accounts for 92% of the world's fresh water footprint, of which 29% of the fresh water resource is either directly or indirectly used in the production of animals. The production of animals thus has the largest share of the total water footprint. Since the production of animals is documented to have a large water footprint, it is crucial that, in production, particularly in the beef industry, freshwater is used in a sustainable manner. Given the large water footprint of animal production, consumers are often advised to change their diets by reducing beef consumption in order to decrease impacts on the scarce freshwater resource, while still meeting protein requirements in their diets (Vanham, Mekonnen & Hoekstra, 2013). For a country such as South Africa, the beef industry is very important from an economic perspective. The beef industry is a major contributor to the Gross Domestic Product of South Africa (DAFF, 2014) and also provides employment to a substantial number of people in South Africa. A decrease in beef consumption thus may cause some serious socio-economic problems in a developing country such as South Africa.

Rather than changing diets, an alternative approach to take to incentivise the sustainable water use might be for consumers to pay a price premium for food products that contain water footprint information, as an indicator of sustainable freshwater use, on their labels. Consumer demand for high-quality food has been on the increase. Based on their increased knowledge about links between diet and health, awareness of quality characteristics, and access to information about new production and processing technology. Driven by increasing consumer demand for healthier, safer, and more environmentally friendly food products, the use of food labelling has become progressively more imperative in recent years (Oni et al., 2005).

McCluskey and Loureiro (2003) discuss the possibility of food labels as providing the answer to the imperfect information dilemma in food safety. McCluskey and Loureiro (2003) further maintain that quality signalling through product labelling promotes market incentives, with relatively limited government involvement. Environmental labels or eco-labels have been used to provide consumers with information about a product, which is characterised by improved environmental performance and efficiency, compared with similar products. The certification and labelling of agricultural products and foodstuffs provide assurance that specific methods or production requirements have been met. According to the EC (European Commission), the idea of labelling product is to enable consumers to express their environmental and social values through their purchasing decisions. Labels, which are convincing, allow firms to signal superiority, quality or the presence of specific desirable attributes, and in so doing, create a potential for charging premiums based on this signal.

With specific reference to environmental labelling, Robin and Brady (2014) indicated that consumers do demonstrate willingness to pay (WTP) for meat products with perceived reductions in environmental impact. Bosworth, Bailey, and Curtis (2013) further elaborated that consumers make consumption decisions based on a product's attributes, rather than on the product itself. Before food labelling can be relied upon as an alternative option for creating a niche market, studies should be done to investigate the confidence range around estimates of consumer WTP a premium price for environmental meat labels, such as the water footprint label, and compare to cost increases associated with reducing environmental impact. There is a wide variety of energy, production practices, and other environmental product labels presently used by producers and manufacturers of food products in the global agri-food market; animal welfare-oriented production (Napolitano, 2007; Schnettler, Vidal, Silva, Vallejos and Sepúlveda, 2009); and traceability or country of origin of products (Loureiro and Umberger, 2007; Schnettler et al., 2009; Cicia and Colantuoni, 2010; Lim, 2012); and as a result, carbon labelling of products is gaining considerable interest (Vandenbergh and Cohen, 2010; Vandenbergh et al., 2011; Mintel, 2011). Thus, one may reasonably expect that consumers may be willing to pay for knowing that a product has been produced using water sustainably, as indicated by such a label on the product.

While product labelling is widely used to convey information to consumers, the problem in this case is that no information is available on consumers' actual awareness and understanding of the concept of a water footprint. Additionally, no information is currently available on consumers' preferences for the inclusion of water footprint information on the labels of the products they consume, or their willingness to pay a price premium, in particular for water footprint information, on products to incentivise sustainable use of freshwater in production. Thus, there is currently no evidence available on the prospects of such a niche marketing strategy being employed as a means to incentivise sustainable use of freshwater for beef production in South Africa.

Numerous studies have been done on consumers' willingness to pay for eco-labelling and carbon footprint information; on Malaysian consumers' WTP towards eco-labelled food products in Klang Valley (Mohamed et al., 2014); on how much consumers are WTP for low carbon products in China (Shuai et al., 2014); on consumer WTP a price premium for environmentally certified wood products in US (Aguilar and Vlosky, 2006) and on eco information and its effect on the consumer values for environmentally certified forest products (O'Brien and Teisl, 2004).

Nevertheless, there is limited research being done on the actual awareness and understanding by consumers of the water footprint concept and their willingness to pay a premium price for a product that is certified to have used freshwater resources in a sustainable manner. Additionally, there is no information available on consumers' preference for the inclusion of water footprint information on the labels of products that they consume, or their WTP a price premium for such information on the product labels to particularly incentivise sustainable use of water in beef production.

The aim of this research is to contribute to quantifying the scope for using water footprint information on product labels as a sustainability indicator to incentivise sustainable freshwater use. This is achieved by examining consumers' awareness of the concept of a water footprint, and their willingness to pay a price premium for water footprint labels on beef products. The aim will be achieved through pursuing a number of objectives.

Objective 1: Explore consumers' awareness of the concept of a water footprint as a measure of sustainable use of freshwater.

Objective 2: Investigate consumers' preferences for information of the water footprint of the food product on the label of the product that is consumed.

Objective 3: Determine the amount of money that consumers are willing to pay for information of the water footprint of the product as an indicator of sustainable freshwater use on the label of the product that is consumed.

Objective 4: Examine the determinants of willingness to pay for water footprint information.

The rationale of this study is to propose a new way to improve the freshwater resource usage in the South African beef industry. This can be achieved by introducing water footprint information labels on beef products. If producers can prove that the freshwater resource has been used sustainably in the production process of beef products, they might then be able to charge a premium price and thereby can create a niche market.

Niche marketing has been gaining popularity amongst research studies that focus on consumer acceptance of value-added differentiated products. Looking at consumer economics literature, there are a number of studies that have focused on consumer preferences, awareness and willingness to pay price premiums for product attributes, such as country of origin, safety attributes, and environmentally friendly or organic products, to mention a few of many attributes (Aguilar and Vlosky, 2006; Janssen and Hamm, 2012; Olynk et al., 2013; Robin and Brady, 2014; Shuai et al., 2014). Attribute labelling on products seems to be a significant factor in creating a new niche market, particularly for the products produced in industries that are considered to have a high water footprint, such as the South African Beef industry.

6.2 DATA AND METHOD

6.2.1 Data

The water footprint concept is a relatively new concept, thus a brief explanation of the concept to consumers is of paramount importance to ensure accuracy of the information. The collection of data involved, firstly, getting the primary idea on generally considered product attributes when consumers differentiate the quality and safety of beef products, labelling of certification, as well as their preferences for these attributes. This knowledge was then used in the development of the of the survey questionnaire. Secondly, direct interviews with consumers were conducted around selected meat retail shops to collect the data for analysis so as to address each objective of the study. In the survey questionnaire, the assumption was made that a consumer's perception of specific beef product attributes would be revealed by the consumer's choice ratings of each carefully selected attribute, through the use of 5-point Likert-type scales and rating methods. In the analysis of the data, a multi-attribute valuation method will be used because of its ability to allow researchers to estimate values for multiple attributes of a product and their trade-offs, concurrently (Merino-Castello, 2003). For the study, the interest is to consider several beef attributes simultaneously and attributes levels, as well the trade-offs among alternatives in the replicated real-life purchasing situation.

6.2.1.1 Development of the questionnaire

The developed questionnaire captured information regarding consumers and household characteristics. The information that was used as bases to frame the questions, including factors that influence consumer preferences and willingness to pay for attributes on beef products, was obtained from a literature review of studies on consumer willingness to pay. The questionnaire that was used to collect the information for this study is a combination of both open- and close-ended question, together with Likert-type scales and rating options for the correspondents to choose from to rate the various levels of importance of the different product attributes presented.

The questionnaire was divided into four sections, which comprise Section A: Personal and Household Characteristics; Section B: Awareness and Knowledge on Environmental Sustainability indicators; Section C: Attitude and Perception towards Environmental Sustainability; and Section D: Choice Experimental Survey.

Section A of the questionnaire outlines quantitative variables, such as age, income, gender, household size, educational level, race, and marital status, as well as type of occupation. The rationale behind including these quantitative variables, according to Verbeke (2005) and Grebitus et al. (2015), is that they have a significant influence on consumers' choices and preferences. The knowledge of variables, such income, age, and gender of the consumers that are willing to pay for sustainability information, will have a significant influence on market segmentation. Sustainability decisions may be directly or indirectly influenced by consumer consciousness and education level.

Numerous studies have revealed that individuals with high levels of education tend to make rational decisions towards environmental sustainability practices (Verbeke, 2005; Da Silva et al., 2014; Grebitus et al., 2015). Similarly, the authors also found that people with high levels of disposable income tend to have positive attitudes towards environmental sustainability. The positive attitudes of these individuals tend to be transferred to willingness to pay for product sustainability attributes. Owusu and Anifori (2013) revealed that the household size has a negative influence on the willingness to pay. The authors further concluded that people with relatively large household sizes tend to be less willing to pay price premiums for product attributes, due to financial constraints. The South African consumer profile is characterised by different races and cultures (Ungerer and Joubert, 2011; Dreyer, 2013). Therefore, heterogeneity reflects in how individuals perceive product sustainability attributes to exist; hence, the importance of the race question in the study.

Section B of the questionnaire outlines awareness and knowledge on a water footprint as an environmental sustainability indicator. According to Prinsloo et al. (2014), product labels have a significant influence in the rational, pre-purchase evaluation of the consumer, and more especially if the consumer is aware of the attributes indicated by the product information label. Consumer awareness and knowledge of environmental sustainability indicators is of utter importance in consumer decision-making and willingness to pay a price premium for product attributes. Section B, in addition, seeks to create consumer awareness and knowledge of product quality through information labelling. This is to promote the concept of water footprints among consumers, across the population, with the hope of creating sustainable water resource usage amongst consumers. Consumer behaviour models have shown that there is a significant role that consumer awareness and knowledge play in all phases of the consumer decision-making process. Therefore, Section C of the questionnaire is there to provide comprehensive information on the awareness, knowledge and preferences for sustainability information in South African consumer market.

Section C of the questionnaire is focused on consumers' perceptions towards environmental sustainability. Research has shown that there is a significant relationship between consumer perception and preferences. Numerous researchers have mentioned that there is heterogeneity in preferences among consumers, which may be significantly explained by consumer perception and attitudes (Roosen, Lust and Fox, 2003; Lusk and Schroeder, 2004; Lusk and Parker, 2009; Olynk et al., 2010). With the knowledge that carbon and water footprints are environmental product attributes, which provide information for environmental sustainability. The questions in Section C seek to investigate consumers' attitudes towards environmental sustainability.

Section D sets out the choice experiment survey that comprises three sets of choices. The choice sets are designed to generate information on beef purchasing behaviour. The choice sets cover four important product attributes. The attributes set out are: the type of beef, which consists of two levels (organic or conventional beef); water and carbon footprint information attributes, at two levels (assured footprint information on product labels or not assured); and finally, prices of the various product options were included.

Price were given at three levels (R179.99/1 kg, 159.99/1 kg, and R185/1 kg) and these prices are consistent with Woolworths' beef prices per Kg for Free-Range Matured, Thick-Cut Beef Rump Steak, and Non-Organic, Mature Thick-Cut Beef Rump Steak.

6.2.1.2 Data collection

Data was collected through a survey conducted on 201 beef consumers, through personal interviews, most of which were conducted on Saturdays from 09:00 to 19:00. The particular day was selected in order to capture a wide spectrum of the targeted sample of consumers.

Subsequently to ensure that the principal aim which is to elicit consumer willingness to pay a premium price for beef products that have water footprint certification labels. The survey was conducted through personal interviews and a questionnaire was used an instrument to collect the data. The questionnaire was a combination of open-ended (House size), closed-ended (Beef Products purchasing frequency – Once per month, 2-3 times per month, 4 or more times per month, Once per week, 2-3 times per week); dichotomous (Awareness of water scarcity: Yes or No); matrix (Water Footprint Knowledge: 1=strongly disagree, 2= disagree, 3=Neutral, 4= Agree, 5=Strongly agree); and multiple-choice (Choice Experimental Survey options: Option A, Option B, or None) types of questions.

In order to have all the possible product attribute combinations in the experimental choice sets, a factorial design would normally be needed to be used. However, a factorial design would result in a significantly large number choice sets, which would not be viable to work with. Therefore, alternative techniques – orthogonal main effects design combined with a blocking strategy – were employed to determine the three different choice scenarios to be contained in the choice experiment design. The latter-mentioned combination of methods resulted in three sets of choices in the experiment design. The choice sets include four important product attributes: i) the type of beef with two levels namely, organic/free range beef and non-organic; ii) Water Footprint (WFP) information with two levels namely, assured WFP information and not assured WFP information; iii) Carbon Footprint (CF) information with two levels, namely Yes or No for assured CF information on product labels; and iv) prices with three levels (ZAR179.99/1 kg, 159.99/1 kg, and ZAR185/1 kg). These prices are consistent with Woolworths' beef prices per Kg for Free-Range, Matured Thick-Cut Beef Rump Steak and Non-Organic, Mature Thick-Cut Beef Rump Steak. The respondents were expected to select one alternative each in all the three sets of choices presented in the choice experiment. The table below shows the attributes and their level in the choice experiment.

Table 6.1: Attributes and their level in choice experiment

Attribute	Beef rump steak	Categorical level
1. Water footprint	1. 15415 l/kg	Low
	2. 17300 l/kg	Medium
	3. 17387 l/kg	High
2. Carbon footprint	1. 22.90 $kgCO_2e$	Low
	2. 26.37 $kgCO_2e$	Medium
	3. 27.50 $kgCO_2e$	High
3. Beef Type	1. Organic beef	
	2. Non organic beef	
4. Price	1. ZAR 159.99/ kg	Low
	2. ZAR 179.99/ kg	Medium
	3. ZAR 185.00/ kg	High

6.2.1.3 Target population characteristics

In this study, the target market comprises threefold characteristics: firstly, the target participants are regular consumers of red meat, especially beef, products; secondly, the participants are the main grocery buyers in their households; and thirdly, the participants are in the middle- to upper-class LSM groups, as measured and classified according to the Leaving Standard Measure (LSM), developed by South African Research Foundation (SAARF). The rationale behind targeting LSM groups 6 to 10 is that these are considered to comprise the largest and the fastest growing consumer segment. Consumers in the aforementioned LSM groups are considered to be affluent enough to potentially afford product price premiums. Furthermore, consumers in the higher LSM groups are assumed to be environmentally and health conscious. These consumers demand information on nutritional value, origin, production process attributes, food safety consequences, social ramifications of production approaches, and animal welfare (Taljaard et al. 2006; Vimiso et al., 2012). The rapidly growing middle-class consumers reveal a significant attraction to animal-based protein sources, showing a similar behaviour to those consumers in the high LSM groups.

The targeted population for this study was selected from Centurion, in the City of Tshwane Metropolitan Municipality. The city is considered to be a home to the middle- to upper-class of consumers, who are classified as being affluent enough to potentially afford beef products, and who are health conscious and consider environmental sustainability product attributes. Figure 6.1 shows a map of the City of Tshwane Metropolitan Municipality.

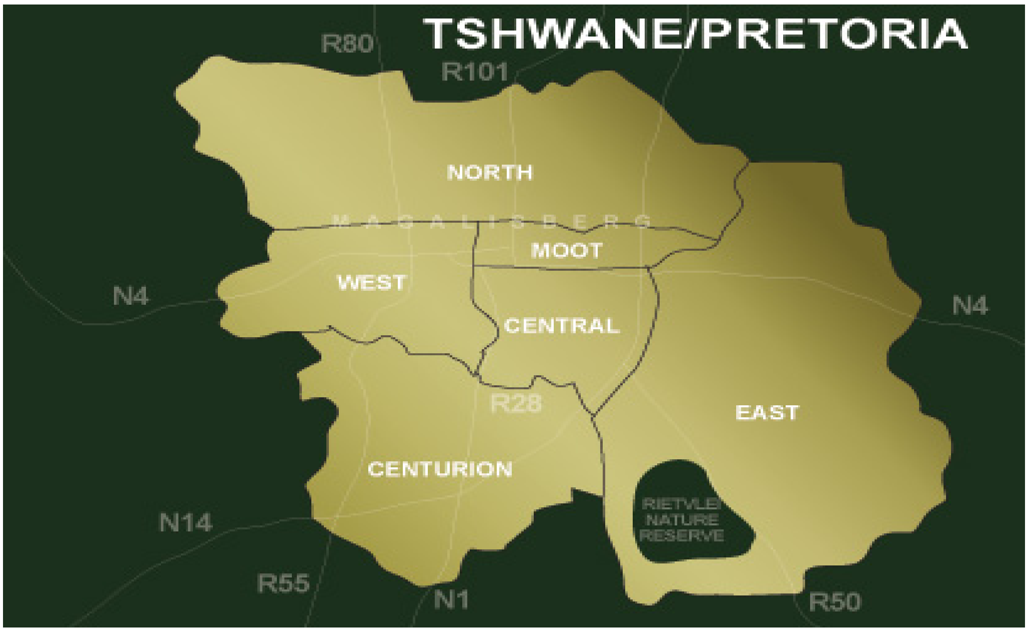

Figure 6.1: Map of the City of Tshwane Metropolitan Municipality

The map above displays the boundaries of the City of Tshwane Metropolitan Municipality. The City of Tshwane is, according to STATS SA, the largest municipality, as measured by land mass, and it is also among the six largest metropolitan municipalities in South Africa, as measured by GDP. The city is the administrative capital of South Africa and has a diverse economy, which enables it to contribute about 26.8% of Gauteng's total GDP and 9.4% of the total national GDP (STATS SA). The census carried out in 2011 reported that the City was then home to approximately 2.9 million people, of whom 75.4% were black Africans, 20.1% white people, 2% coloured people, 1.8% Asian or Indian people, and 0.7% who were 'other races'. The census further reported that 28.3% of the population was married, 7.7% were living together as married partners, 58.5% were never married, 2.9% were widowed, 0.6% were separated, and 2% were divorced.

The study was conducted in Centurion, located between Pretoria and Midrand (Johannesburg), which falls under the City of Tshwane Metropolitan Municipality. Centurion is described by many as a picturesque city that provides the best of both the city and residential experiences. According to the 2011 census, Centurion then had a population of about 236 580, with the largest portion of the population, at 59.0%, being white people, followed by black people at 29.3% as the second largest portion of the population, and then 8.4% of the population being Indian/Asian people, 2.3% being coloured people, and 1.0% being reported as 'other races'.

6.2.2 Method

6.2.2.1 Choice experiment framework

With cognisance that a good or a product has intrinsic qualities from which utility can be derived, these qualities will give rise to good satisfaction in regard to such a good or product. The choice experiment method theoretical framework is founded in Lancaster's model of consumer behaviour, and the econometric basis in random utility theory (RUT). Numerous hypothetical markets use experimental methods because of their many advantages, such as: (i) their superior CVM for analysis simulating actual choice behaviour, (ii) they rely on the accuracy and completeness of the attributes of a product, (iii) they provide use-values based on surveys for new products, and (iv) they solve for some biases in CVM, and respondents are more familiar with a choice rather than a payment approach.

The choice experiment based approach uses a random utility function that represents the integrated behavioural theory of decision-making and choice behaviour. The random utility function is composed of a deterministic component and a stochastic component, and is generally represented as:

$$Uij = Vij + \varepsilon ij \tag{6.1}$$

where V_{ij} is the deterministic component and ε_{ij} is the stochastic component (Olynk, Tonsor and Wolf, 2010). In the equation above, U_{ij} represents the ith consumer's utility of choosing option j, and V_{ij} represent the systematic portion of the utility function determined by beef product labelled information or attributes in alternative j, and ε_{ij} is a stochastic component (Lusk and Parker, 2009).

The probability of choosing alternative j is defined as, or is the probability that, the added utility from this selection that is greater or equivalent to choosing another alternative presented in the choice set. The utilities associated with each alternative are not directly observable because they consist of an unobserved component (Olynk, Tonsor and Wolf, 2010). Thus, the probability of selecting alternative j is denoted as:

$$P(j)=P(Vj+\varepsilon j\geq V\kappa+\varepsilon\kappa)\quad;\quad j\neq\kappa\ \forall j\in N \tag{6.2}$$

where N is the total set of alternatives that is available to the participant, and the resulting probability that alternative j can be expressed by:

$$P(j)=\frac{e^{u\beta Xj}}{\sum_{K\in N}e^{u\beta Xk}} \tag{6.3}$$

where u is a scale parameter that is inversely related to the variance of the error term (Olynk et al., 2010; Lusk et al., 2003). With the assumption that the systematic component of the utility U_{ij} is linear in parameter, the specification of the general model is given as:

$$Vj=\beta 1Xj1+\beta 2Xj2+\ldots\ldots+\beta nXjn$$

(6.4)

where X_{jn} is the nth attribute for alternative j, and β_n is a vector of parameters associated with the nth attribute of the jth alternative. With multinomial logit models, the assumption is that homogenous preferences exist for the product attributes. With the knowledge revealed in recent literature which suggests that consumers have heterogeneous preferences (Roosen et al., 2003; Lusk and Schroeder, 2004; Lusk and parker, 2009; Olynk et al., 2010). The usage of a model that takes into account heterogeneous consumer preference is necessary for this study. A commonly used method to evaluate preference heterogeneity is through the estimation of Random Parameters Logit (RPL) models. By making use of the RPL models, heterogeneity can be directly estimated across the evaluation attributes. In addition, the RPL model allows for random taste variation within the surveyed population and allows correlation in unobserved factors overtime, and is free of independent of irrelevant alternative assumption (Olynk et al., 2010).

Choice experiments are built on the assumption that individual i achieves utility [U_{ijt}] from selecting alternative j from a predetermined set of κ alternatives contained in choice set C, in situation t. Utility is composed of a systematic utility function [V_{ijt}] which depends on the attributes of an alternative and a stochastic component [ε_{ijt}]. When following Olynk et al. (2010) and Lusk et al. (2003), the utility of alternative j can generally be presented as follows:

$$Uijt = Vijt + [Uij + \varepsilon ijt] \quad (6.5)$$

where Vijt is the systematic utility function, Uijt is the normally distributed alternatives over all consumers and alternative error term, but not choice set, and $\varepsilon\mathrm{ijt}$ is the stochastic error term which is independently and identically distributed over all consumers, attributes and choice sets. Therefore, the assumption is that individual i will choose alternative j if $\mathrm{Uijt} > \mathrm{Ui\kappa t}$ $\forall \kappa \neq \mathrm{j}$. Subsequently, individual i's probability of selecting alternative j can be expressed as:

$$P_{ijt} = \mathrm{Prob}(V_{ijt} + \left[U_{ij} + \varepsilon_{ijt}\right] > V_{i\kappa t} + \left[U_{i\kappa} + \varepsilon_{ijt}\right]; \quad \forall_{\kappa} \in c \quad \forall_{\kappa} \neq j \quad (6.6)$$

The study will estimate two specifications of the RPL model. The first model will only include the choice specific attributes. These attributes include beef type, water footprint, carbon footprint and price.

$$Vi = \beta_1 beeftype + \beta_2 WFP + \beta_3 CFP + \beta_4 price + \varepsilon \quad (6.7)$$

The second specification of the RPL model will allow interaction between individual characteristics and the specific attributes.

$$\begin{aligned} V_j = {} & \beta_1 beeftype + \beta_2 WFP + \beta_3 CFP + \beta_4 price + \beta_5 WFP * age + \beta_6 WFP * gen \\ & + \beta_7 WFP * edu + \beta_8 WFP * hsize + \beta_9 WFP * awereness + \beta_{10} WFP * race \\ & + \beta_{11} WFP * inc + \beta_{12} WFP * maritalstatus + \beta_{13} CFP * gen + \beta_{14} CFP * age \\ & + \beta_{15} CFP * edu + \beta_{16} CFP * hsize + \beta_{17} CFP * awereness + \beta_{18} CFP * race \\ & + \beta_{19} CFP * inc + \beta_{20} CFP * maritalstatus + \varepsilon \end{aligned} \quad (6.8)$$

Numerous studies on Willingness To Pay always include as an attribute and literature reveals that to estimate willingness to pay, a price attribute is required. “Willingness to pay” in this study is defined as a price at which the respondent is indifferent between buying and not buying the product. This simply means that if the product is offered to a consumer at his willingness to pay, his probability of making a purchase is equal to 50%. With the use of this definition, willingness to pay can be said to be the ratio between the product preference β as well as the product-specific attribute X, divided by the price perimeter P, which is the change in utility due to a rand price change. This can be expressed as:

$$WTP = -\frac{\beta * X}{P} \quad (6.9)$$

6.3 RESULTS AND DISCUSSION

The chapter will be divided into 3 sections starting with section. This section provides a discussion of the results on consumer awareness of the water footprint information. A discussion will follow on consumers' preference for water and carbon footprint information on food products, and willingness to pay for water and carbon footprint labelled food products.

6.3.1 Consumer Awareness of Water Footprint Concept

An analysis was done in SPSS to assess consumers' awareness of the environmental factors that need to be considered in the water footprint information. Assessing consumer awareness is very important and it is evident in numerous WTP studies (Aguilar and Vlosky, 2007; Wong, 2009; Owusu-Sekyere, Owusu and Jordaan, 2014; Grebitus, et al, 2015). Hence, questions concerning climate change and scarcity of water in the agricultural sector were covered. The results are presented in Figure 6.2 below. The sampled population results indicate that 98% of the respondents are aware of climate change, 95.5% are aware of water scarcity, 94.5% are aware that water scarcity in South Africa is expected to worsen in the future, 90% are aware that water used for production purposes in South Africa is scarce, and 85% of the respondents are aware that some crops use more water than others do.

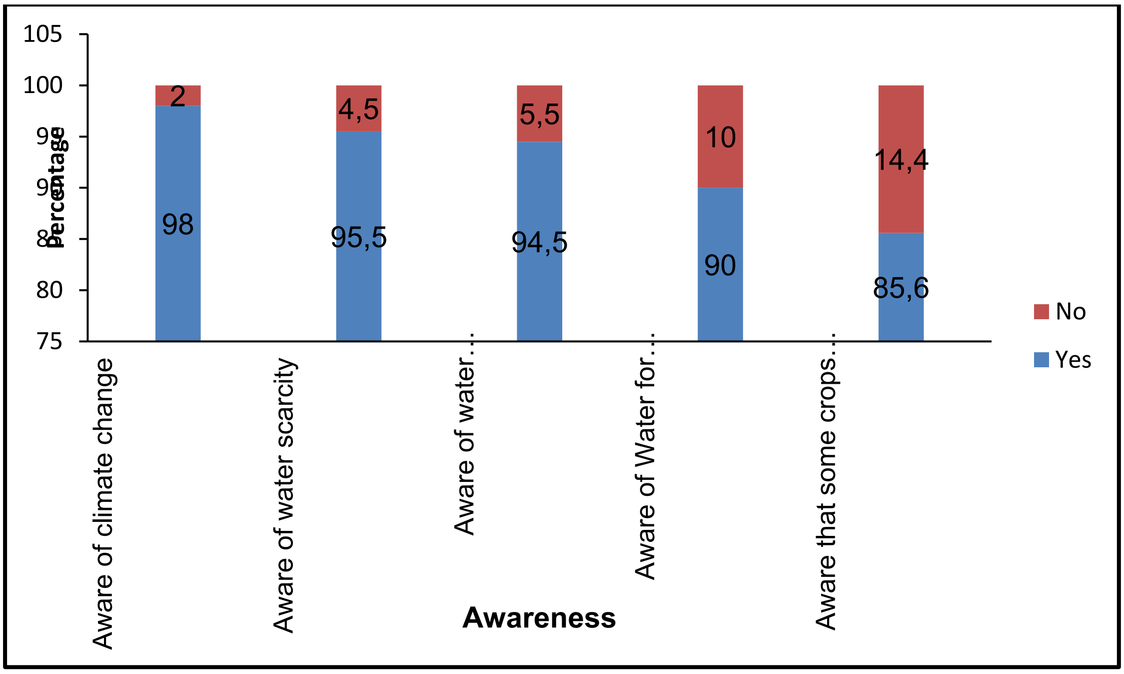

Figure 6.2: Consumer awareness of water scarcity and climate change
Authors' calculations (2016)

The results imply that most of the respondents are aware of the environmental impact that agricultural production has, especially for the freshwater resource. Figure 6.3 shows the sources of information distribution about environmental sustainability. The greatest source of information as indicated in the figure is the radio, at 25%, followed by newspapers, at 24%. The reason for these two sources being so prominent may be that, because 38.3% of the respondents do private work and 35.3% work for government, the respondents are occupied for the larger part of the day and may not have time to use other mediums as effectively as the radio and newspapers.

While product labels can be used to convey information to consumers, the water footprint concept may not be well known among all consumers, thus a niche marketing strategy may not be able to incentivise producers for sustainable water use. Consumer awareness of the water footprint, as a sustainability indicator, may be very important in the sustainability of the niche market. Policymakers and producers may use different media platforms to create awareness concerning the importance of sustainable water use.

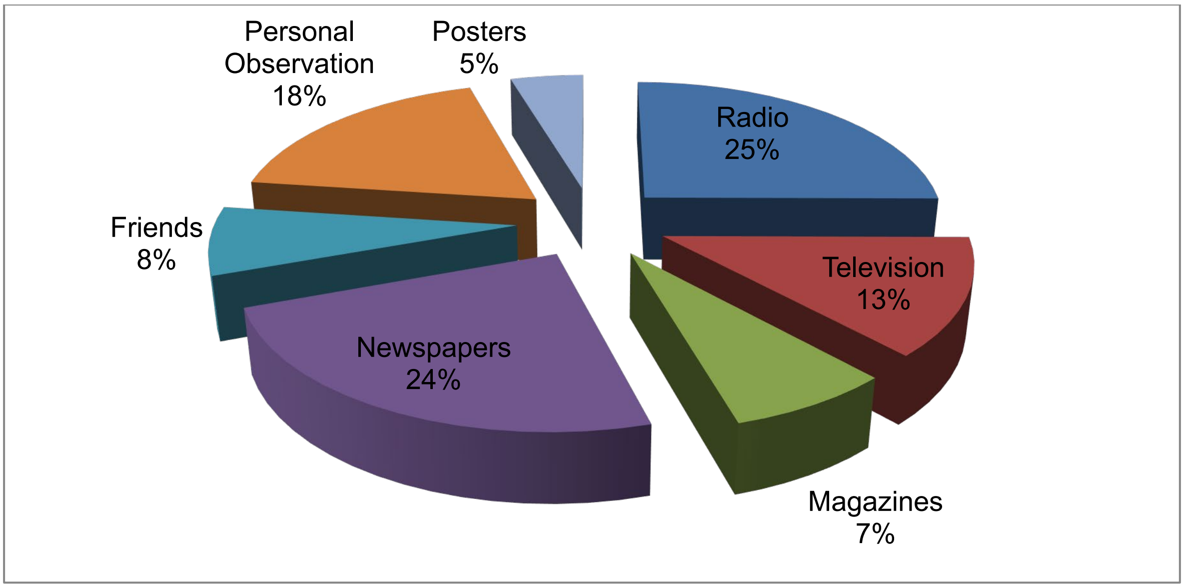

Figure 6.3: Consumer sources of information concerning environmental conditions
Authors' calculation (2016)

For the purposes of this study, consumers were asked to select their sources of information concerning climate change and environmental conditions. The results are presented in Figure 6.3 and show that 25% of the respondents sourced information from radio, 24% from reading newspapers, 18% from personal observation, 13% from television, 8% from friends, 7% from magazines, and 5% from posters. The results have proven that consumer sources of information differ according to their preferences and daily occupations. Therefore, policymakers may have to consider different platforms for different consumer segments. For producers to reach the minimum required awareness to successfully create a niche market for water footprint sustainable beef products, the results show that they may have to use the radio, newspapers and television, as these platforms sequentially have the highest percentages of the surveyed population using them as sources of information.

6.3.2 Consumer Preference for Water Footprint Information

To establish the determinants of consumer willingness to pay for beef product attributes, two specifications of the RPL model were estimated. The first specification of the RPL model included only the choice-specific attributes of Price, WFP and CFP. The dependent variable was set to be binary, therefore '1' if the consumer selects an alternative, and '0' otherwise. To account for the heterogeneity in consumer preferences, all the explanatory variables were specified to vary normally across consumers, except price. The second specification of the RPL model included both the specific attributes and interaction terms.

Table 6.2 presents the empirical results derived from the random parameter logit model. The price coefficient, as shown in the results, is statistically significant and it is negative, as expected. Utility is expected to decline with higher prices (Hensher and Greene, 2003; Lusk and Schroedern, 2004; Janssen and Hamm, 2012) hence the negative price coefficient. The water footprint coefficient estimate is statistically significant, at 10% level, and it is negative. This implies that the respondents tend to choose beef products with lower water footprints, rather than beef products with higher water footprints.

The standard deviation for the water footprint estimate is significant, at 1% level. This shows that preference heterogeneity exists among the respondents for water footprint information. This also implies that some respondents tend to prefer beef products with a lower footprint more than others do. Similarly to the water footprint, the results reveal significant negative coefficient and standard deviation estimates for the carbon footprint. This also implies that the respondents tend to choose beef products with a low carbon footprint. The significant standard deviation shows that respondents have heterogeneous preferences concerning beef product carbon footprints.

The results provide the rationale for the inclusion of carbon and water footprint information labels on beef products as sustainability indicators for influencing consumers' purchasing choice behaviour. In Table 6.2, the standard deviation estimates of WFP and CFP are both statistically significant, and the utility estimates of the significant standard deviation estimates calculated cannot be interpreted as being representative of the entire sample. In order to account for the differences in marginal utilities and the effects of socio-economic factors, interaction terms were included in the random parameter model.

Table 6.2: Random parameter logit estimates with only choice-specific attributes

Variable	Coefficient estimates		Standard deviation estimates	
	Coefficient	Std. deviation	Coefficient	Std. deviation
Water footprint (WFP)	-6.07*	3.15	0.39***	0.05
Carbon footprint (CFP)	-8.39 **	3.92	0.52***	0.02
None	-0.06***	(0.01)	-0.15***	(0.04)
Price	-1.15***	0.29		
AIC	88.65			
BIC	73.32			
Log-likelihood	-27.32			
McFadden's (ρ^2)	0.23			
Observations	201			

*** =significant at 1%, ** =significant at 5%, * = significant at 10%
Presented model was estimated using NLOGIT 3.0.
Values in parentheses are standard errors.
Source: Authors' calculations, 2016

The results presented in Table 6.3 reflect the random parameter logit model with interaction terms. Literature has revealed that people's choice behaviour is significantly influenced by socio-economic factors (Verbeke, 2005; Grebitus et al., 2015).

The inclusion of the socio-economic factors as interaction terms allowed us to account for the different marginal utility that may exist with respect to beef product consumption. The socio-economic factors that were considered in the random parameter logit model are age, gender, educational level, household size, marital status, consumer awareness, and income. The results show that the coefficient estimate of WFP and consumer awareness interaction terms is statistically significant, at 1% level. This implies that preference heterogeneity exists, and that respondents with higher WFP awareness tend to choose beef products that have a lower water footprint. Concerning the carbon footprint interaction terms, the results show the coefficient estimates for CFP with gender and CFP with awareness to have a statistically significant standard deviations, at 1% and 5% levels, respectively. This implies that preference heterogeneity exists among the respondents.

The coefficient estimates of the interaction term of WFP with the socio-economic factors of age, gender, education, marital status, income and awareness are statistically significant. Education has a negative influence on preferences for beef products with high water footprints. With all other things equal, this means that the higher the level of education of the respondents is, the higher their preference for beef products with a low water footprint will be. This is in line with the findings of Owusu-Sekyere et al. (2014) and Grebitus et al. (2015). Those authors found that there are a number of factors that significantly influence consumer behaviour, and that education level is among the most prominent influencers of consumer choice or behaviour.

The interaction between WTF and marital status is significant, at 1% level, and it negatively influences consumer preferences for beef products with a high water footprint. This implies that married consumers prefer beef products with low water footprints. The interaction between WTP and gender, age, income and awareness of water scarcity are significant, at 10% level. Concerning the interaction between WTP and gender, the results show that there are disparities in terms of preference for sustainable fresh water use. Age, income and awareness of water scarcity have a negative influence on consumer preference for beef products with high water footprints.

Table 6.3: Random parameter logit estimates with choice-specific attributes and demographic interaction terms

Variable	**Coefficient estimates**		**Standard deviation estimates**	
	Coefficient	Std. error	Coefficient	Std. error
Price	-1.15***	0.29		
Water footprint (WFP)	-6.07*	3.15	0.39***	0.05
Carbon footprint (CFP)	-8.39 **	3.92	0.52***	0.02
Interaction for WFP				
WFP*age	-0.68*	0.35	-0.00	0.02
WFP*gender	23.04*	12.87	0.09	0.96
WFP*education	-5.51***	1.12	0.01	0.03
WFP*household size	-2.54	1.61	-0.15	0.45
WFP*marital status	-27.05***	6.47	0.01	0.65
WFP*income	-10.56*	5.63	1.05	4.03
WFP*aware_water_scarcity	-3.25 *	1.91	0.89***	0.08
Interaction for CFP				
CFP*age	0.55	0.35	0.00	0.01
CFP*gender	-19.58***	2.69	1.59***	0.13
CFP*education	5.21*	3.11	0.48	0.36
CFP*household size	2.10	1.63	0.29	0.46
CFP*marital status	-22.93	16.18	-3.47	9.51
CFP*income	-4.86***	0.99	-14.95	14.81
CFP*aware_$C0_2$_emission	-0.68*	0.35	-1.61**	0.75
AIC	87.06			
BIC	76.96			
Log-likelihood	-26.53			
LR	24.06***			
McFadden's (ρ^2)	0.33			
Observations	201			

*** =significant at 1%, ** =significant at 5%, * = significant at 10%
Presented model was estimated using NLOGIT 3.0. Values in parentheses are standard errors. Source: Authors' calculations, 2016

With all other things held constant, as age, income, and awareness of water scarcity of the consumer increases, their preference for beef products with a low water footprint increases. These finding are in accordance with Owusu-Sekyere et al. (2014) and Grebitus et al. (2015).

The coefficient estimates of the interaction terms of carbon footprint with gender, education, income and awareness of C02 emission are statistically significant. The interaction coefficient estimates between CFP and gender, income and awareness of C02 emissions are statistically significant, at 1% level and coefficient estimate between CFP and is statistically significant at 10% level. Income and awareness of C02 emissions respectively have a negative influence on preferences for products with high carbon footprints. Most interestingly, the results show the interaction coefficient and standard deviation estimates for both WFP with awareness and CFP with awareness to be statistically significant. This suggests that sustainable fresh-water use policies in South Africa should not only take socio-economic characteristics into account, but should also consider consumer awareness.

6.3.3 Willingness to Pay for Water Footprint Labelled Products

In the analysis of whether, and how much, consumers are willing to pay a price premium for WFP information labelled on beef products, the average willingness to pay a premium for beef products attributes and WFP labelled information were estimated by making use of the ratio of the beef product attribute and the price coefficient.

Table 6.4: WTP estimates for the RPL Model with interaction term

Attribute	WTP amounts
WFP	ZAR5.26
CFP	ZAR7.27

Source: Author's calculations, 2016

Details of the willingness to pay amounts are presented in Table 6.4. The results show that for water footprint labelled beef products, the consumer is willing to pay a price premium of ZAR5.26. In other words, this means that for the consumer to buy a beef product with a high water footprint, he or she is willing to accept a compensation of ZAR5.26 for it. For water footprint sustainable beef producers, this means that labelling products with water footprint information, which can prove that you are a water footprint sustainable producer, can be profitable.

For policymakers, this means that they may still come up with strategies that will a producer to charge a premium price for producing sustainably. This will, in turn, compensate the producer and may reduce water demand per unit of production by improving efficiency in water use. Consumers have indicated that they are willing to pay a premium to incentivise water footprint sustainable production of beef products. This implies that the strategy of charging a premium price for a water footprint sustainability indicator label on beef products may be feasible. Nevertheless, because of the preference heterogeneity among consumers, the strategy may not be applicable to all consumers and thus to the relevance of the niche marketing strategy.

6.4 CONCLUSION

The general findings were that age, gender, education and income have a significant influence on consumer preferences. Finally, from the empirical results of the random parameter logit model, details regarding consumer willingness to pay amounts were calculated. The study concludes that there is considerable preference heterogeneity at an individual level for water sustainability attributes of beef products. The profound heterogeneity in preferences is explained by socio-economic factors such as the age, gender, education and income of respondents. Besides socio-economic factors, public awareness creation and campaigns regarding threats associated with climate change, as well as water scarcity, play a significant role in influencing consumers' preferences for environmentally sustainable products.

The study also concludes that respondents were generally willing to pay a price premium for the inclusion of information indicating the sustainable use of fresh water. The willingness to pay estimates hinge on the consumers' socio-economic factors such as age, gender, education and income, as well as awareness. This suggests that the prospects of environmentally sustainable attribute labelling on beef product, and the creation of niche market for sustainability products, is feasible and may incentivise the sustainable use of freshwater for beef production in South Africa.

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CHAPTER 7

SOCIAL AND ECONOMIC IMPACT OF CHANGED WATER USE BEHAVIOUR

Authors

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Summary

Irrigated agriculture contributes significantly to the agricultural output of South Africa. The recent worst drought in South Africa forced government, policymakers and various stakeholders to change the behaviour of direct, indirect and end users of water by policy interventions (increasing of water tariffs) and implementing water restriction interventions. This Chapter applies a slightly modified version of International Food Policy Research Institute Computable General Equilibrium (CGE) and the SWIP – E (Soil Water Irrigation Planning – Energy) model. A recent Social Accounting of South Africa was utilised as a database, with other behavioural parameters. Result from SWIP – E and a CGE model established that when water restrictions are set, it is more profitable to reduce the number of hectares planted and to rather apply full irrigation to produce higher yields. The increase in the irrigation water tariff has an impact, to some extent, although the impact is at a minimal level. The main challenge is the availability of the scarce resource (water), and not the incremental of water tariff. As a result, the study recommends that without a behaviour change of farmers, it will not achieve the desired output. A government with different stakeholders should introduce a mechanism to educate farmers and enhance their understanding about the past, current and future trends of water and drought in order to plan for the future and mitigate unexpected shocks.

7.1 BACKGROUND AND MOTIVATION

Water has traditionally been considered as one of the most important natural resources in terms of contribution to the development of civilisations. The importance of water lies in the fact that it satisfies a broad group of needs, both in its role as a necessary good upon which public health and life itself depend, and in its role as a basic input in most agricultural and industrial production processes (Roibas *et al*., 2007).

Demographic and climatic factors will have the effect that periods of water shortages can be expected to reappear in the future. The factors include population growth, urbanisation, migration, industrialisation, food and energy security policies, legislation and management, and macro-economic processes such as trade globalisation and changing consumption patterns (e.g. increases in the consumption of meat and the use of technological devices have increased water consumption). This, in turn, will give rise to the need for the formulation of policies that limit consumption and change consumers' behaviours towards water use (Connor *et al*., 2015).

The increase in population and urbanisation threatens resource allocation, sustainable intensification of agriculture, food security, and environmental sustainability (FAO, 2009). With the world's population projected to reach over 9 billion by 2050, governments, stakeholders, development partners, practitioners and organisations are becoming interested in the development and implementation of agricultural and water-related polices that will yield positive impacts in terms of saving resources (water) and changing the behaviour of water users. As populations keep increasing, greater quantities of food and livestock feed will need to be produced in the future and larger volumes of water will be applied to this purpose. Irrigated agriculture will have to claim large quantities of water to produce the food required to feed the world. The main source of food for the population of the world is agriculture (Leenthech, 2016).

Cereals are by far the most important source of total food consumption: in developing countries, the consumption of cereals represents 56% of total calories taken in. It is expected that cereals will continue to supply more than 50% of the food consumed in the foreseeable future. A large proportion of cereals is produced for animal feed. Food production in the livestock sector includes meat (beef, pork, poultry, etc.), dairy production and eggs. The amounts of water involved in agriculture are significant, and most water is provided directly by rainfall.

Alavian *et al*. (2009) have suggested that changes in policies, legislation, and management could directly or indirectly induce extra and considerable effects on water demand and water availability (quantity and quality). In the absence of policy changes, population growth, urbanisation, migration, industrialisation, food and energy security policies, legislation and management, and macro-economic processes such as trade globalisation and changing consumption patterns are not only likely to aggravate water availability and quality, but also to have a significant influence on water demand.

In particular, one of the most serious causes of water shortage in many regions, including South Africa, is drought, and when this cyclical phenomenon reoccurs, the entities responsible for water supply often impose water cuts and restrictions in order to match the available supply with demand. Water restrictions have already been applied in some provinces of South Africa. Generally, water shortages give rise to the need for rationing, but the authorities frequently resort to supply cuts. The effects of policies aimed at limiting water consumption have been the subject of several studies, including those of Woo (1994) and Renwick and Archibald (1998), who quantified the welfare losses associated with various alternative rationing systems in household consumption. Under a price rise, consumers are free to consume whenever they wish. A supply cut, on the other hand, reduces the availability of the resource to consumers. This generates a distortion in demand behaviour because consumers cannot freely choose the timing of their consumption, which in turn implies that consumer utility is affected (Roibas *et al*., 2007).

South Africa, a leader in agribusiness on the continent, has a well-established agri-food sector that is facing increasing pressure from climate variability that affects production (Pereira and Ruysenaar, 2012). South Africa is not different from other countries, and recently various provinces of South Africa have had to cut water usage (water restriction) by 15%, with the agricultural sector having to reduce water use by 50%.

General Equilibrium Models (GEMs) are widely applied as a tool for economic policy analysis. CGE models have been applied in water management studies, such as that by Berck *et al*. (1990), who used a CGEM to examine the utility of reducing water consumption to solve drainage problems in the San Joaquin Valley in California. Dixon (1990) applied a CGE model to analyse the impact and efficiency of water pricing in Melbourne, Sydney, and Perth. Gomez *et al*. (2004) simulated possible water savings in the Balearic Islands using a CGE model, and Cazcarro *et al*. (2011) applied a CGE model to analyse different payment scenarios affecting direct users, exporters and end-users in order to examine user responsibilities, the impact of international markets, and macroeconomic effects on agriculture and industry in Spain.

Water resources have been crucial to South Africa agriculture. The expansion of irrigation and the creation of large-scale irrigation systems intensified public intervention, with the result that water planning has become a key tool for economic development. The main objective of this study is to assess the impacts of changes in water costs (rate) and of water restrictions on output, yield, consumption, and other macroeconomic variables. A modified version of IFPRI CGE and the SWIP – E (Soil Water Irrigation Planning – Energy) model was applied. An IFPRI CGE model was defined and adapted to suit the objectives of the study, and it was solved using GAMS and calibrated to the 2009 SAM for South Africa. The results can apply not only to South Africa, but also to Southern Africa, and globally. However, despite the increased interest in sustainable water management in food production, especially in South Africa, no empirical research exists, to the best of our knowledge, to explore and integrate human behaviours into the diverse factors influencing water use behaviours in food production.

7.2 DATA AND METHOD

7.2.1 Data

7.2.1.1 Development of the questionnaire

A structured questionnaire was designed for collecting the primary data. The questionnaire contained information on the variables that were to be used for structural equation modelling. The questionnaire captured information on the perceptions of irrigators on behavioural intentions, values and attitudes, social factors, and technical and legal factors. The items in the questionnaire were measured using continuous scales (e.g. 'strongly agree' to 'strongly disagree'), Likert scales and categorical scales (e.g. yes/no, rank from highest to lowest importance). The questionnaire was tested prior to its actual administration to establish its content validity and to improve questions, format, and scales. The questionnaire was administered through face-to-face interviews.

Behavioural intention (BIT) is the dependent variable. Farmers' behaviours toward water use was measured by exploring their behavioural intentions towards policy issues contained in the 1998 National Water Act of South Africa and other water conservation strategies. Farmers' behavioural intentions were measured regarding water pricing, water transfer, irrigation scheduling and technology, best farm management practices, water reuse, legal regimes, participating in retrofit programmes, and awareness raising (by asking participants to indicate the extent to which they agree/disagree with the statement).

Farmers' behavioural intentions (FVA) towards water use are associated with their values and attitudes and were measured by asking them to rank or rate the importance of their values and attitudes towards water use – this is mainly because the attitude of a person influences the actual behaviour of that particular individual (Luzar and Cosse, 1998). (Indicate the extent by using a 7-point Likert scale: 1 = "strongly disagree"; 7 = "strongly agree").

Subjective norms (SNO) (i.e. normative beliefs) will measure the influence of significant others towards a farmer's acceptance of water use behaviours. More clearly, farmers were asked to rate how others would approve or disapprove of their water use behaviours (Farmers' behavioural intentions towards water use are related to their subjective norms and perceived behavioural control) (indicate the extent using a 7-point Likert scale 1 = "strongly disagree", 7 = "strongly agree").

Perceived behavioural control (PBC) will measure how the acceptance of water use would be influenced by a farmers' perceived control over how water is conserved. The farmers were asked to rate factors that could help facilitate or retard their water use and conservation strategies. (Indicate the extent using a 7-point Likert scale 1 = "strongly disagree", 7 = "strongly agree").

Farmer characteristics (FAC) comprised a farmer's gender, age, education, off-farm/on-farm income, and/or employment of farmers, farming experience, knowledge about water conservation strategies, access to credit, and membership of an association.

Farm characteristics (FACA) focus on farm's size, ownership of land, land security, trajectories of farm business development, and successor plans (Farmers' values and attitudes toward water use are associated with individual, farm, and farmer characteristics, as well as trust and information/knowledge).

Household characteristics (HHC) include household size, average age of family members, and off-farm work status of farm operator's spouse.

Technical factors (TEF) include frequency of extension service delivery; government support through subsidies; and changing cropping patterns.

Institutional and legal factors (INLEF) relate to penalising unauthorised water users, blocking unauthorised wells on farms, enforcing legally required distances between wells, registering all existing lawful water uses, and issuing licences for water use (Farmers' behavioural intentions towards water use are associated with existing institutional and legal regimes).

Perceived risks and benefits (PRRB) address perceived risks of crop failure due to limited water supply, and benefits derived from water conservation.

Information factors (INF) focus on knowledge and information on water use and conservation. These include access to farming and irrigation information; knowledge of water use and conservation; and training of farmers. (Farmers' behavioural intentions towards water use are associated with their knowledge and information regarding water use).

Trust factors (TRF) include trust in the managers of irrigation facilities and trust in other irrigators/farmers (Farmers' behavioural intentions towards water use are significantly predicted by their trust for an implementing authority and trust for others to use water).

Water restriction (WR) is measured by asking farmers whether they would change their water use behaviour or not.

Prepaid water (PPW) *is* measured by asking farmers whether they would change their water use behaviour in conserving water or not (pre-paid water meters were viewed as a means of conserving water, including improved knowledge of water use; proper budgeting; convenience; no disconnection/reconnection costs; no deposits; and empowered water users (Tewari and Shah, 2003). Empirically derived weight/coefficient for each factor (a…z). The strength and the perceived power of each factor item

7.2.1.2 Data collection

Trained data collectors were recruited for administering the questionnaires to the respondent farm households. The researcher monitored the data collection process. The researcher was guided by a number of ethical considerations in the collection of primary data regarding informed consent, privacy, and confidentiality, as well as guarding against the fabrication and falsification of data. The researcher ensured that informed consent was obtained from every research participant before the research instruments were administered. An informed consent statement was designed that fully informed the participants about what the research entailed and the purpose. Strict adherence was and will be enforced in ensuring that the privacy and confidentiality of the participants are protected at all times. No personally identifiable information on the participants will be disclosed to a third party, and all interviews were conducted in the absence of third parties.

7.2.2 Method

7.2.2.1 CGE model

To evaluate the impact of different policy is driven scenarios of water on grain sub-sector (maize and wheat) was applied a modified International Food Policy Research Institute (IFPR's) economy-wide computable general equilibrium (CGE) model. A CGE model is economy-wide in the sense that it includes all sectors. Such models have gained increasingly wide acknowledgment in terms of policy evaluation. This model permits a systematic analysis to be made of external price shocks and shifts in other exogenous variables, while tracking the effects of such changes on various actors in the economy. It is possible to distinguish the implications of various policies and external price regimes with respect to their effects on several variables of interest: macroeconomic variables, sectoral output, employment, household income, and welfare (Nielson, 2002; Bahta *et al*., 2014).

The underpinning database used for the model is a social accounting matrix (SAM) of the base year 2009, developed in 2014 by the International Food Policy Research Institute (IFPRI) (2014). The model is initially set up to replicate the base year SAM by appropriately calibrating the parameters of the model (see Addendum 'A' for a mathematical summary for the standard CGE model – Lofgren *et al*., 2002). Most of the parameters of the model can be and are calibrated from the SAM; however, the Armington elasticities are obtained from Gibson for some agricultural and non-agricultural products and for selected agricultural products (Gibson, 2003; Ogundeji et al. 2010)

Adopting the work Cazcarro *et al*. (2011), taxes will be included in the model after calibration as follows:

$$TAXPAR('TX', AC) = TAXPAR('TX', AC) + Scenario('TX", AC) \tag{7.1}$$

Using the tax rates defined by:

$$t_{AC} = \frac{TAXPAR('TX', AC)}{SAM(AC, 'TOTAL')} \tag{7.2}$$

where TAXPAR is the set of the tax accounts, TX comprises activity tax, export taxes and consumption taxes, AC represents activities or commodities, and Scenario is the increment in payment in proposed scenarios.

A CES production technology is used for irrigated farming:

$$QA_a = \alpha_a^a (\delta_a^a \cdot QVA_a^{-P_a^a} + (1 - \delta_a^a) \cdot QINTA_a^{-P_a^a})^{\frac{-1}{-P_a^a}} \tag{7.3}$$

$$\frac{QVA_a}{QINTA_a} = \left(\frac{PINTA_a}{PVA_a} \frac{\delta_a^a}{1-\delta_a^a}\right)^{\frac{1}{1+P_a^a}} \tag{7.4}$$

α_a^a is used change the level of agricultural productivity. The production technology of the rest of activity is a Leontief technology expressed as:

$$\mathrm{QVA_a} = \mathrm{iva_a} \cdot \mathrm{QA_a} \tag{7.5}$$

$$\mathrm{QINTA_a} = \mathrm{inta_a} \cdot \mathrm{QA_a} \tag{7.6}$$

The water saving of the model will be estimated as:

$$water\ saving\ via\ export_c = \lambda^1 \cdot QE.L_c - \lambda^0 \cdot QEC_C \tag{7.7}$$

$$water\ saving\ via\ households_{c,h} = \lambda^1 \cdot QH.L_{c,h} - \lambda^0 - QHC_{c,h} \tag{7.8}$$

where QEC_c exports in calibration scenario; $QE.L_c$ exports in final scenario; $QHC_{c,h}$ household consumption in calibration scenario; $QH.L_{c,h}$ household consumption in final scenario; λ^0 vector of water value in calibration scenario; ; λ^1 vector of water value in calibration in final scenario.

The consumer price index (CPI) is fixed and functions as numeraire will be in the model:

$$CPI = \sum_{c \epsilon C} PQ_c - cwts_c \tag{7.9}$$

where $cwts_c$ weight of commodity 'c' in the consumer price index and PQ_c is price of composite good 'c'.

The production elasticities were set at 1.2 and 0.6. Household expenditure was aggregated into 14 income classes, up to three broad categories (i.e., poor household, encompassing the bottom 40% of the income earning households; a middle class, covering 40-80% of the income earning households; and the rich households above 81% income earning households). The household income elasticities were set for all rich households at 0.5 for agricultural products, 0.7 for mining products, 0.8 for industry sectors, and 1.3 for other service sectors. Middle-class households were assumed at 0.6 for agricultural products, 0.8 for mining products, 0.85 for industry sectors, and 1.4 for other service sectors. Income elasticities for all poor households were assumed at 0.7 for agricultural products, 0.9 for mining products, 0.9 for industry sectors, and 1.5 for other service sectors. The general trend is consistent with literature in that poor households exhibit higher income elasticities than richer households do, reflecting the larger consumption share of subsistence expenditure (Philippides, 2011). Export demand elasticities were set at 0.9 and 2. The Frisch parameter, which allows for the determination of a subsistence floor in household expenditure, was set to a constant across all household deciles at a value of 2.

7.2.2.2 SWIP-E model

The SWIP – E (Soil Water Irrigation Planning – Energy) model (Venter, 2015) was used to calculate the effect of water restrictions on the crop yield, the area planted, and the gross margin of maize and wheat. The SWIP – E programming model is based on the SAPWAT optimisation (SAPWAT – OPT) model (Grové, 2008) that optimises a daily soil water budget for a single crop. The SAPWAT – OPT model was further developed to optimise water use for a crop rotation system. Detailed electricity cost calculations are included in the model to facilitate electricity management in an irrigated way.

The objective function maximises the gross margin of a crop rotation system. Equation (7) represents the objective function used in the SWIP – E model:

$$MAX \; GM := \sum_c PI_c - \sum_c YDC_c - \sum_c ADC_c - \sum_c IDC_c \qquad (7.10)$$

where:

GM	Total gross margin (R)
PI_c	Total production income for crop *c* (R)
YDC_c	Total yield dependent costs for crop *c* (R)
ADC_c	Total area dependent costs for crop *c* (R)
IDC_c	Total irrigation dependent costs for crop *c* (R).

The first four terms of the objective function calculate the gross margin for a specified crop rotation. The gross margin is calculated by subtracting the yield, area, and irrigation dependent costs from the production income.

Production income, yield, area, and irrigation-dependant costs are based on the calculation procedure recommended in Venter (2015). Production income is a function of yield and area planted for each crop and the price of the crop. Production income is calculated by multiplying the crop yield with the crop price and area planted. The calculation of yield-dependent costs is based on a cost reduction method (Grové, 1997). Area-dependent costs include all input costs which will change the area planted. Irrigation dependent costs (IDC) include electricity costs, labour costs, repair and maintenance costs, and water costs of the irrigation system. Total electricity costs depend on the type of electricity tariff in force. All tariff options include a fixed cost and a variable cost. Fixed costs have to be paid every month, irrespective of whether electricity was used or not, while variable costs have to be paid for actual electricity consumption. Variable electricity costs are a function of management (hours pumped), electricity tariffs, and irrigation system design (kW).

The calculation procedures for labour, repair and maintenance costs are based on formulas proposed by Meiring (1989). Water charges are a function of the irrigation water applied, the area planted, and the water tariff charged by the water user association.

7.2.2.3 Description of scenarios

The reasoning behind the selection of the particular policy scenarios used for the analyses was an increase of water tariff and water restriction measures affecting direct user (farmers), the indirect user (agri-food industry) and end users (households), in order to examine user responsibility and macroeconomic effects on agriculture and other industries. It believed that supply cuts (water restriction measures) and pricing policies (increases in the water tariff) can be seen as a water conservation strategy.

The reasoning behind the selection of the particular scenarios used for the analyses is as follows: the worst drought in South African history since 1982 and climate change triggered to reduce water usage by 15% (Water and Sanitation Department, 2016) and water restriction tariff (an increase of water tariff) and punitive measure. The restriction tariffs are imposed in a stepped manner: 10% extra on consumption between 20 000 litres and 30 000 litres/month; 20% on consumption between 30 000 and 40 000 litres/month; and 30% on consumption above 40 000 litres/month. Based on details from the Water and Sanitation Department (2017), the South Africa irrigation water tariff is currently 14.91cents/m^3, on average.

A steep fall (15%) in water usage and an increase of 30% in the water tariff was chosen for the purpose of determining the relative size of impact in the CGE model and the SWIP – E (Soil Water Irrigation Planning – Energy) model, which was used to calculate the effects of water restrictions on the crop yield, area planted, and gross margin of maize and wheat. Considering the potential implications of such events to direct user (farmers), yield, the indirect user (agri-food industry) and end users (households) in order to examine user responsibility and macroeconomic effect on agriculture and other industries.

7.3 RESULTS AND DISCUSSION

7.3.1 The SWIP-E Model

The analysis was done for a full water allocation scenario and for a water restriction scenario, where a small centre pivot and a large centre pivot were used. A scenario was the amount of hectares is fixed and where the number of hectares are variable was analysed. A water restriction of 15% was used, thus the full water allocation of 1000 mm/ha/year was reduced to 850 mm/ha/year.

Table 7.1 reflects the results for a fixed and a variable hectare scenario for a full water allocation and a water restriction scenario. When the amount of hectares is fixed, the crop yield is close to the potential yield for maize (18 ton/ha) and for wheat (8 ton/ha) under a full water allocation for both centre pivot sizes. However, when water restrictions are introduced, the crop yields decrease to 13.98 ton/ha and 7.10 ton/ha for maize and wheat, respectively. The decrease in yields results in a decrease in gross margins for both centre pivot sizes. Gross margin decrease by ZAR157 475 and ZAR248 513 for the small centre pivot (30.1 ha) and the large centre pivot (47.7ha), respectively.

The decrease in gross margin is mainly attributable to the decrease in production income. Area-dependent costs remain constant, but irrigation- and yield-dependent costs decrease due to the decrease in water applications and crop yields. However, the effect of the decrease in production income is more significant than the decrease in irrigation- and yield-dependent costs, and therefore, the decrease in gross margin.

When the amount of hectares is variable, the crop yields for maize and wheat remain constant with a full water application as well as with a water restriction scenario. However, the amount of hectares planted to maize reduces. The main reason for the decrease in the number of hectares planted to maize is to apply full irrigation and produce a higher yield, since the income received from higher yields is more than the costs to produce on more hectares, thus resulting in higher gross margins. The gross margins for the small and large centre pivots increased by ZAR27 386 and ZAR18 519, respectively, under a water restriction scenario.

Table 7.1: Results for a fixed and variable hectare scenario for full water allocation and water restriction

		Fixed Hectare Water Allocation (mm/ha)				Variable Hectare Water Allocation (mm/ha)			
		1000 Maximum Pivot Size (ha)		850 Maximum Pivot Size (ha)		1000 Maximum Pivot Size (ha)		850 Maximum Pivot Size (ha)	
		30.10	**47.70**	**30.10**	**47.70**	**30.10**	**47.70**	**30.10**	**47.70**
Yield (ton/ha)	Maize	17.53	17.53	13.98	13.98	17.95	17.95	17.95	17.95
	Wheat	7.45	7.45	7.10	7.10	7.50	7.95	7.50	7.95
Hectare (ha)	Maize	30.10	47.70	30.10	47.70	29.10	40.80	21.10	28.20
	Wheat	30.10	47.70	30.10	47.70	30.10	47.70	30.10	47.70
Applied Water (mm/ha)	Maize	553	553	429	429	568	568	568	568
	Wheat	447	447	421	421	452	514	452	514
Irrigation Dependant Costs (ZAR)	Maize	30700	52240	24477	41563	30467	45932	22134	31753
	Wheat	27292	47037	25672	44246	27548	54054	27548	54054
Gross Margin (ZAR)		899210	1425825	741735	1177312	900884	1403664	769121	1195831

7.3.2 The CGE Model I

The increase of the tariff for irrigation farming has a multiplier effect on industry and household expenditure. The output or quantity of the aggregate of marketed commodity output for agriculture, irrigated and non-irrigated wheat and maize decreases as a result of the scenario simulation and affects the relative prices of agricultural products directly, but it is insignificant (Table 7.2). This could be because the slump in the value of the rand was increasing the costs of imports such as oil and fertiliser, with shipping costs also being paid in dollars and were linked to the dollar-based oil price; however, these aspects should not outweigh the benefits of exporting on a weaker rand.

The price of value added is the amount available to pay primary inputs. The price of value added is the weighted average price that every industry pays for all the factors of production that it uses (Table 7.2). It is therefore influenced by the wage rates of labour and the rate of returns and capital. The result of the scenario indicated that the grain sector (irrigated and non-irrigated maize and wheat) value-added price decreased insignificantly.

Price of intermediate inputs paid by agricultural, maize and wheat industries, where the weights are the volume shares of individual products in the aggregate intermediate product. The result showed an increase in the price of intermediate inputs in the agriculture and grain (wheat and maize) sectors as a result of increases in purchaser prices (Table 7.2). The price of intermediate inputs for each industry depends on the production structure of each industry and the prices of the intermediate products. The majority of inputs, either imported or price derived from international prices, such as fertiliser and fuel. Based on various studies, for every one cent increase in the diesel price, the spending on fuel in the agricultural sector would increase by R10 million/annum. The industry average output price is the weighted average of the price of intermediate inputs and the price of value added. The result indicates that when the export prices of grain (maize and wheat) and agriculture sector decrease average output price decrease at a minimal rate. Moreover, the quantity of exports for the grain sub-sector (maize and wheat) and agriculture decreased, but not by much; however, the quantity of imports of maize and wheat increased insignificantly. The quantity of maize and wheat for domestic sale increased at a minimum level (Table 7.2).

Table 7.2: Result of CGE simulation

	QXXP	PAXP	PVAXP	PEXP	PMXP	PXXP	QMXP	QEXP	QDXP	PINTAXP
Agriculture and live animals	-0.00000004	-0.00000022	-0.00000036	-0.00000049	-0.00000042	-0.00000022	0.00000020	-0.00000058	0.0000000001	0.00000014
Irrigated maize	-0.00000002	-0.00000025	-0.00000030	-0.00000052	-0.00000042	-0.00000049	0.00000017	-0.00000009	0.00000012	0.00000019
Non-irrigated maize	-0.00000002	-0.00000025	-0.00000033	-0.00000052	-0.00000056	-0.00000048	0.00000023	-0.00000009	0.00000011	0.00000014
Irrigated Wheat	-0.00000002	-0.00000026	-0.00000027	-0.00000044	-0.00000042	-0.00000043	0.00000025	-0.00000004	0.00000019	0.00000014
Non-irrigated wheat	-0.00000002	-0.00000025	-0.00000028	-0.00000044	-0.00000048	-0.00000043	0.00000028	-0.00000004	0.00000018	0.00000002

Note: QXXP – quantity of aggregate marketed output (% ch); PAXP – output price of activity a (% ch); PVAXP – value added price (% ch); PEXP – price of export (% ch); PMXP – price of import (% ch); PXXP – average output price (% ch); QMXP – quantity of imports (% ch) ; QEXP – quantity of exports (% ch) ;QDXP – quantity of domestic sales (% ch) and PINTAXP Percentage **c**hange in the industry intermediate inputs

Table 7.3 gives details of the percentage change price of a factor for activity (WFAXP), economy wage (rent) for activity factor (WFXP) and factor income (YFXP) for all labour categories decrease except worker completed secondary school (FLABT).

Table 7.3: Percentage change price of factor for activity (WFAXP), economy wage (rent) for activity factor (WFXP) and factor income (YFXP)

	WFAXP				WFXP
	FLABP	FLABM	FLABS	FLABT	FCAP
Agriculture and live animals	-0.00000031	-0.00000032	-0.00000033	0.00000010	-0.00000040
Irrigated maize	-0.00000031	-0.00000032	-0.00000033	0.00000010	-0.00000031
Non-irrigated maize	-0.00000031	-0.00000032	-0.00000033	0.00000010	-0.00000034
Irrigated Wheat	-0.00000031	-0.00000032	-0.00000033	0.00000010	-0.00000026
Non-irrigated wheat	-0.00000031	-0.00000032	-0.00000033	0.00000010	-0.00000033
WFXP	-0.00000031	-0.00000032	-0.00000033	0.00000010	
YFXP	-0.00000031	-0.00000032	-0.00000033	0.00000010	-0.00000004

Note: WFAXP – price of factor f for activity a (%ch); WFXP – economy-wide wage (rent) for factor f (%ch); FLABP – workers with primary school or less; FLABM – workers completed with middle school; FLABS – worker completed secondary school; FLABT– worker completed secondary school; FCAP – Capital and YFXP – factor income (%ch)

Results for selected macro-economic indicators are shown in Table 7.4. An increase of irrigation water tariff leads to increase GDP and net income tax at a minimal level, at nominal and real value. However, at the industry level, the increase of irrigation water tariff does not have an impact on the GDP of industry, except irrigated wheat. The consumption level remains increasing at a minimal level even if the tariff increase.

Table 7.4: Macroeconomic Indicators

Variables	Nominal	Real
PRVCON	0.00000006	0.00000001
EXPORTS	-0.00000104	-0.00000061
IMPORTS	-0.00000101	-0.00000058
GDPMP	0.00000007	0.000000003
NETITAX	0.00000146	0.00000005
Agriculture and live animals	-0.00000041	-0.00000005
Irrigated maize	-0.00000031	-0.00000001
Non-irrigated maize	-0.00000034	-0.00000002
Irrigated Wheat	0.00000026	0.00000002
Non-irrigated wheat	-0.00000034	-0.00000005

Table 7.5 shows the results for household consumption, expenditure, income, and welfare. The result for household consumption expenditure indicated that poor household categories are the most affected when compared with the rest of household categories as a result of a weaker rand. The impacts on household income and welfare, measured in terms of equivalent variation, are also presented in Table 7.5. According to Gohin (2003), one of the main tasks of applied economists is the computation and explanation of the welfare effects of policy reform or other shocks to the economy that may be of interest. The effects of the simulated results on household welfare in the South Africa can further be measured by the concept of Equivalent Variation (EV). EV is a welfare measure indicating whether the money equivalent of the households are better (worse) off as a result of the shock/simulation.

The results indicated that poor household groups are the most affected. The highest gain observed was in rich-income households' gain in welfare (EV). The lowest welfare gain was observed in poor households. The quantity of consumption of grain (wheat and maize) commodities by the households considered in this study does not affect all households, but compared with other households, the poor-class households' consumption less than (decrease) more than other categories of households.

Table 7.5: Household consumption, expenditure, income and welfare

				Consumption			
Households	EHXP	YIXP	EV	Agriculture and live animals	Irrigated maize	Non-irrigated maize	Irrigated Wheat
Poor-Class-Households	-0.00000011	-0.00000024	-0.00009213	0.00000007	0.00000014	0.00000017	0.00000013
Middle-Class-Households	0.00000003	-0.00000013	-0.00013096	0.00000009	0.00000017	0.00000020	0.00000015
Rich-Class-Households	0.00000018	0.00000002	0.00029254	0.00000012	0.00000020	0.00000023	0.00000018

Note: EHXP = Household consumption expenditure, YIXP = Households' real income and EV = Equivalent variation (welfare). EHXP and YIXP are in percentage and EV is in rands
Source: CGE simulation result

7.4 CONCLUSION

The findings indicate that when water restrictions are set, it is more profitable to reduce the number of hectares planted and to rather apply full irrigation to produce higher yields. However, various factors will influence the decision of the irrigator, such as crop prices, water, and electricity tariffs. It is thus important to analyse the current economic environment to make the best decision when water restrictions are set.

From the results of the CGE model, we conclude that the increase in the irrigation water tariff has an impact, to some extent, although the impact is at a minimal level. The main challenge is the availability of a scarce resource (water), and not the incremental increases in the water tariff. As a result, the study recommends that, without the behaviour change of farmers, it will not achieve the desired output. A government with different stakeholder should introduce a mechanism to educate farmers and enhance their understanding of the past, current and future trends of water and drought in order to plan for the future and mitigate unexpected shock.

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CHAPTER 8

WATER FOOTPRINT AND ECONOMIC WATER PRODUCTIVITIES OF FEED CROPS AND DAIRY PRODUCTS IN SOUTH AFRICA

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Summary

The global water scarcity situation is a major issue of concern to sustainable development and requires detailed assessment of water footprints and water productivities in all sectors of the economy. This chapter has analyses economic water productivities along the dairy value chain in South Africa. The findings reveal that the value added to milk and water, as it moves along the value chain, varies from stage to stage, with the highest value being attained at the processing level, followed by the retail and farm gate levels, respectively. Milk production in South Africa is economically efficient in terms of water use. Feed production accounts for about 98.02% of the total water footprint of milk with 3.3% protein and 4% fat. Feed production is economically efficient in terms of cost and water use. Value addition to milk and economic productivity of water are influenced by packaging design. Not all economically water productive feed products are significant contributors to milk yield. Future ecological footprint assessments should take into account the value added to output products and economic water productivities along the products' value chain, rather than relying only on water footprint estimates.

8.1 INTRODUCTION

The global water scarcity phenomenon has become a major issue of concern to governments, organisations, policymakers, water users and water managers. A significant proportion (two-thirds) of the world's population faces difficulties in getting freshwater (Mekonnen and Hoekstra, 2016). The pressure on freshwater resources arises as a result of population growth, climate change, pollution of existing water resources, and urbanisation, among other things (Jefferies et al., 2012). In many parts of the word, quantities of water supply do not meet the quantity demanded by the various sectors of the economies. Food production has been identified as the major user of the available scarce water resources, accounting for about 86% of all global water use (IWMI, 2007). However, given the fact that food production is vital for human survival and the essential role that water plays in food production, there is the need to design strategies and methods to make efficient use of water in all sectors, particularly in agriculture which uses most of the world's water.

Based on this, two internationally accepted concepts of water footprints have been developed; the water footprint concept as described by Hoekstra et al. (2011), and the Life Cycle Assessment (LCA) as described in the ISO standards. The water footprint (WF) approach introduced by Hoekstra (2003) is gaining prominence because it gives a comprehensive assessment of freshwater use, and quantifies and maps water consumption and pollution in relation to production or consumption. The concept of the water footprint in the Life Cycle Assessment approach (LCA) has also been applied in many studies (Ridoutt et al., 2014; Zonderland-Thomassen et al., 2014).

Various authors have assessed the water footprints of products in the agricultural sector. Ridoutt et al. (2014) and Zonderland-Thomassen et al. (2014) assessed the water footprints of beef cattle and sheep production systems in Australia and New Zealand, respectively. In China, the water availability footprint of milk and milk products from large-scale farms has been assessed by Huang et al. (2014). Matlock et al. (2012) examined the potential water use, water stress, and eutrophication impacts arising from US dairy activities. Environmental impacts associated with freshwater consumption along the life cycle of animal products were analysed by De Boer et al. (2013) in the Netherlands. Amarasinghe et al. (2010) assessed water footprints of milk production in India. Water footprint analyses of milk production in Germany and Argentina have been examined by Drastig et al. (2010) and Manazza and Iglesias (2012), respectively.

The growing body of literature is limited to the quantification of water footprint indicators and, to some extent, the environmental impact. The economic aspect of water footprint indicators has received little attention, particularly in the semi-arid and arid regions of southern Africa. Meanwhile, Hoekstra et al. (2011), and Pérez-Urdiales and García-Valiñas (2016) have indicated that economic water efficiency and water-efficient technologies are very important to ecologically sustainable environmental policies. Existing studies on economic water productivities are limited to that of Chouchane et al. (2015) who assessed the economic water and land productivities related to crop production for irrigated and rain-fed agriculture in Tunisia. Similar assessments have been done for case studies in Morocco and Kenya (Mekonnen and Hoekstra, 2014; Schyns and Hoekstra, 2014). Zoumides et al. (2014) also included economic water productivity when assessing the water footprint of crop production and supply utilisation in Cyprus. It is clear that the focus has been on economic water productivities of crops, with no similar research being done in the livestock sector. To the best of our knowledge, no known study has evaluated the economic productivity of water along the dairy value chain. Therefore, current knowledge is insufficient to understand whether, how and why water users and managers along the dairy value chain might shift to more sustainable and economically efficient production patterns.

The present study contributes to filling this gap in knowledge by assessing the economic water productivity along the dairy value chain in South Africa. We estimated the economic water productivity for milk and important feed crops because evidence shows that a significant proportion of water usage in the dairy sector goes into feed production. This will be the first step towards forming an assessment of economic water productivities for feed crops and dairy products, particularly in Africa. The economic water productivity is the value of the marginal product of the agri-food product with respect to water (Chouchane et al., 2015; Molden, 2007; Playan and Matoes, 2006). The economic productivity gives an indication of the income that is generated per cubic metre of water used. The economic water productivity is calculated in two steps. First, the physical water productivity (in kg/m^3 of water) is calculated by dividing the yield (kg) by the water footprints (m^3) of the product. In the second step, the economic productivities (US$/m^3 of water) of the product are calculated by multiplying the physical water productivity (kg/m^3) of each product by their monetary value (US$//kg).

8.2 DATA AND METHODS

8.2.1 Conceptual and Empirical Framework

The concept of the Global Water Footprint Standard of the Water Footprint Network was employed in this study. The water footprint network approach adopted gives a distinction between green, blue and grey water used along the value chain (Berger and Finkbeiner, 2010; Hoekstra et al., 2011). The calculations of blue, green and grey water footprints of the feed crops and milk followed the terminologies and procedures set out in The Water Footprint

Assessment Manual (Hoekstra et al., 2011). The blue water footprint ($WF_{proc,blue}$, m^3/tonne) is estimated as the blue component in crop water use (CWU_{blue},m^3/ha), divided by the crop yield (Y, tonne/ha) in relation to the feed crops. This is specified as:

$$WF_{proc,blue} = \frac{CWU_{blue}}{Y} \quad (volume / mass) \tag{8.1}$$

The green water footprint (WF_{green}, m^3/tonne) is calculated in a similar manner as the blue water footprint. The green water used for feed crop production and natural vegetation for pastoral grazing constitutes the total green water footprint considered along dairy value chain because we found that no green water is used at the processing and retailing stages of the dairy value chain. The final calculated green water footprint is an indicator of the total amount of rainwater that was evapotranspired by the crop and incorporated into the crop.

$$WF_{proc,green} = \frac{CWU_{green}}{Y} \quad (volume / mass) \tag{8.2}$$

The crop water use component of Equations (8.1) and (8.2) is defined as the sum of the daily evapotranspiration (*ET*, mm/day) over the complete growing period of the feed crop (Hoekstra et al., 2011). This is expressed as:

$$CWU_{blue,green} = 10 \times \sum_{d=1}^{lgp} ET_{blue,green} (volume / area) \tag{8.3}$$

The blue and green water evapotranspiration is denoted by $ET_{blue,\ green}$. The water depths are converted from millimetres to volumes per area (m^3/ha) by using the factor 10. Summation is done over the complete length of the growing period (lgp) from day one to harvest (Hoekstra et al., 2011). Grey water footprints ($WF_{proc,grey}$, m^3/tonne) of the feed crops are estimated by taking the chemical application rate for the field per hectare (AR, kg/ha) and multiplying it by the leaching-run-off fraction (α). The product is divided by the difference between the maximum acceptable concentration (c_{max}, kg/m^3) and the natural concentration of the pollutant considered (c_{nat}, kg/m^3). The result is then divided by the crop yield (Y, tonne/ha). This is expressed empirically as:

$$WF_{proc,grey} = \frac{(\alpha \times AR)/(c_{\max} - c_{nat})}{Y} \quad [volume / mass] \tag{8.4}$$

In the study area, fresh water used in cleaning the processing facilities was recycled and later used for cleaning the cattle runs and the floor of the dairy parlour. The dairy processing water thus becomes grey water in the effluent pond and was accounted for according to the grey water methodology. The grey water emanating from the faeces and urine of the lactating cows was estimated with the use of an effluent sample analysis, and the volume measured as the flow into the effluent pond. After estimating the blue, green and grey water footprints, they were summed up to obtain the total water footprint.

After calculating the water footprint of the feed crops, we calculated the marginal water productivities for the feed crops. In estimating the water productivities for the feed crops, a distinction was made between crop yield from rainfall and that of irrigation. Once such distinction is made, water productivities can be discussed in terms of green and blue water. The blue water productivity is described as the incremental yield attained due to irrigation, divided by the blue water footprint or the volume of blue water consumed (Hoekstra, 2013). This is expressed as:

$$WP_{blue} = \frac{Yt_{blue}}{ET_{blue}} \tag{8.5}$$

where Yt_{blue} is the crop yield under irrigation, and ET_{blue} is the evapotranspiration of blue water. Green water productivity, on the other hand, can be defined as the crop yield obtained from rainfall only, without irrigation, divided by the total green water used by the crop (Hoekstra, 2013). This is specified as:

$$WP_{green} = \frac{Yt_{green}}{ET_{green}} \tag{8.6}$$

where Yt_{green} is the crop yield under rain fed conditions only, and ET_{green} is the evapotranspiration of green water that would have occurred without irrigation. Crop yield under rain fed conditions only (Yt_{green}), according to Chouchane et al. (2015) and Doorenbos and Kassam (1979), can be calculated as:

$$\left(1 - \frac{Y_a}{Y_m}\right) = RF_y\left(1 - \frac{ET_a}{CWR}\right) \tag{8.7}$$

where RF_y is a yield response factor, Y_a is the actual crop yield in kg per hectare, and Y_m is the maximum yield attainable at optimum water level. ET_a denotes the actual crop evapotranspiration measured in millimetres per period, whereas CWR is the crop water requirement in millimetres per period. The total water productivity then becomes the sum of the blue and green water productivities for the feed crops:

$$Total\ WP = WP_{green} + WP_{blue} \tag{8.8}$$

Regarding the primary product (milk), the chain-summation approach was used to estimate the water footprint since our focus was only on milk, and not a variety of derived dairy products (Hoekstra et al., 2011). The water footprint of milk consists of direct and indirect water footprints (Mekonnen and Hoekstra, 2010a). The water footprint for the output product (processed milk with 3.3% and 4% fat) is denoted by $WF[\Upsilon]$. The output product (Υ) is produced from *x* inputs. Let *x* inputs be numbered from *i=1…. x*. Assuming that *x* inputs are used to produce only Υ dairy product. The output product's (Υ) water footprint is represented as:

$$WF_{prod}[\Upsilon] = \frac{\sum_{i=1}^{x} WF_{proc}[i]}{P[\Upsilon]} \quad (m^3 / tonne) \tag{8.9}$$

where $WF_{prod}[\Upsilon]$ denotes the total water utilised in order to produce Υ. The water footprint of input *i* is represented by $WF_{prod}[i]$ and $P[\Upsilon]$ is the production quantity of product Υ. Given that $WF_{prod}[\Upsilon]$ is measured in m³ per tonne; the physical water productivity (*PWP*) of the output product Υ is expressed in kilograms per cubic metre (kg/m³) and specified as:

$$PWP(kg / m^3) = \frac{1}{WF_{prod}[\Upsilon](m^3 / tonne)} * 1000 \tag{8.10}$$

After calculating the physical water productivity, the economic water productivity for the output product Υ is then attained by multiplying the physical water productivity by the monetary value added to Υ per kilogram. Various authors in recent literature have used producer prices as a proxy for value added in estimating economic water productivities due to difficulties in getting data for estimating value added to the products being investigated (Chouchane et al., 2015; Schyns and Hoekstra, 2014; Zoumides et al., 2014). However, this chapter adds some novelty in our economic water productivity estimates by moving a step further to calculate the value added to milk along the dairy value chain, as well as some important feed products for our productivity estimates. As the main product moves along the value chain, value is added at each stage. Hence, we estimated the value added to milk at the farm gate, processing or wholesale, and retail levels in order to ascertain the point along the dairy value chain where most value is added. The value added to the out product (Υ) was estimated by deducting the cost per kilogram of Υ from the sales revenue obtained from selling one kilogram of Υ at each stage of the value chain (Crafford et al., 2004). Thus, the value added to the output product (Υ) is the total revenue from the product, minus the cost of all intermediate inputs employed in the production of Υ . We denote the value added to Υ at a particular stage of the value chain as $\mathrm{VAD}_{ivc}[\Upsilon]$ and expressed this empirically as:

$$VAD_{ivc}[\Upsilon] = \mathrm{Re}_{ivc}(\Upsilon) - Co_{ivc}(\Upsilon) \qquad ZAR/kg \tag{8.11}$$

where $\mathrm{Re}_{ivc}(\Upsilon)$ is the sales revenue obtained from selling one kilogram of Υ at each stage of the value chain and $\mathrm{Co}_{ivc}(\Upsilon)$ is the cost of all intermediate inputs employed to produce a kilogram of Υ . $\mathrm{Co}_{ivc}(\Upsilon)$ consists of the cost of water usage, capital, land, labour, feed, taxes, veterinary, transport, packaging, fuel, repairs and maintenance, etc. The total value added ($\mathrm{TVAD}[\Upsilon]_{vc}$) along the complete value chain was calculated by summing the value added at each stage of the value chain. This is specified as:

$$TVAD_{vc}[\Upsilon] = \sum_{i=1}^{3} VAD_{ivc} \qquad ZAR/kg \tag{8.12}$$

The value added to water as the product moves along the value chain can be expressed as the ratio of the value added to the output product (Υ) at each stage of the value chain over the quantity of water utilised at the respective stages (Crafford et al., 2004). Given the value added to the output product (Υ) along the value chain, the marginal contribution from water $\mathrm{MVAD[water]}$ is specified as:

$$MVAD[water]_{vc} = \frac{VAD_{ivc}}{WU_{ivc}} \tag{8.13}$$

VAD_{ivc} denotes value added to the product at *i* stage of the value chain and WU_{ivc} is the quantity of water used at *i* stage of the value chain. We then expressed the economic water productivity as:

$$EWP(ZAR/m^3) = PWP(kg/m^3) * VAD(ZAR/kg) \tag{8.14}$$

The economic water productivity (EWP) is expressed in ZAR[1]/m³. The procedure for estimating the physical and economic water productivities for the output product was applied to estimate the physical and economic water productivities for the feed crops.

8.2.2 Data

Both primary and secondary data pertaining to the South African dairy sector were used. Primary data on cost and revenue expenditures on feed products and raw milk were obtained from dairy agribusiness companies that form part of the South African Milk Processors' Organisation (SAMPRO), and Milk South Africa (Milk SA). Milk SA was established in 2002 to oversee the South African dairy industry. These organisations comprise dairy producers and processors, who produce different dairy products for the local and international markets. These companies comprise both commercial dairy and processing plants where milk is processed and bottled. Data on price consisted of producer, wholesale and retail prices. Secondary data on feed production, inputs cost, water usage for feed crops and servicing water used in the dairy industry were attained from SAMPRO, Milk SA and Van Rensburg et al. (2012). Van Rensburg et al. (2012) assessed water utilisation for important field and forage crops.

The dairy producers considered have feed calculation systems with electronic recordkeeping, and as such, accurate data on feed composition and the quantities fed to animals were

1 Average exchange rate for December, 2015: US$1 = ZAR 15.05.

available. The data obtained were aggregated and average values were used in further calculations. The electronic feed calculators record information on quantities of the various feed products and ingredients in feed ration, moisture content, dry matter, nutritional values of the inputs and the complete ration for the lactating cows. Data obtained from these sources were used to calculate the volumes of blue, green and grey water utilised in milk production. Our estimated water footprints for feed crops, such as maize, soy and sun flower, were compared with the estimates obtained by Mekonnen and Hoekstra (2010a) for South Africa. Secondary data on prices of feed crops were obtained from the Bureau of Food and Agricultural Policy and Southern Africa (BFAP).

8.3 RESULTS AND DISCUSSION

8.3.1 Water Footprints, Marginal and Economic Water Productivities of Feed Products

Table 8.1 presents the water footprints of key feed products included in a balanced ration formulated for dairy cows. We estimated blue, green and grey water footprints for these feed stuffs in order to ascertain which of them uses more water than others do. The results show that high protein concentrates (HPC) and yellow maize meal had the highest total water footprints, while oats silage had the lowest. Among all the feed crops, lucerne hay and maize silage had the highest blue water footprints. In terms of green water, high protein concentrate and yellow maize meal had the highest footprints, respectively. In all instances, the grey water footprint was lower than both blue and green water footprints were, with the exception of yellow maize meal and sun flower cake. Additionally, maize meal and lucerne hay recorded the highest grey water footprints.

Table 8.1: Water footprint of main feed products in a complete ration for dairy cows

Feed products	Blue WF (m^3/year)	Green WF (m^3/year)	Grey WF (m^3/year)	Total WF (m^3/year)
Lucerne hay	217942	263165	99682	580788
Oats Silage	103587	23397	9965	136948
Sorghum Silage	122421	107529	18031	247981
Maize Silage	188961	179215	28872	397047
Yellow maize meal	0	2256175	195969	2452143
HPC	74643	2512770	47560	2634972
Soybean cake	53400	1662502	8797	1724698
Sun flower cake	21207	850268	38800	910274

HPC: High Protein Concentrate

Prior to the estimation of economic water productivities of the feed products, their dry matter contribution and marginal water productivities were calculated for a balanced ration providing an average of 26.32 kilogram of dry matter per day for dairy cows, and the results are presented in Table 8.2. It must be emphasised that water productivities were estimated for the main feed stuffs and ingredients. Out of the 26.32 kilogram of dry matter (DM) supplied, 28.42%, representing 7.48 kg, was provided by yellow maize meal. High protein concentrate (HPC) contributed 18.47% (4.86 kg) to the total dry matter.

Lucerne hay and maize silage contributed 16.03% and 14.78%, respectively, to the dry matter. Sorghum and oat silage also contributed 9.80% and 3.99% of the total daily dry matter, respectively. This result implies that yellow maize meal, high protein concentrate and lucerne hay are very important contributors to dry matter for dairy cows, not excluding the other feed stuffs. In order to arrive at meaningful conclusions, the study estimated the marginal contributions of the individual feed products to the total milk output. The total average milk yield per year for the dairy farms considered for this study was 13 197 tonnes. The results reveal that yellow maize meal is the highest contributor to yearly milk yield.

Table 8.2: Dry matter contribution and marginal water productivities of main animal feed products in a complete ration for dairy cows

Feed products	Total WF (m^3/year)	Kilogram of dry matter per day	Percentage contribution to milk output[2]	Actual contribution to yearly milk output (tons)	Marginal water productivities (kg/m^3)
Lucerne hay	580788	4.22	16.04	2117	3.64
Oats Silage	136948	1.05	3.99	527	3.84
Sorghum Silage	247981	2.58	9.80	1293	5.22
Maize Silage	397047	3.89	14.78	1950	4.91
Maize meal	2452143	7.48	28.42	3750	1.53
HPC	2634972	4.86	18.47	2437	0.93
Other ingredients	1409485	2.24	8.50	1122	0.80
Total	7859363	26.32	100	13197	20.87

Similarly, we found that high protein concentrate and lucerne hay are the second- and third-highest contributors to the yearly milk yield, respectively. Maize silage contributed 14.78% of the total yearly milk output, with the lowest contribution coming from oat silage. Soybean and

2 Average dry matter to milk yield ratio for South Africa = 1 kg DM : 3.8 output (Mekonnen and Hoekstra (2010b).

sun flower cakes are incorporated into HPC and not fed to the animals separately, so we did not estimate separate contributions to dry matter for these feed ingredients. After estimating the contributions to yield from the individual feed crops, water productivities of the feed products were estimated by dividing their contributions to yield by their respective water footprints.

The results are presented in the last column of Table 8.2. The findings show that feed products, such as sorghum silage, maize silage, and oats silage and lucerne hay, have high marginal water productivities. However, expressing water productivities in physical terms is not sufficient to meaningfully explain the economic benefits of water-use. Hence, we estimated economic water productivities, which gives insight into the economic benefits of water usage in the feed production sector. The results are presented in Table 8.3. The value added to the feed crops and ingredients were estimated for economic and policy purposes. In terms of value addition, the results show that more value is added to high protein concentrate and yellow maize meal, as ZAR 6.91 and ZAR 4.39 are attained from these feed products, respectively. This is followed by lucerne hay, sorghum and maize silages, respectively. The least value added is associated with oats silage. The results generally suggest that the production of all the feed products considered is economically efficient since the monetary value attained from them is positive. However, the value added varies from product to product.

The results in Table 8.3 further revealed that sorghum silage and lucerne hay are the top two feed products that have high economic water productivities, as every cubic metre of water used in producing sorghum silage and lucerne hay results in ZAR 8.72 and ZAR 6.82, respectively. This is followed by yellow maize meal and high protein concentrate (HPC), as every cubic metre of water used in their production yields about ZAR 6.71 and ZAR 6.43, respectively. Maize silage had the least economic water productivities. The above results provide vital information for livestock feed producers and water users along the dairy value chain as to which feed crops or products are economically efficient to produce in terms of water use and profitability. Notwithstanding this, the contribution to dry matter and milk yield should be taken into consideration in order to attain higher proceeds. For instance, the total economic water productivity estimates and contributions to milk output indicate that feed products such as yellow maize meal, high protein concentrate and lucerne hay are very economical in terms of water and have high contributions to milk yield. Hence, profit-maximising dairy farmers and feed manufacturers with sustainable and efficient water-use objectives can focus more on such feed products, which are good contributors to milk yield and have high economic water productivities.

Despite the high economic water productivity of sorghum silage, our findings indicate that its contribution to milk yield is low, relative to feed products such as maize meal, HPC and lucerne hay. This implies that not all economically active feed products are significant contributors to milk output. Similarly, maize silage has low economic water productivity and somewhat low contribution to milk output.

Table 8.3: Value addition and economic water productivity of main feed products

Feed products	Marginal water productivities (kg/m^3)	Value added (ZAR/ kg)	Economic water productivities (ZAR/m^3)
Lucerne hay	3.64	ZAR 1.88	6.84
Oats Silage	3.84	ZAR 1.37	5.22
Sorghum Silage	5.22	ZAR 1.67	8.72
Maize Silage	4.91	ZAR 1.66	3.25
Yellow maize meal	1.53	ZAR 4.39	6.71
HPC	0.93	ZAR 6.91	6.43

Average exchange rate for December, 2015: US$1; ZAR 15.05

Therefore, dairy farmers can replace maize silage with feed products such as triticale silage, which is known to have high contribution to milk output and economic water productivities (Cosentino et al., 2015).

8.3.2 Water Footprint and Physical Water Productivity of Milk Produced and Processed in South Africa

Table 8.4 presents the water footprint and physical water productivities of milk produced and processed in South Africa. The results show that the total yearly water footprint for producing 13 196.58 tonnes of milk with 3.3 per cent protein and 4 per cent fat is 1024.95 cubic metres per tonne. Based on this figure, we estimated the physical water productivity of milk along the complete dairy value chain to be 0.98 kilograms per cubic metre. Precisely, the green water footprint constitutes 862.20 cubic metres per tonne, whereas the blue and grey water footprints constitute 96.99 and 65.76 cubic metres per tonne, respectively. This suggests that green water (84.12%) forms the largest constituent of the total water footprint of milk, followed by the blue water (9.46%) and grey water (6.42%) footprints, respectively. In terms of physical water productivities, the results indicate that 10.31 kilograms of milk is attained from every cubic metre of blue water used, whereas 1.56 kilogram of milk is obtained from every cubic metre of green water utilised.

The results further show that about 80.92% of the total yearly water footprint in the dairy industry in South Africa is attributed to feeding lactating cows only, whereas 17.10% is utilised for feeding non-lactating cows. This indicates that about 98.02% of the total water footprints along the dairy value chain go into the feeding of animals. This concurs with the findings of Mekonnen and Hoekstra (2010b) who opined that more than 95% of the water footprints of animal products relates to water used for feed production. The remaining amount constitutes the water consumed by the live animals and servicing water used at the processing stage.

Table 8.4: Water footprint and physical water productivity of milk in South Africa

Parameters	Yield (tonne/year)	Blue WF (m^3/year)	Green WF (m^3/year)	Grey WF (m^3/year)	Total WF (m^3/year)
		Drinking water			
Lactating cows	-	31153	-	-	31153
Non-lactating animals	-	15557	-	-	15557
		Feed production water			
Lactating cows	-	707553	5342213	400040	6449806
Non-lactating animals	-	-	1362837	-	1362837
Total yearly water usage	-	754262	6705050	400040	7812643
Yearly Milk Production	7777	-	-	-	-
Total yearly production WF		97 m^3/tonne	862 m^3/tonne	51 m^3/tonne	1011 m^3/tonne
		Service water			
Service		-	-	188961	188961
Yearly milk processed	13197	-	-	-	-
Total yearly servicing water		0 m^3/tonne	0 m^3/tonne	14 m^3/tonne	14 m^3/tonne
Total water footprint		97 m^3/tonne	862 m^3/tonne	66 m^3/tonne	1025 m^3/tonne
Physical water productivity		10.31 kg/m^3	1.56 kg/m^3	15.21 kg/m^3	0.98 kg/m^3

8.3.3 Value Additions and Economic Water Productivities of Milk at Different Stages and for Different Packaging Designs

For dairy producers with profit maximisation and water sustainability objectives, the value generated from their production inputs and economic water productivities are very important to their production decisions. For instance, inputs such as blue water use is directly associated with production costs, and may be limiting dairy production (Chouchane et al., 2015). This implies that particular attention should be paid to activities that result in higher value addition and economic water productivities, while focusing on making rational and efficient use of water in order to be economically productive along the dairy value chain. Hence, we have estimated the value added to milk as it moves along the dairy value chain in order to determine the point along the dairy value chain where most value is added.

Given the value added along the value chain, we conducted sensitivity analysis for economic water productivities of milk at different stages of the value chain and for different packaging sizes. We considered one-litre and three-litre packaging sizes with different sales revenues per kilogram. The results are presented in Table 8.5. The results show that a total value of ZAR 12.11 is added to a kilogram of milk when packaged in a 1-litre bottle, relative to ZAR 9.04 per kilogram of milk when packaged in a 3-litre bottle. This implies that more value is attained when milk is packaged in smaller sizes.

Along the value chain, our results show that more value is added to milk at the processing or whole sale level, irrespective of the packaging size, as indicated by the amounts of ZAR 5.84 and ZAR 4.01 per kilogram of milk for one and three litres packages, respectively, and relative to the other stages along the value chain. The second highest value is added at the retail level, where ZAR 4.70 and ZAR 3.46 per kilogram of milk were added to one-litre and three-litre packaging sizes, respectively. At the farm gate level, we found that an amount of ZAR 1.57 each was added to milk for both packaging sizes considered. It is worth noting that the value added to milk at the retail level for the one-litre packaging size is higher than the value added to the three-litre packaging size at the processing or wholesale level. Generally, the results indicate that milk production is economically efficient since the revenue attained at each stage of the value chain exceeds the cost incurred.

Regarding the economic productivity of water, the results show that the economic water productivity of milk packaged in a one-litre bottle is ZAR 11.88 per cubic metre, whereas that of the three-litre package is ZAR 8.87 per cubic metre. This means that every cubic metre of water used to produce one kilogram of milk, with 3.3 per cent protein and 4 per cent fat, yields ZAR 11.88 and ZAR 8.87, when packaged in one-litre and three-litre packages respectively. The implication from this finding is that milk production in South Africa is economically efficient in terms of water usage, since the value attained from every cubic metre of water used exceeds its cost.

At the production stage where larger proportions of water is used, our results indicate that every cubic metre of water utilised results in ZAR 1.55. Water use is highly economical at the processing stage, as every cubic metre of water used in the production of a kilogram of milk, with 3.3 per cent protein and 4 per cent fat, resulted in ZAR 5.72 and ZAR 3.93, respectively, for one-litre and three-litre packaging sizes. At the retail level, every cubic metre of water utilised yielded ZAR 4.61 and ZAR 3.39, when milk is packaged in one-litre and three-litre containers, respectively. The above results indicate that water use along the dairy value chain is very productive at the processing and retail levels. The type of packaging sizes used for selling the dairy product has a bearing on the value addition and economic water productivity estimates.

Table 8.5: Value additions to milk as it moves along the value chain and economic water productivities of milk at different stages and different packaging sizes

Stage of value chain	Value addition (ZAR/ kg)		Economic water productivity (ZAR/m^3)	
	1 Litre packaging	3 Litres packaging	1 Litre packaging	3 Litres packaging
Farm gate	1.57	1.57	1.55	1.55
Processing/whole sale	5.84	4.01	5.72	3.93
Retail	4.70	3.46	4.61	3.39
Total	12.11	9.04	11.88	8.87
Total physical water productivity (farm gate)				0.99 kg/m^3
Total physical water productivity (wholesale and retail levels)				0.98 kg/m^3

1 litre of milk =1.033 kilogram

Average exchange rate for December, 2015: US$1; ZAR 15.05

8.4 CONCLUSIONS

The current global water scarcity situation and the pressures on governments, organisations, policymakers, water users and water managers to develop sustainable and economically efficient water-use policies require the rigorous assessment of water footprints and water productivities in all sectors of the economy that use water. Water footprint assessment in the agriculture and food sectors has emerged as a vital sustainability indicator. The present research has contributed to earlier water footprint studies in South Africa, and Africa as a whole, by adding the economic aspect of water use along the dairy value chain. The study focused on the economic productivity of water along the dairy value chain, starting from feed production, through to the final product.

The findings have important economic and efficient water use implications for actors along the dairy value chain. In terms of water use, the study concludes that the highest proportion of water utilised along the dairy value chain goes into feed production. Different feed products have different water footprints. This suggests the need for water footprint assessments of different feed products to be conducted to identify those that are higher users of the existing scarce water resources. Given the blue water scarcity situation in South Africa, our findings suggest that feed products, such as lucerne hay, maize silage and sorghum silage, are higher consumers of blue water resources. However, judging these products based on their water footprint estimates alone will be biased. Hence, the study's findings have highlighted the contributions of the feed products to milk output. Yellow maize meal, high protein concentrate and lucerne hay are the top three feed products with high contributions to milk output, respectively. Hence, dairy livestock producers should pay particular attention to these feed products when formulating rations for dairy cows, with the aim of attaining high milk yields, which in turn will lead to low water footprints, high value addition and economic water productivities.

Although feed production uses the highest proportion of water along the dairy value chain, our assessment of value addition and economic water productivities of the feed products proves that the production of the feed products is economically efficient in terms of cost and water use. The economic implication of this finding is that the revenue attained from producing the feed crops and the value added to water along the dairy value exceeds the cost incurred.

Hence, the study concludes that dairy livestock farmers and producers are economically efficient in their production. The findings further provide vital information for livestock feed producers and marketers on the feed products that are more profitable, as our results indicate that the values added to the feed products vary from product to product. High economic values are associated with high protein concentrate, yellow maize meal, lucerne hay, and sorghum and maize silages, respectively.

Of further importance from our study is the finding which points to the fact that not all economically water productive feed products are significant contributors to milk yield. Feed products such as yellow maize meal, high protein concentrate and lucerne hay appear to be very economical in terms of water and have high contribution to milk yield, with positive value addition. Maize silage has low economic water productivity and somewhat low contribution to milk yield, and as such, we suggest that dairy farmers can substitute it with a better option such as triticale silage, which is known to have a high contribution to milk yield and is economically productive in terms of water use. This provide the rationale for profit-maximising dairy farmers with sustainable and efficient water use objectives to reconsider their dairy livestock feed formulation by incorporating more of the feed products with good contributions to milk output and economic water productivities.

The study further concludes that the value added to milk as it moves along the value chain varies from stage to stage, with the highest value being added at the processing level, followed by the retail level and the farm gate, respectively. Furthermore, the study's estimates suggest that milk production at each stage along the value chain is economically efficient in terms of cost and water use. From a marketing point of view, the findings suggest that more value is added to milk and water when packaged in smaller sizes. This indicates that the type of packaging design used at the processing level of the dairy value chain has an influence on value addition and economic water productivity estimates.

It is generally recommend that future research conducted on estimations of ecological footprints and economic productivities of ecological indicators, such as water, should not focus only on quantifying the footprint indicators. Rather, researchers should take into account economic water productivities and the monetary value added to the product along its value chain, since this gives meaningful economic implications. In order to be sustainable and economically productive in water use, all water users and managers along the dairy value chain can rely on such context-specific and concrete research outcomes to reduce the pressure of animal feed production on fresh water use in the livestock sector, while maintaining milk yield and profitability. The findings provide detailed insights into profitability and economically productive water-use in the dairy industry. We suggest that policymakers, water users and managers along the dairy value chain should not rely on water footprint estimates alone to judge the industry.

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CHAPTER 9
COMPENSATING WELFARE ESTIMATES OF WATER FOOTPRINT SUSTAINABILITY POLICY CHANGES IN SOUTH AFRICA

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Summary

The implementation of environmental sustainability policies in the food and agricultural sector demands an understanding of consumers' preferences for environmentally sustainable food products and the welfare effects arising from their preferences and willingness to pay. We employed a choice experiment and latent class model to estimate consumers' preferences and compensating surplus estimates for water footprints policy changes in South Africa. Our findings reveal that there is profound preference heterogeneity at segment level for water and carbon footprint attributes. Three distinct consumer segments were identified. Besides socio-economic factors, we demonstrate that public awareness creation and campaigns about threats posed by climate changes, trust in food labelling regulatory bodies, subjective and objective knowledge on environmental sustainability significantly explain consumers' choice of environmentally sustainable products. Our compensating surplus estimates indicate that the welfare effects arising from water footprint sustainability policies vary from one class to another. Our findings suggest that there are pertinent segmental equity issues that need to be addressed when designing environmental sustainability policies. Future studies on preferences for environmentally sustainable products should not be limited to a willingness to pay estimates only; rather, compensating surplus estimates should be computed in addition, for efficient and effective policy guidance.

9.1 INTRODUCTION

Governments and policymakers across the globe are increasingly getting interested in the design and implementation of environmental or ecological sustainability policies (IPCC, 2007). Carbon and water footprint sustainability assessments, in particular, are gaining particular attention, as some industries, agribusinesses and governments rely on these sustainability indicators to evaluate their environmental and water-related risks and impacts. The food and agricultural sector is one of the sectors where carbon and water footprint assessment is gaining much prominence. This is a result of the association between the production and consumption of agricultural food products and the effects that these activities have on water resources and the environment (IPCC 2007). For instance, food and agricultural production utilise about 86% of global freshwater (IWMI 2007). In terms of carbon emissions, the agricultural sector, in general, accounts for about 30-35% of global GHG emissions (Foley et al. 2011).

Given the significant impacts that the food and agricultural sector has on the environment and water resources, governments, producers and policymakers in recent years have become keen to develop policies and strategies aimed at changing the sustainability behaviour of producers and consumers, while sustaining the environment. The South African government in 2013 developed a policy document known as “Carbon Tax Policy Paper”. This policy paper outlines ways of minimising environmental challenges, particularly GHG emissions. It also touches on water scarcity, water pollution and climate change, as a whole (Carbon Tax Policy Paper, 2013). The development of such policy document is anticipated to propel the needed policy and price signals to producers, manufacturers, businesses, institutions and consumers to inform them of the need to make sure that future investments are carried out in an environmentally sustainable manner (Carbon Tax Policy Paper 2013; Suranjan et al. 2017). This sustainability policy initiative is expected to motivate producers to change their production patterns to more sustainable patterns, through the adoption of innovative technologies with minimal environmental effects (Carbon Tax Policy Paper 2013).

The introduction of the carbon tax is expected to have a significant impact on the prices of food and non-food products, which in turn will have some economic and welfare implications for consumers (Kearney, 2008). For instance, the extra costs incurred by investors to produce environmentally sustainable products will either be transferred to the consumer or be borne by the producers, or be shared by both. On the other hand, the government can provide incentives to ecologically sustainable producers. Food producers, agribusinesses and companies are expected to make their sustainability information available through product labelling, since sustainability information cannot be identified at the point of sale without labels. Carbon labelling has received some attention in the food and agricultural industry in South Africa. Although the carbon footprint was added as an attribute, the main focus of this research is on water usage.

Currently, the Water Research Commission has directed their attention to water footprint assessments, particularly in the agricultural sector because the sector has been identified as a major user of scarce water resources in South Africa (DWA 2013). Therefore, the Commission and concerned food companies seek to rely on sustainability campaigns and awareness creation through footprint labelling as a possible marketing strategy for marketing environmentally sustainable food products, with the aim of sustaining water resources. Consumer preferences for environmental environmentally sustainable food products have received some attention in the recent literature (Grebitus et al. 2015:2016; Peschel et al. 2016). Peschel et al. (2016) assessed German and Canadian consumers' decisions to buy environmentally sustainable products, and found that consumer preference for such products hinges on subjective and objective knowledge levels. Grebitus et al. (2016) performed a cross-cultural analysis of preferences for food and non-food products with carbon and water footprint labels, and reported that consumers are highly heterogeneous in their preferences, regardless of their cultural background. Grebitus et al. (2015) further found that human values are very relevant in explaining consumers' behaviour and preferences for carbon and water footprint labelled products in Germany. Additionally, assessments of carbon footprint labelling in respect of exports of agricultural product (Edwards-Jones et al., 2009) and legal issues concerning carbon labelling (Cohen and Vandenbergh 2012) have been explored.

Ecological footprints have been used as an indicator for sustainability assessments in areas such as the mining industry (Suranjan et al. 2017), and the impacts of globalisation on ecological footprints have been studied (Figge et al. 2017). However, the growing body of literature has focused on consumer preferences (Grebitus et al. 2015: 2016; Peschel et al. 2016; Schumacher 2010), trading (Edwards-Jones et al. 2009) and labelling issues (Cohen and Vandenbergh 2012; Van Loo et al. 2015). None of these studies has considered the welfare impacts arising from consumers' preferences and choices of footprint-labelled products. Nonetheless, Ambrey and Daniels (2017) have related carbon footprints to individuals' wellbeing, without considering water footprints. Additionally, these studies have focused only on developed countries, with little or no study being conducted in arid and semi-arid African countries, including South Africa. Therefore, the current knowledge on the impact of consumers' behaviour and choices of environmentally sustainable products on their welfare is insufficient. In the context of the current chapter, compensating surplus or consumers welfare is defined as the income change needed to keep consumers at their initial utility level, assuming that the water sustainability policy changes highlighted in this study are implemented (McKenzie and Pearce 1982; Vartia 1983).

The main objective here is to estimate consumers' willingness to pay and to compile compensating surplus estimates of water arising from footprint sustainability policy changes in South Africa. The overall effect of introducing a new product or changes in product attributes on consumer welfare is described as the compensating surplus. Consumer surplus in this context is related to changes in the price of environmentally sustainable food products and/or their attributes (Morey, 1985). It can also be explained as changes in utility arising from changes in sustainability policies, measured in monetary terms (Morey, 1984). The compensating surplus estimation approach was chosen over compensating variation because Morey (1985) and Hanemann (1984) have opined that compensating surplus is appropriate in situations where changes in policies are the result of government provisions or restrictions, as it is with our case study. Compensating variation is appropriate in instances where consumers are assumed to optimally alter their consumption patterns due to changes in policies (Morey, 1985). However, this assumption is not always the case (Hanemann, 1984).

The welfare effects (gain or loss) resulting from water footprint sustainability policies are very important for policy decision-making (Grebitus et al., 2013). An understanding of the segments of consumers or individuals whose welfare will be improved or reduced due to the sustainability policy changes will add to the current policy debate on environmental sustainability. Welfare assessment of environmentally sustainable policy changes provides economic justification for implementing such policies. Welfare assessments also help to minimise the economic costs of sustaining the environment and to reduce environmental risk (Carbon Tax Policy Paper, 2013). The assessments further provide evidence-based policy scenarios for developing the food and agricultural sector, for improved policymaking and regulation towards achieving environmentally sustainable food production, marketing and consumption (Thøgersen and Ölander, 2002).

9.2 METHOD AND DATA

9.2.1 Choice Experiment and Compensating Surplus Estimation Approaches

The choice experiment method was employed in this study to solicit the relevant data because it is one of the prominent methods used in recent literature for evaluating preferences for environmental sustainability attributes (Grebitus et al., 2013, 2015, 2016; Peschel et al., 2016). The choice experiment approach encompasses the establishment of a hypothetical market for the product in consideration, described in terms of its attributes or characteristics (Birol et al. 2006). Respondents are requested to make their choices from different choice sets that are presented to them in a sequential manner during the survey. This approach is based on Lancaster's characteristics methodology which states that the overall utility obtained from a product originates from the product's characteristics, rather than the product itself (Lancaster, 1991). The theory regarding how respondents choose between different discrete choice sets is modelled under the random utility theory, which assumes respondents to be rational and to prefer products that give them the highest utility (McFadden, 1974). The underlying assumption of the random utility theory is that consumers are heterogeneous in their preferences for sustainable product attributes (Grebitus et al., 2013; Hensher et al., 2005). Hence, the latent class model is adopted to account for unobserved heterogeneity among different consumer segments. Compensating surplus estimates for each segment will be determined afterwards.

Under the latent class modelling approach, consumers are assumed to be organised implicitly into a set of classes. The class to which a consumer belongs, whether known or unknown, is unobserved by the analyst. Consumers within each class are presumed to be homogeneous, but vary across different classes (Wedel and Kamakura, 2000). The number of classes among the sampled respondents is determined by the data. Belonging to a specific latent class hinges on the consumer's observed personal, social, economic, perceptional, attitudinal and behavioural factors. Assuming that a rational consumer *i* belonging to class *l* obtains utility *U* from product option *k*, the random utility is specified as:

$$U_{ik/l} = \beta_l Z_{ik} + \ell_{ik/l} \tag{9.1}$$

where β_l denotes class-specific vector of coefficient, Z_{ik} represents a vector of characteristics allied with each product option, and the error term of each class is denoted by $\ell_{ik/l}$. The error term is assumed to be distributed independently and identically. The likelihood that product option *k* is chosen by consumer *i* in *l* class is specified as:

$$\Pr_{ik|l} = \frac{\exp(\beta_l Z_{ik})}{\sum_n \exp(\beta_l Z_{in})} \tag{9.2}$$

The probability that consumer *i* belongs to a particular class is denoted by P_{il} and defined by a probability function *G*. The likelihood that consumer *i* belongs to class *l* is represented by the function $G_{il} = \delta_l X_i + \varsigma_{il}$ where X_i denotes a vector of consumers' personal, social, economic and other relevant factors, and ς_{il} represents the error term. The error term is assumed to be distributed independently and identically. The likelihood of consumer *i* belonging to class *l* is then specified as:

$$\mathrm{P}_{il} = \frac{\exp(\delta_l X_{il})}{\sum_s \exp(\delta_l X_i)} \tag{9.3}$$

The combined possibility that consumer *i* belongs to class *l* and selects product option *k* is represented by:

$$P_{ikl} = (P_{ik/l}) * (P_{il}) = [\frac{\exp(\beta_l Z_{ik})}{\sum_n \exp(\beta_l Z_{in})}] \times [\frac{\exp(\delta_l X_i)}{\sum_l \exp(\delta_l X_i)}] \tag{9.4}$$

The choice experiment employed and the random utility underlying the latent class model adopted in this study correspond with utility-maximising theory and demand (Birol et al., 2009).

Therefore, compensating surplus welfares estimates can be calculated from the estimated parameters (Birol et al., 2009; Hanemann, 1984) using the formula below:

$$CSW_l = \frac{\ln \sum_l \exp(IV_{l1}) - \ln \sum_l \exp(IV_{l0})}{\beta_{price}} \tag{9.5}$$

where CSW_l is the compensating surplus welfare estimate for a particular class IV_{l0} and IV_{l1} represents indirect utility before and after sustainability policy changes. Once the utility estimates for consumer segments are estimated, their willingness to pay estimates can be computed as:

$$WTP = -\frac{\partial U/\partial X}{\partial U/\partial P} = -\frac{\beta_{sustainability\ attributes}}{\beta_{price}} \tag{9.6}$$

where X is a vector of the product attributes, P denotes the price, $\beta_{sustainability\ attributes}$ is a non-monetary coefficient of sustainability attributes, and β_{price} is the monetary coefficient on price. The class-specific WTP estimates are computed using a parametric bootstrapping technique.

9.2.2 Sampling and Data Description

The survey was conducted in the Gauteng province of South Africa using trained interviewers. Gauteng is the most populous province in South Africa and is very diverse in terms of social, economic and demographic characteristics (Statistics South Africa, 2012). This allowed for high representation in the data. Specifically, the data was collected from Centurion, Pretoria and Midrand (Johannesburg). The data consisted of 47.3% black people, 43.3% white people, 16% coloured people and 2% Indian people, thus showing that the data comprises a representation of all the different racial groups in South Africa. Multistage sampling procedure was employed to sample 402 meat consumers from various households. The study was conducted in Centurion, located between Pretoria and Midrand (Johannesburg).

The survey focused on meat buyers, with particular reference to beef because beef is one of the meat products extensively purchased and, as such, it was easy to find greater numbers of respondents. Furthermore, the water footprints of beef products in South Africa are known to be larger, relative to the global averages (Mekonnen & Hoekstra, 2010; Owusu-Sekyere, Scheepers & Jordaan, 2016). Prior to the data collection, the survey instrument was pre-tested among 15 respondents in selected supermarkets. Face-to-face interviews were conducted in the selected markets, using samples of the labelled products. The surveyed sample ultimately consisted of 402 meat consumers. Of these, 150 were sampled from Midrand, 120 from Centurion, and 132 from Pretoria. The response rate for the survey was 75%. The questionnaire consisted of both closed- and open-ended questions, as well as Likert-scale-type questions. The questionnaire focused on the choice experiment, respondent's socio-economic characteristics, knowledge of environmental sustainability, and attitudinal data. We initially assessed respondents' subjective and objective knowledge of environmental sustainability before conducting the choice experiment. The assessment of subjective and objective knowledge followed the approach of Brucks (1985).

9.2.3 Experimental Design

An attribute-based choice experimental design was employed. The choice experiment allows respondents to choose from a set of product alternatives, with different attribute combinations. The choices made by respondents assist in revealing their preferences, without subjectively asking them to value the product attributes. This method minimises social desirability bias (Norwood and Lusk, 2011). The choice experiment consisted of different combinations of water usage (water footprint), carbon emissions (carbon footprint) and prices. Different choice sets were designed for beef rump steak. The water footprint values were estimated using South African data and the Water Footprint Network Standard Approach, as outlined in the Water Footprint Assessment Manual. Water footprint estimates for beef from Mekonnen and Hoekstra (2010) was also included. The carbon equivalents were obtained from Milk South Africa (Milk SA) and Scholtz et al. (2014). The prices considered were the mean observed prices for beef rump steak without carbon and water footprint labels, with standard deviations of plus and minus one (Grebitus et al. 2015).

Water footprint, carbon footprint and price attributes had three levels each in the choice sets as designed (Table 9.1). The attributes and their levels were combined using Ngene software to create a random parameter panel efficient design with three alternatives (A, B and "none")

(Choice Metrics, 2014). D-error efficiency and blocking strategy were also used during the design. The blocking strategy circumvents respondent fatigue during the survey (Savage and Waldman, 2008). All the choice questions were generated using the Ngene software and blocked into ten, with each block containing two choice sets. Each person was randomly allocated to a block. Since the concept of carbon and water footprints is new, the possibility that some respondents may not be aware of water and carbon footprints was resolved by generating statements explaining the carbon and water footprints, their measurements, and the meanings of the footprint values to the respondents in their local and preferred language before the survey. These statements were approved by the Water Research Commission (WRC) of South Africa before the survey was conducted. The likelihood ratio test was employed to formally test whether the data from the two markets could be pooled together (Wooldridge, 2002).

Table 9.1: Attributes and their level in the choice experiment

Attribute	Beef rump steak	Categorical level
1. Water footprint	1. 15415 l/kg	Low
	2. 17300 l/kg	Medium
	3. 17387 l/kg	High
2. Carbon footprint	1. 22.90 kgCO_2e	Low
	2. 26.37 kgCO_2e	Medium
	3. 27.50 kgCO_2e	High
3. Price	1. ZAR 159.99/ kg	Low
	2. ZAR 179.99/ kg	Medium
	3. ZAR 185.00/ kg	High

The Water Research Commission (WRC) of South Africa approved these statements prior to the survey. The likelihood ratio test was employed to formally test whether the data from the two markets could be pooled together.

9.3 RESULTS AND DISCUSSION

9.3.1 Descriptive Characteristics of Respondents

The descriptive characteristics of respondents are presented in Table 9.2. The average age of the sample was about 35 years. This compares favourably with Stats SA's population estimates, which indicate that about 66% of the members of the South African population are about 35 years of age (Stats SA, 2014). The mean number of years of formal education was

15 years, and an average monthly income of ZAR10 132.24. Most of the respondents were females, as indicated by the percentage of 67.70%. The high proportion of females is not surprising, given that women are mostly in charge of household grocery shopping and purchasing decisions in South Africa (Mare et al., 2013). About 53.50% of the respondents were aware of the Department of Water and Sanitation's campaign about threats posed by climate changes in South Africa. This suggests the need for greater numbers of awareness campaigns to be conducted on climate changes, as 46.50% of the people were not aware of climate change issues. Most of the respondents (73.44%) trust in food labelling regulatory bodies in South Africa.

Table 9.2: Descriptive statistics of respondents' socio-economic characteristics

Variable	Description	Mean (SD)
Age	Years	35.08(12)
Education	Years of formal education	15.08(2)
Income	Monthly income in ZAR	10132.24(44)
Subjective knowledge index (SUBKI)	Subjective knowledge about environmental sustainability	3.41(1)
Objective knowledge index (OBJKI)	Objective knowledge about environmental sustainability	2.68(1)
Variable	Description	Percentage
Female	1 if female, 0 otherwise	67.7
Awareness	1 if respondents is aware of the department of water and sanitations campaign on climate changes	53.5
Trust	1 if respondent trust in food labelling regulatory bodies	73.4

In terms of respondents' subjective and objective knowledge regarding environmental sustainability, the results revealed an average subjective knowledge (SUBKI) index of 3.41. Similarly, the objective knowledge index was found to be 2.68. The subjective and objective knowledge estimates show that the respondents consider themselves as moderately knowledgeable about environmental sustainability. Generally, the index for subjective knowledge is higher than objective knowledge is, implying that what respondents think they know about environmental sustainability is higher than what is actually observed or practical. This is in agreement with findings of Peschel et al. (2016) among Canadian and German consumers.

9.3.2 Latent Class Estimates

The latent class model estimates are provided in Table 9.3. Prior to the latent class estimation, the likelihood ratio test was employed to formally test whether the data from the two supermarkets could be pooled together (Wooldridge, 2002). Based on the test results, the null hypothesis for pooling the data was not rejected. Furthermore, a Ben-Akiva and Swait (1986) test was conducted to ascertain whether the latent class model or the mixed logit models best fitted our data. It was found that the latent class model is the best fit and that the heterogeneity in our data is better explained at the segment level, rather than at individual level. Therefore, we present the results of the latent class model. Using McFadden's (ρ^2), AIC and BIC selection criteria, the three-latent class model was found to be optimal. The McFadden (ρ^2) statistic of 0.21 indicates that the model was a suitable fit (Hensher et al., 2005).

The results reveal that the respondents are heterogeneous in their preferences for water usage, carbon emission, and price. This is indicated by the differences in magnitude, direction, and significance of the utility function estimates. This concurs with recent findings of Grebitus et al. (2015). Three distinct consumer classes were found. Price is significantly negative in all the classes, as expected, and in accordance with economic theory (McFadden, 1974). This means that all the three classes of consumers are sensitive to price and consider it as a relevant attribute in their decision to purchase environmentally sustainable food products (Grebitus *et al.,* 2015, 2016; Peschel *et al*., 2016). Therefore, the pricing of environmentally sustainable products should be carefully reviewed in order to not exceed what consumers are willing to offer to pay.

For class one, the utility estimates show that low levels of water usage and carbon emissions are significantly positive. This means that respondents in this class prefer beef products with low water and carbon footprints. Medium water usage level was significantly negative. Furthermore, high levels of water usage and carbon emission variables were significantly negative. This suggests that, apart from low water and carbon footprint levels, respondents in this class will not prefer beef products with medium or high footprint estimates. This is confirmed by the status quo bias observed for the "none" option. The significantly negative coefficient estimate of the "none" option implies that respondents in this class prefer to select one of the product options, rather than to choose the "none" option. This class accounts for 46% of the sampled respondents.

The class membership estimates for this class reveal that having high levels of formal education and income, as well as subjective and objective knowledge on environmental sustainability, increases the likelihood of a particular respondent belonging to this class, relative to class three. Additionally, members of class one are likely to be aware of threats posed by climate changes through the campaigns of the Department of Water and Sanitation. They are also likely to trust the food labelling regulatory bodies in South Africa. Members of this class are likely to be younger individuals, as indicated by the significantly negative coefficient of the age variable.

For the second class, the utility estimates for low levels of water usage and carbon emissions are significantly different from zero and positive. High levels of water usage and carbon emission variables are significantly negative. This suggests that members of this class have negative preferences for beef products with high water and carbon footprints. The status quo variable "none" is significantly different from zero and positive. This implies that respondents in this class also prefer beef products without water and carbon footprint sustainability information. Class two accounts for 35.10% of respondents. The class membership estimates for this segment indicate that respondents in this class are likely to be older females with low income, relative to class three members. Respondents in this class are less likely to trust food labelling regulatory bodies, relative to class three members. They are also less likely to report having high subjective and objective knowledge on environmental sustainability, compared with class three members.

For class three, the significance and directions of the utility function estimates differ. The utility function estimates for low water usage and carbon emission levels are significantly different from zero and positive. This suggests that respondents in class three do prefer beef products with low water and carbon footprints. However, their utility estimates for this level are lower relative to the other two classes. The utility estimates for medium and high levels were positive, but insignificant at the conventional levels, relative to the other classes. Members of this class also have positive utility estimates for medium and high carbon footprint estimates, compared with the other two classes. However, their preferences were not significant. The status quo variable "none" is significantly positive, indicating that respondents in class three prefer products without water and carbon footprint sustainability information. Class three accounts for 18.90% of the respondents. Class membership estimates for this class were normalised to zero, such that the other classes could be compared with it.

Table 9.3: Latent class results for beef consumers

Attributes	Class 1	Class 2	Class 3
Water footprint			
Low	2.55***(0.65)	2.07***(0.43)	0.33**(0.13)
Medium	-0.75***(0.23)	-0.50(0.36)	0.24(0.12)
High	-1.56**(0.71)	-0.46*(0.24)	0.14(0.17)
Carbon footprint			
Low	1.57***(0.41)	1.25***(0.33)	0.22***(0.03)
Medium	-0.69(0.40)	1.16(0.81)	1.02(0.73)
High	-1.36***(0.42)	-1.08**(0.48)	0.54(0.37)
None	-3.11*** (0.66)	1.23***(0.69)	0.74**(0.30)
Price	-0.35***(0.11)	-0.37*** (0.07)	-0.18***(0.05)
Class share	**46%**	**35.10%**	**18.90%**
Class membership estimates			
Constant	-1.66***(0.24)	-2.43***(0.39)	
Age	-0.57**(0.2)	0.33**(0.12)	
Female	-0.34(0.24)	0.27**(0.11)	
Education	0.72**(0.22)	0.23(0.19)	
Income	0.62**(0.31)	-0.32**(0.12)	
Awareness	0.46**(0.22)	0.55(0.41)	
Trust	0.41** (0.20)	-0.39**(0.19)	
SUBKI	0.27** (0.11)	-0.16*(0.09)	
OBJKI	0.21**(0.09)	-0.13*(0.07)	
Diagnostic statistics	LL= -514.80; AIC=1051; BIC=1251.98; McFadden's (ρ^2) =0.21		

Values in parentheses are standard errors
*** =significant at 1%, ** =significant at 5%, * = significant at 10%

9.3.3 Willingness to Pay Estimates for Water and Carbon Footprint Sustainability Attributes

Class-specific willingness to pay the estimates for the different levels of sustainability attributes were evaluated at 95% confidence interval, and are presented in Table 9.4. The WTP estimates for the attributes were estimated across the latent classes in order to ascertain the differences in preference structure. The results show that respondents in class one and class two are willing to pay ZAR 7.29, ZAR 5.59 and ZAR 1.83, respectively, for a kilogram of beef with a low water footprint level. This suggests that, for low water footprint levels, respondents in class one offered the highest amount, whereas class three members offered the lowest amount.

Respondents in class one are willing to accept ZAR 2.14 and ZAR 4.46 as compensations to choose beef products with medium and high water footprint levels, respectively. In terms of carbon emissions, respondents in all the classes were willing to pay ZAR 4.49, ZAR 3.38 and ZAR 1.22 per kilogram of beef with low carbon emission levels, respectively, from class one to class three. The above results show that for all the three classes, willingness to pay estimates for low water usage are higher than for low carbon emissions. This implies that preference for a low water footprint among consumers is higher than for low carbon footprints. Finally, class two and three members were willing to pay for beef products without water and carbon footprint sustainability information, whereas class one members will only choose this product when they are compensated at ZAR 8.89. Given that class one forms the largest share of the respondents, the estimates suggest that willingness to pay premiums for low water and carbon footprint products could be a possible marketing strategy for producers to consider.

Table 9.4: Class-specific willingness to pay estimates and 95% confidence intervals

	Class 1 (ZAR)	Class 2 (ZAR)	Class 3 (ZAR)
Water footprint			
Low	7.29 (5.22 to 9.57)	5.59 (3.55 to 7.99)	1.83 (0.40 to 2.95)
Medium	-2.14 (-4.33 to -1.85)	NS	NS
High	-4.46 (-7.75 to -3.15)	-1.24 (-4.44 to -0.99)	NS
Carbon footprint			
Low	4.49 (2.45 to 8.10)	3.38 (2.33 to 5.80)	1.22(1.03 to 1.99)
Medium	NS	NS	NS
High	-3.89 (-6.42 to -3.05)	-2.84 (-4.12 to -2.05)	NS
None	-8.89 (-10.06 to -5.50)	3.32 (2.69 to 5.45)	4.11 (3.24 to 6.90)

NS: Not significant: All values are in South African Rand (ZAR)
Values in parentheses are confidence intervals at 95%.

9.3.4 Sustainability Policy Simulations and Compensating Surplus Estimates

The willingness to pay estimates presented in Table 9.5 are not compensating surplus welfare estimates for changes in water and carbon footprint sustainability policy scenarios. As a result of that, the respondents' compensating surplus estimates for changes in environmental sustainability management policies over the existing condition, which are conditional on belonging to any of the three classes, are created by three sustainability labelling scenarios. Scenario 0: this is the existing condition where carbon and water footprint sustainability information are not accounted for by producers, and as such there is no footprint labelling of products. Scenario 1: under this scenario, carbon and water footprints are reduced to low levels and the values are presented on beef products through labels. Scenario 2: under this scenario, carbon and water footprints are reduced to medium levels and the values are presented on beef products through labels. Scenario 3: under this scenario, carbon and water footprints remain high and the values are presented on beef products through labels. Compensating surplus estimates for these scenarios are presented in Table 9.5.

The results indicate that sustainability management scenarios 1 and 2 resulted in welfare gains in class one. Specifically, the highest welfare gain for respondents in class one is ZAR 17.08, followed by ZAR 8.80 per month per person for scenarios 1 and 2, respectively. However, scenario 3 resulted in a welfare loss of ZAR 6.73 per month per person. These findings indicate that welfare of respondents in the first class improves the most when they made decisions to pay more for products with low water and carbon footprints, and compensated for choosing products with a medium levels of water usage and carbon emissions.

For class two, the only welfare improvement was attained for scenario 1. The remaining two scenarios resulted in a welfare loss for respondents in this class. However, scenario 2 is insignificant in class two, and the welfare estimates revealed that paying for medium water and carbon footprint levels will not result in any welfare improvement. For respondents in class three, the improvement in welfare is attained from scenario 1. Specifically, the only welfare gain for respondents in class three is ZAR 3.14 per month per person. This suggests that the welfare of respondents in the third class improves the most when they are paid low premiums for purchasing products with low water usage and carbon emissions. Scenarios 2 and 3 resulted in welfare losses in this class. The results show that for both classes two and three, welfare losses are associated with scenarios 1 and 3.

Table 9.5: Compensating surplus estimates for carbon and water footprints labelling scenarios

Scenarios	Class 1	Class 2	Class 3
Scenario 1	17.08 (10.45 to 20.55)	4.26 (2.11 to 5.33)	3.14 (1.55 to 4.99)
Scenario 2	8.80 (4.22 to 9.50)	-0.28 (-1.56 to -0.09)	-4.00 (-9.10 to -2.43)
Scenario 3	-6.73 (-8.76 to -3.78)	-3.43 (-4.12 to -2.55)	-2.75 (-4.49 to -1.78)

Values in parentheses are confidence intervals at 95%.
All values are in South African Rand (ZAR) per consumer per month

9.4 CONCLUSION

In this research, choice experiment and latent class modelling approaches have been employed to estimate consumers' preferences and compensating surplus estimates for water and carbon sustainability policy changes in South Africa. The study concludes that there is considerable preference heterogeneity at segment level for water sustainability attributes of beef products. Specifically, the study concludes that there are three distinct consumer segments within the sampled respondents, with each class exhibiting different preference attitudes for the same set of water usage levels. Respondents in segment one derive positive utilities from low levels of water usage, while negative utilities are attained from medium and high levels of the same attributes. Segment two members also derive positive utilities from low levels of water footprint values, while negative utilities are derived from high levels of same footprint attributes.

Respondents in segment three derive positive utilities from low water usage levels. Members in this segment derive positive but insignificant utilities from medium and high water usage levels. The profound heterogeneity in preferences is explained by socio-economic factors such as age, gender, education and income of respondents. Besides socio-economic factors, public awareness creation and campaigns regarding threats associated with climate changes play a significant role in influencing consumers' preferences for environmentally sustainable products. Therefore, demographic targeting of consumer segments, awareness creation, and segment-specific educational campaigns aimed at enhancing subjective and objective knowledge on environmental sustainability are important tools for governments, food companies, and agribusinesses for promoting and marketing environmentally sustainable food products.

Furthermore, respondents' subjective and objective knowledge levels on environmental sustainability will significantly impact on their choices of environmentally sustainable products. Hence, enhancing and improving the subjective and objective knowledge levels of people regarding environmental sustainability are important drivers that can be employed to change the behaviour of South Africans and Africans as a whole. The study concludes that trust in regulatory bodies in charge of food labelling, including environmental sustainability labelling, is very relevant in ensuring preferences for sustainable products.

Willingness to pay for different levels of water usage varies across the identified classes. The study concludes that willingness to pay exists for low water usage in classes all the identified segments. It is further concluded the amounts that respondents are willing to pay for a low water footprint level exceed what they are willing to offer for a low carbon footprint level. The compensating welfare evaluations reveal that the introduction of water footprint sustainability policy scenarios have varied implications on consumers. The only welfare improvements for classes two and three are related to the changes in water footprint scenario 1 when respondents pay premiums for products with low water footprint values. However, it is worth noting that welfare of class one members is improved considerably when they pay premiums for low water and carbon footprint levels, while they receive compensation for medium levels of water usage. Generally, the welfare gains and losses vary from one class to another. Therefore, there are imperative segmental equity issues that need to be taken into consideration when designing environmental sustainability strategies to change consumers' behaviour, while aiming at minimising environmental impacts.

The main implication of these findings is that preferences for environmentally sustainable products should not be limited to only willingness to pay estimates; rather, compensating surplus estimates should go along with WTP estimates for efficient and effective policy purposes. Therefore, food policymakers should take into account whose welfare will be impacted upon positively or negatively by environmentally sustainable food policy changes. Successful implementation of water footprints policies will need to strike a compromise between environmental sustainability and improvements in the welfare of the general public. If the aim is to maximise the welfare of consumers and to sustain the environment, then the cost of producing environmentally sustainable products should not be transferred to all consumer classes equally, because of the variation in welfare effects. This study has contributed to the existing literature on the preferences for environmentally sustainable food product by adding welfare implications of consumers' choices.

As limitations, it has to be noted that our sampled respondents consisted of consumers who purchased beef products from formal supermarkets that practised sustainability labelling. Hence, the external validity was limited, given that consumers who buy products from informal markets were not included in our survey. It is suggested that future research should consider consumers who purchase products from the informal markets in order to ascertain if the behaviour of consumers reported in this chapter remains robust, when compared with the behaviour of consumers in the informal markets in the context of this study. Secondly, this study focused only on beef. Future research should consider examining other food and non-food products to determine if the results reported in this chapter remain vigorous, when compared with other food and non-food products. Finally, the stated preference choice experimental approach and the questionnaire method employed may have some component of self-selection, which can lead to biased results (Grebitus et al., 2016). This potential limitation was minimised by obtaining a large sample of respondents.

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CHAPTER 10
PRODUCTIVE WATER USE BENCHMARKS ALONG THE WHEAT-BREAD VALUE CHAIN

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Summary

Efficient and wise management of freshwater resources in South Africa has become critical because of the alarming freshwater scarceness. The situation requires a thorough examination of how water is utilised across various departments that use water. This research reports on an examination of the water footprint and economic water productivities of the wheat-bread value chain. The assessment methodology of the Water Footprint Network was employed. The findings reveal that 954.1 m^3 and 1026.1 m^3 of water are utilised in the production of a ton of wheat flour in Bainsvlei and Clovelly in South Africa. The average water footprint for wheat bread was 954.5 m^3 per ton in Bainsvlei and 1026.5 m^3 per ton in Clovelly. More than 99% of the water is used in producing the grain at the farm level. The processing stage of the value chain uses less than 1% of the total water footprint. About 80% of all the water utilised along the wheat-bread value chain is attributed to blue water. The findings revealed a significant shift from green water consumption to higher blue water use, and this is a major concern for water users and stakeholders along the wheat-bread value chain, given that blue water is becoming scarce in South Africa. The groundwater contributes about 34% and 42% of the average total water footprint of wheat at the farm level in Clovelly and Bainsvlei, respectively, suggesting the need to have an idea of the contribution of groundwater in the water footprint evaluation and water management decisions of farmers. This insight will assist in minimising irrigation water use and pressure on groundwater resources. A total of ZAR 4.27 is obtained for every m^3 of water utilised along the wheat-bread value chain. Water footprint assessments have moved away from sole indicator assessment, as a deeper awareness of, and insight into, the productive use of water at different stages has become vital for policy. To make a correct judgment and to assess the efficient and wise use of water, there is a need for catchment- or region-specific water

footprint benchmarks to be ascertained, given that water footprint estimates and economic water productivities vary from one geographical area to another.

10.1 INTRODUCTION

Freshwater is a renewable resource, but when considering its availability regarding unit per time per region, the limitations of this resource cannot be ignored (Ababaei and Etedali, 2014; Agudelo-Vera et al., 2011). In global terms, agriculture accounts for 99% of freshwater consumption (Ahmed and Ribbe, 2011) and is therefore considered as the single largest freshwater user, globally. Hoekstra and Chapagain (Aldaya and Hoekstra, 2010) show that visualising the amount of water used in producing products can further increase our understanding of the global picture of freshwater utilisation – a concept that is explored by the Global Water Footprint Network Standard approach (GWFNS). The GWFNS approach has come to the fore as an important sustainability indicator in the agricultural sector, as well as in the agri-food-processing industry (Aldaya et al., 2010; Berger and Finkbeiner, 2010; Bulsink et al., 2009). This assessment includes both the indirect and direct uses of freshwater by a consumer or a product along with its value chain (Chouchane et al., 2015; Jefferies et al., 2012).

South Africa is deemed to be water scarce and a water limited country (Crafford et al., 2004; DWA, 2013; World Wide Fund (WWF), 2015). Irrigated agriculture uses about 60% of South Africa's available surface and freshwater resources (DAFF, 2012). Moreover, 30% to 40% of this water is lost through leaks and evaporation, which gives the impression that water use in this sector is inefficient [10]. According to the Department of Agriculture Forestry and Fisheries (DAFF, 2012), South Africa's agricultural sector is the least direct contributor to the gross domestic product (GDP), measured per million cubic metres of freshwater use, and is also the least direct employer per million cubic metres of freshwater (DAFF, 2012; DAFF, 2016; Mukheibir, 2005). This is in contrast with the commitment of the National Water Research aim of achieving sustainable and efficient use of freshwater by all South Africans, especially among producers of key food crops.

Wheat is the most-cultivated commercial crop, globally (DAFF, 2016). In South Africa, wheat is the largest winter cereal grain, with a total requirement of 2.7 million metric tonnes per year (DAFF, 2016). Most of the wheat used for bread production is produced locally. Wheat production is spread among 32 of the 36 crop-production regions, with an estimated 3200 to 4000 producers. South Africa's wheat production was estimated at 1.88 million metric tonnes for the 2016/17 production year (DAFF, 2016). About 69.63% of South Africa's total wheat demand is produced locally, and 30.37% is imported. About 60% of the wheat flour is used to produce bread. In South Africa, existing statistics indicate that 2.8 billion loaves of bread are consumed per year. This indicates that, in a year, sixty-two loaves of bread, with an average weight of 700 g, are consumed per person per year, with a noticeable difference in preferences and consumptions among the provinces (DAFF, 2016; Grain SA, 2016). Given the relative importance of the crop and the water scarcity situation in the country, potential strategies that will reduce and identify large water uses along the value chain will be identified.

Two well-known concepts are applied in the assessment of a water footprint. These are the Life Cycle Assessment (LCA) approach and the Water Footprint Assessment Manual (WFAM) approach. Recently, some developments in the Water Footprint framework have taken place within the framework of Life Cycle Assessment (Dong et al., 2013; Zoumides et al., 2014). The LCA approach proposed to weight the original volumetric water footprint by the water scarcity in the catchment where the water footprint is situated (ISO, 2014), with the aim of attaining a water-scarcity weighted water footprint that portrays the possible local environmental impacts of water usage (Hoekstra, 2016). This proposal has received some criticism in recent years (Hoekstra, 2016).

The criticism, as elaborated by Hoekstra [15], is that there will be confusion about water scarcity if volumes of water use are counted differently, based on the level of local water scarcity (Hoekstra, 2016). This relates to the allocation of water resources to opposing uses and reduction at a global scale. Secondly, the LCA approach ignores green water usage, and this neglect suggests that the LCA does not accept the fact that green water is scarce amidst changing climates. The third criticism is that since water scarcity in a given geographical area increases with increasing total water consumption in the area, multiplying the consumptive water use of a given process with water scarcity suggests that the subsequent weighted water footprint of a process will be impacted upon by the water footprints of other processes (Hoekstra, 2016). The fourth criticism is that the manner in which the LCA approach treats the water footprint is inconsistent with definitions of other environmental footprints. Finally, the Water Stress Index, as described by the LCA approach, lacks relevant physical understanding (Hoekstra, 2016).

In terms of the water footprint of wheat, the WFAM approach has been employed by various authors in recent years. For instance, Mekonnen and Hoekstra (2010) gave an overview of the green, blue and grey water footprints of several crops and derived crop products, worldwide, including for South Africa. Mekonnen and Hoekstra (2010) estimated the water footprint of wheat. Aldaya and Hoekstra (2010) calculated the water footprint of pasta and pizza margarita in Italy. Ahmed and Ribbe (2014) explored the green and blue water footprints of rain-fed and irrigated wheat in Sudan. Neubauer (2012) calculated the water footprint required to produce 1 kg of bread in Hungary. Sundberg (2012) conducted a water footprint assessment of winter wheat and derived wheat products in Sweden. Ababaei and Etedali (2014) calculated the water footprint of wheat produced without irrigation in Iran.

None of these studies considered an assessment of the water footprint along the entire wheat value chain in South Africa. For instance, Le Roux et al. (2016) evaluated the water footprint of wheat in South Africa, but they only focused on quantifying the water footprint at the farm level, without considering water utilisation along the entire wheat-bread value chain. Nonetheless, Mekonnen and Hoekstra (2011) quantified the water footprint of wheat for several countries, including South Africa. Additionally, Mekonnen and Hoekstra (2010) evaluated the water footprint of several crops and derived crop products, worldwide, including South Africa. Their estimates were reported at the national and provincial levels, and, as such, there is no current information on the water footprint of wheat at the catchment-specific level in South Africa. Catchment- or regional-specific estimates are needed to better inform water managers and policymakers about water management policies across different regions. Furthermore, it has been found that catchment- or region-specific water footprints vary from national footprint estimates (Owusu-Sekyere et al., 2016: 2017).

Furthermore, no current studies have examined the economic water productivity of bread along its respective value chain links, which include farm level, milling, and bakery stages, in South Africa. Aldaya et al. (2010) estimated the economic water productivity of wheat in Central Asia. Similarly, Chouchane et al. (2015) and Zoumides et al. (2014) added water productivities evaluation when assessing the water footprint of crops in Tunisia and Cyprus, respectively. The main objective of this study was to account for the water footprint and economic productivity of water along the wheat-bread value chain. The present study contributes to the existing literature on water footprints and economic water productivities of crops. The water footprint estimates calculated from this study can act as benchmarks for the catchment area considered in this study. The findings of this study can potentially advise policymakers and water users on economically efficient and sustainable water management strategies.

10.2 METHODOLOGY

10.2.1 Choice of Theoretical Framework and Models

This study followed the water footprint concept of Hoekstra et al. (2011). The definitions of blue, green and grey water footprints followed those of Hoekstra et al. (2011) in the Water Footprint Assessment Manual. The study employed this method because it involves several dimensions, showing the sources of water utilisation in quantities (Van Rensberg et al., 2012). The conceptualisation procedure of the study is presented in Figure 10.1.

According to the water footprint concept adopted in this study, the water footprint can be calculated in four phases, namely, goal setting, water footprint accounting, sustainability assessment, and formulation of response (Hoekstra et al., 2011). However, in this study, our third phase focuses on water productivity assessment. In the first phase of this study, the step-wise accumulation approach was followed because, along the wheat value chain, each output product serves as an input for the next product. The total water footprint will include proportional water footprints of the various inputs within the value chain (Hoekstra et al., 2011). The analysis was made for a single production year.

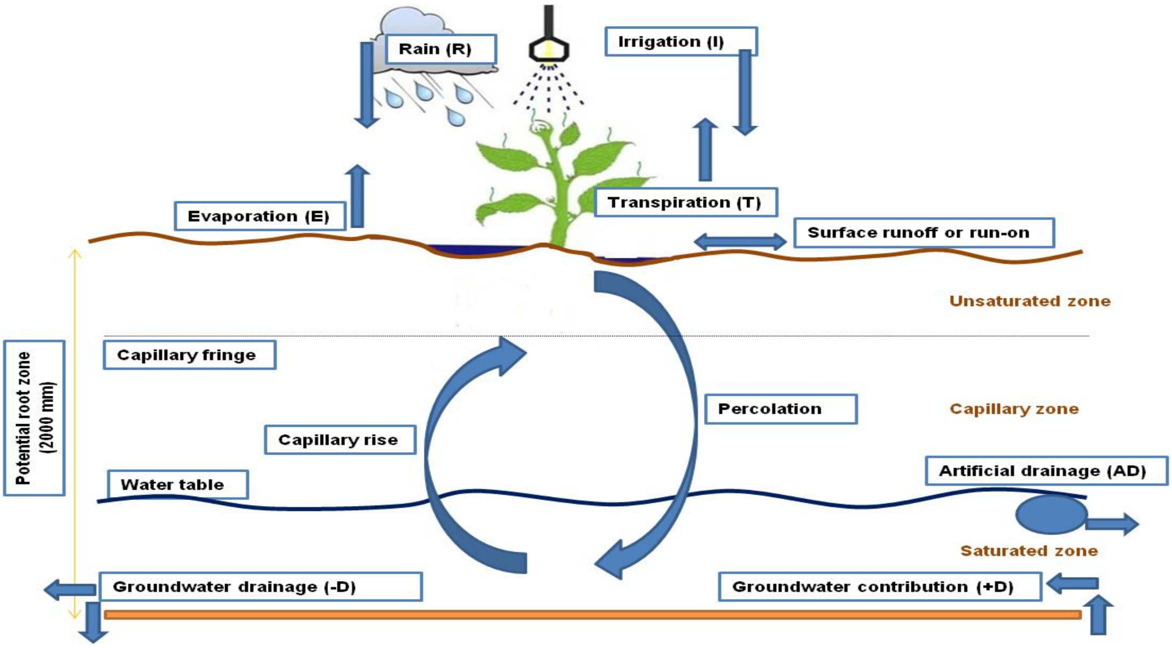

Figure 10.1: Procedure conceptualisation of the field experiment

The step-wise accumulation approach is expressed empirically in Equation (10.1). By this approach, the water footprint of wheat bread (W), which the main output product, is stated to be made from *z* inputs (e.g. wheat and flour). We denote the *z* inputs to range from j = 1… *z*. Given that *z* inputs are utilised to produce w wheat products, we denote the different wheat output products as W = 1…*w*. The wheat products' (W) water footprints are specified as:

$$WF_{prod}[\mathrm{W}] = \left(WF_{proc}[\mathrm{W}] + \sum_{i=1}^{z} \frac{WF_{prod}[j]}{f_w[\mathrm{W}, j]} \right) * f_v[\mathrm{W}], \tag{10.1}$$

$WF_{prod}[\mathrm{W}]$ represents the total water used in producing W. $WF_{prod}[j]$ denotes the water footprint of input *j.* The water utilised in the processing *z* inputs to W outputs is represented by $WF_{proc}[W]$ (Hoekstra et al., 2011). $f_w[W, j]$ and $f_v[\mathrm{W}]$ are the product and value fractions, respectively, (Hoekstra et al., 2011). Thus, the water footprint of wheat along the product cycle at the farm level is the sum of a process water footprint of the different sources of water used in production, according to Aldaya and Hoekstra (2010) and Ababaei and Etedali (2014). The process water footprint is specified as:

$$WF_{proc,blue,green,grey}[\mathrm{W}] = \left(\frac{CWU_{blue}}{Y_t}\right) + \left(\frac{CWU_{green}}{Y_t}\right) + \left(\frac{(\alpha \times AR)/(c_{\max} - c_{nat})}{Y_t}\right), \tag{10.2}$$

The blue, green, and grey water footprints of wheat at the farm level are denoted as $WF_{proc,blue,green,grey}[\mathrm{W}]$. The blue component of the water footprint is represented by $\frac{CWU_{blue}}{Y_t}$, where CWU_{blue} represent the blue water used in producing wheat and Y_t is wheat yield [8]. In this chapter, blue water use was categorised into surface and groundwater sources. This will give an idea about the proportion of water extracted from the ground and surface, according to Hoekstra et al. [8].

$$WF_{blue} = \frac{CWU_{surface}}{Y_t} + \frac{CWU_{ground}}{Y_t}, \tag{10.3}$$

The green component of the water footprint is represented as $\frac{CWU_{green}}{Y_t}$ and CWU_{green} indicates the green water used in producing wheat (Hoekstra et al., 2011). The crop water use components in Equation (10.2) summed the daily evapotranspiration over the complete growing period of the wheat crop [8] and are stated empirically as:

$$CWU_{blue,green} = 10 \times \sum_{d=1}^{\mathrm{lgp}} ET_{blue,green}, \tag{10.4}$$

$ET_{blue,green}$ characterises the blue and green water evapotranspiration. The water depths are changed from millimetres to volume per area by using the factor 10 (Hoekstra et al., 2011). The last part of Equation (10.2) is the grey water footprint component. This is calculated by taking the chemical application rate for the field per hectare (AR, kg/ha) and multiplying by the leaching-run-off fraction (α). The product is divided by the difference between the maximum acceptable concentration (c_{max}, kg/m^3) and the natural concentration of the pollutant considered (c_{nat}, kg/m^3) [8]. It is worth mentioning that grey water was not used at the processing stage. Grey water was only used at the farm level and the pollutant considered is nitrogen.

At the milling stage, the water footprint of flour is specified as set out in Equation (10.5):

$$WF_{milling}[flour] = \frac{TWU_{mill}}{Q_{flour}}, \tag{10.5}$$

where $\mathrm{TWU}_{\mathrm{mill}}$ is the total water used to produce a given quantity of flour (Q_{flour}) and at the water utilised at the bakery ($\mathrm{TWU}_{\mathrm{bakery}}$) for a given quantity of bread (Q_{bread}) is specified as in Equation (10.6).

$$WF_{baking}[bread] = \frac{TWU_{bakery}}{Q_{bread}}, \tag{10.6}$$

The total water footprint of bread along the wheat-bred value chain is a combination of all the footprints in this value chain. After calculating the water footprint ($WF_{prod}[W]$), we estimated physical water productivity (*PWP*) of the output products (W) in kilograms per cubic metre, expressed as:

$$PWP(kg/m^3) = \frac{1}{WF_{prod}[W](m^3/ton)} * 1000, \tag{10.7}$$

Subsequently, we estimated the economic water productivities for the different outputs at different stages by multiplying the physical water productivity by the monetary value added to each *w* output per kilogram. The value added to the output products along the value chain is calculated by subtracting the cost per kilogram of *w* from the sales revenue obtained from selling one kilogram of w at each stage of the value chain (Chouchane et al., 2015; Hoekstra and Chapagain, 2007). Consequently, the value added to the output product (*w*) becomes the total revenue of the output product, minus the cost of all intermediate inputs (z) used to produce it. Let the value added to *w* at a specific stage of the value chain be represented by $VAD_{jvc}[W]$ and specified as:

$$VAD_{jvc}[W] = \mathrm{Re}\,v_{Jvc}(W) - Cost_{jvc}(W), \tag{10.8}$$

where $\mathrm{Re}\,v_{jvc}(W)$ represents sales revenue attained from one kilogram of *w* and $Cost_{jvc}(W)$ denotes all intermediate inputs costs, including the cost of water usage, capital, land, labour, feed, taxes, conveyance, packing, fuel, repairs and maintenance. The sum of the value added at each stage of the product cycle became the total value added ($\mathrm{TVAD[W]}_{vc}$), stated as:

$$TVAD_{vc}[W] = \sum_{j=1}^{3} VAD_{jvc} \quad , \tag{10.9}$$

Value added to water along the wheat-bread value chain is quantified as the ratio of the value added to the output product (*w*) at a given stage, over the volume of water used at that stage [27,28]. From this, we calculated the marginal value of water $\mathrm{MVAD[water]}$ as the partial derivative of total value added ($TVAD_{jvc}$) with respect to water use (WU_{jvc}):

$$MVAD[water]_{vc} = \partial \frac{TVAD_{jvc}}{WU_{jvc}}, \tag{10.10}$$

The marginal value added to water is then multiplied by physical water productivity to attain the economic water productivity, according to Chouchane et al. (2015) and Owusu-Sekyere et al. (2017):

$$EWP(ZAR/m^3) = PWP(kg/m^3) * VAD(ZAR/kg) \tag{10.11}$$

10.2.2 Data Description

This research employed primary data that cover the wheat-bread value chain. Data on water usage for wheat production were sourced from Van Rensburg et al. (2012), who conducted a lysimeter experiment to solicit spatiotemporal data from the Vaalharts and Orange-Riet regions. This study made use of actual measurements through a lysimeter trial to avoid any assumptions that come with water use models. The experiment consisted of five treatments replicated three times, and an average was taken to represent each sample. The cultivars used were selected because of their wide use in all the central parts of South Africa. Aboveground biomass was harvested when the crops were dry by cutting it just above the soil surface. The lysimeter trial evaluation procedure for the different treatments employed in the two study areas captured data on groundwater levels, irrigation, drainage and changes in soil moisture content.

The lysimeter procedure consisted of five treatments for groundwater levels, namely no groundwater considered (control), one metre to constant, 1.5 m to constant, one metre to falling, and 1.5 m to falling. The results are presented in Table 10.1, which sets out the recorded data used in the estimation of the blue and green water footprints.

Table 10.1: Collective data for wheat production

Treatments	Cum. ET	R	WUE	I + R	I	G	DM	Yield
BAINSVLEI								
Control	880	183	11.23	864	681	0	15,999	9881
1 m − Constant	954	183	11.00	371	188	605	16,123	10,475
1.5 m − Constant	914	183	10.87	481	298	467	16,319	9921
1 m − Falling	906	183	11.57	400	217	532	16,776	10,458
1.5 m − Falling	881	183	11.63	460	277	443	15,578	10,230
CLOVELLY								
Control	825	183	9.83	834	651	0	14,708	8375
1 m −Constant	869	183	10.40	469	286	424	13,995	9010
1.5 m − Constant	860	183	10.63	540	357	330	15,185	9161
1 m − Falling	830	183	10.77	426	243	408	15,230	8937
1.5 m − Falling	824	183	10.47	472	289	360	14,898	8620

Cum. ET = cumulative evapotranspiration; R = effective rain; I + R = irrigation and rain; I = irrigation; G = groundwater; DM = dry matter. Source: Authors' calculations.

The data used in the estimation of grey water footprints are presented in Table 10.2. The nitrogen (Kg N/ha) and phosphorus fertilisation (Kg P/ha) fertilisation rates were based on targeted yields under irrigation. The wheat farmers usually apply nitrogen and phosphorus fertilisers, although farmers apply potassium fertilisers. However, in this trial, only nitrogen and phosphorus fertilisers were considered. The leaching runoff coefficients of nitrogen for the two areas are 0.074 and 0.138, whereas those of phosphorus were 0.080 and 0.280. The nitrogen application rates were presented for different potential yields.

The target yields range from 2 to 5 tons per hectare to above 8 tons per hectare, with corresponding nitrogen application rates ranging from 80 to 130 kg N/ha to 200+ kg N/ha. Prior to the phosphorus application, the soil phosphorus status was examined to ascertain the quantity of phosphorus to apply. The quantities of phosphorus already in the soil were categorised into less than 5 mg/kg, 5-18 mg/kg, 19-30 mg/kg, and above 30 mg/kg. The application rates of phosphorus varied depending on the amount that was already available in the soil. Soils with less than 5 mg/kg received a higher amount of phosphorus, followed by 5-

18 mg/kg, with soils containing above 30 mg/kg receiving the least amount of phosphorus applied.

The field trial captured data on evapotranspiration (ET), rainfall, irrigation, ground and surface water consumed by the crop, as well as yields in Bainsvlei and Clovelly. From Table 10.1, it can be seen that the yield of wheat from the different trials varied depending on the scale of measurement, ranging from 9881 to 10 458 per hectare in Bainsvlei, and from 8375 to 9161 kg per hectare in Clovelly.

Table 10.2: Nitrogen (Kg N/ha) and phosphorus fertilisation (Kg P/ha) based on targeted yield under irrigation

Nitrogen Application Rates				
Target Yield (ton/ha)	**Nitrogen (Kg N/ha)**			
4-5	80-130			
5-6	130-160			
6-7	160-180			
7-8	180-200			
8+	200+			
***Phosphorus Application Rates* (Kg P/ha)**				
Target Yield (ton/ha)	**Soil Phosphorus Status (mg/kg)**			
	>5 *	**5-18**	**19-30**	**>30**
4-5	36	28	18	12
5-6	44	34	22	15
6-7	52	40	26	18
7+	>56	>42	>28	21

*Minimum quantity that should be applied at the low soil phosphorus level
Source: DAFF [30].

The cumulative ET, crop total evapotranspiration, indicates the crop water requirement. Bluewater is further distinguished as either surface or groundwater. The average crop water requirement (Cum. ET) is between 880 mm and 954 mm in Bainsvlei, and between 824 mm and 869 mm in Clovelly. Effective rainfall in this period was only 183 mm per annum. Figure 10.2 shows a map of the catchment area where the study took place.

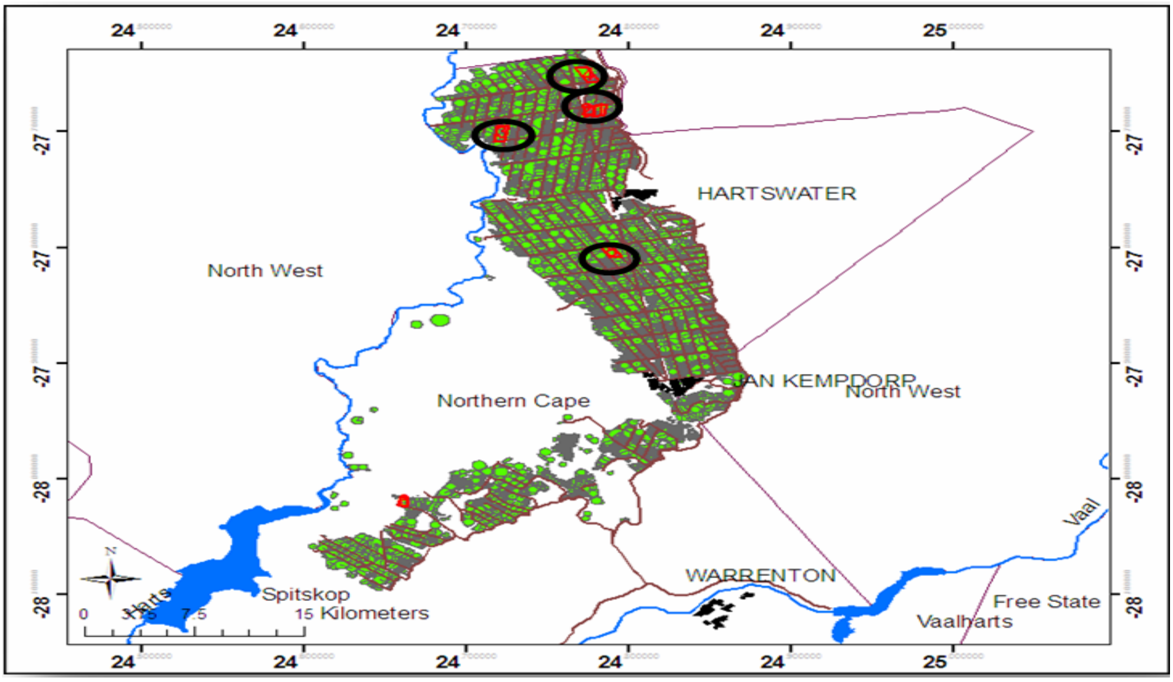

Figure 10.2: Map of the study area
Source: Van Rensburg et al. (2015).

At the processing level, primary data were acquired through a questionnaire conducted at a bread milling company that has a total of five mills and 15 commercial bakeries across South Africa. Data collected from this source included the quantities of wheat milled, quantities of flour used, volumes of water used to produce a specified quantity of flour and bread, and total water used at the mill and bakery. In addition, the cost of water and the prices of wheat, flour and bread were obtained. Thus, production costs and income received along the flour-bread supply chain were known. In the case of wheat, the producer prices were obtained from GrainSA (2016).

10.3 RESULTS AND DISCUSSION

10.3.1 Water Footprints of Wheat Production at the Farm Level in Bainsvlei and Clovelly

The estimated water footprint of the two areas is presented in Table 10.3. The results show that, for all the trials and the control, wheat production uses more blue water than green water. In Bainsvlei, blue water ranged from 7200 m^3 to 7930 m^3 per hectare, whereas that of Clovelly ranged from 6490 m^3 to 7100 m^3. This shows that the crop water use in Bainsvlei is higher than that of Clovelly. For both study areas, the blue water use for the control group was lower than the trial estimates. In addition, the blue water use for the control group in Bainsvlei was 6810 m^3 per hectare, while that of Clovelly was 6510 m^3 per hectare.

Regarding the water footprint, the results show that the blue water footprint was higher than the green water footprint was. This implies that wheat farmers in the two areas rely mostly on blue water resources. The green water footprint in Bainsvlei ranged from 174 m^3 per ton to 185 m^3 per ton. The blue water footprint from the surface fluctuated from 179 m^3 per ton to 272 m^3 per ton in Bainsvlei for the treatment group, while the blue water footprint from the water table ranged from 432 m^3 per ton to 576 m^3 per ton for the treated group in Bainsvlei. This suggests that much of the blue water footprint arises from groundwater resources. Regarding percentage usage, the results show that the proportion of groundwater used is about 37% to 69% of the total blue water footprint in Bainsvlei. The grey water footprint in Bainsvlei ranged from 52 to 55 cubic metres per ton, suggesting that about 52 to 55 cubic metres are required to reduce nitrogen and phosphorus pollutants to ambient levels.

The total water footprint in Bainsvlei ranges from 928 to 983 m^3 per ton. The total water footprint for the control is lower than that of the treated groups. These water footprint estimates are lower, relative to the global average water footprint of 1827 m^3 per ton reported for wheat by Mekonnen and Hoekstra (2010). At the national level, the water footprint of wheat in South Africa was found to be 1363 m^3 per ton for the period of 1996-2005 (Mekonnen and Hoekstra, 2010), whereas our findings revealed a range of 928 to 983 m^3 per ton.

In Clovelly, the green water footprint ranged from 199 to 218 m^3 per ton. In terms of blue water footprint, the results indicate that the blue water footprint from the surface ranges from 273 to 388 m^3 per ton for the treated group, while the blue water footprint from the ground ranges from 370 to 471 m^3 per ton for the treated group. The volume of water utilised to reduce the nitrogen and phosphorus pollutants to ambient levels ranged from 54 to 60 cubic metres. The total water footprint in Clovelly ranges from 993 to 1053 m^3 per ton. For the surface blue water footprint, we observed that the water footprint for the control group was higher than that for the treated group. Furthermore, it is clear from the results that the total water footprints vary in the two areas and for the different treatments. Further, the total water footprint estimates for wheat in Clovelly are lower than the global and South African averages reported by Mekonnen and Hoekstra (2010).

From the results, it was found that the water footprint estimates for the control and treatment groups in Clovelly were higher than those of Bainsvlei. The high water footprint in Clovelly may be attributed to the low wheat yield, compared with the Bainsvlei yield per hectare. The high water footprint can also be attributed to the high surface water (irrigation) utilisation in Clovelly, relative to the irrigation water usage in Bainsvlei. Furthermore, more groundwater was used in Bainsvlei than in Clovelly. This may be attributed to the high water-holding capacity of the soil in Bainsvlei. The average water footprint of wheat in Bainsvlei was 954 m^3 per ton, and that of Clovelly was 1026 m^3 per ton.

In Bainsvlei, the average green water footprint was found to be 180 m^3 ton^{-1}, and this accounted for only 19% of the total average water footprint in this region. The average blue water from the surface (323 m^3 per ton) accounted for about 34%, and that from the groundwater (398 m^3 per ton) accounted for about 42% of the average total water footprint in Bainsvlei. In Clovelly, the average green water footprint was found to be 208 m^3 per ton, and this accounted for about 20% of the average total water footprint. The average blue water footprints from the surface (irrigation) and ground were 418 m^3 per ton and 344 m^3 per ton, respectively. These estimates accounted for 41% and 34% of surface and groundwater, respectively. Generally, the average blue water footprints in Bainsvlei and Clovelly are 721 m^3 per ton and 762 m^3 per ton, respectively.

Table 10.3: Summary of the blue and green water footprints of wheat at the Vaalharts and Orange-Riet sites

SAMPLE	ET Crop (mm)	ET Green (mm)	ET Blue S (mm)	ET Blue G (mm)	CWU (m^3)	CWU Green (m^3 ha)	CWU Blue (m^3 ha)	Yield (ton ha)	WF Green (m^3 ton)	WF_{blue} Surface (m^3 ton)	WF_{blue} Ground (m^3 ton)	WF Grey (m^3 ton)	Total WF (m^3 ton)
BAINSVLEI													
Control	880	183	681	0	8800	1830	6810	9.9	185	688	0	55	928
1 m − Constant	954	183	188	605	9540	1830	7930	10.5	174	179	576	52	981
1.5 m − Constant	914	183	268	467	9140	1830	7350	9.9	185	271	472	55	983
1 m − Falling	906	183	217	532	9060	1830	7490	10.5	174	207	507	52	940
1.5 m − Falling	881	183	277	443	8810	1830	7200	10.2	179	272	434	54	939
CLOVELLY													
Control	825	183	651	0	8250	1830	6510	8.4	218	775	0	60	1053
1 m − Constant	869	183	286	424	8690	1830	7100	9.0	203	318	471	56	1048
1.5 m − Constant	860	183	357	340	8600	1830	6970	9.2	199	388	370	54	1011
1 m − Falling	830	183	243	408	8300	1830	6510	8.9	206	273	458	56	993
1.5 m − Falling	824	183	289	360	8240	1830	6490	8.6	213	336	419	58	1026

S = Surface water; G = Groundwater.

10.3.2 Blue Water Footprint Benchmarks and Economic Water Productivities at the Farm Level

Table 10.4 presents the blue water footprint benchmarks for wheat production at different groundwater levels in the Vaalharts and Orange-Riet regions. In this section, we estimated water footprints for a control group where irrigation was done without considering the water from the ground. Secondly, four treatments for different groundwater levels were considered. Figure 10.3 presents the different ground water levels considered in this study.

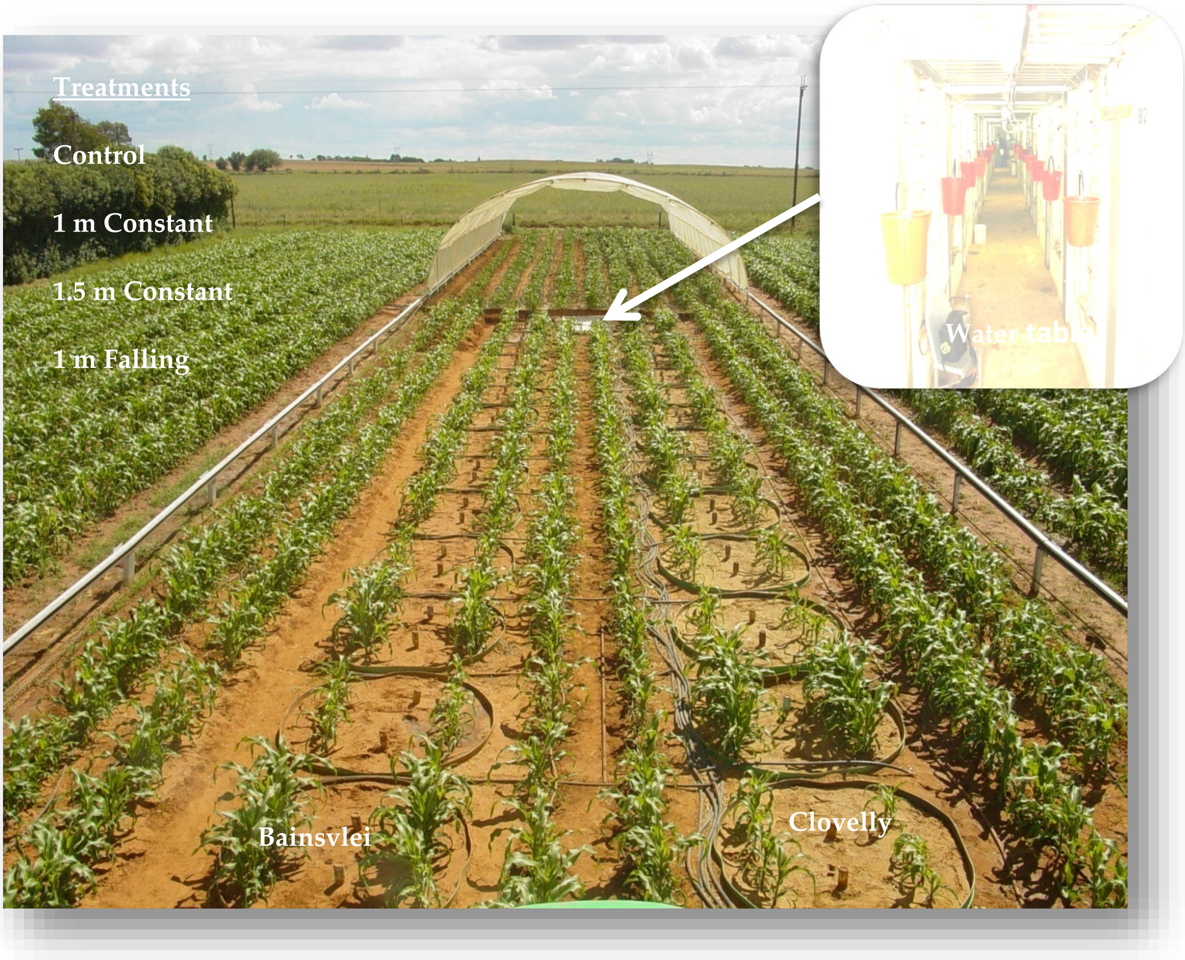

Figure 10.3: Lysimeter trial for evaluation of different groundwater levels.

The results indicate that the yield of wheat varies depending on the level of groundwater available to the crop, and this impacts on the water footprint estimates. The blue water footprints calculated for the two areas can act as benchmarks for water utilisation in wheat production in Bainsvlei and Clovelly soils. In Bainsvlei, the results indicate that without considering the groundwater, 688 m^3 per ton of blue water from the surface is required. However, with the consideration of blue water from the ground, the results indicate that farmers will require between 179 to 272 cubic metres of water from the surface (irrigation) to produce a ton of wheat in the study area. This is because about 434 to 576 m^3 per ton is contributed by groundwater.

In Bainsvlei, the optimal blue water footprints for 1 m − Constant, 1.5 m − Constant, 1 m − Falling and 1.5 m − Falling groundwater levels are 755 m^3 per ton, 743 m^3 per ton, 714 m^3 per ton, and 706 m^3 per ton, respectively. About 61% to 76% of the total blue water footprint is from groundwater. This provides the rationale for the consideration of the available groundwater contribution to crop water requirement. This gives an understanding of how the groundwater is depleted.

Similarly, in Clovelly, the results indicate that 775 cubic metres of blue water from the surface (irrigation) are required to produce a ton of wheat, without accounting for water from the ground. When the groundwater levels were considered, it was revealed that the total blue water footprints for the different groundwater levels range from 731 to 789 m^3 per ton. Nonetheless, about 370 to 471 m^3 per ton of the total blue water footprint originated from the groundwater source, emphasising the significant contribution of water from the ground to the total water footprint. In Bainsvlei, the optimal blue water footprints for 1 m − Constant, 1.5 m − Constant, 1 m − Falling, and 1.5 m − Falling groundwater levels are 789 m^3 per ton, 758 m^3 per ton, 731 m^3 per ton, and 755 m^3 per ton, respectively. The results from the two areas imply that, without considering the groundwater and the volume of water it provides to the root zones of crops, water will be utilised inefficiently.

We calculated economic water productivities for both surface and groundwater utilisation to understand the how much can be saved in monetary terms if the contribution of water from the ground is taken into consideration. The results indicate that in Bainsvlei, only 5.81 ZAR is attained per cubic metre of water used without considering contribution from the ground (controlled). When the contribution of the ground was accounted for, about 14.71 to 22.35

ZAR m^3 can be attained due to the reduced surface irrigation requirement and cost of irrigation. The water from the ground can contribute about 12.31 to 13.78 ZAR m^3 as indicated in Table 10.4. In Clovelly, an amount of 5.16 ZAR is attained per cubic metre of water used for the control group. When the contribution from the ground was considered, about 10.31 to 14.65 ZAR was attained per cubic metre of blue water (surface) used. The increase in economic water productivities was a result of reduced irrigation costs due to water contribution from the ground. Economic water productivities from the ground range from 11.18 to 12.80 ZAR. The results imply that it is economical to account for water contribution from the ground when taking water management decisions at the farm level.

Given that blue water from the surface (irrigation) contributes to the production cost, it can be said that the adoption of objective irrigation, which takes into account the volume of water available to the crop from the ground before irrigating, is more efficient and economical. Thus, objective irrigation scheduling conserves water (better utilisation of rainfall and shallow groundwater as water sources) relative to subjective irrigation scheduling.

Table 10.4: Blue water footprint benchmarks for different groundwater levels at the Vaalharts and Orange-Riet regions.

SAMPLE	**Yield (ton ha)**	**WF_{blue} Surface (m^3 ton)**	**WF_{blue} Ground (m^3 ton)**	**Total Blue WF (m^3 ton)**	**PWP Surface (kg m^3)**	**PWP Ground (kg m^3)**	**Total PWP (kg m^3)**	**EWP Surface (ZAR m^3)**	**EWP Ground (ZAR m^3)**
				BAINSVLEI					
Control	9.9	688	0	688	1.45	-	1.45	5.81	-
1 m − Constant	10.5	179	576	755	5.59	1.74	7.32	22.35	12.71
1.5 m − Constant	9.9	271	472	743	3.69	2.12	5.81	14.76	12.31
1 m − Falling	10.5	207	507	714	4.83	1.97	6.80	19.32	13.42
1.5 m − Falling	10.2	272	434	706	3.68	2.30	5.98	14.71	13.78
				CLOVELLY					
Control	8.4	775	0	775	1.29	-	1.29	5.16	-
1 m − Constant	9.0	318	471	789	3.14	2.12	5.27	12.58	11.18
1.5 m − Constant	9.2	388	370	758	2.58	2.70	5.28	10.31	14.27
1 m − Falling	8.9	273	458	731	3.66	2.18	5.85	14.65	12.77
1.5 m − Falling	8.6	336	419	755	2.98	2.39	5.36	11.90	12.80

S = Surface water; G = Groundwater; PWP = Physical water productivity; EWP = Economic water productivity.

10.3.3 Water Footprint at the Processing Stage of the Wheat-Bread Value Chain

In this section, water footprint estimates are calculated for wheat flour and bread. The results are presented in Table 10.5. Water utilisation at the processing level of the value chain consisted of the volume of water utilised at the milling and bakery units. Given the volume of water used in the milling process and the mass of flour produced, the water footprint of wheat flour at the milling stage was found to be 0.07 m^3 per ton. At the bakery stage, 0.46 m^3 of water was utilised to produce a ton of bread. Summing the water footprint of the milling and bakery stages resulted in 0.53 m^3 per ton.

Table 10.5: Water use at the processing stage of the value chain (milling and bakery)

Parameter	**Unit**	**Quantity**
	Milling stage	
Quantity of wheat	ton	767,545
Volume of water used	m^3	46,053
Quantity of flour	ton	632,348
Water footprint (flour)	m^3 ton	0.07
	Bakery stage	
Quantity of bread produced	ton	379,803
Volume of water used	m^3	174,452
Water footprint (bread)	m^3 ton	0.46
Total water footprint processing	m^3 ton	0.53

Source. Authors' calculations.

Details of the physical and economic water productivity of the individual products involved in this value chain are presented in Table 10.6. We found that wheat is considerably high in terms of physical and economic productivities. Therefore, more value is created per m^3 of water utilised to produce the grain than for other products, such as wheat flour and bread, along the wheat-bread value chain. The physical water productivity estimates show that 1.037 kg of wheat is gained per cubic metre of water utilised.

Table 10.6: Physical and economic water productivity of wheat, flour and bread along the wheat-bread value chain

Parameters	**Wheat**	**Flour**	**Bread**
Physical and Economic Water Productivities			
Yield	9.01 ton ha	632,348 ton	379,803 ton
Total water use	8690 m^3 ha	46,053 m^3	17,447 m^3
Physical water productivity	1.037 kg m^3	0.014 kg m^3	0.022 kg m^3
Value added	4.0 ZAR kg	5.7 ZAR kg	1.7 ZAR kg
Economic water productivities	4.15 ZAR m^3	0.08 ZAR m^3	0.04 ZAR m^3

Source: Authors' calculations.

Furthermore, 0.014 kg of flour and 0.022 kg of bread are gained per cubic metre of water utilised at the milling and bakery stages, respectively. In the case of value addition, results indicated that the total value added to wheat along the wheat-bread value chain is ZAR11.43 per kilogram. Of this amount, the highest value was added in the milling stage, followed by the farm-level and bakery stages. Regarding percentage contribution to the total value added, the results indicate that about 65% of the value is experienced at the processing level and only 35% at the farm level (see Table 10.7). Economically, more value is obtained per cubic metre of water used at the farm gate, followed by the milling stage and bakery stage.

Table 10.7: Summary of the value added to wheat along the wheat-bread value chain

Production Stage	**Value Added**	**% Share of Value Added**
Farm level	4.0 ZAR kg	35
	Processing level	
Milling	5.7 ZAR kg	50
Bakery	1.7 ZAR kg	15
Sub-total	7.4 ZAR kg	65
Total value added	11.4 ZAR kg	100

Average exchange rate for December 2016: US$1 = ZAR 14.62.

Summing the water footprints of the different stages resulted in average total water footprints of 954.07 m^3 per ton and 954.53 m^3 per ton for wheat flour and bread, respectively, in Bainsvlei. In Clovelly, the average water footprints for wheat flour and bread are found to be 1026.07 and 1026.53 m^3 per ton, respectively.

10.4 CONCLUSIONS

The efficient and sustainable management of freshwater resources in South Africa has become a critical policy issue in recent years because water scarcity in the country is becoming alarming. The situation requires a thorough examination of water utilisation. One of the sectors that is gaining particular attention is the agricultural sector because it is known to utilise greater volumes of freshwater, globally. This chapter examined the water footprint of the wheat-bread value chain, with a particular emphasis on the contribution of groundwater.

From the findings of the study, it is concluded that it takes 991 m^3 of water to produce one ton of bread in the Vaalharts and Orange-Riet regions of South Africa. The water footprint estimates obtained for wheat flour and bread in this study are lower than the global and national averages reported by Mekonnen and Hoekstra (2010). In Bainsvlei and Clovelly, the total water footprint estimates for wheat flour are 31% and 26% lower than the South African average reported from 1996 to 2005 (Mekonnen and Hoekstra, 2010). For bread, the total water footprint estimates for Bainsvlei and Clovelly are 21% and 15% lower than the national average reported for South Africa. The water footprint of wheat in the study areas is lower than the global average. This may be attributable to the high yields. Higher yields result in low water footprint estimates. The blue water footprint accounted for about 80% of the total water footprint of bread.

Although the total water footprints in these areas are significantly lower, what is crucial for policy concerns is the share of the blue WF, which is much larger than that in the study of Mekonnen and Hoekstra (2016) from 1996 to 2005. For instance, the current blue water footprint estimates for wheat in Bainsvlei and Clovelly are about 68% and 69% higher than the blue water footprint estimated for the period 1996-2005. From 1996 to 2005, much of the water used in wheat production was green water, suggesting that there has been a significant shift from green water usage to higher blue water consumption over the years. This might be as a result of changes in climate and rainfall patterns over the years. The significant differences support the rationale for area-specific estimates and seasonal evaluation of water footprints to be made to understand the dynamics of water consumption.

The shift to higher blue water consumption is a major concern for water users and stakeholders along the wheat-bread value chain, given that blue water is becoming scarcer in South Africa. Therefore, it is important that wheat farmers adopt good farm management practices that will continue to improve wheat yields. Such practices could include the adoption and breeding of high-yielding wheat cultivars which are drought resistant.

The water utilised in the processing stage is insignificant, as it accounts for less than 1% of the total water footprint, and as such, much attention should be paid to water consumption at the farm or production levels. We conclude that the water footprint of wheat varies from one production area to another, and from season to season.

Of further importance is the conclusion that groundwater contributes about 34% and 42% of the average total water footprints in Clovelly and Bainsvlei, respectively. This provides the rationale for the consideration of the contribution of water from the ground to total water footprint. Previous studies aggregated blue water footprints without giving an indication of the proportion contributed by the ground water source. Meanwhile, an understanding of this contribution to ET can help minimise irrigation water usage and also reduce the cost of production, since blue water is a constituent of production costs. Our findings support the idea that the adoption of objective irrigation scheduling conserves water through the better utilisation of rainfall and the shallow groundwater available to the root zone of crops. This approach is also proven to be economically efficient regarding water usage. The depth of the groundwater has a significant influence on the contribution of groundwater to the total blue water footprint and, as such, the depth of the groundwater should be examined. Furthermore, it is revealed that the total water footprint varies in the two areas and for different groundwater levels. It is worth concluding that, by not accounting for the water available to the crop (controlled) from the ground, more blue water will be applied and this leads to an upsurge in the blue water footprint (surface).

More value is gained at the farm gate, followed by the milling stage and the bakery stage for every m^3 of water utilised. Furthermore, we conclude that more value is added to wheat at the milling stage, followed by the farm gate and bakery stages. The study recommends that, to minimise blue water utilisation, wheat farmers should investigate the groundwater levels and ascertain the water available to the crop before irrigation. In other words, accounting for the water contribution of groundwater to the total water footprint will provide a better understanding of water utilisation in crop production and of how it influences the surface water needed. Secondly, objective irrigation scheduling can be adopted to reduce irrigation water usage. Wheat farmers and breeders can rely on drought-resistant wheat varieties or cultivars that are able to depend on the available rainfall and available water from the ground. Generally, water footprint assessment has moved away from sole indicator assessment, and a deeper awareness of the productive usage of different sources of water has become vital for policy.

Given the absence of benchmarks or metrics for different catchment areas in South Africa, our findings can potentially act as blue water footprint benchmarks for wheat production in Bainsvlei and Clovelly, particularly for the same ground water levels in Bainsvlei and Clovelly. A similar assessment should be conducted in other regions or catchment areas to make a correct judgment and to assess the efficiency and wise use of water, given that water footprint estimates and economic water productivities vary from one geographical area to another. This will help in achieving the objective of the National Water Research bodies, which seek to achieve sustainable and efficient water use for the benefit of all users. Finally, we recommend the inclusion of economic water productivities, as well as value addition, to a water footprint assessment along a given production chain.

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CHAPTER 11
SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

The environmental impacts of human activities and climate changes on water resources and the environment constitute a major issue of concern (Hoekstra et al., 2011; ISO, 2006). The food and agricultural sector has received particular attention in recent years because the sector is known to be a major consumer of the available scarce water resources, utilising about 86% of all global freshwater (IWMI, 2007). The current water scarcity situation in South Africa poses a threat to human survival and sustainable development in South Africa (DEA, 2015). South Africa is considered as one of the semi-arid regions in Africa and is rated as the 30th driest country in the world (DWA, 2013). More than 60% of the available fresh water in South Africa is consumed by irrigated agriculture. Currently, the water required by the various sectors of the economy exceeds the quantity of water available in different catchment areas across the country (DWA, 2013). Irrigated agriculture utilises about 40% of the utilisable runoff (Backeberg and Reinders, 2009).

Climate change adds another dimension of stress to the pressure on water resources (DWS, 2012) by causing more erratic precipitation patterns and increased variability in river flows and aquifer recharge. Thus, irrigated agriculture may face significant water-related risks that will constrain the contribution of irrigated agriculture towards poverty alleviation in South Africa. According to DWS (2012), water requirements already exceed availability in the majority of water management areas in South Africa, despite significant transfers from other catchments. The pressure is thus mounting on the effective management of our freshwater resource. In the proposed National Water Resource Strategy 2 (NWRS 2), it is acknowledged that appropriate strategies, skills and capabilities are required to ensure the effective management of the freshwater resource (DWS, 2012). DWS (2012) further acknowledges that economic growth has to be planned in the context of sector-specific water footprints, as well as the relevant socio-economic impacts and contributions, since economic growth targets cannot be achieved at the expense of the ecological sustainability of water resources, or the obligation to meet people's basic needs.

Water footprints are emerging as an important sustainability indicator in the agriculture and food sectors (Ridoutt *et al*., 2010). Hoekstra *et al*. (2011) define the water footprint of a product as the volume of fresh water (direct and indirect) that is used to produce the product, measured over the whole supply chain (or life cycle) of the product. A distinction is made between green, blue and grey water footprints. The green water footprint refers to the volume of green water (i.e. rainwater insofar as it does not become run-off) that is used to produce the product. The blue water footprint refers to the consumption of surface and ground water (blue water resources) along the life cycle of the product. The grey water footprint, on the other hand, refers to pollution and is defined as the volume of fresh water that is required to assimilate the load of pollutants, given natural background concentrations and ambient water quality standards. Importantly, all components of the water footprint are also specified geographically and temporally.

The water footprint assessment of different products, businesses, and nations has received a very limited amount of attention within South Africa (Jordaan and Grové, 2012). As a matter of fact, only two studies have, as yet, been undertaken in South Africa to calculate water footprints. SABMiller and the World Wildlife Fund (WWF) quantified the water footprints of the beer value chains in South Africa and the Czech Republic in order to understand the ecological and business risks they face. Specifically, the volume of research within the South African context is insufficient to effectively guide the management of water resources and to set benchmarks for sustainable water use in different agri-food industries. It also has to be accepted that changes in water use behaviour will have economic and social implications. Economic and social models, however, have not yet been linked to water footprint analyses to assess the economic and social implications of changing water use behaviour. Thus, it is not clear what the economic and social implications will be of changing water use behaviour towards the more efficient use of fresh water.

The aim of this research is to contribute to the limited body of knowledge by calculating the water footprints of selected field and/or forage crops in South Africa, and assessing the social and economic implications of changing water use behaviour towards ensuring the more efficient use of fresh water when producing the crops under irrigation. To achieve the aims mentioned above, as well as addressing the gap in research, the following objectives were addressed. Firstly, we calculated the water footprints of selected field and/or forage crops in South Africa in order to develop benchmarks for fresh water use for the production of the selected crops under irrigation in South Africa. Secondly, we reviewed and established standardised procedures for calculating green and blue water footprints of field and forage crops in South Africa. Thirdly, we developed benchmarks for fresh water use in South Africa through the application of the standardised procedures for calculating the green and blue water footprints for selected field and forage crops, e.g. wheat, maize, lucerne. The fourth objective assessed consumers' awareness of the concept of water footprints and their willingness to pay a price premium for information on labels regarding the water footprint of the product. Lastly, we modelled the economic and social impacts that will result from the implementation of recommended actions to improve the efficiency with which fresh water is used along the life cycles of the selected field and/or forage crops in South Africa.

A thorough review of literature was done. The review of literature on the water footprints and economic water productivity of products reveals that water footprint assessment is gaining much attention and has developed into a major issue of policy concern to governments, organisations, policymakers, water users and water managers. This is because water is a scarce resource and a large proportion of the world's population faces difficulties in getting fresh water. It is concluded that food production is the major user of freshwater resources. South Africa is among the most arid countries in the world and agriculture is the highest user of the available water resources. Water footprint assessments have received some attention in South Africa, but the economic aspects of water footprints have received little attention.

Few studies have linked the economic aspect of water to water footprint indicators in South Africa. The present knowledge is inadequate to efficiently guide South African policy and decision makers, water users and managers in formulating appropriate policies to guide freshwater use and for water users to be economically efficient in water use. The review of the concepts of water footprints reveal that the Global Water Footprint Standard of the Water Footprint Network, described by Hoekstra et al. (2011), gives an all-inclusive indicator of freshwater use, relative to the Life Cycle Assessment (LCA).

The estimation of economic water productivity builds upon the estimation of a total water footprint. The estimation of economic water productivities follows certain steps; the first stage involves the estimation of physical water productivities, and finally the economic water productivities are estimated. Research on the economic productivities of water is very scanty from the viewpoint of the semi-arid and arid regions of Southern Africa. Hence, there is the need for an assessment of economic water productivities to be undertaken. Available methods of estimating water footprints include the consumptive water-use-based volumetric water footprint, stress-weighted water Life Cycle Assessment (LCA), adapted LCA water footprint methodology, and the hydrological water balance method. The consumptive water-use-based volumetric water footprint, as accepted by the Water Footprint Network, accounts for blue, green, and grey water footprints, with clear distinctions being made between the sources of water, and hence was used in this study.

The review of consumers' preferences, WTP, and welfare effects of water footprint sustainability information shows that it is very relevant to know how environmentally sustainable attributes and information will change consumers' and producers' sustainability behaviour, as well as to identify the welfare implications of their changed behaviour. Despite the relevance of understanding consumers' preferences, willingness to pay, and welfare effects, the review of literature has revealed that existing research on environmental sustainability assessments has ignored South Africa. Hence, present knowledge is inadequate to understand how South African consumers would react to changes in water footprint sustainability attributes and policy changes. The review further shows that consumers' awareness of water footprint information plays a significant role in shaping consumers' behaviour.

The review of the methods for assessing consumers' preferences and WTP for product attributes emanates from McFadden's standard statistical framework and Lancaster's characteristic methodology for explaining consumer behaviour and choices. The methods for assessing consumers' preferences and WTP for sustainability attributes can be categorised into revealed and stated preferences approaches. The stated preference approach was used in this study because no data currently exists on preferences and WTP for water and carbon footprint sustainability attributes in South Africa. The review of the methods for estimating consumers' preferences and welfare estimates reveals that a choice experiment is appropriate when dealing with multiple sustainability attributes or policy changes. Hence, in this study, the choice experiment was used to assess preferences and welfare estimates arising from consumers' choice of water and carbon footprint sustainability attributes.

11.1 CONCLUSIONS

The main objective of this case study was to explore the water footprint of lucerne (*Medicago sativa*) produced under irrigation in South Africa and used as an important fodder crop for milk production. The findings show that 457 cubic metres of water were used to produce one ton of lucerne under irrigation in the Vaalharts Irrigation Scheme in South Africa. Of that, 207 cubic metres of water was effective rainfall that contributed to the evapotranspiration of the crop, while the remainder of the evapotranspiration of 171 cubic metres was supplied by irrigation. A further 78 cubic metres of water was required to assimilate the salts from the production process to the natural levels in the receiving water body. Evaporation of water during transport (via canals and diversions) and storage (from dams and reservoirs) was not considered in the calculation of the water used in the production of lucerne. Water usage in the supply chain of inputs for the production of lucerne was also not considered in the calculations.

Rainwater evapotranspired, or green water, accounted for of 45 per cent of the lucerne water footprint. Abstracted surface and groundwater used to irrigate the lucerne contributed a further 38 per cent of the water footprint, with the remaining 17 per cent being attributed to grey water. The blue and green water footprints can be reduced by improving the efficiency with which the lucerne uses the water, thus the use of cultivars that produce more dry matter from the same volume of water will decrease the water footprint per ton. Excessive salt leaching in the lucerne production case study can be attributed to the over-irrigation that was recorded. The average evapotranspiration over the course of the growing season was 1 157 mm, while the sum of the effective rainfall and applied irrigation over the same period was 1 238 mm. This difference is the total surplus irrigation that was responsible for leaching the salts and resulting in an unnecessarily high grey water footprint. Better irrigation scheduling could, therefore, reduce the grey water footprint.

The findings further showed that feed production accounted for the greatest portion of the water usage for milk production. Water related to feed production accounted for 1 004 litres of water for one kilogram of milk with a fat content of 4 per cent and 3.3 per cent protein. This relates to 98.02% of the total water usage of 1 025 litres. Drinking water thus only contributes 0.6% of the total water usage, while the remaining 1.4% originated from the cleaning and sanitation procedures used at the dairy parlour and processing plant.

The total water usage can be divided into the different types of water. Investigating the origin of the total water use reveals that only 96 litres of water per kilogram of milk produced is from blue water (surface and groundwater). The majority of the water use, 862 litres, originates from rainwater that does not become runoff (i.e. used by the vegetation) and is considered to be green water. Grey water of 66 litres makes up the remainder of the 1 025 litres of water used to produce one kilogram of milk. This grey water is the water required to assimilate the salts originating from the production processes to below the acceptable level prescribed by the DWAF (1996a).

Since the greatest portion of the total water footprint is for the production of feed, it is important to investigate the type of water footprint of the feed. Blue water only accounts for 9% of the total feed water, and grey water accounts for a further 5%. The greatest portion of water used for the production of feed is therefore attributed to effective rainfall or green water. Reducing the irrigation requirement of the irrigated crops can decrease the consumptive water use in milk production. However, by eliminating irrigation altogether, the water footprint of the feed production could only be decreased by 9%. Measures to decrease the water footprint indicator of milk production in South Africa include using crop hybrids that use the water more efficiently with better harvest indices, and increasing the feed conversion efficiencies of the cows (more milk from the same feed).

Ultimately, the aim of all water footprint assessments is to determine the environmental sustainability of producing the product under consideration in a specific river basin of a catchment area. All the production of feeds for the dairy farm in the case study was done within the greater Orange River Basin. The sustainability assessment was conducted by evaluating the monthly blue water scarcity according to the methodology and dataset of Hoekstra and Mekonnen (2011).

The feed consumed to produce milk on the farm in the case study came from irrigated crops that required the majority of water during the warmer months, from November to February. This is indeed the case for all the crops, apart from oats that were produced during the cooler months. Sorghum was planted in December and cut at the end of February for silage, while the maize planted in early November was also cut for silage in February. The ET_a of lucerne, which is a perennial crop, was much higher during the warm months, from November to February.

The main summer crop production months, apart for November that has moderate blue water scarcity, have low blue water scarcity. The production of lucerne, maize and sorghum under irrigation in the greater Orange River Basin is sustainable in the sense that the production thereof does not distort the natural runoff significantly, and environmental flow requirements are met.

Oats under irrigation are produced for silage between June and October, depending on the planting date. June has moderate blue water scarcity and significant blue water scarcity occurs in July, while August, September and October experience severe water scarcity. Therefore, oats produced under irrigation in the Orange River Basin are not sustainable from an environmental water flow requirement perspective. The production of oats in this basin should be strongly reconsidered.

The water footprint indicator as a stand-alone measure of freshwater use may be misleading. Therefore, the focus should be placed on the impact and sustainability of freshwater use, and not solely on the volumetric indicator. Despite the fairly large water footprint of milk production, the results of the case study show that this water footprint remains sustainable. The water used in the production of milk is used to create a product that consumers demand, and in the process, value is added to the water allocated to the production of milk. By adding value to the scarce resource, progress is made towards ensuring environmental sustainability, resource efficiency and social equity.

Economically, we found that that, by packaging the processed milk in a bottle with a capacity of one litre, a total value of R11.7 was added per litre of milk. The value added per kilogram of milk (4% fat, 3.3% protein) is then R12.1. The greatest value is added to the milk during processing, where R5.84 is added per kilogram. Retailers added a further R4.7 per kilogram, with farmers adding only R1.6 per kilogram of milk. Comparing the total value added to the milk packaged in three-litre bottles shows that only R9 of value was added per kilogram, in comparison with the R12.1 added to the smaller containers. The dairy farmer receives the same price for the raw milk, regardless of the value added to the milk further along the value chain, so the value added to the milk by the farmer is again R1.6 per kilogram. It is thus clear that the greatest value is added to the milk when it is bottled in smaller, rather than larger, containers.

The volume of water used along the value chain is the constant, regardless of the size of the container in which the milk is sold. The value added from processing to retail varied did, however, differ with the packaging sizes. The value added per cubic metre of water, once the processed milk reaches the final consumer, was evaluated for the two different product volumes. Milk sold in the one-litre bottle added the greatest value per kilogram of milk, while the same quantity of water was used in the production thereof. It therefore makes sense that the value chain of milk packaged in bottles with a volume of one litre adds significantly more value to the water than the larger container's value chain does. The value chain of the smaller container added R11.8 per cubic metre of water, as opposed to the R8.8 added to the water along the value chain of the three-litre bottles. One can then draw the conclusion that selling milk in smaller containers results in higher returns per cubic metre of water used.

Despite only 13% (17% for the 3 L bottle) of the total value being added to the water on the farm, in excess of 98% of the all the water along the value chain was used on the farm. This heavily skewed distribution of water used and value added emphasises the importance of focusing on the farm level to optimise the water used and value added to the water in the production of milk.

Based on the findings from this case study, the following conclusions are drawn: it is concluded that in both sites of the study area, the blue water footprint of maize production is greater than the green water footprint of maize production is. The blue water footprint accounts for 60% of the consumptive use of freshwater and more than double the grey water footprint. This suggests that there is great reliance on blue water in the Orange-Riet Irrigation Scheme. The grey water footprint associated with nitrogen fertilisation accounts for about 17% of the water footprint at measuring points or18 and or20, and approximately 24% of the water footprint at measuring points or4 and or5. The total grey water footprint (GWF_N) makes up 21% of the total water footprint in the Orange-Riet Irrigation Scheme, thus the grey water footprint accounts for a significant share of the total water footprint of maize production in the scheme. This suggests that there is great potential for lowering the total water footprint by reducing the total grey water footprint through minimisation of leaching and runoff of nitrogen into blue water.

Despite the large blue water footprint of maize production in the Orange-Riet Irrigation scheme and the 60% share of maize in broiler feed, the results show that the green water footprint accounts for 67.88% of the total water footprint of producing a tonne of chicken meat. The blue and grey water footprint account for 23.13% and 9%, respectively. Secondly, the water footprint of chicken production varies from the farm to abattoir to the processing plant. About 97% of the farm-level water footprint of broiler production goes into broiler feeding. Thus, other uses of water on the farm account for 3% of the water footprint of on-farm broiler production. The slaughtering of broilers makes up 0.18% of the volume of water used to produce a tonne of chicken, whilst processing contributes 0.25%. Together, the slaughtering and processing of chickens account for 0.43% of the total water footprint of producing a tonne of chicken.

Additionally, the study concludes that the economic value derived per unit of water used depends on the type of chicken product produced. Chicken meat sold fresh yields higher economic returns per unit of freshwater than frozen chicken meat does. In terms of fresh chicken, a tonne of chicken portions yields more economic returns per unit of water consumed than a tonne of whole chicken does. Therefore, the EWP is higher for chicken portions that are sold fresh. South Africa's water resources are limited. Irrigation puts pressure on freshwater, but ensures an adequate supply of broiler feed.

Based on the findings of this case study, it is concluded that the total water footprint of irrigated wheat in the Vaalharts region is 991 cubic metres per ton. Of this footprint, ground water accounts for 470 cubic metres per ton, surface water 317.79 cubic metres per ton, and water from effective rainfall 203 cubic metres per ton.

The total water footprint of irrigated wheat in Vaalharts is 61 percent lower than that of the global average, which depicts a certain level of efficiency in water use in the Vaalharts region. Approximately 79 percent of the water footprint of wheat was from absorbed surface and ground water (irrigated water), which show a high dependency on surface and ground water for wheat production in the Vaalharts region. This is higher than the global average blue water footprint for irrigated wheat, which was found to account for only 50 percent of the total water footprint.

At the processing stage, it is concluded that the total water footprint of the processor is 0.5 cubic metres per ton. Of this footprint, the wheat milling accounts for 0.07 cubic metres per ton, and the bakery accounts for 0.5 cubic metres per ton. This implies that 86 percent of the total water footprint in the processing stage of bread along the wheat-bread value chain is from the bakery, and only 14 percent from the mill process.

Given the total water footprint of bread along the wheat-bread value chain of 991 cubic metres per ton, it is concluded that 99.95 percent of the water footprint of bread along the wheat-bread value chain is from primary input (wheat production), while processing is only accountable for 0.06 percent. The water footprint of bread is 59 percent lower than the global average of bread is. The findings show that the water footprint of grain wheat has a large impact on the overall water footprint of bread, which means that the blue water footprint is a major contributor of the water footprint of bread produced in South Africa. Total value added to water from the water footprint assessment of the wheat-bread value chain varies from one stage to another. About 65 percent of this value is added at the processing level, and only 35 percent at the farm level.

The aim of this case study was to contribute to the debate on using water footprint information on beef product labels as a sustainability indicator to incentivise sustainable freshwater use. The study examined consumer awareness of the water footprint concept, consumer preferences, and their willingness to pay a price premium for water footprint labelled beef products. This research was done in Centurion, South Africa. The study concludes that there is considerable preference heterogeneity at the individual level regarding the water sustainability attributes of beef products. The profound heterogeneity in preferences is explained by socio-economic factors such as age, gender, education and income of respondents. Besides socio-economic factors, public awareness creation and campaigns regarding threats associated with climate change, as well as water scarcity, play a significant role in influencing consumers' preferences for environmentally sustainable products.

The study also concludes that respondents were generally willing to pay a price premium for the inclusion of information indicating the sustainable use of fresh water. The willingness to pay estimates hinged on the consumers' socio-economic factors such as age, gender, education and income, as well as awareness. This suggests that the prospects of environmental sustainable attribute labelling on beef products and the creation of a niche market for sustainability products is feasible and may incentivise the sustainable use of freshwater for beef production in South Africa. In general, the study concluded that the scope of using water footprint information on product labels as a sustainability indicator to incentivise sustainable freshwater use may be possible.

The study further concludes that consumers' trust in food labelling regulatory bodies, their awareness, and their knowledge on water sustainability, as well as traditional socio-economic factors, are areas for policy options that can be adopted by stakeholders in the meat value chain, with the aim of changing consumers' and producers' behaviour towards water sustainability.

The research assessed consumer awareness of the water scarcity and climate change situation in the South African agricultural industry. The general finding was that consumers are aware of the water scarcity and the impact of agricultural production on the availability of fresh water and climate change. In addition, it was also found that awareness plays a significant role in explaining consumers' preferences and choices for environmentally sustainable beef products.

Based on the findings from this case study, we conclude that if water use is to be restricted, it is more profitable to reduce the number of hectares planted and to rather apply full irrigation to produce higher yields. Factors such as crop prices, water, and electricity tariffs affect the decisions of the farmers. It is vital to analyse the current economic environment to make the best decisions when water restrictions are set. Furthermore, an increase in the irrigation water tariff has an impact to some extent, although the impact is at a minimal level. The main challenge is the availability of a scarce resource (water), and not the incremental water tariff.

The findings from this chapter provide important economic and efficient water use implications for water users in the livestock sector. Regarding water use, the study concludes that the highest proportion of water utilised along the dairy value chain goes into feed production. Different feed products have different water footprints. The research has highlighted the contributions of the feed products to milk output. Yellow maize meal, high protein concentrate and lucerne hay are the top three feed products with high contributions to milk output, respectively. Henceforth, livestock producers should pay particular attention to these feed products when formulating ration for dairy cows, with the aim of attaining high yield, which in turn will lead to low water footprints, high value addition and economic water productivities.

Even though feed production uses the highest proportion of water along the dairy value chain, it is economically efficient in terms of cost and water use to produce these feed crops. The study concludes that dairy livestock farmers or producers are economically efficient in their production. High economic values are associated with high protein concentrate, yellow maize meal, lucerne hay, and sorghum and maize silages, respectively. More importantly, this study points to the fact that not all economically water productive feed products are significant contributors to milk yield.

This case study reveals that there is considerable preference heterogeneity at segment level regarding the water sustainability attributes of beef products. The study found three distinct consumer segments within the sampled respondents, with each class exhibiting different preference attitudes for the same set of water usage levels.

The profound heterogeneity in preferences is explained by socio-economic factors such as age, gender, education and income of respondents. Besides socio-economic factors, public awareness creation and campaigns on threats associated with climate change play a significant role in influencing consumers' preferences for environmentally sustainable products. Consequently, demographic targeting of consumer segments, awareness creation, and segment-specific educational campaigns aimed at enhancing subjective and objective knowledge on environmental sustainability are important tools for governments, food companies, and agribusinesses for promoting and marketing environmentally sustainable food products.

Enhancing and improving the subjective and objective knowledge levels of people regarding environmental sustainability are important drivers that could be employed to change the behaviour of South Africans, and Africans as a whole. The research reveals that trust in regulatory bodies in charge of food labelling, including environmental sustainability labelling, is very relevant in enhancing preferences for sustainable products. Willingness to pay for different levels of water usage varies across the identified classes. The study concludes that willingness to pay exists for low water usage in classes of all the identified segments.

Welfare gains and losses vary from one class to another. Consequently, there are imperative segmental equity issues that need to be taken into consideration when designing environmental sustainability strategies to change consumers' behaviour, while aiming at minimising environmental impacts. The main implication of these findings is that preferences for environmentally sustainable products should not be limited to only willingness to pay estimates; rather, compensating surplus estimates should go along with WTP estimates for efficient and effective policy purposes.

The assessment from this case study reveals a shift towards higher blue water consumption. This is of great concern for water users and stakeholders along the wheat-bread value chain, given that blue water is becoming scarcer in South Africa. The water utilised in the processing stage is insignificant, as it accounts for less than 1% of the total water footprint. Much attention should be channelled towards water consumption at the farm and production levels.

Groundwater contributes about 34% and 42% of the average total water footprint in Clovelly and Bainsvlei, respectively. Better understanding of groundwater contribution to ET could help to minimise irrigation water usage and also reduce the costs of production since blue water is a constituent of production costs. The adoption of objective irrigation scheduling conserves water through the better utilisation of rainfall and shallow groundwater available to the root zone of crops. The depth of the groundwater has a significant influence on the contribution of groundwater to the total blue water footprint. Without accounting for the water available to the crop (controlled) from the ground, more blue water will be applied, and this leads to an upsurge in the blue water footprint (surface).

Generally, water footprint assessments have moved away from a sole indicator assessment, and a deeper awareness of the productive usage of different sources of water has become vital for policy. With the lack of benchmarks or metrics for different catchment areas in South Africa, the findings might possibly act as blue water footprint benchmarks for wheat production in Bainsvlei and Clovelly, particularly for the same ground water levels in Bainsvlei and Clovelly.

11.2 RECOMMENDATIONS

11.2.1 Recommendations Based on the Water Footprint of Milk Produced from Lucerne Feed

In light of the results from this case study, the following implications can be drawn for water users in the production of processed milk policy implications:

- Milk production in the greater Orange River Basin does not disrupt the natural runoff significantly and satisfies the environmental flow requirements. Milk production in this basin is thus environmentally sustainable. However, oats and other crops produced under irrigation from July to October in this basin result in severe blue water scarcity, and thus should be reconsidered.
- The distribution of water use in the milk value chain is heavily skewed, with the production node accounting for more than 98% of the total water footprint. Emphasis should therefore be placed upon optimising water use at farm level in order to improve the water use efficiency of the value chain.
- Inefficient irrigation scheduling that results in over-irrigation is not reflected in the blue and green water footprints, and only influences the leaching of salts from the soils. Better irrigation scheduling will result in lower grey water footprints.
- Grey water from the dairy parlour should be properly treated before leaving the effluent pond.
- Despite using vast quantities of water, significant value is added to the water along the milk value chain. Allocating water to this sector is not an inefficient allocation of freshwater. Therefore, instead of just taking the primary production into account, the complete value chain of agricultural products should be considered before policy recommendations are made.
- The dairy industry is important from a socio-economic perspective and since the most value is added to the water during processing, incentives should be put in place to move the milk processing facilities to the rural production areas.

- The deterioration of irrigation water quality should be carefully monitored to ensure the sustainability of irrigated agriculture. Better guidelines and regulations for the timely evaluation of irrigation water quality should be established. More importantly, these guidelines and regulations should be implemented and action plans should be developed to manage the deterioration of water quality.

- Research and development of irrigated field and fodder crops that have improved water use efficiencies should be promoted. New varieties with better water use efficiencies will reduce the water footprints per unit of output.

11.2.2 Recommendations Based on the Water Footprint of Broiler Produced from Maize Feed

- Poultry farmers should consider the water footprint of their feed formulation in their production decisions since water use for feed production accounts for the largest share of the total water footprint at the farm level.

- Feed products with high water footprints can be substituted with products with low water usage. This will help to minimise the water requirement for feed production in the poultry industry.

- Given that the highest water footprint was observed at the farm level, farmers can adopt high-yielding maize varieties and this will lead to a reduction in water footprints.

- At the poultry section, farmers should improve the feed conversion efficiency of broilers and this will help to improve their output, which in turn will lead to reduction in water footprints.

11.2.3 Recommendations Based on the Water Footprint of Bread Produced from Wheat

- Wheat farmers in the Vaalharts region are efficient in water use in their production. This is shown by the low water footprint compared with the global average. The low water footprint can be attributed to high wheat yields. It is therefore recommended that wheat farmers should adopt farm management practices that improve yields per hectare. For instance, wheat farmers should adopt high-yielding wheat cultivars, improve soil fertility and so on.

- The higher utilisation of surface and ground water in wheat production has negative implications on sustainability. In periods of drought or forced reallocation of freshwater resources to other sectors in the economy, wheat production will come to an abrupt stop. Due to the high dependency of the wheat industry on surface and ground water, it is recommended that increased attempts should be made by farmers to maximise the use of green water in order to combat the negative externalities of blue water resources. Farmers can optimise on the effective rainfall by adopting rain water harvesting technologies and, if possible, farmers could shift wheat production to wet seasons.

- Bread producers in South Africa are efficient. This is shown by the low water footprint compared with global averages. The study recommends that bread processors and bakers should adopt production practices that would further decrease their use of water by recycling water used in the processing stages. At the processing level, millers should strive to attain higher wheat-to-flour conversion ratios and reduce wastages.

- Any measures to increase or decrease efficiency in how water resources are employed at farm level have a 95.95 percent impact on the water footprint of bread along the wheat-bread value chain. It is recommended that stakeholders along the wheat-bread value chain should consider water footprint benchmarks to ascertain wheat suppliers who are water efficient. Stakeholders should require water footprint assessment information from wheat farmers, as this water footprint largely determines the water footprint of their product.

- In terms of value added to the water footprint of bread along the wheat-bead value chain' there is stronger socio-economic impact per metre cubed of water used from processors and wholesales. Value added from water footprint at the processing stage of the wheat-bread value chain should be increased in order to increase the socio-economic contributions per metre cubed of water used.

11.2.4 Recommendations Based on Consumer Awareness and Willingness to Pay for Water Footprint Information

- Given that consumers are heterogeneous in their preferences for water footprint sustainability attributes, the study recommends that demographic targeting of consumer segments, awareness creation, and segment-specific educational campaigns aimed at changing consumers of water use behaviour and sustainability would be important tools for governments, food companies and agribusinesses when it comes to the promoting and marketing of environmentally sustainable food products.

- The research also reveals that heterogeneity among consumer preferences and WTP is attributable to the differences in consumer awareness and socio-economic factors. This implies that while many consumers may prefer environmentally sustainable products, this may not be equally true for all the respondents. The study suggests that, when designing strategies that endorse environmental sustainability, the producers and agribusinesses involved in the red meat industry must take into account the differences in consumer segments and preferences.

- Since consumers are willing to pay premiums for water footprint sustainability labelling or information, the study recommends that meat producers and agribusinesses should create niche markets for sustainable meat products and rely on water footprint labelling as a product-differentiation strategy.

- Based on the findings on socio-economic factors, the study recommends that policies that are designed to support sustainable fresh water use behaviour must take into cognisance the consumers' age, gender, education level, and income group. This should be done in order to achieve a change in consumer and producer behaviour towards sustainable water use, and factors such as awareness and socio-economic factors must be considered in policy development.

- In terms of communicating sustainability information, the study revealed that the sources of consumers' information varies. Therefore, the study suggests that, in order for policymakers to effectively communicate and achieve maximum consumer response, they must use various forms of media, especially the type of media that will reach the majority of the people. For instance, it was evident that the most effective communication platforms were radio, newspapers and personal observation, in that order. Nevertheless, television, magazines and posters could be used to communicate to the general public, but preferably for the high-income group that has access to these sources.

11.2.5 Recommendations Based on Social and Economic Analysis of Changed Water Use Behaviour

- We recommend that, without the behaviour change of farmers, it will not achieve the desired output. A government with different stakeholders should introduce a mechanism to educate farmers and enhance their understanding of the past, current and future trends of water and drought in order to plan for future and mitigate unexpected shock.

11.2.6 Recommendations Based on Water Footprint and Economic Water Productivities of Feed Crops and Dairy Products

- The findings suggest the need for water footprint assessments of different feed products to be undertaken to identify the products that are higher users of the existing scarce water resources.
- Given the blue water scarcity situation in South Africa, our findings suggest that feed products, such as lucerne hay, maize silage and sorghum silage, are higher consumers of blue water resources.
- Profit-maximising dairy farmers, with sustainable and efficient water use objectives, should reconsider their dairy livestock feed formulation by incorporating more of the feed products that give good contributions to milk output and economic water productivities.
- The findings provide detailed insights into profitability and economically productive water-use in the dairy industry. We suggest that policymakers, water users and

managers along the dairy value chain should not rely on water footprint estimates alone to judge the industry.

11.3 SUGGESTIONS FOR FUTURE RESEARCH

11.3.1 Suggestions Based on the Water Footprint of Milk Produced from Lucerne Feed

The following recommendations for further research arise from the study:

- Research is needed to explore the water usage of different dairy production systems and it is of cardinal importance to enable comparisons to be made between different production systems.
- Ideally, all the information required to determine the water footprint of the milk value chain in South Africa should be obtained from actual measurements collected from various farms over a period exceeding one production season. Accurate *in situ* data will eliminate the need for estimations and ultimately result in more accurate findings related to water use. Furthermore, such data will facilitate the making of comparisons of water footprints and contribute to the sustainability thereof, over time. It will also be possible to formulate more accurate monthly blue water scarcities estimates for more localised areas.
- Research can also be extended to include pollutants, other than just salts, in the calculation of the grey water footprint.
- Research into the better management of dairy effluent might result in less pollutants originating from the dairy effluent.
- The value added to water along the value chains of more processed dairy products (cheese, yogurt, butter, etc.) should be explored. It is expected that such value chains would have substantially higher returns per cubic metre of water.
- The value of the meat at the end of the dairy cow's productive lifetime should be explored to determine the effect that the value of the meat will have on the water footprint of milk and meat.

11.3.2 Suggestions Based on the Water Footprint of Broiler Produced from Maize Feed

Future research should:

- Investigate the water footprint of broilers in other provinces and take into consideration all or most of the ingredients in broiler feed for a more accurate assessment.
- Include the end consumer and account for the indirect water footprint associated with packaging.
- Conduct an assessment on the water footprint of different broiler cuts to give an idea of the impact of each cut on each pillar of sustainability.
- Conduct a water footprint assessment of layers to allow for the comparison between the impact of layer production and broiler production.
- Conduct a sustainability assessment with local, context-specific data to obtain a more accurate indication of sustainability because the monthly blue water data provided by Hoekstra and Mekonnen (2011) did not take into account the water in dams and inter-basin water transfers.

11.3.3 Suggestions Based on the Water Footprint of Bread Produced from Wheat

Future research should:

- Consider a blue water sustainability assessment of wheat production at the Orange River Basin in order to determine whether wheat farmers are sustainable in their blue water usage.
- Consider the grey water footprint along the wheat-bread value chain in order to better inform farmers and policymakers of the national grey water footprint of bread along the wheat to bread value chain.

11.3.4 Suggestions Based on Consumer Awareness and Willingness to Pay for Water Footprint Information

- For future research, the study recommends that modelling approaches that account for consumers' unobserved heterogeneity in preferences should be adopted in future studies on preferences for water footprint sustainability attributes. Researchers could use methods such as the latent class modelling approach to identify different consumer segments based on their preferences and explanatory variables.

- Further studies could be done to investigate how much consumers are willing to pay across the different LSM groups in South Africa. This will help to identify in detail the categories of consumers who are willing to patronise sustainable food products. Furthermore, such studies should be done for other food and non-food products due to the current water scarcity situation and the relevance of water sustainability.

11.3.5 Suggestions Based on the Water Footprint and Economic Water Productivities of Feed Crops and Dairy Products

- Future research on estimations of ecological footprints and economic productivities of ecological indicators such as water should not focus only on quantifying the footprint indicators. Rather, researchers should also take into account economic water productivities and the monetary value added to the product along its value chain, since it gives meaningful economic implications.

11.3.6 Suggestions Based on Compensating Welfare Estimates of Water Footprint Sustainability Policy Changes in South Africa

- The main implication of these findings suggests that preferences for environmentally sustainable products should not be limited to only willingness to pay estimates; rather, compensating surplus estimates should go along with WTP estimates for efficient and effective policy purposes. Therefore, food policymakers should take into account whose welfare will be impacted upon, positively or negatively, by environmentally sustainable food policy changes.

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APPENDIX A: CONSOLIDATED CAPACITY BUILDING REPORT

INTRODUCTION

During the course of this project, capacity was developed in a variety of aspects, ranging from activities to build the capacity of the project leader, to the training of students, and other activities that contributed in developing capacity in the scientific community. This section presents an overview of the capacity building activities that took place during the course of this project.

CAPACITY BUILDING AT INSTITUTIONAL LEVEL

- **The project leader**

Dr Henry Jordaan, the project leader, participated in a number of activities during the course of this research project that contributed towards building his capacity as a scientist, and also as a project leader. Dr Jordaan attended training courses in the theory and application of water footprint assessment; he organised and participated in a workshop on the use of water footprint assessment; participated in a number of international and local conferences, presenting findings from the research of this project; and also gained experience in leading and managing a multi-disciplinary research project.

Dr Jordaan gathered valuable experience in project management throughout the duration of this research project.

Dr Jordaan attended an international course, "Global Water Footprint Standard Training Course" presented by the Water Footprint Network, 13-15 May 2014, Amsterdam, The Netherlands. The training course focused on the Water Footprint Network approach to water footprint assessment. The course was presented by the Water Footprint Network and the Twente Water Centre of the University of Twente.

Dr Jordaan also participated in a short training course in the use of the Water Footprint Network approach to water footprint assessment presented by Dr Ashok Chapagain, the

Science Director of the Water Footprint Network from the Netherlands. The training course was presented on the 5th September 2014 in Bloemfontein.

- **Initiate, host and participate in expert workshop on the method of water footprint assessment**

Dr Jordaan initiated, convened and participated in an expert workshop, *Towards a method for Water Footprint Assessment in South Africa*, at the University of the Free State, Bloemfontein, 4 September 2014. Two international experts, Dr Ashok Chapagain from the Water Footprint Network in the Netherlands and Dr Brad Ridoutt from CSIRO Australia, and other scientists from South Africa participated in the workshop. The international experts respectively represent the two schools of thought in terms of the method for water footprint assessment globally.

- **Participation in international and local conferences**

The project leader participated in a number of international and local conferences where findings from this research project were presented. International conferences attended include the World Water Congress XV (2015); the European Geoscience Union (EGU) General Assembly (2017); 6th World Sustainability Forum (2017); and the 1st conference of the Water Footprint Research Alliance (2016).

At the World Water Congress XV, Dr Jordaan represented the UFS as co-convener of a special session on water footprint assessment at WWC XV, where he also delivered a presentation on water footprint assessments in South Africa. At the Congress, the Water Footprint Research Alliance (WFRA) was launched, with the UFS being a founding member.

Local conferences where Dr Jordaan participated include the Biennial SANCID Symposiums, and the annual conference of the Agricultural Economics Association of South Africa. At the conferences, Dr Jordaan either presented the papers, or was co-author of the presented papers presented at the conferences.

- **Students**

Students at different levels of education participated in capacity building activities, from undergraduate to PhD level. A short summary of the capacity building activities of students during the course of this project is set out below.

Undergraduate students

As part of class attendance, undergraduate students who were enrolled in the final year module in *Natural and Environmental Resource Economics* at the University of the Free State attended the Water Footprint Symposium, hosted on 3rd September 2014, where the international experts and scientists from South Africa presented the work they had done on water footprint assessment.

Honours students

Students at Honours Level were involved in this project where they actively worked on this project, and also attended and participated in other activities that contributed towards their professional development.

- Mr Phoka Nkhuoa

Mr Phoka Nkhuoa attended the Water Footprint Symposium in Bloemfontein on 3rd September 2014, where leading international scientists on the topic of water footprint assessment, as well as scientists involved in water footprint assessment in South Africa, presented the work they had done and are currently busy with on water footprint assessment. Mr Nkhuoa was involved in the literature review, and also conducted a water footprint assessment of a grain milling agribusiness in Bloemfontein for his Honours research project.

- Mr Yondela Mahlathi

Mr Yondela Mahlathi attended the Water Footprint Symposium in Bloemfontein on 3rd September 2014, where leading international scientists on the topic of water footprint assessment, as well as scientists involved in water footprint assessment in South Africa, presented the work they had done and are currently busy with on water footprint assessment. Mr Mahlathi was also involved in the literature review.

- Ms Pascalina Mohlotsane

For her Honours research project, Ms Pascalina Mohlotsane was involved with the assessment of the water footprint of wheat and derived wheat products.

- Honours class in *Natural and Environmental Resource Economics*

Water footprint assessment was included as a topic in the Honours module in *Natural and Environmental Resource Economics* in the Department of Agricultural Economics at the University of the Free State. Students were trained on the concept of water footprint assessment, the different applications of water footprint assessment, and the different methods for water footprint assessment.

Masters students

A number of students, at Masters level, participated in this project. Four Masters students completed their degrees, based on research that they had conducted as part of this project. It is noted that some the Honours students reported above enrolled for the Masters studies after successfully completing their Honours degrees.

- Mr Morné Scheepers

Mr Scheepers was involved as a Masters student in the project team. He completed his MSc Agric (Agricultural Economics) Degree in 2015, with the title of his dissertation being, "*Water footprint and the value of water in the lucerne-dairy value chain*". He passed his degree with distinction. As the best Master's dissertation in the Department of Agricultural Economics at UFS in 2015, his Master's dissertation was also submitted to the 2015 conference of the Agricultural Economics Association of South Africa (AEASA) for the Best Master's dissertation award at the 2015 AEASA conference, 30 September-2 October 2015, where he was awarded with the second prize.

Mr Morné Scheepers also participated in other activities. He attended the Water Footprint Symposium in Bloemfontein on 3rd September 2014, where leading international scientists on the topic of water footprint assessment, as well as scientists involved in water footprint assessment in South Africa, presented the work they had done and are currently busy with on water footprint assessment. He also attended and participated in the expert workshop on 4th September 2014 that was hosted in Bloemfontein to scrutinise the different methods that are available for water footprint assessment. Again, the international experts and other scientists from South Africa participated in the workshop. Lastly, Mr Scheepers participated in a short training course in the use of the Water Footprint Network approach to water footprint assessment presented by Dr Ashok Chapagain, the Science Director of the Water Footprint Network from the Netherlands. The training course was presented on the 5th September 2014 in Bloemfontein.

Mr Scheepers also presented a contributed paper at the SANCID 2014 Symposium on 18-20 November 2014, at Glenburn Lodge.

- Mr Phoka Nkhuoa

Mr Phoka Nkhuoa was involved in this project for his Masters research. He is involved in assessing the water footprint of maize and broilers as derived maize products. He has submitted his dissertation for examination, and the degree was awarded to him. He received the degree at the Summer Graduation Ceremony of the University of the Free State in December 2017.

Mr Nkhuoa presented a paper at the 2016 SANCID Symposium in Worcester

- Mr Yondela Mahlathi

Mr Yondela Mahlathi has been exploring consumers' awareness of the concept of a water footprint as an indicator of sustainable freshwater use for food production. He has also explored the consumers' willingness to pay a price premium for water footprint information on product labels to indicate that freshwater was used sustainably for the production of the food product under consideration. He successfully completed his degree, and received the degree with distinction, in 2017.

- Ms Pascalina Mohlotsane

Ms Pascalina Mohlotsane was involved in the assessment of the water footprint of wheat and derived wheat products (bread) for her Masters studies. She completed her MSc Agric (Agricultural Economics) degree in 2017, with a dissertation titled "*Water footprint of irrigated wheat and derived wheat products in South Africa*".

Ms Mohlotsane also presented papers at the 2016 SANCID Symposium in Worcester, the General Assembly of the European Geoscience Union (EGU) in 2017, and at the conference of the Agricultural Economics Association of South Africa in 2017.

- Mr Enoch Owusu-Sekyere

Mr Enoch Owusu-Sekyere received some capacity building experience through his involvement in the literature review. Although his Masters research was not based on this project, he was involved with this project with the aim to do his PhD on this project.

- Masters students in Environmental Management

Dr Henry Jordaan presented annual lectures on water footprint assessment to the Masters Class in Environmental Management (MOB) at the University of the Free State from January 2017.

PhD students

Two PhD students were involved in this project and successfully completed their degrees. While their theses are not solely based on research directly related to this project, the research from this project made significant contributions towards their final theses.

- Dr Frikkie Mare

Dr Mare was involved in the project team as a PhD student. For his PhD research, he was involved especially in the assessment of the water footprint of maize, with special emphasis on the maize used as feed for beef production in South Africa.

Dr Frikkie Mare attended the Water Footprint Symposium in Bloemfontein on 3rd September 2014, where leading international scientists on the topic of water footprint assessment, as well as scientists involved in water footprint assessment in South Africa, presented the work they had done and are currently busy with on water footprint assessment.

Dr Mare also attended and participated in the expert workshop on 4th September 2014 that was hosted in Bloemfontein to scrutinise the different methods that are available for water footprint assessments. Again, the international experts and other scientists from South Africa participated in the workshop.

Lastly, Dr Mare participated in a short training course in the use of the Water Footprint Network approach to water footprint assessment presented by Dr Ashok Chapagain, the Science Director of the Water Footprint Network from the Netherlands. The training course was presented on the 5th September 2014 in Bloemfontein.

- Dr Enoch Owusu-Sekyere

Dr Enoch Owusu-Sekyere joined the research team as a PhD student in the second half of 2015. He was involved, among others, with the water footprint assessment of the irrigated pastures for dairy production for the purpose of his PhD research. He successfully completed his PhD degree in 2018, with a thesis titled "*Multiple footprint indicator assessment: Implications on consumers' preferences and welfare".*

Dr Owusu-Sekyere has also received some capacity building experience through his involvement as co-supervisor to some of the Masters students working on this project. He was instrumental in the generation of the final manuscripts submitted for publication, and was also actively involved in disseminating knowledge through the participation in international and national conferences.

CAPACITY BUILDING FOR THE SCIENTIFIC COMMUNITY

Two different activities were conducted where capacity among the scientific water research community was built.

Workshop

Scientists from South Africa participated in the expert workshop that was hosted on 4th September 2014 in Bloemfontein to scrutinise the different methods that are available for water footprint assessment. The scientists from South Africa benefited substantially from being involved in a discussion where leading scientists from the two main schools-of-thought in terms of water footprint assessment participated.

Short course

Other members of the research team and academics from the Department of Agricultural Economics of the University of the Free State participated in a short training course in the use of the Water Footprint Network approach to water footprint assessment presented by Dr Ashok Chapagain, the Science Director of the Water Footprint Network from the Netherlands. The training course was presented on the 5th September 2014 in Bloemfontein.

KNOWLEDGE DISSEMINATION

Knowledge was mainly disseminated through the publication of scientific articles in peer-reviewed journals, and also through the presentation of papers at international and local conferences. During the course of this project, five scientific papers were published in peer-reviewed journals and conferences. These contributions are categorised into local and international levels:

Local Level Contributions

- Jordaan, H., Mare, F., Owusu-Sekyere, E., Scheepers, M.E., Mohlotsane, P., and Nkhuoa, P. (2017). *Water footprint assessment to inform sustainable food production in South Africa*. Paper presented at the 6th World Sustainability Forum on 27-28 January 2017 in Cape Town.

- Owusu-Sekyere, E., Mahlathi, Y.Y., and Jordaan, H. (2017). *Assessment of Consumers' Stated Preferences for Water and Carbon Footprint Sustainability Information: Insights from the Gauteng Province of South Africa*. Paper presented at the 6th World Sustainability Forum, 27-28 January 2017, Cape Town, South Africa.

- Jordaan, H. (2016). *Water footprint of agri-food products in South Africa*. Paper presented at the 1st conference of the Water Footprint Research Alliance, Garden Court Nelson Mandela Boulevard, Cape Town, 4-7 April 2016.

- Owusu-Sekyere, E., Scheepers, M.E. and Jordaan, H. (2016). *Economic productivity of water along the dairy value chain of South Africa*. Paper presented at the 1st conference of the Water Footprint Research Alliance, Garden Court Nelson Mandela Boulevard, Cape Town, 4-7 April 2016.

- Scheepers, M.E., Owusu-Sekyere, E., and Jordaan, H. (2016). *Water footprint of milk produced and processed in South Africa: Implications for policy-makers and stakeholders along the dairy value chain.* Paper presented at the 1st conference of the Water Footprint Research Alliance, Garden Court Nelson Mandela Boulevard, Cape Town, 4-7 April 2016.

- Mohlotsane, M.P., Owusu-Sekyere, E., and Jordaan, H. (2017). Accounting for the water footprint along the wheat-bread value chain: Does ground water matter? Paper presented at the 56th conference of the Agricultural Economics Association of South Africa: Durban, South Africa, 19-21 September.

- Maré, F.A., Jordaan, H., and Mekonnen, M.M. (2017). The water-economy nexus of different beef breeds at the abattoir and deboning plant. Paper presented at the 56th conference of the Agricultural Economics Association of South Africa: Durban, South Africa, 19-21 September.

- Mohlotsane, M.P., Owusu-Sekyere, E., and Jordaan, H. (2016). *Assessing the sustainability of the water footprint of bread in South Africa.* Paper presented at the 6th South African National Commission on Irrigation and Drainage Symposium: Worcester, South Africa, 11-13 October 2016.

- Nkhuoa, P., Matthews, N., and Jordaan, H. (2016) *Water footprint of broiler production in South Africa.* Paper presented at the 6th South African National Commission on Irrigation and Drainage Symposium: Worcester, South Africa, 11-13 October 2016.

- Jordaan, H. and Backeberg, G.R. (2014). *Water footprint assessment and ISO 14046: A synthesis from an expert workshop*. 6th South African National Commission on Irrigation and Drainage Symposium, Glenburn Lodge, 18-20 November 2014.

- Scheepers, M.E., Jordaan, H., and Barnard, J.H. (2014). *The Lucerne-Dairy water footprint: some preliminary findings from the Free State Province*. 6th South African National Commission on Irrigation and Drainage Symposium, Glenburn Lodge, 18-20 November 2014.

- Owusu-Sekyere, E., Mahlothi, Y., and Jordaan, H. (2017). Assessment of consumers' stated preferences for water and carbon footprint sustainability information: Insights from the Gauteng Province of South Africa. Paper presented at the 56th conference of the Agricultural Economics Association of South Africa: Durban, South Africa, 19-21 September.

International Level Contributions

- Owusu-Sekyere, E., Mahlothi, Y., and Jordaan, H. 2019. Understanding South African Consumer's preferences and market potential for products with low water and carbon footprints. *Agrekon*, https://doi.org/10.1080/03031853.2019.1589544

- Mohlotsane, P.M., Owusu-Sekyere, E., Jordaan, H., Barnard, J.H., and van Rensburg, L.D. (2018). Water footprint accounting along the wheat-bread value chain: implications for sustainable and productive water use benchmarks. *Water* 2018(10):1-16.

- Owusu-Sekyere, E., Jordaan, H., and Chouchane, H. (2017). Evaluation of water footprint and economic water productivities of dairy products of South Africa, *Ecological Indicators* 83(2017):32-40.

- Owusu-Sekyere, E., Scheepers, M.E., and Jordaan, H. (2017). Economic water productivities along the dairy value chain in South Africa: Implications for sustainable and economically efficient water-use policies in the dairy industry. *Ecological Economics* 134(2017):22-28.

- Owusu-Sekyere, E., Scheepers, M.E. and Jordaan, H. (2016). Water footprint of milk produced and processed in South Africa: Implications for policy-makers and stakeholders along the dairy value chain. *Water* 2016, 8,322:1-12.

- Scheepers, M.E. and Jordaan, H. (2016). Assessing the blue and green water footprint of Lucerne for milk production in South Africa. *Sustainability* 2016, 8, 49:1-9.

- Owusu-Sekyere, E. and Jordaan, H. (2017). *Compensating welfare estimates for water and carbon footprint sustainability policy changes in South Africa*. Paper presented at the Agricultural Economics Society Annual Conference to be held at The Royal Dublin Society, Dublin, Ireland, 24 to 26 April, 2017.

- Mohlotsane, P., Owusu-Sekyere, E., Jordaan, H. (2017). *Water footprint assessment along the wheat-bread value chain towards the sustainable use of freshwater in South Africa*. Paper Presented at the European Geoscience Union (EGU) General Assembly 2017, 23-28 April 2017, Vienna, Austria.

- Scheepers, M.E., Jordaan, H., and Barnardt, J.H. (2015). *Water footprint of milk production in the Free State Province of South Africa.* Paper presented at the 5th World Sustainability Forum, Basel, Switzerland, 7-9 September 2015.