

A WATER FOOTPRINT ASSESSMENT OF DRYLAND PASTURE BASED DAIRY ENTERPRISE IN THE EASTERN CAPE: A CASE STUDY

A thesis submitted in the fulfilment of the requirements for the degree of

MASTERS IN COMMERCE

Of

RHODES UNIVERSITY

By

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December 2016

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DECLARATION

I, Paige Catherine Jenje, hereby declare that this dissertation is submitted by me for the degree of Masters of Commerce (MCom) in the Department of Economics and Economic History at Rhodes University. I declare that this is my own independent work and has not been submitted by me to any other university.



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Water scarcity continues to pose a threat to South Africa, with severe water scarcity predicted within the next fifty years. As a result, national interest has been sparked over the development of market based water resource allocation strategies to alleviate pressures on South Africa's freshwater resources, and ensure compliance with the National Water Act. Agriculture is the largest water user internationally and within South Africa, highlighting the importance of improving the water use efficiency within the industry.

This study performed a full water footprint assessment (WFA) of a dryland pasture based dairy enterprise in the Eastern Cape. Following the guidelines of the WFA, this study calculated the blue, green and grey water footprints of dryland pasture based dairy production from crop-to-farm gate by assessing the water footprints of pasture production, bought in feed and concentrates, drinking water and servicing water processes over a period of five years. Following the accounting the of the water footprint, economic and environmental sustainability indicators were used along with the incorporation of the Water Risk Filter tool. This revealed that the case study farm was operating efficiently with the enterprise's highest water related risk being governmental regulation.

Water footprint accounting results highlighted that green water was largest contributor to the overall water footprint of over 80%, and grey water contributed the least to the water footprint of dryland pasture based dairy production. Economic productivity results indicated that milk production is highly correlated with annual rainfall due to the breeding strategy undertaken by the farm. Results also indicated little correlation between the monthly water footprint and milk production, with the majority of the enterprise's milk production occurring in the last quarter regardless of the water footprint. The study demonstrated the relationship between the water footprint and economic land and water productivity, along with the value of milk to costs ratio which indicated that approximately R1.00 worth of costs generates between R1.80 and R2.06 value of milk. The sustainability indicators suggested that the farm's management of its effluent dam requires attention to meet the Department of Water and Sanitations effluent waste quality guidelines.

The overall analysis of the water footprint suggested that the highest water related risk to dryland dairy production was regulatory risk. This risk suggests that the government cannot be relied upon for the management of freshwater resources within the study area, leaving the onus on the individual dairy farmers. As such, farmers should utilise the water footprint to formulate water stewardship programmes which have the potential to influence the regulation and protection of freshwater resources.

Keywords: water footprint assessment, sustainability, water productivity, dairy production, economic indicators, water risk, water stewardship.

ACKNOWLEDGMENTS

I would like to extend my gratitude to the ENREFA team and the NRF for the bursary I was awarded in order to complete this research this year. To Professors Gavin Fraser and Jen Snowball, your guidance and supervision has been invaluable in this process. With your encouragement, support, and tolerance of my frantic emailing, you have made this journey one that I am proud of.

Further thanks needs to go to Simon Matthews and Renier Pienaar from Glen Dye dairy farm who assisted me so greatly with my research, as well as Craig Galloway from Woodlands Dairy. Thank you for teaching me so much and being so patient with me. A special thanks to Greg Vroom from Thorn Farm for his assistance in my research. To Caren Jarmain for her help with the capturing of evapotranspiration data, and the ARC for the provision of weather station data.

This research would not have been made possible without the support and love from both family and friends who have supported me throughout this journey. It has not been easy, but it has been worth it. To my parents, thank you for being there when I needed you most, and providing me with the skills and the platform to grow into the person I have become and whom without I would not be here today. Thank you to Jos Armstrong, a brave and courageous woman taken from us too soon, but whom I think about daily and try to emulate in everything I do.

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LIST OF ABBREVIATIONS

ARC-ISCW	Agricultural Research Council-Institute for Soil, Climate, Water
BWS	Blue water scarcity
BWSI	Blue water scarcity index
CF	Characterisation factor
CMA	Catchment management agency
CWR	Crop water requirements
CWU	Crop water use
DAFF	Department of agriculture, forestry and fisheries
DMI	Dry matter intake
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
DWS	Department of water and sanitation
EFR	Environmental flow requirements
ELP	Economic land productivity
ET	Evapotranspiration
EWP	Economic water productivity
EWR	Environmental water requirements
FAO	Food and Agriculture Organisation of the United Nations
FD	Freshwater depletion
FEI	Freshwater ecosystem impact
FWI	Free water intake
HPC	High protein concentrates
ISO	International Standards organisation
LCA	Life cycle assessment
LCI	Life cycle inventory
LCIA	Life cycle impact assessment
MAR	Mean annual run-off
NWA	National Water Act (Act 36 of 1998)
SA	South Africa

UNEP/SETAC	United Nations Environment Programme/Society of Environmental Toxicology and Chemistry
WF	Water footprint
WFA	Water footprint assessment
WFN	Water Footprint Network
WMA	Water management area
WP	Water productivity
WR	Water reserves
WRF	Water Risk Filter
WSA	Water services authority
WSI	Water stress index
WSP	Water services provider
WU	Withdrawals for humans
WUA	Water use association
YRB	Yellow river basin

CHAPTER 1 INTRODUCTION

South Africa is one of many countries which experiences water scarcity and shortages, with severe water scarcity predicted within the next 50 years (Walter et al., 2011; Jarman et al., 2014). The country is described as a water stressed semi-arid country experiencing an average rainfall of approximately 450mm per year, well below that of the world average of 860mm per annum (Otieno & Ochieng, 2004; Jarman et al., 2014), and experiences a low quantity of fresh water availability per capita of 1700m³ (Otieno & Ochieng, 2004). This lack of fresh water availability due to pre-existing factors, as well as climate change, is being perpetuated by decreasing water supply levels along with increasing demands (Perret, 2002; Mukheibir, 2008; Blignaut & van Heerden, 2009; Gbetibouo & Ringler, 2009; CSIR, 2010; Walter et al., 2011; DWAF, 2013; Meissner et al., 2013; Jarman et al., 2014). Such demands include those of industry and agriculture in order to meet the demand of population increases and economic development (Jarman et al., 2014).

As a result of its water scarcity, South Africa was one of the many countries which re-evaluated the way the nation used its freshwater resources, in an attempt to achieve goals of efficient, equitable and sustainable water allocation and use. This was done through the development of a new National Water Policy in 1997 and later the National Water Act in 1998 (Nieuwoudt et al., 2008). Over the years, national interest has been growing in terms of developing market based water allocation strategies which require information on the value of water, water use efficiency, regulatory landscapes and the price elasticities of water (Walter et al., 2011). Regulators have been urged, as a consequence of the mounting water scarcity, to find solutions which may alleviate the pressures placed on South Africa's freshwater resources in addition to ensuring compliance with the National Water Act (Jarman et al., 2014). Numerous tools have been developed in order to serve as a platform to address water scarcity issues, such as the water footprint assessment (WFA) method. The WFA has become a popular tool to address the distribution of freshwater consumption whilst accounting for environmental, social and economic sustainability considerations (Reddy et al., 2014).

The water footprint (WF) is the newest member of the footprint family alongside the energy, carbon and ecological footprints (Hastings & Pegram, 2012). Unlike the other footprints, the water footprint focuses on the effects of public and private consumption explicitly within the hydrological cycle. In doing so, the WF is able to inform water management practices and generate awareness regarding water scarcity and appropriation (Hoekstra et al., 2011; Tillotson et al., 2014). There are two primary water footprinting methodologies, the water footprint assessment (WFA), developed by the Water Footprint Network (WFN), and the Life Cycle Assessment, which follows the International Standards Organisation framework (ISO 14046) (Zonderland-Thomassen & Ledgard, 2012; Scheepers, 2015). This paper aims to use the WFA due to its economic application, whereas the LCA's primary focus is environmental impact assessment (Jefferies et al., 2012; Hoekstra, 2016). This is discussed in section 2.1 of this thesis.

The water footprint assessment, which is a consumption based volumetric water footprint, is a fast growing field of research, used by 140 scientific papers in 2014 alone (Hoekstra et al., 2015). This water footprinting method is used to measure, describe, and formulate water management policies regarding the direct and indirect freshwater consumption of producers and consumers (Hoekstra et al., 2011; Jefferies et al., 2012; Boulay et al., 2013). The WFA does this by quantifying water consumption into the categories of blue, green and grey water that address extracted freshwater, rainfall and water pollution. The method applies these categories in four phases; goals and scope, WF accounting, sustainability assessment, and response formulation (Hoekstra et al., 2011).

Agriculture is the largest water consuming economic sector in South Africa (DWAf, 2013). The Eastern Cape hosts 14.82 million hectares of farming land (86.8% of the total area of the Eastern Cape), with the majority of this land used for grazing, and 188 901 hectares of land registered as utilising irrigation practices. As of 2007, the Eastern Cape was home to over 4000 commercial farming units, of which 238 farms produced field crops (224 266 hectares) and the majority of farms participated in animal production (9.15 million hectares) (DAFF, 2016). Of the 2.3% contributed by agriculture to South Africa's GDP, fresh milk production contributed approximately R15 billion towards the gross value of agriculture in 2015 (DAFF, 2016), producing milk every day, and providing 60 000 direct and 40 000 indirect jobs for

skilled and unskilled workers (Milk SA, 2013; DAFF, 2014; Coetzee, 2015; Esterhuizen et al., 2015).

The second largest environmental issue concerning dairy production, the first being greenhouse gas emissions, is the large water footprint the industry incurs, particularly for fodder crops production, contributing to water scarcity and competition with other users for freshwater resources (Levin et al., 2012). Although Hoekstra (2012) suggests that the best way to reduce the water footprint of milk and dairy products is through a decrease in product consumption, this is not the most economically viable option for developing countries, and South Africa specifically, due to the socio-economic benefits the industry provides throughout the dairy value chain (Meissner et al., 2013). Thus alternative measures and methods are required in order to reduce the industry's water footprint.

In order for a farmer to assess his/her freshwater consumption in economic terms, he/she requires information on crop water use, yield, and field scale at farm level. With these variables the farmer can determine their water use, reduce their water wastage and optimise fertilizer use and crop production across farm management areas and processes (Jarman et al., 2014). These variables are the same variables required for the WFA (Hoekstra et al., 2011). The WFA enables the farmer to assess his/her freshwater consumption by evaluating sustainability indicators such as economic water productivity, the opportunity costs of water consumption, and water scarcity (Hoekstra et al., 2011).

Few studies have been performed on the water footprint of dairy production, globally and in South Africa (Drastig et al., 2010; Mekonnen & Hoekstra, 2010b; Hoekstra, 2012; Zonderland-Thomassen & Ledgard, 2012; De Boer et al., 2013; Huang et al., 2014; Bosire et al., 2015; Palhares & Pezzopane, 2015; Scheepers, 2015). Thus, this thesis aims to add to the knowledge base by conducting a water footprint assessment (WFA) on a dryland pasture based dairy enterprise in the Eastern Cape within a positivist paradigm. By doing this, this research hopes to add to the existing WFA field of research as well as providing economic recommendations, based on the results established in the accounting and sustainability assessment phases of the project. Through the identification of potential future and current environmental and economic risks involved in dairy production's water consumption, the WFA has the potential to assist in the adoption of improved water practices and reduced water related risks on

dryland pasture based dairy enterprises in the Eastern Cape (Hoekstra et al., 2011; Pahlow et al., 2015; Munro et al., 2016).

The water footprint assessment of dryland dairy production enterprises from crop to farm gate will assess the processes which are involved in the production of milk on farm. Such processes include pasture production, bought in feed and concentrates, drinking water, and servicing water. The study follows the method as prescribed by the Water Footprint Assessment manual, and will utilise the SAPWAT 3 program in order to determine the water use values of fodder crops within the WFA accounting phase. The Water Risk Filter tool is used in the sustainability assessment phase with the intention of assessing both the basin and business related water risk associated with dryland dairy farming.

By conducting a full water footprint assessment this thesis achieves the goals of research which include: the calculations of the WF of a dryland pasture based dairy enterprises using primary and spatial data which addresses geographic and temporal estimates, the exploration and application of environmental and economic sustainability indicators of dairy enterprises, identifying potential and future water risks along with mitigation and efficiency measures for a pasture based dairy farm using SAPWAT 3 and the Water Risk Filter tool, and giving insight into the applicability and relevance of water footprints within South Africa.

The WF of dryland pasture based dairy enterprises from crop-to-farm gate provides insight into the processes along with production variables which are involved in the production of milk on farm. Highlighted insights include the economic water and land productivity of dryland pastures, the economic value of dryland pastures, farm productivity gains, economic and environmental sustainability of dryland pastures, and basin and business related water risk (seen in chapter five).

The study achieves the above by considering pre-existing literature and theoretical frameworks regarding the water footprint and dairy production in chapter two. Chapter three addresses the background principles and motivations for the water footprint in relation to South Africa and the study area's water scarcity and policy. The study methods and processes found in chapter four follow the methods and information found in chapters two and three. The final water footprint assessment results are calculated and assessed in chapter 5 within

the water footprint accounting, sustainability assessment and response formulation phases of the WFA.

CHAPTER 2

LITERATURE REVIEW

This chapter aims to review the different water footprint methodologies within the water footprint theoretical framework, in order to choose the most applicable methodology for the calculation of the water footprint of a dryland pasture based dairy enterprise. Subject to the chosen methodology, this chapter will assess and compare water footprint case studies in general, and within the bounds of the economic applications and sustainability implications for dairy enterprises.

2.1 Theoretical frameworks of the water footprint

2.1.1 The water footprint concept

The water footprint (WF) is the newest member to the footprint family alongside the energy, carbon and ecological footprints (Wichelns, 2010; Hastings & Pegram, 2012). Unlike the other footprints, the water footprint focuses on the effects of public and private consumption explicitly within the hydrological cycle. In doing so, the WF is able to inform water management practices and generate awareness regarding water scarcity and appropriation (Hoekstra et al., 2011; Tillotson et al., 2014). The water footprint does this by improving individuals' consciousness towards products and services, which have incorporated water content, through trade, productions and diets (Lovarelli et al., 2016). The WF categorises water consumption into quantitative indicators which provide comparisons for production and consumption systems whilst addressing the water quality and scarcity of global freshwater resources (Ridoutt & Pfister, 2010; Deurer et al., 2011; Tillotson et al., 2014). These indicators signal 'hotspots' related to activities within a product's life cycle, thus providing sufficient information to evaluate a product's direct and indirect impacts on freshwater resources (Wichelns, 2010; Jefferies et al., 2012).

There are three freshwater consumption categories acknowledged by the WF methodologies. These are blue, green and grey water. Blue water is an indicator of ground and surface water, green water is an indicator of precipitation before it becomes blue water, and grey water is used to indicate the amount of freshwater required to assimilate pollutants in a water body back to ambient water quality standards (Ridoutt & Pfister, 2010; Hoekstra et al., 2011). It is

important that blue and green water are distinguished, where green water is only available to plants within a precise location and blue water is generally used for “human managed systems” (Milà i Canals et al., 2008: 11). Blue and green water flows have productive uses for humans in terms of domestic and industrial use, as well as their significant contribution to agriculture. Such agricultural freshwater consuming activities include irrigation, sustained crop production, grazing lands, forestry and terrestrial ecosystems, which produce various ecosystem services such as food, biofuel, timber and livestock products (Wichelns, 2010; Schyns et al., 2015).

2.1.2 Methods used to calculate the water footprint indicator

There are two primary schools of thought which attempt to calculate the water footprint. These are the water footprint assessment (WFA), developed by the Water Footprint Network (WFN), and the life cycle assessment (LCA), which follows the International Standards Organisation framework (ISO 14046) of life cycle assessment for the calculation of the water footprint (Zonderland-Thomassen & Ledgard, 2012; Scheepers, 2015).

Kounina et al. (2012) categorised the various water use research performed, in the water footprinting field, which have contributed to the studies of the hydrological cycle (figures 2.1 and 2.2), ultimately addressing the three areas affected by water consuming activities. These activities (as indicated in figure 2.1), along cause-and-effect chains, effect human health, ecosystem quality and resources. Different water studies on the hydrological cycle identify with either inventory assessment, midpoint impact assessment, endpoint assessment, or a combination of these assessments. Examples of each type of assessment include direct human consumption activities, primary socio-economic and environmental impacts as a result of human water consumption activities, and magnified externalities caused by human water consuming activities respectively (Kounina et al., 2012). Figure 2.2 summarises the various studies based on the hydrological cycle, and categorises these studies according to impact category and water index. As indicated in figure 2.2, research on the WFA primarily focuses on inventory and midpoint impact assessments with particular interest in consumption-to-availability water indexes, whilst the LCA addresses inventory, midpoint impact and endpoint impact assessments with water indexes indicating withdrawal-to-availability information (Kounina et al., 2012).

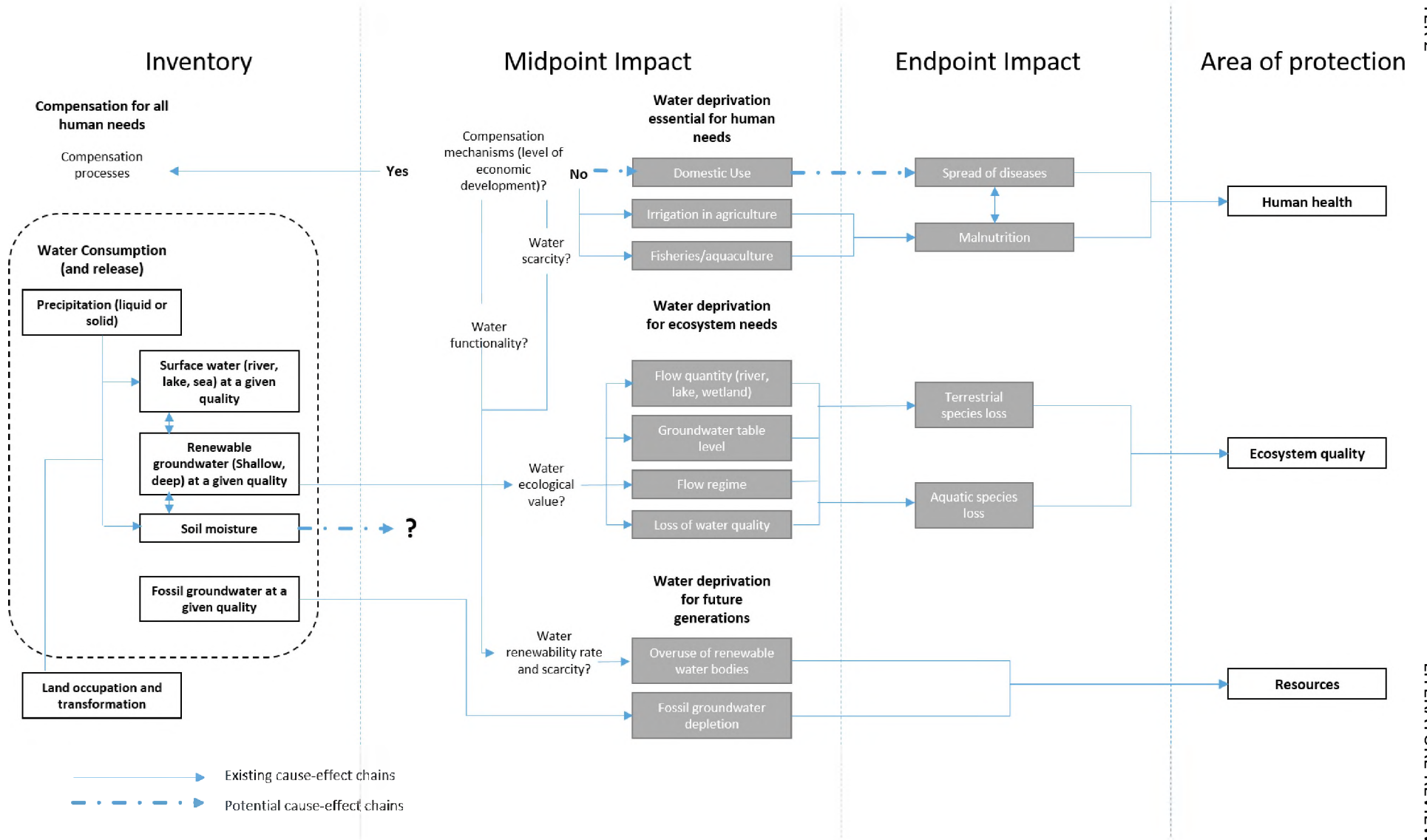


Figure 2.1: the cause-effect chains which lead from inventory to areas of protection
Source: Kounina et al. (2012)

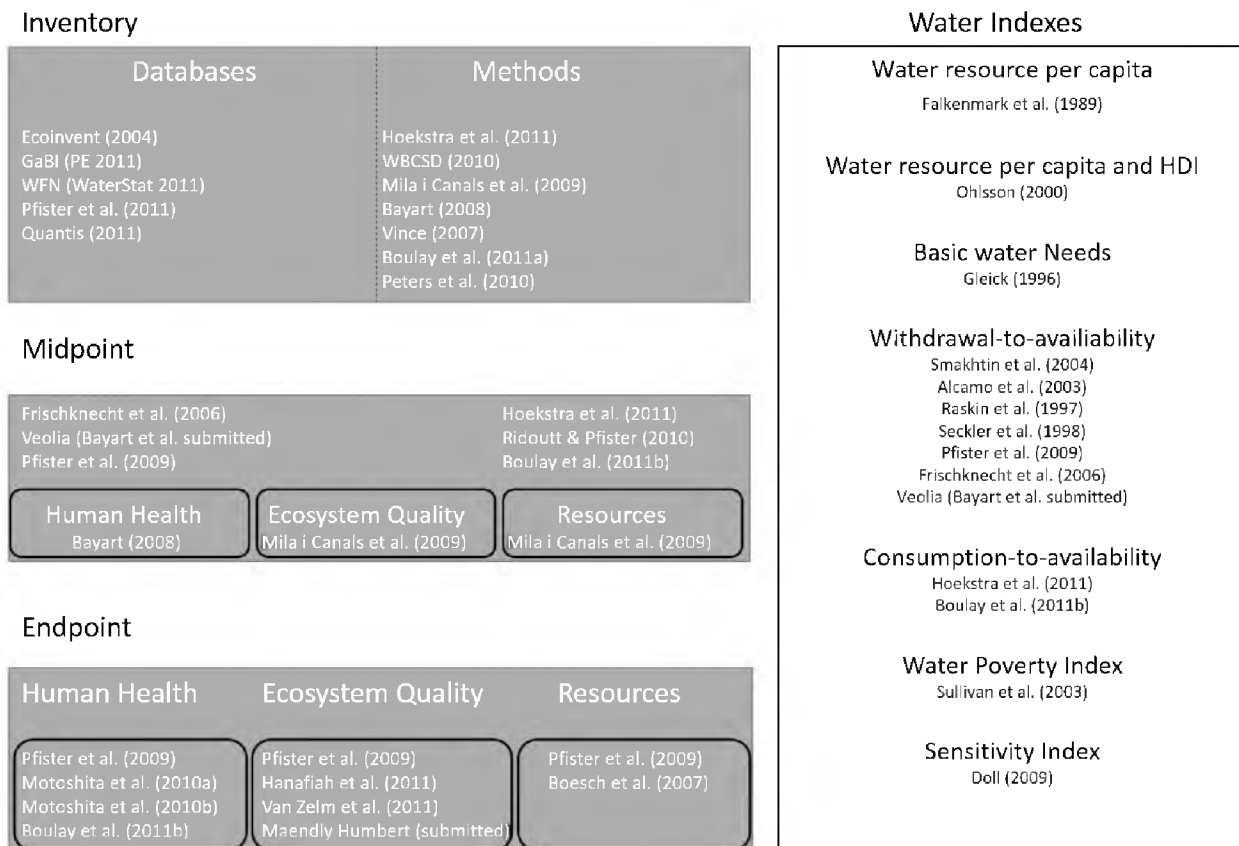


Figure 2.2: The relationship and scope of the various freshwater use inventory and impact assessment methods and contributing studies

Source: Kounina et al. (2012)

2.1.2.1 Historical context

2.1.2.1.1 Water footprint assessment

The water footprint assessment is a fast growing field of research, producing 140 scientific papers in 2014 alone (Hoekstra et al., 2015). This form of water footprint was first introduced in the early 1960s by Professor Tony Allan, whose research focused on the idea of virtual water and volumes of water required to produce goods and services throughout the production supply chain. This initial research also looked into the virtual water potential of imports, promoting trade of water through products on a global scale, in order to address trade and water scarcity (Berger & Finkbeiner, 2010; Jefferies et al., 2012; Lovarelli et al., 2016;). Following this, the WFA was further developed by Arjen Hoekstra in 2002 in coalition with UNESCO-IHE and later taken over and developed by Twente University and the Water Footprint Network (Berger & Finkbeiner, 2010; Jefferies et al., 2012; Hastings & Pegram, 2012; Hoekstra et al., 2015; Scheepers, 2015). Originally the WFA was conducted on a national level, and has since developed over time to incorporate direct and indirect fresh water consumption

measures for companies, individuals, organisations, consumers and governments on product, producer, river basin, regional, national, continental and global scales (Berger & Finkbeiner, 2010; Jefferies et al., 2012; Hastings & Pegram, 2012; Hoekstra et al., 2011).

2.1.2.1.2 Life cycle assessment

The life cycle assessment (LCA) is a framework which originated in the 1960s in industrialised countries in order to evaluate the environmental impacts of products and services, from cradle-to-grave, over the concern towards limited raw material and energy resources (Berger & Finkbeiner, 2010). It became apparent that freshwater use impacts had been underrepresented in the LCA, where most industrialised systems relied on some form of fresh water use or abstraction (Mila i Canals et al., 2008), and thus an emerging focus was placed on water scarcity as a global problem. As a result, the International Standards Organisation (ISO) developed a set of standards and methodologies regarding water LCA in order to support decisions regarding sustainability (Berger & Finkbeiner, 2010; Hastings & Pegram, 2012; International Standards Organisation, 2014; Boulay et al., 2015). Today there are various adaptations to the LCA, with varying focus on impact assessments which cover human health, ecosystem quality, stress based indicators and potential ecosystem deprivation indicators (International Standards Organisation, 2014; Boulay et al., 2015).

2.1.2.2 The water footprint assessment (WFA)

The water footprint, as described by the WFN, is also known as a consumption based volumetric water footprint. This footprint is a multidimensional inventory and midpoint impact indicator (Kounina et al., 2012) used to measure, describe, and formulate water management policies regarding the direct and indirect freshwater consumption of producers and consumers (Hoekstra et al., 2011; Jefferies et al., 2012; Boulay et al., 2013). This involves insight into various sources of freshwater extraction and volumes of freshwater required to assimilate pollution. Through this the WFA is able to link human consumption and fresh water appropriation (Hoekstra et al., 2011; Hastings and Pegram, 2012; Zonderland-Thomassen & Ledgard, 2012; Hoekstra et al., 2015; Scheepers, 2015). Once measured the WFA uses freshwater availability as a sustainability indicator which is then used to assess and determine the impact of freshwater use on various stakeholders within a local context (Hoekstra et al., 2011).

The water footprint is separated into three consumptive categories of blue, green and grey water. The blue water footprint indicates the volume of ground and surface water which evaporates during a production process, and the green water footprint represents the evapotranspiration of rain water during the plant growth of relevant agricultural products. Finally, the grey water footprint refers to the water returned to the environment which has been degraded, and the amount of fresh water required to dilute the polluted water back to ambient water quality standards (Berger & Finkbeiner, 2010; Hoekstra et al., 2011; Jefferies et al., 2012)

There are four phases which the WFA uses to address fresh water consumption, according to the Water Footprint Network assessment manual (Hoekstra et al., 2011). These four phases are as follows:

1. Goals and scope- The various process steps are determined in this phase, as well as the indicators which the WFA will include over a prescribed time period.
2. Accounting- The accounting phase accounts and maps the types of freshwater use in terms of the three quantitative water footprint categories. This phase looks specifically at consumptive water depletion (CWD) and consumptive water use (CWU), as well as crop evaporation, cultivation and processing (when looking at the water footprint of crop production).
3. Sustainability assessment- This phase provides comparisons of freshwater availability regarding environmental, social and economic factors. These include environmental flow requirements, water allocation for human needs, and requirements for economic efficiency.
4. Response formulation- The response formulation is based on findings in the accounting and sustainability assessment phase of the WFA.

Due to the impact freshwater consumption has on hydrological flows and socio-economic systems, it is important that the blue water footprint is weighted. This weighting, according to the water footprint assessment manual, is done with an explicit characterisation factor (CF) such as the water stress index (WSI) in order for the WF to be meaningful and account for environmental relevance (Tillotson et al., 2014). The WSI used by the WFN was developed by Smakhtin et al. (2004), and measures the ratio of annual water withdrawals to availability

using mean annual runoff (MAR) less environmental water requirements (EWR) (Smakhtin et al., 2004; Jefferies et al., 2012).

2.1.2.3 The life cycle assessment (LCA)

The LCA, as defined by ISO 14046, is a modular methodology which identifies potential environmental impacts through freshwater abstraction within geographical and temporal dimensions, from inventory to midpoint and endpoint impacts. This methodology identifies the quantities, quality and scarcity of fresh water within the hydrological cycle and aims to provide an assessment of potential environmental impacts and opportunities during the various life cycle stages of a product. The LCA also aims to provide support to decisions regarding human use effects on the environmental performance of freshwater (Koehler, 2008; Boulay et al., 2013; International Standards Organisation, 2014). The LCA has been developed to incorporate freshwater indicators and comprehensive methods for accounting and inventory impact assessments on manufactured goods and services, business operations, and consumer behaviour (Koehler, 2008; Jefferies et al., 2012), with focus on blue water flows (Mila i Canals et al., 2008). This has resulted in the LCA being recognised as the generally accepted tool for measuring the environmental impact of a product from “cradle-to-grave” (Berger & Finkbeiner, 2010).

There are various sources of water which are addressed by the LCA within the ISO 14046. This includes water sources such as precipitation, surface water, sea water, brackish water, ground water and fossil water (International Standards Organisation, 2014). According to the LCA, freshwater use is separated into consumptive use and degradative use. Degradative use refers to the deterioration of the water quality of fresh water once used, and is then discharged back into different water sheds (Berger & Finkbeiner, 2010). The LCA looks at these freshwater uses and incorporates a weighting factor in order to understand their impacts on freshwater scarcity (Hastings & Pegram, 2012).

The life cycle assessment, as interpreted by Ridoutt & Pfister (2010), defines the quantitative water categories as follows:

Green water- Green water has three different impact pathways through the occupation of land (which limits the availability of land and social access to green water), land use (which

influences the partition between blue and green water), and the conversion of natural land to agricultural land (thus resulting in loss of habitats and ecosystem biodiversity).

Blue water- Blue water is classified as the irrigation water incorporated into a product's lifecycle. The potential impacts of blue water consumption include impacts on human health (malnutrition due to short term consumption rates being larger than short term freshwater replacement), the consumption of non-renewable freshwater resources (limits the availability of freshwater for future users), and negative impacts on ecosystems and biodiversity (occurs when water required for irrigation competes with environmental water requirements).

There are four phases involved in the LCA water footprint, as stipulated in ISO 14046 and UNEP/SETAC (Benoît et al., 2009). These phases are:

1. Goals and scope- The goals and scope of the LCA define the product or service to be assessed, as well as a clearly defined field of study and basis for comparison.
2. Inventory analysis- The inventory analysis is an analysis of the various water consuming activities and their related externalities on the environment. This is combined with a process flow chart.
3. Impact assessment- The impact assessment addresses the effects of resource activities and their externalities, as well as the various weighted importance of these effects within impact categories.
4. Result interpretation- An interpretation of the results from the inventory analysis and impact assessment in order to inform potential opportunities to reduce negative environmental impact.

Methods have been developed based on the life cycle assessment using life cycle inventory (LCI) and life cycle impact assessment (LCIA) (Berger & Finkbeiner, 2010), where the LCI provides a single value for the impact category in order to explain potential impacts and the LCIA aims to aggregate a metric considered similar to that of the carbon footprint (Jefferies et al., 2012). These methods use indicators to formulate characterisation factors (CF) which are then used to convert the freshwater flows of LCI into a common unit impact category (Berger & Finkbeiner, 2010).

There are two highly regarded methodologies within the LCA which address LCI and LCIA. These are the freshwater ecosystem impact method as determined by Milà i Canals et al. (2009), and the stress weighted water footprint as developed by Ridoutt & Pfister (2010).

1.2.3.1 Freshwater ecosystem impacts method by Milà i Canals et al. (2009)

This method is an adaption of the LCA WF and addresses two separate impact pathways, being fresh water ecosystem impact (FEI) and freshwater depletion (FD). This method was developed after acknowledging that most previous studies had failed to mention the sources of freshwater for, and the condition of water once it leaves, the production system (Milà i Canals et al., 2009). Through this, the freshwater ecosystem impacts method found that water should be further categorised in terms of evaporative and non-evaporative uses. The method does this by differentiating between green water inputs, blue water inputs, fossil blue water inputs and water use due to land changes (Berger & Finkbeiner, 2010).

Freshwater Ecosystem Impact (FEI): The FEI is the volume or mass of ecosystem equivalent water, i.e. water volumes which are most likely to affect freshwater ecosystems. This impact indicator thus only looks at evaporative water use of blue water and land use changes. The FEI looks at the water stress index (WSI) and the water use per resource (WUPR) calculations in order to develop a definitive CF. Unlike the WSI as used by the WFA, the WSI, as proposed by Milà i Canals et al. (2009), is used in order to weight and normalise freshwater volumes rather than provide an aggregate value (Jefferies et al., 2012). The WSI of a region can be calculated by dividing total freshwater withdrawals for humans (WU) by the annually available water reserves (WR) less total annual environmental requirement (EWR).

Freshwater depletion (FD): FD addresses the decreased availability of freshwater resources for future generations, in instances where freshwater use exceeds the rate of renewability. This indicator applies more specifically to freshwater consumption from aquifers and blue fossil water.

1.2.3.2 Stress weighted water footprint by Ridoutt and Pfister (2010)

The stress weighted WF is a method within the LCA framework which looks at region specific effects of fresh water consumption (Scheepers, 2015) and hydrological conditions which are consistent with water deprivation (Zonderland-Thomassen & Ledgard, 2012). This method is considered by Ridoutt & Pfister (2010) to be the ideal method in terms of meaningful

comparison of products at different stages within their lifecycle, and the method's ability to provide a foundation for corporate sustainability accounting and practices.

The stress weighted WF addresses the midpoint and endpoint impacts of blue water consumption in order to enable a comprehensive impact assessment of freshwater within a product's lifecycle (Berger & Finkbeiner, 2010). At the midpoint impact level, the method quantifies water availability linked to production systems (Zonderland-Thomassen & Ledgard, 2012). The method also contains three categories of endpoint impact indicators. These categories are the protection of human health, ecosystems quality and resources (Pfister et al., 2009; Ridoutt & Pfister, 2010).

This method within the LCA, like the method developed by Milà i Canals et al. (2009), uses the water stress index as a characterisation factor. However, this is calculated differently, according to Pfister et al. (2009), who believe that the WSI serves as a characterisation factor for water deprivation, and should be based on the water to availability (WTA) ratio, which is primarily focussed on abstracted water rather than consumed water (Berger & Finkbeiner, 2010; Zonderland-Thomassen & Ledgard, 2012). From this, blue water consumption for a region can be multiplied by the WSI of that region in order to provide a characterised result (Berger and Finkbeiner 2010).

2.1.3 Discussion

There are both pros and cons to the different water footprint methodologies. This section aims to address these, as well as the common ground on which the water footprint methodologies stand.

The methodological scopes for both the LCA and the WFA differ with regards to water use, inclusion of water scarcity, and differentiation between water quality indicators. In choosing which methodology to follow there is a trade-off between precision and applicability (Berger & Finkbeiner, 2010). There is a distinct similarity between these methodologies in methods for data collection (Zonderland-Thomassen & Ledgard, 2012) and the goals of the methodologies (Boulay et al., 2013). However, the disparities occur in the estimated results due to the application of various characterisation factors, accounting for land conversion, and the inclusion of normalising procedures (Zonderland-Thomassen & Ledgard, 2012; Hoekstra, 2016).

The biggest dispute between the two water footprint methodologies is related to their use of water scarcity and impact indicators regarding grey water and blue water, specifically with blue water impacts related to water scarcity (Berger & Finkbeiner, 2010; Deurer et al., 2011). Unlike the LCA, the WFA cannot verify environmental impact unless set within a specific local context in order to provide environmentally meaningful sums (Pfister & Ridoutt, 2014). Within the context of blue water scarcity, the WFA uses gross data for evaporation rather than net data, which only accounts for total evaporation less the evaporation which would occur in a region in its natural state, highlighting actual blue water scarcity more effectively in the LCA (Hastings & Pegram, 2012). Furthermore, LCA supporters argue that the life cycle assessment is able to provide a single number within an impact category which explains potential impact. It does this through its provision of a weighted volumes inventory indicator rather than an aggregate volumes indicator as used by the WFA (Jefferies et al., 2012).

However, according to Hoekstra (2016), the weighting mechanism used by the LCA obscures the debate around water scarcity, accounting for different litres of water differently according to levels of water scarcity. In essence the methods undertaken by the LCA result in double counting. Because of this cumulative approach to water scarcity, the LCA implies that the water footprint of other parties will increase an individual's WF even if that individual has purposefully attempted to reduce his/her water footprint, i.e. the WF of an individual or firm is affected by the consumption of others (Hoekstra 2016). Thus, the WFA suggests that the LCA water scarcity indicator is in fact incorrect.

According to Berger & Finkbeiner (2010) and Ridoutt & Pfister (2010), the WFA has no clearly defined common standards for addressing water quality and is vague in terms of impact categories (Berger & Finkbeiner, 2010; Ridoutt & Pfister, 2010). One of the harshest criticisms of the LCA towards the WFA is the ease with which information on the WF can be misconstrued. Due to its need to be placed within local context, the WFA often lacks acknowledgement of the broader picture such as environmental and socio-economic needs and opportunity costs in terms of water abundance or water scarcity, rather than the mere size of the WF (Ridoutt & Pfister, 2010; Hastings and Pegram, 2012). Often the WFA presents one side of the story and does not contribute to water management, or address food scarcity, due to its lack of description of these water uses and scarcity impacts (Hastings and Pegram, 2012).

The LCA proponents state that the LCA addresses grey water in more depth than the WFA. This is because the WFA loses a lot of information in its grey water indicator, and thus becomes a hypothetical pollution volume (Pfister & Ridoutt, 2014). The LCA claims to be a better indicator for grey water by addressing several impact categories for pollution rather than a single grey water indicator (Ridoutt & Pfister, 2010; Hastings & Pegram, 2012; Jefferies et al., 2012). The LCA does this through its inclusion of water scarcity characterisation factors and its address of impact categories such as eutrophication and freshwater exotoxicity when applied to fate and effect models (Ridoutt & Pfister, 2010; Jefferies et al., 2012).

Through the summation of all of the water footprint indicators in the WFA, the WF as an indicator loses its relevance, with regional water scarcity providing more valuable information to users than volumetric estimates (Zonderland-Thomassen & Ledgard, 2012; Pfister & Ridoutt, 2014). Boulay et al. (2013) suggest that the reason that the WFA is criticised for its lack of sustainability accounting is due to that fact that the WFA does not approach sustainability in the accounting phase, but rather in the sustainability assessment phase. In this phase the WF addresses environmental impact by putting the WF accounting into context (Boulay et al., 2013; Hoekstra, 2016).

Another issue with the WFA, compared to the LCA, is its underdeveloped database. The LCA is a better methodology to measure the WF for large systems analysis due to its highly developed database (Jefferies et al., 2012). The database of the WFA, though developing, is not yet considered to be on the same level, which often results in practical complexities with data (Boulay et al., 2013; Hastings & Pegram, 2012), thus making the LCA the preferred methodology to follow when performing a WF calculation.

Although there are many issues with the WFA from the perspective of impact assessment and lack of a developed data base, such as that of the LCA, the WFA provides many beneficial properties and characteristics. The water footprint assessment is a methodology which prides itself in being a water footprint methodology which promotes freshwater resource management. It does this through its strength in addressing local and temporal water related impacts by focussing on the components of the WF rather than a final figure (Wichelns, 2010; Jefferies et al., 2012; Boulay et al., 2013; Hoekstra, 2016;).

What separates the WFA most from the LCA is its inclusion of a green water indicator. The LCA does not account for the green water footprint (Jefferies et al., 2012; Pfister & Ridoutt, 2014; Scheepers, 2015; Hoekstra, 2016). Although green water currently dominates global food production and is important in its contributions towards food security, the LCA suggests that a land impact indicator is a better measure than a green water footprint (Ridoutt & Pfister, 2010). According to the LCA, the green water footprint does not change from vegetation to crop use, and thus does not have a significant environmental impact (Deurer et al., 2011). This suggests that green water does not contribute towards water scarcity until it becomes blue water (Ridoutt & Pfister, 2010; Jefferies et al., 2012).

However, the green water footprint is important when looking at the water footprint of crop production. Blue water is often considered more valuable than green water, as it is a manageable water resource and it is possible to re-allocate blue water to various other uses. However, green water plays a critical role in sustaining natural ecosystems and ensuring water and food security (Zoumides et al., 2014). The WFA believes that the green water indicator is important. This is because, according to the WFN definition, the green water footprint is evaporated rainwater which has been appropriated for the production of a good or service and is therefore not available for nature (Hoekstra et al., 2011; Jefferies et al., 2012; Schyns et al., 2015). Competition for green water is in the form of production, grazing land, forestry, and terrestrial ecosystems, and the distribution and competition for this freshwater resource is a determining factor as to which environmental goods and services should be produced. These decisions have a considerable effect on food security and nature conservation (Schyns et al., 2015).

Green water is a scarce freshwater resource in itself and should be accounted for in the same manner as blue water consumption (Jefferies et al., 2012), and potentially has lower relative opportunity costs than blue water (Wichelns, 2010). The use of green water scarcity indicators has hardly been recognised by water footprint literature. The competition for this resource occurs implicitly and indirectly due to human choices for land use. With the indirectness of land allocation and the lack of price, green water is absent from the economy (Schyns et al., 2015). Granted, the green water footprint at its current stage is very limited, but preliminary research such as that done by Schyns et al. (2015) into formulating an absolute green water

indicator is beginning to be published, indicating the perceived importance to the WFA of green water scarcity.

Although there are many differences between the LCA and WFA water footprinting methodologies, both methods would benefit from taking advantage of certain aspects of the other. From a LCA perspective, the LCA could benefit from the WFA by incorporating the WFA quantitative indicators within LCA inventory flows. The LCA would also benefit from looking at the WFA blue water scarcity indicator which compares well with LCA scarcity indicators. From the viewpoint of the LCA, it would be to its advantage to incorporate aspects of the WFA response formulation and sustainability assessment (Jefferies et al., 2012; Boulay et al., 2013).

Similarly, the WFA can gain insight from the LCA. This would benefit the WFA accounting by taking advantage of the well-established and comprehensive LCA database. Furthermore, the WFA should consider incorporating impact assessment indicators similar to those in the LCA as part of its sustainability indicators in order to determine a consensual metric for assessing the sustainability of fresh water consumption (Jefferies et al., 2012; Boulay et al., 2013).

2.2 Case studies

The water footprint, as determined by the water footprint network, has been used in collaboration with many studies since its conception. Such studies range from those which are as broad as national studies, to regional and local studies. These studies also range from production to consumption based studies which cover various processes and supply chains (Hoekstra & Mekonnen, 2011a; Hoekstra et al., 2011; Hoekstra et al., 2012). This section will look at some of the studies which have contributed to the water footprint field of research by looking at case studies which have been performed on a national scale, river basins, business, agricultural production, animal product production, and finally address and place emphasis on studies addressing the water footprint of dairy.

2.2.1 National WF

Case studies on the water footprint of nations have been both broadly focused on the global water footprint, and narrowly focused on the water footprint of individual nations. Hoekstra & Mekonnen (2011a) published a paper which addressed the water footprint of humanity. In this paper Hoekstra & Mekonnen (2011a) reported on the consumptive green and blue water

footprints, as well as the grey water footprint estimates, for different countries' production and consumption patterns. Between 1996 and 2005 the global average water footprint was found to be 9 087 Gm³ per annum, made up by 74% green water, 11% blue water and 15% grey water (this breakdown is illustrated in figure 2.3). Of this, agricultural products contributed 92% of the global water footprint. Furthermore, it was found that cereal products (27%) and meat (22%) contributed the most to the consumer's WF (Hoekstra & Mekonnen, 2011a). According to the study, the United States, China and India have the largest water footprints for national production within their territory. India claims the largest blue water footprint, and China had the largest grey water footprint (Hoekstra & Mekonnen, 2011a).

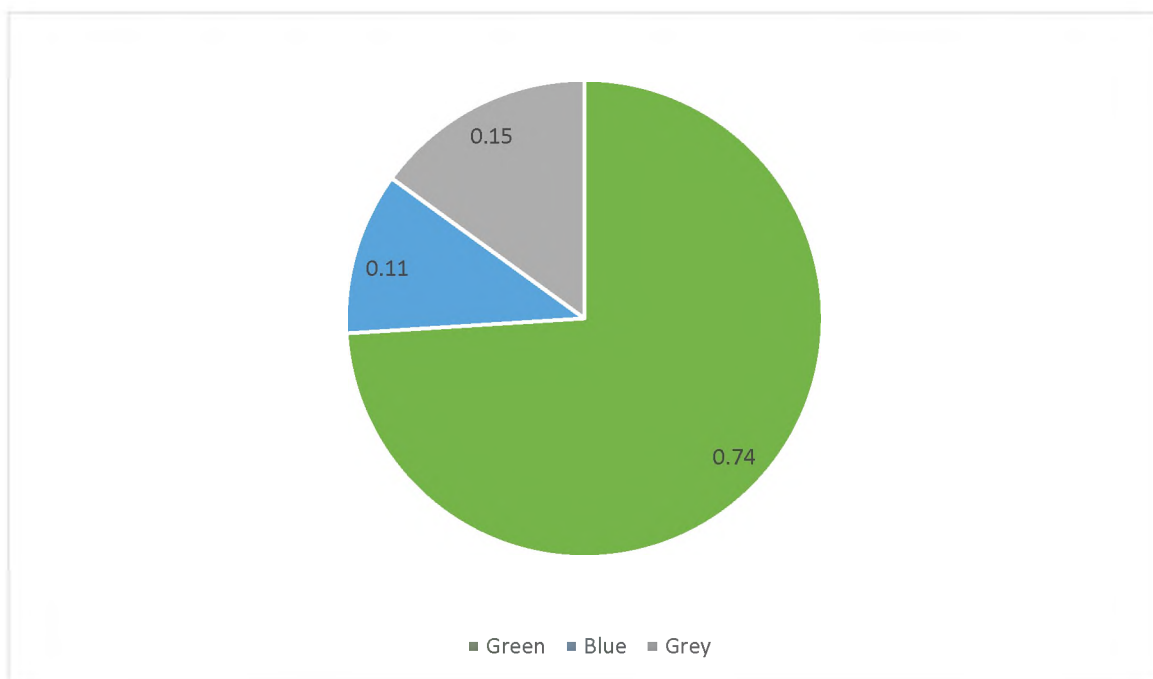


Figure 2.3: Global dispersion of the water footprint from 1996-2005 in terms of blue, green and grey water footprints

Source: Hoekstra & Mekonnen (2011a)

Schyns & Hoekstra (2014) determined the national water footprint of Morocco by addressing all of its river basins. In this study, it was found that crop production contributed to the majority of Morocco's water footprint, which consumed 78% of all green water, 83% of all blue water, and produced 66% of all polluted water. Furthermore a total of 884 Mm³ per annum of freshwater was lost due to evaporative losses from storage reservoirs, i.e. 13% of total blue water (Schyns & Hoekstra, 2014). The study by Zoumides et al. (2014) calculated the water footprint of the island Cyprus. This study looked at the total WF of the island from

1995-2009 and found that blue water accounted for 13% of the national water footprint and green water accounted for 87%, with a high green water import dependency embedded in crops for feed ingredients (Zoumides et al., 2014). In the case of Kenya's production and consumption, Mekonnen & Hoekstra (2014a) found that 97% of the national water footprint was green water, 1% blue water and 2% grey water between 1996 and 2005. The largest share of the country's water footprint occurred from maize production which used 61% of the total green water footprint, and the combination of rice and coffee accounted for 40% of the nation's total blue water consumption in crop production (Mekonnen & Hoekstra, 2014a). A South African study found that South Africa's consumers on average consume 1 255m³ of water per year, which is below the world average of 1 385m³ per year. This water consumption is dominated by meat and cereals, which explain 0.6% of global production. Within South Africa, green water accounts for 78% of that national water footprint, 12.1% is allocated to blue water consumption and grey water contributes 9.9% to the national water footprint (Pahlow et al., 2015).

2.2.2 River basins

Early water footprint research focused on the water footprint of nations (See 2.1.2.1). As research diversified, focus of the WF shifted to more regional specific studies and the water footprint of river basins (Chapagain & Orr, 2009; Hoekstra et al., 2011). Hoekstra & Mekonnen (2011b), as part of the Water Footprint Network's attempt at estimating the water footprint of humanity, studied some of the world's river basins between 1996 and 2005. This study compared 223 river basins and found that within 201 of those basins 2.67 billion people faced severe water scarcity (Hoekstra & Mekonnen, 2011b). Other studies have focused on fewer or individual river basins. The study by Schyns & Hoekstra (2014) found that water consumption differs from basin to basin due to different climatic conditions. A study by Zhuo et al. (2016b) addressed the water footprint of the Yellow River Basin (YRB), the second largest river basin in China. This study found that the water footprint of the basin had been reduced over the years due to improved crop yields, but also found an increase in the grey water footprint due to increased fertilizer application rates on agricultural production within the basin. Within the YRB agriculture was found to be the largest contributor to the blue WF at 77%, of which 91% was used for irrigation purposes (Zhuo et al., 2016b). The Guadiana basin is another example of an individual basin study. This study, performed by Aldaya &

Llamas (2008), analysed the water footprint of the majority of the basin which falls within the borders of Spain, by comparing the upper, lower and middle regions of the Guadiana basin. In this assessment, both rain fed and irrigated agriculture was found to consume 95% of the basin's total water footprint (Aldaya & Llamas, 2008). Zeng et al. (2012) also looked at a single river basin, the Heihe River Basin in northwest China. Between 2004 and 2006 the water footprint of the basin, on average, was 1768 million m³ per year, with agriculture once again being the largest contributor to the WF. Of the 96% of the WF accounted for by agriculture, 92% was related to crop production and 4% to livestock production. Overall the study found that the basin's blue water component (46%) was a lot higher than the global average and China's average. This result being affected by the aridness of the Heihe basin and its high crop dependency on irrigation (Zeng et al., 2012).

2.2.3 Business

Studies have been undertaken by some multinational corporations regarding their product water footprints. What makes these product water footprints important is the fact that their supply chains span the globe between water rich and water scarce regions. Thus, it is important for these companies to look beyond mere water stewardship and water consumption within operations (Coca-Cola, 2011; Hoekstra et al., 2012; Hoekstra, 2014). Coca-Cola is one such company which is considered a pioneer in terms of water footprint accounting for product supply chains. Coca-Cola (2011) produced a report which investigated its sustainability of sugar sourcing in Europe, the second report produced by the company with the first looking at the water footprint of its PET 500 ml bottles which indicated that 99% of Coca-Cola's WF originated from its supply chains (Coca-Cola, 2011). HP (2014) is another company which has reported on its products' water footprint. This report was produced in 2014 and looked at the operations, products and supply chains belonging to the company within its organisational boundaries and operational control. This study incorporated some of its own measures in order to communicate water use for energy. Thus, as of yet, this form of reporting may not be comparable with other studies (HP, 2014). Unilever similarly performed a water footprint assessment of its company as a way of informing the company's business strategy, from supply chains to products within the company's value chain. Unilever found that 85% of water consumption which occurred within its value chain came from the final consumers of Unilever products (Unilever, 2016).

2.2.4 Agriculture

Due to the large contribution made by agriculture towards the water footprint of regions and nations, many studies have been conducted which look both generally at agriculture and focus on crop specific agriculture. The case of Indonesian crop production was investigated by Bulsink et al. (2010), and considered the water footprint of crops for the country and its different provinces. Indonesian crops were found to be grown predominantly with rain water, with the WF related to the consumption of crop products being 1 131 m³ per capita per annum. The study also investigated one of the Islands belonging to Indonesia, Java, which was found to rely on a large external crop water footprint in order to relieve itself of high water scarcity. Results showed that cassava crops had the lowest water footprint in Indonesia at 500m³ per ton, and coffee had the highest at 22 900 m³ per ton. Of the total water footprint of the country, rice represented 73% of the green water footprint, 21% of the blue water footprint, and soy beans contributed to 16% of the blue water footprint (Bulsink et al., 2010). A study based in Tunisia found that between the years 1996-2005 crop production contributed 87% to the country's agriculture WF. Crop production was followed by grazing which contributed 11% to the WF total and 2% of the agriculture WF was accounted for by domestic water supply, livestock production and industrial activities (Chouchane et al., 2015). Chouchane et al. (2015) found that within Tunisia, of total cultivated land, irrigated land uses made up 7% of the total water use and contributed to 35% of production in the agriculture sector, and more than 80% of total water withdrawals.

The Sundays River Valley citrus study is an example of a more crop specific water footprint study within agriculture. The majority of South Africa's agricultural crops (59%) rely on irrigation in order to meet crop water requirements within areas which experience volatile rainfall and climate patterns, both seasonally and geographically (Backeberg, 2005). The study by Munro et al. (2016) looked at the water footprint of citrus within the Sundays River Valley by analysing primary and secondary data captured from online data sources and the Sundays River Citrus Company (Munro et al., 2016). Other studies on agriculture which have considered the WF of specific crops include studies such as the study by Rodrigues & Pereira (2009), which looked at the water footprints of maize, sunflower and wheat in Virgia, South Portugal, in order to assess the feasibility of deficit irrigation. Another study was performed by Aldaya et al. (2010) on the WF of rice, cotton and wheat within central Asian countries.

This study found that agricultural production accounted for 45% of people employed in central Asia and contributed 25% of those countries' GDPs on average (Aldaya et al., 2010). A Spanish case study on strawberry production found that 73% of strawberry production takes place in southwest Spain. The study by Morillo et al. (2015) looked at the production of strawberries on 22 farms in order to assess best water management and irrigation practices on these farms between 2010 and 2012. It was found that the aquifer within the area provided 65% of the fresh water requirements for strawberry production's irrigation lands which spanned 3800 hectares (Morillo et al., 2015).

2.2.5 Animal products

Almost a third of agricultural production is dominated by the production of animal products (Hoekstra, 2012; Mekonnen & Hoekstra, 2012; Gerbens-Leenes et al., 2013), and the production and consumption of these products is likely to increase the already existing pressure on global freshwater resources (Mekonnen & Hoekstra, 2010b). Research suggests that socio-economic development has a positive correlation with the consumption of livestock products, with consumption trends shifting from crop based products to animal based products along with rising incomes per capita (Mekonnen & Hoekstra, 2010b; De Miguel et al., 2015). This shift is particularly noticeable among developing countries which are experiencing significant economic growth and thus improved purchasing power (Gerbens-Leenes et al., 2013).

The increased demand for animal products has driven the demand for the intensification of production systems, influencing the feed composition for animals as well as creating a larger reliance on the use of concentrates over roughages and grazing within the production systems (Mekonnen & Hoekstra, 2010b). Intensification of production systems in itself poses threats to fresh water resources through not only consumption of scarce water resources, but also the potential of water resource pollution through fertilizer application and improper storage and application of manures (Mekonnen & Hoekstra, 2010b; Gerbens-Leenes et al., 2013).

Animal products have a large water footprint in relation to their counterpart crop products of similar nutritional content (Mekonnen & Hoekstra, 2010b; Hoekstra, 2012). For example, the production water footprint of beef per calorie is 20 times larger than that of cereals and starchy roots (Mekonnen & Hoekstra, 2012). Where proteins are concerned, animal proteins

such as milk, eggs and chicken have a water footprint which is 1.5 times larger than that of pulses (Mekonnen and Hoekstra 2010a, 2010b). Mekonnen & Hoekstra (2010a, 2010b) released a report on the water footprint of farm animals and farm animal products which contributed to the water footprint report series on the water footprint of humanity. Table 2.1 provides a comparison, presented in the study, of animal product WFs to crop product WFs, as well as the WF per nutritional value. Furthermore, Mekonnen and Hoekstra (2010b) found that total global animal production contribute to 29% of agriculture production, with the WF of animal product production claiming 32% of green water, 17% blue water and 22% grey water (Mekonnen and Hoekstra 2010b).

Table 2.1: A comparison of the water footprints of crop products and animal products in relation to m³ per ton and per unit of nutritional value

Food item	Water footprint per ton (m ³ /ton)				Nutritional content			Water footprint per unit of nutritional value		
	Green	Blue	Grey	Total	Calorie (kcal/kg)	Protein (g/kg)	Fat (g/kg)	Calorie (litre/kcal)	Protein	Fat
									(litre/g protein)	(litre/g fat)
Sugar crops	130	52	15	197	285	0	0	0,69	0	0
Vegetables	194	43	85	322	240	12	2,1	1,34	26	154
Starchy roots	327	16	43	387	827	13	1,7	0,47	31	226
Fruits	726	147	89	962	460	5,3	2,8	2,09	180	348
Cereals	1 232	228	184	1 644	3 208	80	15	0,51	21	112
Oil crops	2 023	220	121	2 364	2 908	146	209	0,81	16	11
Pulses	3 180	141	734	4 055	3 415	215	23	1,19	19	180
Nuts	7 016	1 367	660	9 063	2 500	65	193	3,63	139	47
Milk	863	86	72	1 020	560	33	31	1,82	31	33
Eggs	2 592	244	429	3 265	1 425	111	100	2,29	29	33
Chicken meat	3 545	313	467	4 325	1 440	127	100	3	34	43
Butter	4 695	465	393	5 553	7 692	0	872	0,72	0	6,4
Pig meat	4 907	459	622	5 988	2 766	105	259	2,15	57	23
Sheep/goat meat	8 253	457	53	8 763	2 059	139	163	4,25	63	54
Bovine meat	14 414	550	451	15 416	1 513	138	101	10,19	112	153

Source: Mekonnen & Hoekstra (2010a, 2010b)

The water footprint of humanity, looking specifically at animal production, provides global values and averages for the animal product categories of beef cattle, dairy cattle, pig, broiler chicken, horse, layer chicken, sheep and goat. The study looked at the different farm animals as well as their related animal products in terms of the products' water footprints and the types of production systems the various animal products are attributed to, according to different countries and conditions (Mekonnen & Hoekstra, 2010b). Table 2.2 has been taken

from the study, and provides information on these farm animal categories along with estimated animal number averages, as well as their annual and average global water footprints from 1996 to 2005. Beef cattle have the largest average global water footprint, contributing 33% to the WF of animal production, and goats have the lowest, only making up 1% of the global farm animal water footprint (Mekonnen & Hoekstra, 2010b; Mekonnen & Hoekstra, 2012).

Table 2.2: *The water footprint averages of farm animals (1996-2005)*

Animal category	Global total number of animals (millions)	Average animal water footprint per animal (m ³ /yr per animal)	Average water footprint of animal category (Gm ³ /yr)	%
Beef cattle	1 267	630	798	33
Dairy cattle	228	2 056	469	19
Pig	880	520	458	19
Broiler chicken	9 923	26	255	11
Horse	112	1 599	180	7
Layer chicken	5 046	33	167	7
Sheep	1 052	68	71	3
Goat	750	32	24	1
Total	19 258		2 422	100

Source: Mekonnen & Hoekstra (2010b)

Gerbens-Leenes et al. (2013) also undertook a global scale water footprint assessment for animal products. This study compared the water footprints of poultry, beef and pork between Brazil, the Netherlands, The United States of America and China, whilst also comparing the different types of production systems (grazing, mixed and industrial) in these countries. Beef was found to have a larger water footprint than pork which in turn had a larger water footprint than poultry, but overall these animal products were found to have similar global water footprints in terms of blue and grey water (Gerbens-Leenes et al. 2013). In relation to production systems, Gerbens-Leenes et al. (2013) found that for poultry production, grazing systems on average required 40% concentrates, and industrial systems required 70%, with industrial systems requiring 3.2 times less feed than grazing production systems. The feed conversion efficiency of pork was found to improve along production systems (from grazing to mixed to industrial) and used 2.9 times less feed in industrial systems than grazing production systems. However, pork production within industrial systems only used concentrates, which have a relatively high water footprint. Beef production's water use efficiency also improved along the production systems with industrial production requiring

3.7% less feed than grazing. However this system required a larger fraction of high water footprint bearing concentrates, as high as 18% compared to the 2% required for grazing. Brazil and China's data showed that the largest blue and grey water footprints for animal product production were in industrial systems, and for the Netherlands and USA this was the case for mixed systems. The study reported that these differences were largely explained by the feed composition within different systems in the different countries.

Other studies have been performed regarding the water footprint of animal products on a regional scale (Drastig et al., 2010; De Boer et al., 2013; Huang et al., 2014; Bosire et al., 2015; De Miguel et al., 2015), and have compared their results to those found by Mekonnen & Hoekstra (2010a, 2010b). De Miguel et al. (2015) studied the production of pork in Spain. The study addressed the 2001-2010 period and estimated that the Spanish pig industry contributed an average of 19.5bn m³/year to the water footprint, of which 82% was green water, 8% blue and 10% grey. Furthermore, in the production of pork, the Spanish systems used 50% of water to produce concentrates while the other 50% was embodied in imported feedstock products (De Miguel et al., 2015).

2.2.6 Dairy water footprint literature

There are both direct and indirect water consuming processes throughout the production of farm animals and animal products within agriculture. These processes include the production of feed, drinking water, servicing water and water used for the mixing of feed (Mekonnen & Hoekstra, 2010b). Feed is the largest contributor to the water footprint of livestock with 40% of cereals grown globally being used for the feeding of agricultural animals between 2001 and 2010 (De Miguel et al., 2015). Feed for agricultural animals accounts for 98% of the total agricultural water footprint and a global contribution of 20% of the global water footprint, of which 94% is green water (Mekonnen & Hoekstra, 2012). From global averages, this water consumption for feed production relates to pasture (38%), maize (17%), fodder crops (8%), soy bean cakes (7%), wheat (6%) and oats (3%) (Mekonnen & Hoekstra, 2012; Gerbens-Leenes et al., 2013).

There are three main contributing factors to the water footprint of feed. These factors are feed conversion efficiency, feed composition and the origin of feed (Mekonnen & Hoekstra, 2010; Hoekstra, 2012; Gerbens-Leenes et al., 2013). Feed conversion efficiency relates to the

amount of feed required per animal product and is largely responsible for the large WF of animal products, where a poor feed conversion efficiency could result in a particularly large WF, often seen in the case of beef (Mekonnen & Hoekstra, 2010; Hoekstra, 2012). Feed composition is the term used to describe the ratio of roughages to concentrates. Concentrates have a large blue water footprint, and are primarily used in industrialised systems. Thus industrialised systems tend to have a larger blue water footprint because of their feed composition (Mekonnen & Hoekstra, 2010; Gerbens-Leenes et al., 2013). The origin of feed is of particular importance when feed is being imported from water scarce areas, thus having the potential to affect the dimensions of the water footprint (Mekonnen & Hoekstra, 2010).

Water use efficiency, and particularly green water use, can be improved through the use of proper agricultural management and technology, resulting in lower water footprints with higher yields (Palhares & Pezzopane, 2015). Along with the factors contributing to feed production, the type of production system undergone to produce animal products plays an important role in the water footprint of livestock. There are three types of animal production systems: grazing, mixed and industrial systems. Green water footprints tend to be larger from grazing systems to mixed systems to industrial systems, and the opposite is true for blue water footprints, with industrial systems having a larger blue WF (Mekonnen & Hoekstra, 2010). The water use efficiency also typically improves from grazing to mixed to industrial production systems due to the amount of concentrate used within the various systems, through the movement of animals (calories burned) and the breeding system of animals (for example animals which are bred to grow faster in order to slaughter younger) (Gerbens-Leenes et al., 2013).

There are a limited number of studies which have been undertaken on the water footprint of milk production, and these studies vary in analysis methodology from water footprint assessment to life cycle assessment. Drastig et al. (2010) studied the WFA of dairy production in Brandenburg, Germany. This study assessed the WF of milk production by addressing the feed, milk processing and servicing of cows over a period of 10 years. Drastig et al. (2010) found that in 2008 the average blue water footprint per kilogram of milk in Brandenburg was $3.94 \pm 0.29L$. Drinking water accounted for 82% of the blue water footprint, milk processing accounted for 11% and service water accounted for 7%. Furthermore, the results of the study

indicated that the demand for dairy production, over the 10 years, decreased due to decreasing animal numbers, improved average milk yields per cow and improved feeding practices. Other improvements involved the shifting of breeding schedules and types of cows in order to produce greater volumes of milk (Drastig et al., 2010).

Another WFA on milk production was a case study by Scheepers (2015), on the value chain of lucerne fed dairy on irrigated pastures in South Africa. Like Drastig et al. (2010), Scheepers (2015) looked at the drinking and servicing water for the cattle, water used for feed production, and overhead water consuming processes. The study found that feed production contributed most significantly to the WF of milk, and that the total WF composition for milk was 84% green water, 10% blue water and 6% grey water (Scheepers, 2015).

Similarly, Palhares & Pezzopane (2015) conducted a study which compared conventional milk and organic milk production through the water footprint. The study found that in both production systems green water was the most significant contributor to the WF of milk, and irrigation accounted for the most significant portion of the blue water footprint of conventional and organic milk (95% and 96% respectively). The grey water footprint was made up of phosphorus and nitrate volumes, and these calculations indicated that phosphorus was approximately 1.7 times higher in conventional milk production compared to organic milk production.

A study by Bosire et al. (2015) looked at the water footprint and land footprint of cattle, sheep and goats (sheeps), and camels in Kenya for meat and milk production to investigate the spatial and temporal changes of freshwater and land resources. The study found that within arid and semi-arid systems, milk production consumed 2 000m³ of water per tonne of milk, and 1 240m³/ton within humid systems, with green water once again being the largest contributing factor to the WF of milk production. The blue water aspect of the total water footprint was found to range, from 2% to 19% of the total WF, among the different production systems within Kenya, showing higher percentages of the total WF in arid and semi-arid production systems. Furthermore, the study found that production volumes and feed conversion efficiencies were the predominant influencing factors in the country's milk production water footprint (Bosire et al., 2015).

Zonderland-Thomassen & Ledgard (2012) compared the water footprint values for irrigated and non-irrigated farms in New Zealand using the WFN approach and the stress-weighted LCA. Overall, the study found that non-irrigated pasture based dairy enterprises had a higher green water footprint, and irrigated pastures had a higher blue and grey water footprint. The paper found that the variables required for the WF calculations were the same, but that the treatment of the variables differed between methods and thus resulted in differing final WF values (as mentioned in 2.1.3) (Zonderland-Thomassen and Ledgard 2012).

Unlike the above WFA studies on the production of milk, De Boer et al. (2013) investigated the water footprint of milk production from cradle-to-farm gate using the life cycle assessment. The study area was focused on milk production in Noord-Brabant province in the Netherlands, where the area consisted of commonly irrigated maize and grassland. Results of the study showed that 1kg of fat-and-protein corrected milk, produced on farm, required 66 litres of water, a value which is higher than values found by Mekonnen & Hoekstra (2010b). De Boer et al. (2013) noted the difference in values as being due to the study area being primarily an irrigated area, and thus using larger quantities of consumptive (blue) water. The study found that the total WF of milk production in Noord-Brabant was made up of 76% irrigation for roughage cultivation, 15% for concentrates, 8% for drinking and cleaning water, and 1% related to energy requirements and fertilizer. Being a LCA, the study ignored green water use, and focused on the impact assessments surrounding the consumptive water use of milk production related to human health, ecosystem quality and resource depletion (De Boer et al., 2013).

Huang et al. (2015) also performed a water footprint analysis using the life cycle assessment. Due to the growing domestic production and import of dairy in China, Huang et al. (2014) undertook a study of the water footprint of large scale milk production in the Heilongjiang area, being the first study to apply the LCA in China. This study only considered consumptive water use. The study found that from cradle-to-farm gate the WF of milk was 11 litres per kilogram fat-protein-corrected milk (weighted by the ISO 14046 water stress index characterisation factors), of which, 76% was attributed to feed production (Huang et al., 2015).

2.2.6.1 Discussion

In choosing between the life cycle assessment or the water footprint assessment, for the WF of dryland dairy enterprise, there is a trade-off between scientific quality of results and applicability of assessment methods (De Boer et al., 2013). Huang et al. (2015) state that the LCA indicators and characterisation factors are more revealing than the WFA indicator. This is because the WFA values are seen as misleading, especially in presenting rain-fed production results which are larger than irrigated production, with these values is largely not related to actual water withdrawals. The implications of using this method is that environmental relevance should take precedence in terms of water consumption considerations (Huang et al., 2014). However, dairy research which has used the WFA disagrees with the use of the LCA. This research finds that a major aspect of the water footprint for milk production is indirect green water from feed crop production. Blue water only accounts for 1% of the total water footprint of dairy, and thus removing the green water indicator would not provide accurate results (Drastig et al., 2010). Further debate on the two methodologies is addressed in the theoretical frameworks discussion section 2.1.3 of this chapter.

2.3 Economic application of the water footprint assessment

The increased demands for water resources due to the pressures of climate change, population growth and increased demand for animal products and biofuels have resulted in greater water scarcity pressures. From an environmental perspective, water resources are important in the formation and maintenance of biodiversity and ground water recharge. Water use, in terms of the environment, involves risk of salt water intrusion into the environment and eutrophication. Water scarcity effects society through the availability of drinking water, cultural and leisure activities. Water scarcity often negatively impacts society as a result of the loss of fisheries, grazing land, hunting land and farm land opportunities. Economically, water has opportunity costs in crop production, tourism activities and hydropower generation potential (Hoekstra, 2014). However, water use externalities can negatively impact an economy through disruptions of water supply and the increase in water costs (Coca-Cola, 2011; Hoekstra, 2014).

The world economic forum has listed water scarcity as one of the three largest systemic risks of the highest concern. This is because fresh water scarcity is being manifested through the

decline in ground water tables and reduced river flow, and increased pollution of surface and ground water resources (Hoekstra, 2014). Through the economic value of water, informed choices can be made regarding water development, conservation, allocation and use in the face of growing water demand and scarcity (Ward & Michelsen, 2002).

The idea of water being an economic good was first considered at the Earth Summit meetings in Rio de Janeiro in 1992, and was brought forward for discussion during the Dublin Conference on Water and the Environment in 1992 (Zaag & Savenije, 2006). There are two economic schools of thought surrounding water as an economic good. The first school of thought supports market proponents and suggests that water should be priced through the market, resulting in water allocation in favour of highest value uses. The second school of thought suggests that the process of integrated decision making of scarce resource allocation, and not necessarily the involvement of financial transactions, should take preference over market allocation (Zaag & Savenije, 2006). Hoekstra (2014) and Zaag & Savenije (2006) suggest that it is unlikely that water use within economies will change unless there is an implementation of structural and regulated policy by government. This is due to the fact that water is a public good which is vulnerable to free rider behaviour, especially under current water prices which tend to be subsidised by government and are considered under-priced (Hoekstra, 2014; Linneman et al., 2015). Therefore, water allocation cannot be left to be determined by market forces (Zaag & Savenije, 2006).

This section addresses the economic relevance of the WF with particular focus on economic relevance in agriculture and pasture based dairy production. This relevance is addressed with water productivity indicators, virtual water and allocative efficiency, blue and green water scarcity, as well as business related water risk.

2.3.1 Productivity indicators

Water scarcity effects water productivity. It is for this reason that there is a need to optimise human water use in activities, agricultural activities in particular (Chouchane et al., 2015). Water productivity, as an indicator, was initially introduced after the frustration from researchers towards water use indicators such as irrigation efficiency (Cook et al., 2003). There are many definitions for water productivity. The first looks at the ratio of actual yield to total water use, the second considers the water productivity term as synonymous with

water use efficiency, and the third is biomass water productivity which considers the physiological and eco-physiological processes involved in biomass production (Rodrigues & Pereira, 2009). The preferred water productivity indicator considers the ratio of the net benefits of crops, fisheries, livestock, forestry and mixed agriculture to the amount of water used to produce those benefits (Chouchane et al., 2015). In simplified terms, this is the ratio of agricultural output to water consumed, i.e. crop per drop in terms of blue and green water withdrawals through evapotranspiration (Rodrigues & Pereira, 2009; Chouchane et al., 2015). This indicator is considered to be the inverse of the WF (Mekonnen and Hoekstra, 2014b). Through the use of the water productivity indicator, three possibilities for water use efficiency can be addressed. These include reducing the water footprint per unit of production at the user level, economically efficient allocation of water at the catchment level, or smart virtual water trade on an international level (Mekonnen & Hoekstra, 2014a).

The economic water productivity (EWP) and the economic land productivity (ELP) indicators are considered to be better economic indicators for water use than the general water productivity indicator (Chouchane et al., 2015). Water productivity alone does not provide insight into the economic benefits of water use, thus, EWP should be considered in order to derive the net productive value per unit of water (Rodrigues & Pereira, 2009; Chouchane et al., 2015). For a farmer, the blue and green water EWP are relevant in determining production decisions and assessing the economic sustainability of production (Chouchane et al., 2015; Pahlow et al., 2015). The EWP (USD/m³) indicator does this by comparing direct blue or green water costs to production, to the availability of blue and green water for production in terms of current market prices (Schyns & Hoekstra, 2014; Chouchane et al., 2015; Munro et al., 2016) by dividing the average market value for a crop (USD/kg) by the water footprint of that crop (m³/kg).

Studies which have looked into economic water productivity include a national study of Tunisia between 1996 and 2005 on crop production, with a resultant average blue EWP of 0.32USD/m³, an average rain fed EWP of 0.35USD/m³ and irrigated EWP of 0.32USD/m³ (Chouchane et al., 2015). A study on Morocco's river basins found that blue water crops had the lowest EWP, with the average blue water EWP for maize being 0.08USD/m³ and almonds having an average blue water EWP of 0.02USD/m³ (Schyns & Hoekstra, 2014). A study on Cyprus's national WF by Zoumides et al. (2014) between 1995 and 2009, in comparison to the

study by Schyns & Hoekstra (2014), found that blue water generated higher value crop production in comparison to green water, on both rain fed and irrigated crop land, indicating the vulnerability of the green EWP to weather. The lowest blue EWP for Cyprus was 0.89Euro/m³, and the highest was 1.15Euro/m³ in direct proportion to the lowest and highest blue water contributions to crop production, indicating a gross value trend (Zoumides et al., 2014). In the study by Aldaya et al. (2010), it was found that certain Asian countries had strategic importance in the production of wheat, cotton and rice due to their high EWP values. These values were 0.1 USD/m³, 0.5 USD/ m³ and 0.2USD/m³ respectively (Aldaya et al., 2010).

Like the EWP, economic land productivity is also considered a more descriptive indicator compared to general water productivity. This indicator is also considered to explain more of current production patterns than the EWP indicator (Chouchane et al., 2015). The ELP measures the economic value of farm output per hectare of harvested land by taking the producer price and multiplying it by crop yield (ton/ha) (Schyns and Hoekstra 2014). Most case studies focus on economic water productivity rather than economic land productivity (Aldaya et al., 2010; Mekonnen & Hoekstra, 2014a; Zoumides et al., 2014) . However, case studies on Morocco, South Africa and the Sundays River Valley citrus have looked at economic land productivity. As with the EWP of Morocco, ELP was found to be the lowest for blue water crops (Schyns & Hoekstra, 2014). In South Africa, grapes have the highest ELP of approximately 13 000 USD/ha, and oats, sorghum, maize, sunflower seeds, wheat and soy beans have the lowest ELPs (Pahlow et al., 2015). A study performed by Munro et al. (2016) on citrus in the Sundays River Valley, South Africa, found that lemon cultivars had the highest ELP of approximately 200 000 ZAR/ha.

However, Wichelns (2014) suggests that water productivity indicators cannot serve as indicators of economic efficiency. Wichelns (2014) states that this is because water productivity values do not apply incremental productivity values, but rather an average. Because of this, maximising water productivity does not necessarily increase yields or net revenue, and in some cases maximising water productivity could result in reducing irrigation and very little crop production (Wichelns, 2014). Thus, the most meaningful measure of water productivity is through marginal value, i.e. the additional value added when water is added (Wichelns, 2014; Cook et al., 2003)

Marginal water productivity is not the only alternative water use indicator. Cook et al. (2003) suggest other indicators such as the sustainable livelihoods concept, which incorporates the complexities of farming systems and ecosystem services. This concept expands on the “water wealth” indicator, which multiplies the ratios of income to water use by water use per person, to a water livelihoods indicator which addresses population density and people’s needs versus water availability (Cook et al., 2003). Munro et al. (2016) used an indicator for employment in terms of farm production as an indicator versus water productivity gains. This method substituted employment for mass in the physical water productivity indicator, resulting in the representation of the average number of workers employed per hectare as well as the number of jobs per water use (Munro et al., 2016).

Another productivity indicator which aids in the economic analysis of the water footprint, particularly in the production of milk, is the milk to feed price ratio. The ratio serves as a proxy measure for dairy farm profitability (Wolf, 2010). This ratio provides an indication of how much feed (kg) a farmer is able to buy with the sale proceeds from 1 kilogram of milk. Thus indicating the ability of a farm’s milk production to cover the costs of feed (IFCN Dairy Network, 2014).

2.3.2 Virtual water and allocative efficiency

As of 2014, 22% of global fresh water consumption and pollution comes from export commodity production (Hoekstra, 2014). In an attempt to reduce this figure virtual water imports have been considered to be an improved mechanism. This mechanism enables water scarce regions to avoid using already scarce water resources domestically, by importing high water consuming products from regions with large water endowments. This plays into allocative efficiency, whereby water is reallocated for its highest marginal benefit purposes (Mekonnen & Hoekstra, 2014a; Schyns & Hoekstra, 2014). Wichelns (2010) suggests that there is nothing inherently good or bad about exporting or importing virtual water, but that it rather reflects underlying trade patterns and their evolution over time, versus their productivity, exchange rates and relative prices (Wichelns, 2010). Zhou et al. (2016a) suggest that the domestic and inter-regional trade of virtual water could potentially worsen rather than relieve a country facing water scarcity if governed by economics rather than regulation and governmental policy (Zhuo et al., 2016a). Thus, for virtual water trade to be beneficial, crops which are exported or imported need to be regulated in order to ensure that these

products have high economic returns with small negative externalities on domestic freshwater resources (Wichelns, 2010; Pahlow et al., 2015).

Schyns & Hoekstra (2014) study illustrate Morocco as an example of a net virtual water importer. Between 1996 and 2005 Morocco had imported 12.4 bn US dollars worth of virtual water, and exported virtual water to the value of 7.1bn US dollars, of which 3.4% of total agricultural water use was used for the production of exports (Schyns & Hoekstra, 2014). Mekonnen & Hoekstra (2014a) found that Kenya exported per unit of virtual water to the value of 0.25USD/m³ for exports such as cut flowers, vegetables, spices and tea (Mekonnen & Hoekstra, 2014a). Pahlow et al. (2015) found South Africa to be a net virtual water importer which consumes large amounts of blue water in both exports and imports, creating a sustainability concern. On average South Africa imports 13 350 million m³ per year and exports 11 991 million m³ per year (Pahlow et al., 2015).

2.3.3 Blue and green water scarcity

High water users such as agriculture need to start enquiring into more sustainable practices. From investigations, these industries can gain benefits of both monetary and physical value (Schyns & Hoekstra, 2014; Munro et al., 2016). This can be achieved through choice of cultivars and irrigation management systems (Pahlow et al., 2015).

Blue water is considered to be more valuable than green water as it can be managed and reallocated to various uses through the utilization of engineering interventions (Zoumides et al., 2014). Blue water scarcity is severe and puts a lot of pressure on ground and surface water resources. Furthermore, the issue of blue water scarcity is reducing the ability of water sources to assimilate pollutants (Schyns & Hoekstra, 2014). Blue water scarcity is measured by the blue water scarcity index (BWSI), the ratio of blue water within a river basin/region to blue water availability in that basin/region, accounting for environmental flow requirements. The blue water scarcity within that basin/region is then classified according to the index provided in the water footprint assessment manual (Hoekstra et al., 2011; Pahlow et al., 2015; Zhuo et al., 2016b). The blue water scarcity index states that a BWSI value of less than 20% indicates low water scarcity, between 20% and 30% indicates moderate water scarcity, between 30% and 40% suggests high water scarcity, and a value greater than 40% indicates severe water scarcity (Hoekstra et al., 2011; Zhuo et al., 2016b).

Conventional water resource management focuses on blue water, however, green water also plays a critical role in the establishment and maintenance of natural ecosystems (Zoumidis et al., 2014). The integration of all water, including green water used in rain fed agriculture, formulate part of the food trade industry and therefore are essential in dealing with food security within arid areas (Schyns & Hoekstra, 2014; Roson & Sartori, 2015). The value of green water can also be established through soil moisture. Soil moisture forms part of the green water footprint, and the incremental value of soil moisture is reasonably high. Even though there is no given market for soil moisture, and the opportunity costs attached to soil moisture may vary between choices available to farmers considering potential gains from trade in rain fed areas, it is still considered to have lower opportunity costs than blue water (Wichelns, 2010).

2.3.4 Water related business risk

Freshwater shortages and pollution pose major risks to business, specifically through a company's operations and supply chains. This risk to business is in the form of potential increased regulation through higher water prices, reduced water ratios, stricter emissions permits and the obligatory use of water saving technology (Hoekstra, 2014). In assessing these risks, business is often forced to choose between reducing their water footprint or their carbon emissions (Hoekstra, 2014). Other risks to business include reputational risks towards the business brand, particularly in an age where media is more aware of company contributions to unsustainable water use (Hoekstra, 2014), as well as the risk and accountability towards investors (Hoekstra et al., 2012). Due to these risks, many multinational corporations such as Unilever, Coca-Cola and Heineken are assessing their water use sustainability and risk mitigating opportunities. This initial form of water sustainability reporting could potentially initiate and result in the development of response formulation and strategy from companies in the next few years (Hoekstra et al., 2012; Hoekstra, 2014).

It is important to note that even business in water rich areas may have large water footprints due to the nature of globalisation, which has resulted in many companies having supply chains reaching across the world. Thus, the sustainability of the water footprint of a business goes beyond mere water stewardship (Hoekstra, 2014). A study by Linneman et al. (2015), on Dutch listed companies, attempted to rank companies based on their water transparency

according to the information each company provided in their annual reports, sustainability reports and company websites. From this initial study, it was found that there is no uniform method with which businesses report on water consumption, with companies tending to report more on their operations rather than supply chains (Linneman et al., 2015).

2.4 Conclusion

This chapter aimed to address three issues regarding the water footprint. The first addressed was which water footprinting methodology should be used to calculate the water footprint of pasture fed dairy, and was answered through a debate within the theoretical framework and through discussion in the WF case studies. The second related to what research had been published on the WF, and particularly the WF of dairy production. The third investigated the economic relevance of the WF in agricultural production.

Agriculture is the biggest water user globally. Therefore it is important that various agronomic measures are applied which use individual best practices in both rain fed and irrigated agricultural systems. The allocation of water cannot be left to the markets due to the risk of free rider behaviour. Thus, water allocation should rather be focussed on integrating scarce resource allocation through government policy and regulation.

There are two predominant methodologies used when calculating the water footprint of a product or production process, being the water footprint assessment and the life cycle assessment. The water footprint assessment and the life cycle assessment differ in methodological scope regarding water use, as well as their methods for the inclusion of water scarcity and the differentiation in quality indicators. In choosing between the two methodologies, one has to acknowledge the trade-off between precision and applicability.

Rain fed agriculture relies on green water alone, thus requires information on both green water scarcity and green water productivity. The case studies in this chapter used the blue water scarcity indicator (BWSI) to indicate the severity of ground water scarcity within a region. Through the inclusion and address of green water within a region, the blue water scarcity index may be improved by supplementing or increasing green water technology in order to reduce production's reliance on ground and surface water. This suggests that the opportunity costs of green water cannot be ignored.

Green water and its opportunity costs also cannot be ignored in the production of milk from cradle-to-gate. This is because green water is the predominant water use contributor to the production of feed, and feed has the largest contribution to the WF of animals and animal products. Thus feed origin, conversion efficiency and composition play an important role in regulating and reducing an animal products' WF. Within dairy production alone, blue water only makes up 1% of the total WF. Thus it does not make sense to exclude green water indicators from the WF of dairy production from cradle-to-farm gate. Therefore, the best method for approaching the WF of pasture fed dairy on dryland pastures is the water footprint assessment.

Following this chapter, chapter three will present the relevant context required to answer the research question and provide research relevance.

CHAPTER 3
BACKGROUND

The purpose of this chapter is to introduce the context in which this research study is performed. The chapter does this by addressing the history of South Africa's freshwater scarcity, the economic importance of agriculture and specifically dairy in SA, as well as providing a narrative on dairy and pasture production practices. These topics are addressed broadly within a South African context, and then narrowed to focus on the Eastern Cape. Once the general context of research has been addressed, chapter three then discusses the specific study area in which the case study takes place.

3.1 Water scarcity in South Africa

South Africa is one of many countries which experiences water scarcity and shortages, with severe water scarcity predicted within the next 50 years (Walter et al., 2011; Jarman et al., 2014). The country is described as a water stressed semi-arid country experiencing an average rainfall of approximately 450mm per year, well below that of the world average of 860mm per annum (Otieno & Ochieng, 2004; DWAF, 2013; Jarman et al., 2014). The country's freshwater statistics illustrate the low amount of fresh water availability per capita (1700m³ per capita) (Otieno & Ochieng, 2004), and of the 19 catchment areas, 12 are facing water deficits (Blignaut & van Heerden, 2009). This lack of fresh water availability due to pre-existing factors, as well as climate change, is being perpetuated by decreasing water supply levels along with increasing demands (Perret, 2002; Mukheibir, 2008; Blignaut & Van Heerden, 2009; Gbetibouo & Ringler, 2009; CSIR, 2010; Walter et al., 2011; DWAF, 2013; Meissner et al., 2013; Jarman et al., 2014). Such demands include those of industry and agriculture in order to meet the demand of population increases and resultant economic development (Jarman et al., 2014).

3.2 South Africa's Water Legislation

Over the years, national interest has been growing in terms of developing market based water allocation strategies (Walter et al., 2011). Regulators have been urged, as a consequence of the mounting water scarcity, to find solutions which may alleviate the pressures placed on South Africa's freshwater resources in addition to ensuring compliance with the National

Water Act (Jarman et al., 2014). The consequences of increased water scarcity include future implications such as negative externalities towards South Africa's socio-economic growth in terms of the National Development Goals, specifically those of food and water security (Mukheibir, 2008; CSIR, 2010; Reddy et al., 2014).

South Africa was one of the many countries which has re-evaluated the way the nation uses its freshwater resources¹, in an attempt to achieve goals of efficient, equitable and sustainable water allocation and use. This was done through the development of a new National Water Policy in 1997, and later, the National Water Act (Act no. 36 of 1998) (Nieuwoudt et al., 2008; Seago, 2016). These laws aim to re-dress the discriminatory laws of the past which have culminated in unequitable distribution of freshwater resources in South Africa (Seago, 2016).

The NWA (1998) is internationally recognised as one of the most promising legal frameworks for the address of water resource management in South Africa (Perret, 2002). The Act is recognised as a legislative framework which has moved away from the previous legislative framework of "command and control" based methods, towards a policy framework which is predominantly market driven (Nieuwoudt et al., 2008). The Act does this by acknowledging and addressing the productive and consumptive water uses required in the various economic sectors in SA such as agriculture, domestic water supply, industry and tourism (DWA, 2013; Seago, 2016). According to the National Water Act No. 36 of 1998, the following mandate falls under the NWA (Republic of South Africa, 1998):

1. Management, allocation and protection of water resources
2. Development, management and control of water use in order to meet water requirements for ecological reserves, international water obligations, management areas transfers, and the use of water for strategic importance.

¹ In order to promote equitable allocation and reallocation of fresh water resources, the four existing policy documents which underpin South Africa's legislation regarding water policy were tabled. These include the White Paper on Water Supply and Sanitation (1994), the White Paper on the National Policy of South Africa (1997), the White Paper on Basic Household Sanitation (2001) and the Strategic Framework for Water Service (2003) (DWA, 2013).

3. The management of water resources for development through allocation and restriction to domestic purposes as well as household gardens and animals. This includes water stored from run-off, water for emergency situations, water used for recreational purposes and water discharge and treatment.

3.2.1 Institutional make-up of water management and policies

The South African national government has a constitutional responsibility to provide regulatory support for local governments in terms of effective water supply and sanitation services performance and duties within South Africa. The following is a summary of the various institutional sectors which govern and regulate water policy in South Africa (DWA, 2013):

- **DWA:** Responsible for water sector policy and legislation
- **Water Boards:** State owned regional water services producers who provide bulk and retail services on behalf of Water Service Authorities
- **Catchment Management Agencies (CMA):** Undertake regional or catchment level water resource management and allocation
- **Water Use Associations (WUA):** Operate at localised levels in order to promote individual cooperation with water associations and water use activities
- **Irrigation boards:** Monitor and regulate irrigation activities locally
- **Water Services Authorities (WSA):** Municipalities with authority towards local municipal water provision
- **Water Services Providers (WSP):** In contract with the WSA for the provision of water services and or waste water treatment

3.3 Agricultural water use in South Africa

South Africa's freshwater resources are dispersed throughout the country, as are its climatic zones (as indicated in figures 3.1 and 3.2). These climatic zones are steppe (arid), desert, sub-tropical wet and sub-tropical winter rain zones (Gbetibouo & Ringler, 2009). As indicated in figure 3.2, the eastern half of South Africa receives the majority of the nation's annual rainfall of up to 1500mm, and the western half experiences the least, as low as 100mm annually (CSIR, 2010; DWAF, 2013).

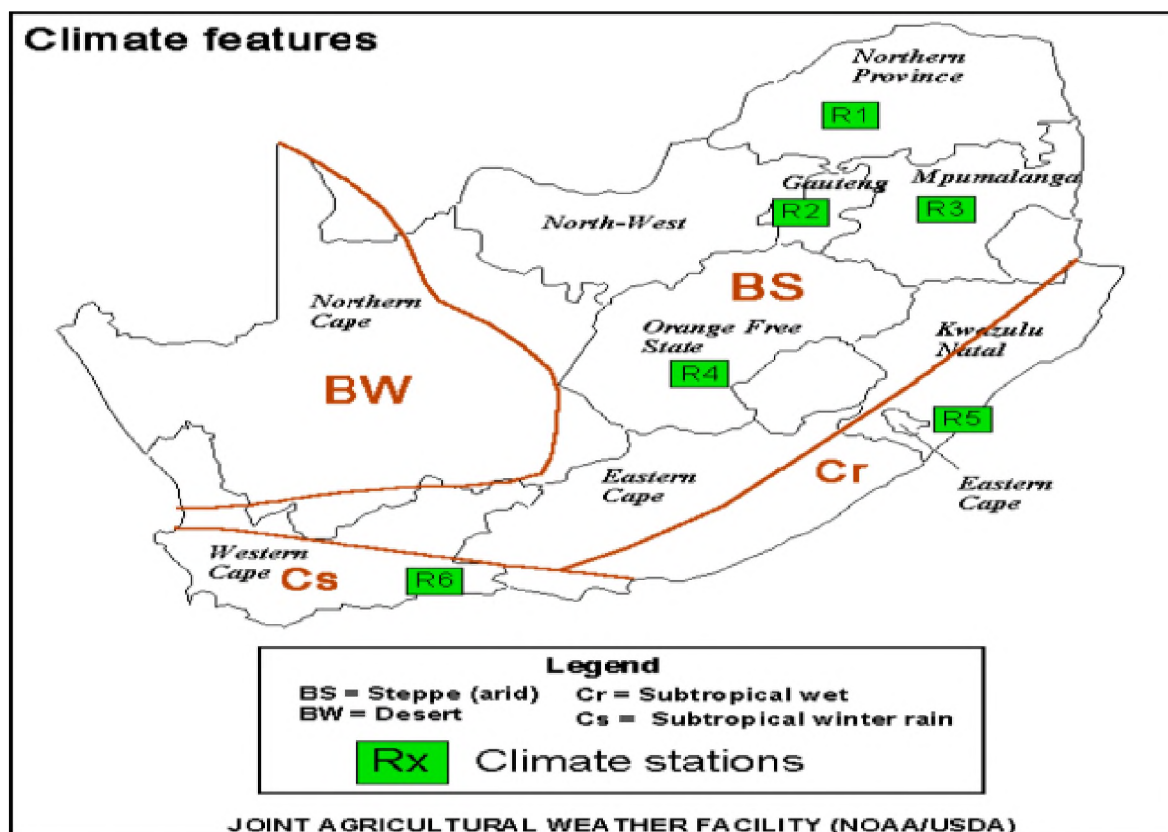


Figure 3.1: Climate features of South Africa

Source: Gbetibouo & Ringler (2009)

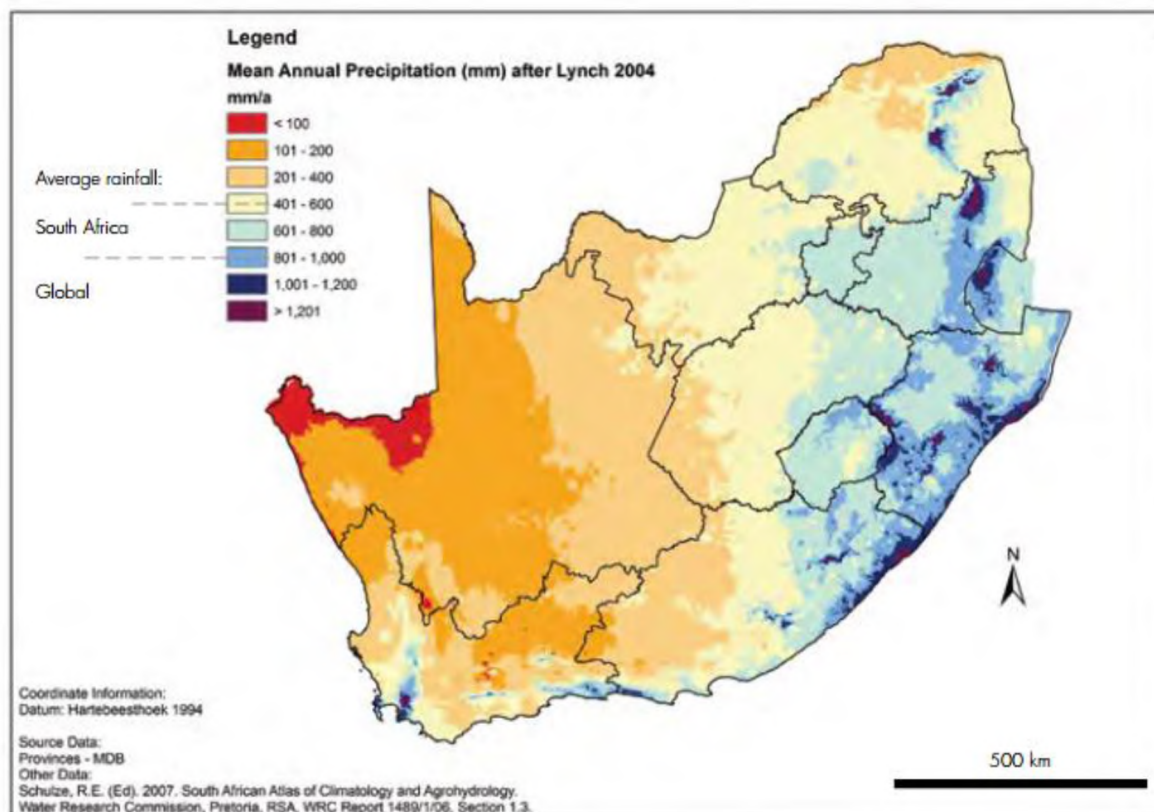


Figure 3.2: South Africa's average annual rainfall
 Source: CSIR (2010)

The total land area of South Africa spans over 122 million hectares, of which 100.66 million hectares are classified as farmland and 83.93 million hectares are utilised for grazing land (DAFF, 2016a). Of this, 1.6 million hectares of land are registered for irrigation within South Africa (Jarmain et al., 2014). The Eastern Cape hosts 14.82 million hectares of farming land (86.8% of the total area of the Eastern Cape), with the majority of this land used for grazing, and 188 901 hectares of land registered as utilising irrigation practices. Values from an agricultural survey in 1993 indicated that of the commercial farming units in the Eastern Cape, 238 farms produced field crops (224 266 hectares) and 4640 farms participated in animal production (9.15 million hectares) (DAFF, 2016a).

Water resource allocations within South Africa's agricultural sector were largely based on riparian rights among farm owners (Pahlow et al., 2015), with agriculture being the largest water consuming economic sector in South Africa, requiring 92% of South Africa's freshwater resources for agricultural product production (Munro et al., 2016). In comparison to other economic sectors within South Africa, irrigated agricultural crops utilise 60%, and livestock

watering and nature conservation consumes 2.5% of the nation's total economic sector freshwater consumption (as indicated in figure 3.3) (DWAF, 2013).

The agricultural sector is an economically important sector within south Africa as it contributes towards growth, exports, employment, food security and livelihoods (Jarmain et al., 2014). STATS SA results, documented in the 2014 agricultural report, indicate that the commercial farming sector brought in R 212 998 million in total income, with animal products

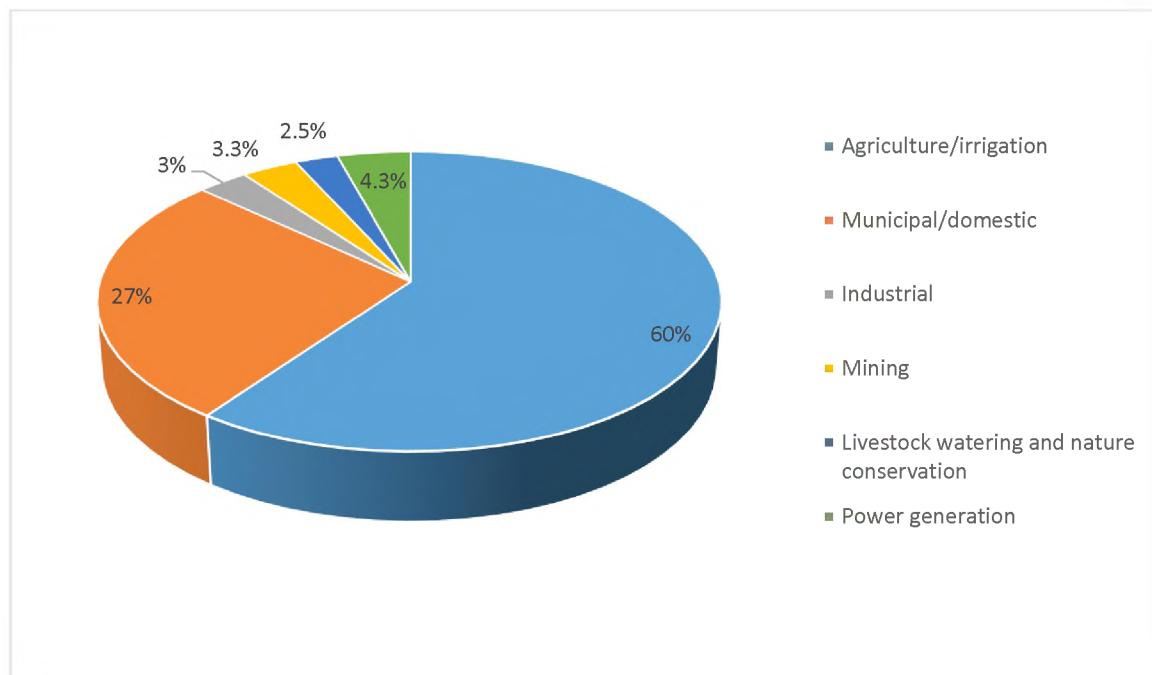


Figure 3.3: Percentage of water use contributing towards the various economic sectors in South Africa

Source: DWAF (2013)

generating the largest sales followed by field crops (Stats SA, 2015). As of 2015, preliminary results indicated that 897 000 skilled and unskilled workers were employed in agriculture, hunting, forestry and fishing, with these sectors contributing to 2.3% of South Africa's gross domestic product (GDP) (DAFF, 2016).

3.4 Dairy overview

3.4.1 Global

There are approximately 264 million cows world wide of which produce 600 million tonnes of milk per annum (Compassion in World Farming, 2012), where cows' milk makes up 83% of total milk produced globally (Coetzee, 2015). Currently, there are an estimated 145 million

dairy farms in the world, with between 0.7 and 1 billion people living on these farms. On average each farm has 2.8 cows, with the largest average number of cows per herd in Saudi Arabia (8125) followed by New Zealand (393), South Africa (357) and Australia (241) (Coetzee, 2015). Furthermore, dairy farms are often family owned and are important in terms of job creation for workers in rural areas (Levin et al., 2012).

Globally, the United States and India produce the largest quantities of milk (Compassion in World Farming, 2012; Dairy Australia, 2013). On average, Africa generates the lowest global contribution to milk production of approximately 5%, and Asia makes the largest contribution of approximately 23% to global milk production (IFCN Dairy Network, 2014). As of 2009, Italy was the largest milk importer, and Germany was the largest milk exporter in the world (Compassion in World Farming, 2012). Through the use of global averages between 2007 and 2011, the WWF reported that the European union consumed 27% of the world's dairy, India consumed 22% and the USA consumed 17% (Levin et al., 2012).

According to the WWF, one of the most critical environmental impacts dairy production imposes on the environment is its production of greenhouse gasses which contribute to 4% of anthropogenic GHGs emissions (Levin et al., 2012; Weindl et al., 2015). The second largest environmental issue concerning dairy production is the large water footprint the industry incurs, particularly for fodder crops production, contributing to water scarcity and competition with other users for freshwater resources (Levin et al., 2012).

The environmental and social risks of dairy production include (Levin et al., 2012):

1. **Land conversion**- conversion of forests can contribute to climate change, loss of ecosystem services, acute habitat degradation, and biodiversity loss
2. **Nutrient loading in runoff**- increased nutrient levels in water ways can lead to the growth of excess algae which consumes oxygen needed for other animal and plant life
3. **Riparian areas**- without specifically allocated cattle areas, environmental degradation may occur through cattle wading directly into streams and causing soil erosion
4. **Cattle feed**- indirect impacts such as land conversion, agrochemical requirements, and fossil fuel inputs

5. ***Loss of pasture biodiversity***- overuse of fertilizer and mono-cropping practices can lead to a loss in biodiversity of native plant species and feed sources for insects and birds
6. ***Air quality***- ammonia emissions can cause nitrogen enrichment downstream with consequences on species biodiversity and habitat
7. ***Greenhouse gas emissions***
8. ***Disease***- cattle disease impacts the export market
9. ***Animal health and welfare***- improper handling can result in decreased productive efficiency
10. ***Water use***- on average an estimated 1000 litres is required to produce 1 litre of milk
11. ***Food safety***- food system safety mechanisms can fail

3.4.2 Market

Between 2005 and 2007, the world market price for milk increased by approximately 75% to 45USD per ton (IFCN Dairy Network, 2014). In 2009 alone, the dairy industry generated 299.7 billion US dollars in global revenue (Levin et al., 2012). Originally price trends were seen to be set by population growth, increasing dairy product demand, but today trends are indicating that the increase in per capita income in developing countries is driving the dairy sector market (Knips, 2005; IFCN Dairy Network, 2014; Coetzee, 2015).

Domestic dairy consumption is often very high due to the limited ability to trade dairy commodities internationally. Thus, dairy is predominantly a local commodity which often undergoes government regulation and is sometimes subsidised (Levin et al., 2012). In developing countries, the majority of milk produced is produced by smallholders and serves the purpose of subsistence, food security, supporting livelihoods and nutrition (Dairy Australia, 2013).

3.5 South Africa's dairy industry

3.5.1 Importance of the dairy sector in South Africa

Although Hoekstra (2012) suggests that the best way to reduce the water footprint of milk and dairy products is through the decrease in product consumption, this is not the most economically viable option for developing countries, and South Africa specifically (Meissner et al., 2013). The South African dairy industry is the fifth largest agricultural industry in the

country, contributing 6% of the gross product of the agricultural industry, producing milk every day, and providing 60 000 direct and 40 000 indirect jobs for skilled and unskilled workers (Milk SA, 2013; DAFF, 2014; Coetzee, 2015; Esterhuizen et al., 2015). Of the 2.3% contributed by agriculture to South Africa's GDP, fresh milk production contributed approximately R15 billion towards the gross value of agriculture in 2015 (DAFF, 2016a). As of 2014, average milk production per cow in South Africa was 20.2 litres per day, and a total of 95% of milk produced was sold on the formal market, culminating in 28 billion litres of milk produced in 2014 alone (Coetzee, 2015). Between 2003 and 2013, an upward trend has existed in terms of gross value and total dairy production in South Africa, reaching R11.6 billion in 2012/2013, displaying an exponential increase of 124% since 2003 (DAFF, 2014; Coetzee, 2015). By limiting the consumption of livestock foods in order to reduce environmental impacts within SA, the above socio-economic benefits of the dairy industry would be reduced. This reduction would not only affect the dairy production industry, but secondary industries along the dairy value chain, through loss of jobs on farm and within the effected secondary industries (Meissner et al., 2013).

3.5.2 Dairy market

South Africa's dairy farming industry focuses on long-term milk production through the rearing of cows, with the production of milk either being processed on site or transported to a processing site (DAFF, 2016b). The SA dairy market is split into 60% liquid and 40% concentrated products, of which UHT and liquid milk contribute towards the majority of liquid dairy products produced, and pasteurised milk accounts for 51% of all dairy products (DAFF, 2014). Differences within the South African dairy industry exist in terms of farming techniques and the different methods used to process dairy products (DAFF, 2014). Typically, SA dairy farms produce their own feed on site, which is fed directly to dairy cattle or stored in silage for later use, with additional bought in concentrate supplements added to supplement the feed of dairy cows on farm (DAFF, 2016b). Average production costs for dairy in SA are slightly above 35USD per 100kg of milk produced, on par with the production costs of New Zealand, and lower than the global average of 46USD per 100kg in 2015 (Coetzee, 2015).

Although showing positive trends, South Africa's dairy industry faces many challenges such as trade liberalization externalities, uncertain product prices, unpredictable interest rates, governmental regulation, disease outbreaks, susceptibility to climate change and the

pressures of labour costs through the minimum wage and the constraining effect labour unions have on farms (Meissner et al., 2013; Milk SA, 2013; DAFF, 2014). Such challenges make it important for the industry to maintain competitiveness, implement mitigating measures against climate change, and develop the skills of workers in order to maintain labour market competitiveness, as well as implement good food management practices (Meissner et al., 2013; FAO, 2016). Other challenges within the South African dairy industry include its barriers to entry. High start-up costs and low profitability of milk production serves as a major entry barrier to many small emerging farmers, with access to financing and credit facilities, lack of capital and infrastructure, and the fact that farmers are price takers also playing a significant role in the formulation of these market entry barriers (DAFF, 2014).

3.5.3 Distribution of dairy production

Milk producing areas in South Africa are split into 6 regions: KwaZulu-Natal (KZN), Southern Cape, Western Cape, Central Highveld and Free State, Central Eastern Cape, and Southern Eastern Cape (Gertenbach, 2007). Over the years, the number of milk producers has decreased in South Africa from 3899 producers in January 2007 to 1834 in January 2015, with the trends of higher production in pasture based systems continuing (Coetzee, 2015).

Since 1997 milk production has moved away from central provinces to coastal provinces with milk production in the Western Cape producing 24.5% and the Eastern Cape producing 20.5% of the national total in 2004 (Gertenbach, 2007; Van der Colf et al., 2015). As of 2014, the Eastern Cape produced the most milk in South Africa, contributing 27% to SA's total dairy production, followed by the Western Cape which contributed 26% (DAFF, 2014). This shift is due to South Africa's coastal areas being more conducive to dairy production, which is attributable to their milder temperature and higher rainfall, resulting in better quality pasture. Furthermore, inland dairy production is less climatically favourable than coastal regions and often requires irrigation intensive farming practices and high cost feed production systems (DAFF, 2014; Van der Colf et al., 2015).

3.5.4 Dairy breeds

The most popular dairy cow breeds in SA include the Holstein (Friesland), Jersey and Ayrshire, with other breeds also being used for dairy production such as the Milk shorthorn, Guernsey,

Dexter, S.A. dairy Swiss, and the Simmentaler (Milk SA, 2013; DAFF, 2016b). This thesis will focus on the Friesland and the Jersey dairy cows.

Friesland cows: Holstein-Friesians (Friesland) are the most popular dairy cow, both in SA and worldwide, due to their ability to produce large quantities of milk as well as their dual purpose of being culled and marketed as a beef product. The milk produced by this cow is low in butterfat content and the breed is not necessarily as heat resistant as some other dairy cattle breeds (Milk SA, 2013).

Jersey cows: The Jersey cow is a very popular dairy cattle breed in South Africa and is primarily known for its "good udders and calving ease" (Milk SA 2013: 26). The milk produced by these cows has a high butterfat and protein content, and the cows themselves are well adapted to warmer climates (Milk SA, 2013).

3.6 Pastures

The production of fodder in South Africa is very important for dairy production systems, and utilises a range of options regarding imported grasses and legumes, specifically during times of drought (Palmer & Ainslie, 2006). South Africa's dairy production industry is comprised of both irrigated and dryland pastures, with the most commonly planted pastures being kikuyu, ryegrass and legumes (Milk SA, 2013). Pasture is important for both feed and stimulus for dairy cows through movement during grazing, however, there are nutritional limitations involved in using pastures. Thus, it is important that pasture feeding is supplemented with concentrates in order to achieve optimal nutritional balance within a dairy herd (Milk SA, 2013).

Constraints to the production of fodder and pasture in South Africa include low and uncertain rainfall, availability and price of seed, costs of clearing natural vegetation, salinization of irrigable soils, and declining water quality (Palmer and Ainslie 2006). Soil health and fertility are also very important factors to consider in order to ensure optimal pasture growth, with manure often applied as a form of fertilizer. Well managed pasture production of forage can result in cost savings, as well as excess forage for storage in times of pasture harvesting losses (Van Vuuren, 2012; Milk SA, 2013; Meissner et al., 2013).

South Africa's variable climate, general water scarcity and often marginal soils means that the majority of dairy farms require irrigation to supplement the growth of feed (Van Vuuren,

2012). The coastal Eastern Cape largely supports pasture based fodder systems (Van der Colf et al., 2015), producing mostly ryegrass and kikuyu pasture for both dryland and irrigated pasture (Van Vuuren, 2012).

Kikuyu is a common pasture grass grown on Eastern Cape pastures. This pasture grass originated in Kenya and was introduced to South Africa in the early 1900s (Meissner, 2014). Today, kikuyu is a predominantly dryland, summer and autumn grass, and is used for its hardiness and ability to adapt to and tolerate a variety of farm management practices (Henning et al., 1995). This form of pasture plays an important role in the larger dairy producing areas, particularly along the East Coast of South Africa, and is often planted with a combination of other crops (Henning et al., 1995; Palmer & Ainslie, 2006; Van Vuuren, 2012; Milk SA, 2013). Kikuyu requires a lot of water, responds well to irrigation, and provides benefit in the form of soil stabilisation against slopes (Milk SA, 2013; Meissner, 2014). This type of pasture is primarily used for its high productivity in milk production and stocking rates per hectare, however the grass itself does not promote high milk yield due to low nutritional value (Meissner, 2014; Van der Colf et al., 2015).

3.7 Study Area

3.7.1 Fish-Tsitsikamma WMA 15 (Now the Mzimvubu-Tsitsikamma WMA 7)

The Eastern Cape faces many freshwater challenges which include the decrease in water resource quality, eutrophication, habitat changes, loss of biodiversity, non-compliance of sewerage works, the pollution of ground and surface water, and resource exploitation (CSIR, 2004).

The Fish-Tsitsikamma WMA covers 97 023km². This area falls within the borders of the Eastern Cape, and consists of three major drainage basins and smaller rivers with the major drainage basins including the Great Fish, Sundays, and the Groot/Gamtoos. These drainage regions are divided into secondary, tertiary and quaternary catchments which are numbered alpha-numerically in downstream order. The WMA receives an average of between 150mm and 1100mm of rainfall per annum, with higher rainfall occurring along the coastline. The small rivers within the coastal catchments serve as high ecological importance and illustrate high sensitivity and resultant ecological flow requirements. As of 1995, the Fish-Tsitsikamma WMA was home to 1.6 million people, with 64% of the population living in the Algoa Coastal area.

Ignoring the water requirements for ecological reserves, the WMA requires approximately 1 158 million m³/annum of water, with main water uses belonging within the agricultural sector of 911 million m³/annum (DWAF, 2004).

Various infrastructure projects have been initiated over the years within the WMA in order to both improve water service efficiency and delivery. These projects have accumulated costs of R2 568 million at year 2000 prices, and were able to produce an additional yield of 476 million m³/annum (DWAF, 2004). However, although there has been focus on the improvement of water quality and supply, many issues need to be addressed. Table 3.1 and figure 3.4 combined, indicate the water quality status within the Fish-Tsitsikamma WMA. According to the table, agricultural irrigation does not meet the DWAF water quality standards, particularly in terms of the parameters; total dissolved solids (TDS), salt (Na) and pH (CSIR, 2004). Figure 3.4 expresses the water quality standards of the WMA graphically and indicates that there are many areas which are characterised by unacceptable levels of chlorine, electrical conductivity, phosphates and pH levels (DWS, 2011). Based on these water quality values there is a clear indication that improvements need to be made regarding the use and delivery of water services.

Table 3.1: Percentage of samples falling outside of the DWAF water quality standards in the Fish-Tsitsikamma WMA (2004)

Parameter	Fish-Tsitsikamma WMA		
	Drinking water Class 1**	Industry Category 3*	Agricultural Irrigation
pH	0	1,7	37,6
EC	52,8	52,8	74
TDS	52,5	52,5	70,4
Ca	2,1		
Mg	7,2		
Na	19,7		56,6
K	1		
Cl	18,6	35,6	35,6
SO ₄	4,1	8,8	
F	6,6		0,5
NO _x as N	0		0
NH ₄ as N	0,3		0,1

Source: CSIR (2004)

*Industry category 3= cooling water, process water, product water and utility water

**Drinking water class 1= domestic water supplies

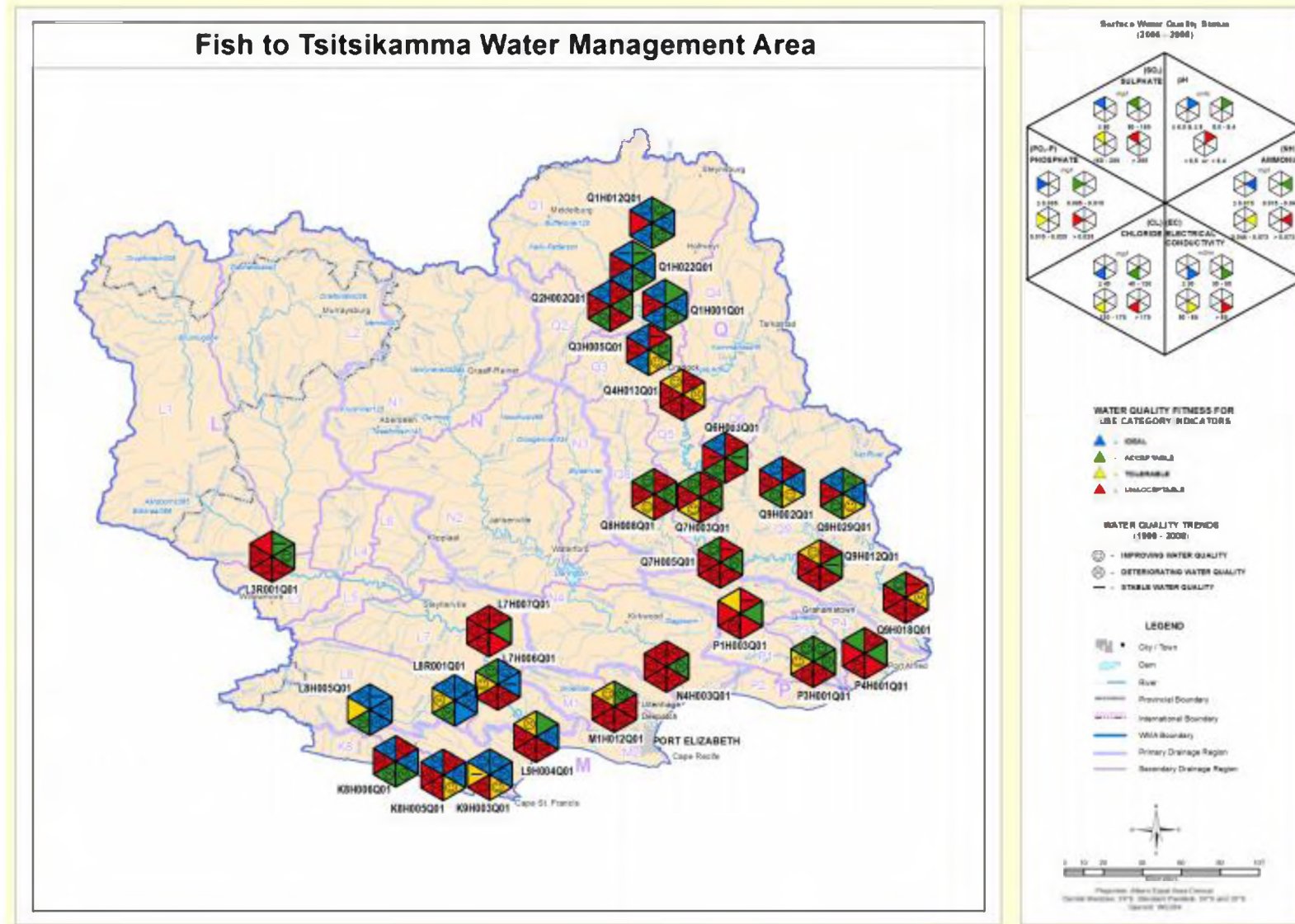


Figure 3.4: Water quality evaluation of the Fish-Tsitsikamma water management area
 Source: Department of Waste and Sanitation (DWS) (2011)

Agriculture in the WMA is largely characterised by large farms averaging 1 551 ha, with the WMA hosting citrus, wool, mohair, vegetables, pineapples and livestock to name a few of the agriculture activities within the area. Of total land use, livestock grazing is the dominant agricultural land use, approximately 90% of the WMA's total surface area. Between both irrigated and dryland farming practices, irrigated land occupies roughly 1% of the WMA and dryland farming practices cover an area of 2273km² (DWAF, 2002).

3.7.2 Glen Dye dairy farm

3.7.2.1 Geographical area

Glen Dye dairy farm is a dryland farm situated in the Algoa Basin Sub-province (see figure 3.5), within quaternary catchment P20A. The quaternary catchment covers an area of 422km², is part of the Albany coast ISP area, and is under the jurisdiction of the Ndlambe Municipality. This catchment is characterised by a high rainfall along with favourable groundwater recharge. The ground water recharge is characterised by the high ground water potential of both the fractured Witteberg Aquifers' and the primary Algoa Aquifer' along the coastal belt, which supply the Albany coast ground water (groundwater region No. 64). This groundwater is made available to the farm and the rest of the P20A quaternary catchment (DWAF, 2002, 2005).

3.7.2.2 Farm history and characteristics

The farm is owned by Simon Matthews, and has been in the family for the last thirty years since its establishment as a permanent kikuyu based dryland pasture dairy farm by his father in 1981. The farm started producing milk for Woodlands dairy in 2009 and has participated in one of the first pioneering carbon footprint assessments (2013-2015) (see Appendix A) undertaken by Woodlands dairy.

The total area of the farm covers 270ha of which 210ha are used for the growing of kikuyu pasture. As the farm is a dryland farm, its predominant water source is rain water (see table 3.2 for monthly and annual rainfall measurements), however, the farm also uses four boreholes which supply ground water for drinking and servicing water activities on farm, with no access to municipal water. The pastures are fertilized five times a year (on average) with a 46% nitrogen fertilizer, and are further fertilized by recycled slurry, collected in a slurry dam after dairy parlour cleanings, once every two months.

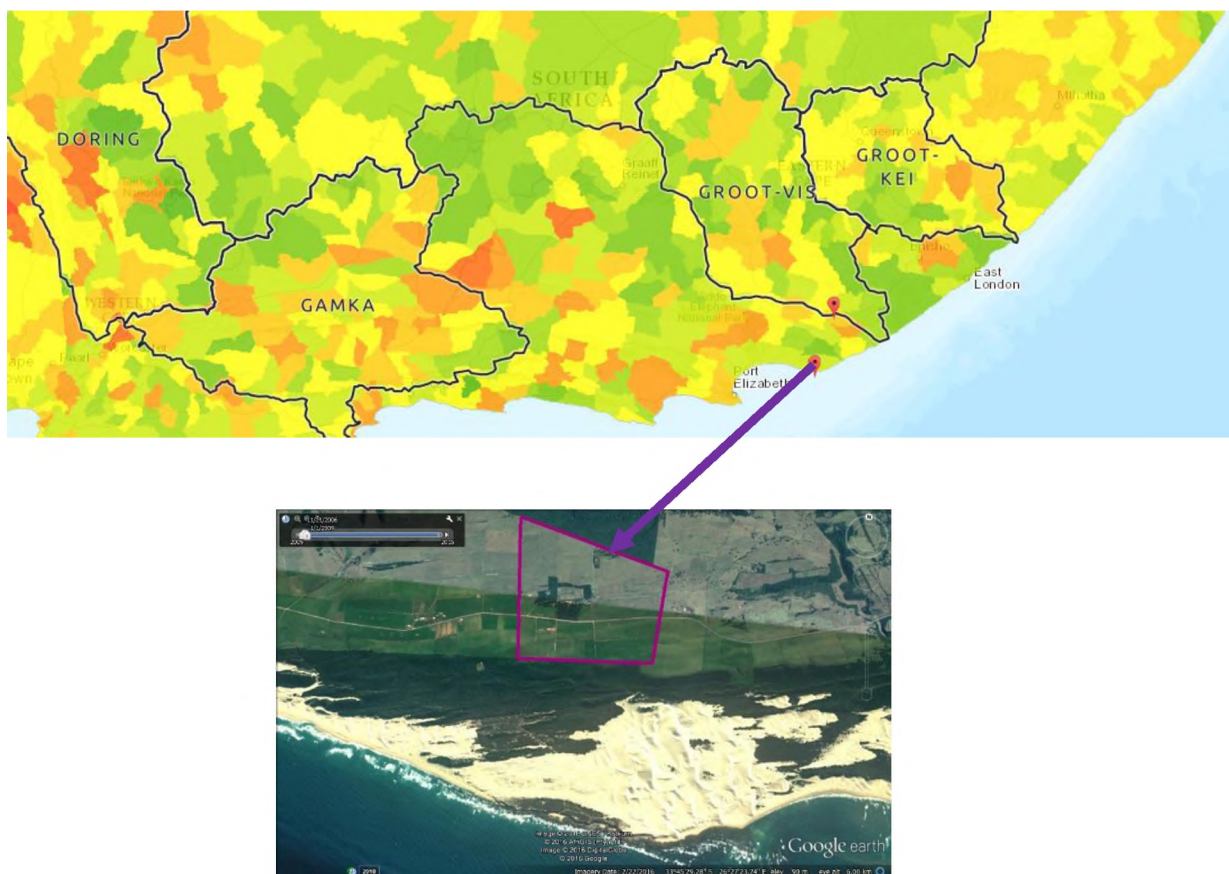


Figure 3.5: The study area of Glen Dye dairy farm

Source: Google Earth (2016); WWF (2016)

Table 3.2: Monthly and annual rainfall (mm) for Glen Dye dairy farm (2011-2015)

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual Rainfall
2011	26	53.5	94	58.5	120	317	187.5	92.5	29	29	127	60.5	1 194,5
2012	26	174.5	59.5	49	16	124.5	105	97	46	390	21.5	24	1 133
2013	30	26	82	73	48	13.5	46.5	47	30	105.5	60	70	631,5
2014	19.5	136	71	124	44.5	29	32.5	52	98	13	83	79	781,5
2015	41	69.5	34	192	11.5	76	213	64	61	56	98	24	940

The farm consists of both Jersey and Friesland cows and utilises a 60 point rotary milking parlour system, which is able to milk over 600 dairy cows an hour (table 3.3 indicates the annual milk production produced on farm from 2011 to 2015). In addition, the farm employs 13 full time and 2 seasonal workers annually, and provides indirect jobs through the use of contactors for certain pasture management practices.

Table 3.3: Annual milk production (kg) for Glen Dye dairy farm (2011-2015)

	Milk production (kg)
2011	5 121 004
2012	5 034 316
2013	4 493 567
2014	4 672 050
2015	4 959 395

The farm's herd management revolves around two calving seasons, where a third of the herd calves in March/April and the other two thirds calve down in July through to September, in order to allow for cows to reach their peak stage of lactation during the peak growth periods of pasture (April to September). Pasture management is contracted out in order to reduce capital expenditures through the contracting of balers and tractors when required.

CHAPTER 4
RESEARCH METHOD

In succession to chapters two and three, where chapter two introduced the theoretical frameworks of the water footprint and chapter three provided the research study context, chapter four aims to address and elaborate on the methods used to calculate the water footprint of dryland pasture based dairy enterprises according to the water footprint assessment (WFA) methodology. This chapter breaks down the method by investigating the dairy process chain, the four phases of the WFA, and lastly the data sources required to answer the research question.

4.1 Dairy water-consuming production processes

The dairy value chain (figure 4.1) consists of many water consuming processes (Levin et al., 2012), with on farm milk production consuming the most freshwater within the value chain (Milk SA, 2013). Most large dairy farms in themselves cannot produce enough milk to supply a processing plant, and so, many dairy farms tend to supply a small share of the total milk required by a processing plant, along cooperative lines (Knips, 2005). On-farm milk production requires various applications of freshwater use and consumption within the water categories established by the water footprint. These water-consuming processes include the direct and indirect water footprint components of feed, drinking water and servicing water (Mekonnen & Hoekstra, 2010). As discussed in the literature review chapter, within the process steps of on-farm dairy production, green water is applied to the production of feed (which utilises rain water), and blue water is incorporated throughout on-farm milk production. These water consuming processes culminate in a milk product at farm gate level with an incorporated water footprint (Mekonnen & Hoekstra, 2010; Levin et al., 2012; De Boer et al., 2013).

Figure 4.2 illustrates the generalised process chain for milk production of a dryland pasture based dairy enterprise from crop-to-farm gate. The water consuming processes required for milk production within the enterprise include pasture production, servicing water, drinking water and the virtual water content of bought in feed and concentrates. These processes fall within two categories; animal husbandry and milk production.

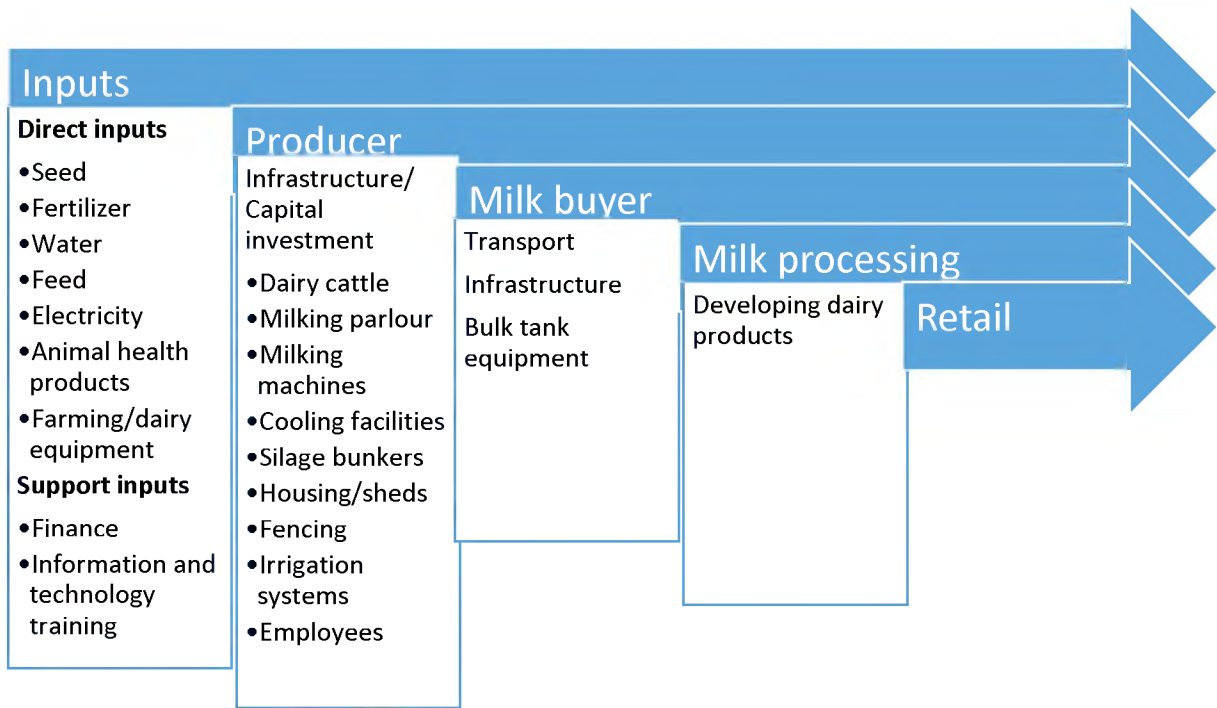


Figure 4.1: The dairy value chain
Adapted from: Milk SA (2013); Levin et al. (2012)

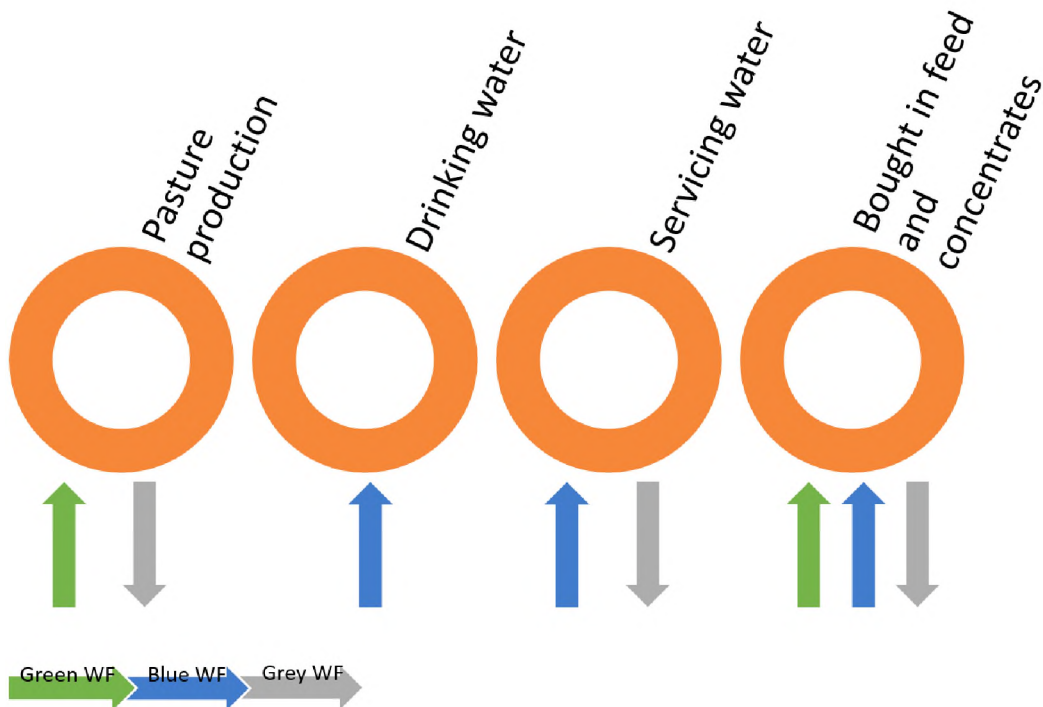


Figure 4.2: The water consuming processes of dryland pasture based dairy production from crop-to-farm gate
Adapted from: Milk SA (2013); Own extrapolation

4.2 Water footprint assessment

As mentioned in the literature review chapter, there are four phases according to the water footprint assessment (WFA). These are defining the goals and scope, water footprint accounting, sustainability assessment and response formulation phases (Hoekstra et al., 2011). The following section breaks down the study method according to the four phases, along with their methods as adapted from the Water Footprint Network's water footprint assessment manual.

4.2.1 Phase 1- Goals and Scope

The purpose of the goals and scope phase of the water footprint assessment is to define the aims and context of the research, as well as the research objectives. This is completed through the selection of a target product, process, business, consumer etc. along with the final objectives of the study, and the period in which the study will take place along a certain scale.

For the purposes of this study the goal and scope were defined as follows:

The ultimate target for this study on the water footprint of dryland pasture based dairy enterprises in the Eastern Cape, was to perform an economic analysis identifying the strengths and weaknesses, opportunity costs and economic relevance within a dryland pasture based system, information of which disseminated to the relevant farmers. These were achieved through the calculation of the direct and indirect volumetric water footprint of pasture based dairy enterprise, using the product chain summation approach, focussed on the enterprise as a whole, with primary focus on the sustainability assessment and response formulation phases of the WFA. Through the use of the WFA, this study aimed to assess dryland dairy production's water risk, with this particular thesis using one dryland farm as a case study. This will enable farmers to minimise their total water footprint whilst maximising economic efficiency and reducing risk.

The study does this by addressing both the monthly trending and average blue and green water footprints, of the farming system over five years, from feed crop production to farm gate. Farm volumetric water footprints were determined through water footprint calculations for pasture production, drinking water, virtual water content of bought in feed and concentrates, and servicing water. Further, for the purposes of this paper the grey water footprint was acknowledged in brief.

4.2.2 Phase 2- Water footprint accounting

A general water footprint of a product is represented by the following equation:

$$\frac{\text{Volume Water per unit of product [per unit of time]}}{\text{Quantity of product}} \dots\dots\dots[1]$$

The results of this water footprint can either be expressed in litres/kilogram or in m³/ton. There are two approaches to calculating the WF of a product or service using the WFA developed by Hoekstra et al. (2011). These are the chain summation approach or stepwise accumulation approach. The chain summation approach is an approach used when a single output is produced. The WF of a single output product is associated with the various process steps in producing that output. The general equation used to express this approach is as follows:

$$WF_{prod}[p] = \frac{\sum_{s=1}^k WF_{proc}[s]}{P[p]} \dots\dots\dots[2]$$

The chain summation approach of a product breaks down the production process into several steps, dictating that the WF of product p (WF_{prod}[p]) is equal to the sum of the water footprint process steps s (WF_{proc}[s]), and the production quantity of product p (P[p]). This approach is illustrated in figure 4.3.

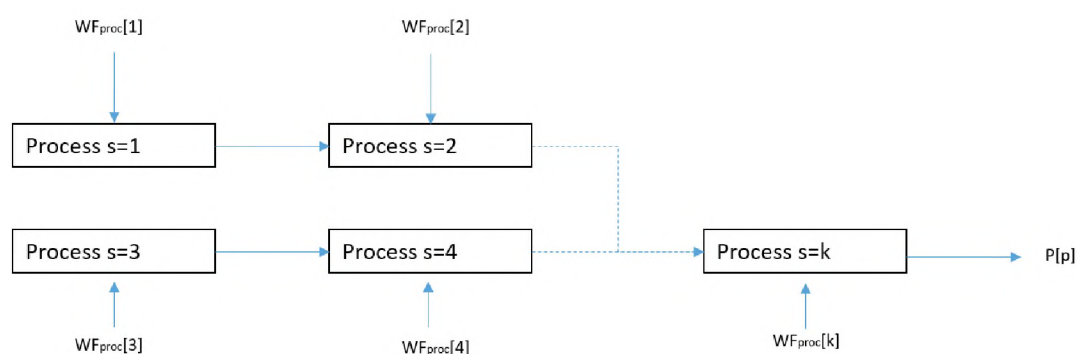


Figure 4.3: A schematic illustration of the chain summation approach to calculate the WF of a product

For the purposes of calculating the WF of pasture based dairy production systems from crop-to-farm gate, founded on the processes in figure 4.2, it was determined that the most appropriate approach for the calculation of pasture based dairy enterprises is the chain summation approach (Scheepers, 2015).

The volumetric water footprint of pasture based dairy production from cradle-to-farm gate, according to Mekonnen & Hoekstra (2010b), is calculated through the chain summation of the various process steps (feed production, drinking water and servicing water), which contribute to the production of raw milk. The volumetric WF of pasture based dairy is therefore expressed as follows:

$$WF[a, s] = WF_{feed}[a, s] + WF_{drink}[a, s] + WF_{serv}[a, s] \quad \dots\dots\dots[3]$$

Where the $WF_{feed}[a, s]$, $WF_{drink}[a, s]$, and the $WF_{serv}[a, s]$ are the individual volumetric water footprint calculations for feed, drinking water and servicing water of an animal in category a, within a production system s (Mekonnen & Hoekstra, 2010b).

However, due to the nature of the goals and scope of this research, this study adapted the method as suggested by Mekonnen & Hoekstra (2010b), in order for the water footprint to avoid double counting, particularly in feed variable calculations. Thus the calculation used for the water footprint of pasture based dairy enterprises is adjusted as follows:

$$WF = WF_{Pasture} + \sum WF_{drink}[a] + WF_{serv} + WF_{bought\ in} \quad \dots\dots\dots[4]$$

Where the total water footprint of a pasture based dairy enterprise equates to the summation of the water footprints of pasture growth ($WF_{pasture}$), the sum of the drinking water footprints (WF_{drink}) for cow type(s) a, servicing water (WF_{serv}) and the water footprint of bought in feed and concentrates ($WF_{bought\ in}$).

Each process step's volumetric water footprint was calculated through the summation of the three quantitative WF categories being blue, green and grey water. In general terms the WF of each process step is calculated as follows:

$$WF_{proc} = WF_{proc,green} + WF_{proc,blue} + WF_{proc,grey} \dots\dots\dots[5]$$

4.2.2.1 Water footprint of pasture

Feed production plays a significant role in the overall water footprint of raw milk products (Hoekstra, 2012; De Boer et al., 2013; Scheepers, 2015). In order to calculate the pasture component required for the volumetric water footprint of dryland pasture based dairy enterprises (equation 4), the green and grey water footprint methods were broken down in the following sections.

4.2.2.1.1 Green water footprint

Dryland pasture production simply utilises green water, as no irrigation is applied to dryland pastures. Thus, the blue water footprint of pasture production was ignored in the calculation of the WF of dryland pasture based dairy enterprises. The green WF of crop production equates the ratio of crop water use (CWU) to crop yield (Y)(ton/ha), as schematized in figure 4.4.

The parameters of the calculations illustrated in figure 4.4 are explained below:

- ET_c = Crop evapotranspiration under standard conditions = $k_c \cdot ET_0$
- ET_a = Total water evapotranspiration
- ET_0 = Reference evapotranspiration from a hypothetical crop which is not short of water
- K_s = Soil water stress (1= optimal <1= stressed)
- K_c = Crop coefficient = ET_c/ET_0
- P_{eff} = Total effective rainfall
- ET_{green} = The minimum of the total crop ET and rain-fall
- CWU = Crop water use over a crops total growth period

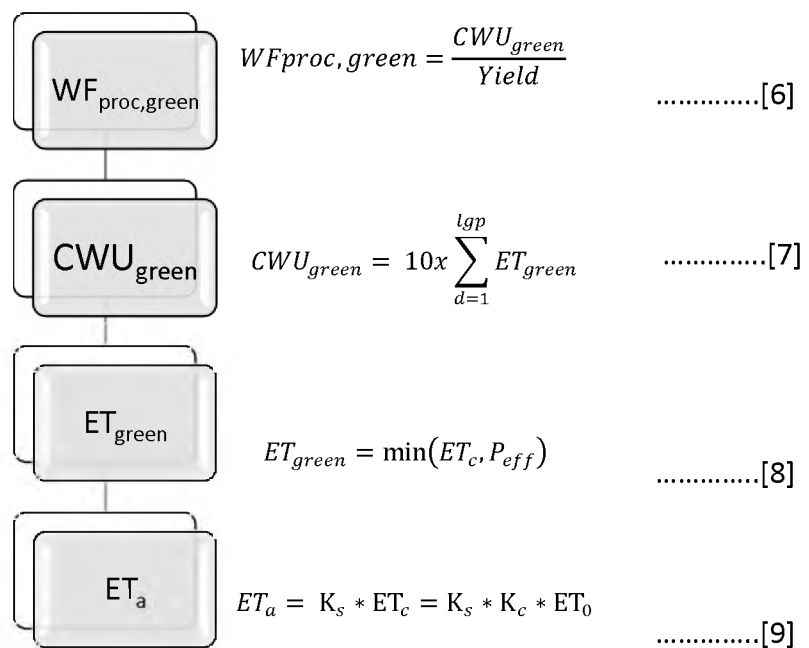


Figure 4.4: A schematised illustrations of the calculations required to calculate the water footprint of dryland pasture
Adapted from: Hoekstra et al. (2011)

The above equations illustrated in figure 4.4 are calculated according to equations for crop water use (CWU) (m^3/ha), which calculate the accumulation of daily evapotranspiration (ET) (mm/day) over the complete growing period of the crop. Where lgp is the length of a crop's growing period from the day of planting, and the factor 10 in the CWU equation 7 converts water depths in millimetres to water volumes per land surface area in m^3/ha .

A key calculation for the computation of crop water use is the evapotranspiration (ET) of green water (ET_{green}) (equation 8). This value represents the total rainwater evaporated from a field during a crop's growing period, and is calculated as the minimum of crop evapotranspiration under standard conditions (ET_c) and effective rainfall (P_{eff}), as a crop cannot consume more water than the maximum amount of water it requires. Any excess water is absorbed into the crop's surrounding soils, or contributes to surface run-off (Brouwer and Heibloem, 1986). These ET measures were estimated using the SAPWAT model for South African specific data (Van Heerden et al., 2009). The SAPWAT 3 program (version 1.0) was used to determine the values required to calculate the water footprint of pasture crop production. The program was developed following the original SAPWAT model. The benefits of using this model include its applicability to South Africa, consistency with FAO model

guidelines, utilisation of the four stage crop development curve, and the program's ability to be applied to individual farms. The SAPWAT 3 program is able to calculate variables which contribute to the WF. Such variables include the evapotranspiration values which contribute to crop production, crop coefficients (K_c), and irrigation variable estimates. The data required for this calculation includes; maximum temperature, minimum temperature, wind speed, radiation and rainfall for the years 2011-2015. This data was provided by the ARC-ISCW and from on farm data collection.

4.2.2.1.2 Grey water footprint

The grey water footprint refers to the water required to dilute degraded returned water back to ambient water quality standards (Berger & Finkbeiner, 2010; Hoekstra et al., 2011; Jefferies et al., 2012). The grey water footprint for crop production objectives focussed on the most critical pollutants such as nitrogen and phosphates. As the dryland farm under analysis did not apply phosphates to pastures (see 3.7.2.2), the following grey water footprint method focussed on the grey water footprint of nitrogen fertilizer and slurry applications.

Nitrogen fertilization

In order to calculate the grey water footprint of nitrogen pasture fertilization, this thesis utilised the diffuse source water pollution calculation, as seen below in equation 10, as prescribed by Franke et al. (2013) in the tier 1 grey water footprint calculations manual.

$$WF_{\text{grey}} = \frac{\alpha * Appl}{C_{\text{max}} - C_{\text{nat}}} \dots\dots\dots[10]$$

Referencing the tier 1 grey water footprint calculation, α indicates the leaching fraction, affected by both environmental factors and farm practices, as calculated using the qualitative method prescribed in the tier 1 report (see Appendix B) (Franke et al., 2013). Appl represents the total fertilizer application, calculated as the product of application rate (AR) and total pasture area (A), and C_{max} and C_{nat} indicate the maximum concentrations and natural concentrations of a receiving body of water for a given time period. The quality standards used to calculate the C_{max} and C_{nat} were taken from those found in DWAF (1996) for nitrogen (see table 4.1).

Table 4.1: C_{nat} and C_{max} values for nitrogen

	C_{nat} (mg/L)	C_{max} (mg/L)
Nitrogen	0.5	5

Source: DWAF (1996)

Slurry

The grey water footprint of dryland pastures is not only affected by nitrogen fertilizer application, but by the application of slurry over the pastures, as an alternative form of pasture fertilization. The slurry used to fertilise pastures is created through the collection of used water for the cleaning of the on-farm milking parlour, and collected in a slurry pit (see 4.2.2.5 for more information). This study will not calculate the grey water footprint of slurry on-farm, but rather utilise the information provided by Woodlands Dairy's slurry quality report (see Appendix C), as part of the sustainability assessment phase of the WFA (see 5.1.1.2.2).

4.2.2.2 Water footprint of bought in feed

Glen Dye dairy farm buys in approximately 200 tonnes of Lucerne feed per annum in order to supplement the dry matter consumed by the dairy cows per year. Calculations for the water footprint of bought in Lucerne are based on the water footprint values determined by Scheepers & Jordaan (2016), illustrated in table 4.2². The values found by Scheepers & Jordaan (2016) were thus multiplied by the mass of bought in feed by the farm, so as to calculate the bought in feed water footprint component of the dryland enterprise.

Table 4.2: *The WF of Lucerne (m³/tonne)*

Blue WF (m ³ /tonne)	Green WF (m ³ /tonne)	Total WF (m ³ /tonne)
171,28	206,9	378,18

Source: Scheepers & Jordaan (2016)

4.2.2.3 Water footprint of bought in concentrates

Concentrates are made up of high protein and energy content sources such as those from grains, oil cake meals, minerals, fishmeal and vitamins. These can be mixed on farm or bought ready mixed (Erasmus, 2009; Milk SA, 2013). According to Glen Dye dairy farm, 2150 tonnes of concentrate were bought in 2015. There were no figures available for the years 2011

² It must be noted that the values calculated by Scheepers & Jordaan (2016) ignore the grey water footprint of Lucerne in this calculation

through to 2014. Using this value, and the estimated kilograms of concentrates per cow (7.5kg, 6.8kg, 2.5kg for lactating Friesland, Jersey and dry cows respectively), provided by the farm, and the amount of concentrate per cow type were calculated as according to the weighted ratio of cow numbers to concentrate estimates for the year 2015 (see Appendix D). Based on these values, the concentrate estimates for the remaining years (2011-2014) were calculated, and are illustrated in table 4.3.

Table 4.3: *Estimated total concentrates (tonnes per year) per cow type*

Year	Lactating Friesland (tonnes per year)	Lactating Jersey (tonnes per year)	Dry cows (tonnes per year)	Total (tonnes per year)
2011	1 337	809	143	2 289
2012	1 360	894	134	2 388
2013	1 176	837	120	2 133
2014	1 092	844	115	2 052
2015	1 072	972	107	2 150

Source: Own extrapolation

Unfortunately, this study was limited in its ability to calculate the most accurate WF value for concentrates, as concentrate data was unavailable due to patent recipes belonging to the concentrates' producer. Thus this study used the WF value, as calculated by Owusu-Sekyere et al. (2016), of 1785m³ per tonne of high protein concentrates. These water footprint figures were separated into blue green and grey WFs. By adjusting the WF values for high protein concentrates (HPC) the estimated water footprints per tonne of concentrate were calculated in table 4.4.

Table 4.4: *The WF (m³) of high protein concentrates per tonne*

Tonnes HPC	Blue WF	Green WF	Grey WF	Total WF
1476	74 643	2 512 770	47 560	2 634 973
1	50,57	1 702,42	32,22	1 785,21

Source: Owusu-Sekyere et al. (2016)

Thus, the water footprint for bought in concentrates was calculated by utilising the values found in tables 4.3 and 4.4 for the years 2011 to 2015.

4.2.2.4 Water footprint of drinking water

Not only is feed important, but calves, heifers and lactating cows require ample amounts of drinking water to maintain efficiency. Approximately 70% of a dairy cow's body is made up of

water, which forms part of the cow's bodily functions. Therefore it is important that a herd has access to sufficient drinking water (Subcommittee on Dairy Cattle Nutrition et al., 2001; Cardot et al., 2008; Milk SA, 2013). The water footprint of drinking water is dependent on the total drinking water per cow (Mekonnen & Hoekstra, 2010b) i.e. the free water intake (FWI) per cow. The FWI of dairy cows is affected by daily factors such as dry matter intake, daily milk production, dry matter content of diet, the temperature of environmental factors, and sodium intake (Subcommittee on Dairy Cattle Nutrition et al., 2001). The drinking water methods which follow elaborate on the calculations which were necessary to estimate the drinking water requirements for lactating and non-lactating dairy cows.

4.2.2.4.1 Lactating cows drinking water footprint

A variety of papers offer different calculations for the FWI of lactating cows (Subcommittee on Dairy Cattle Nutrition et al., 2001; Loofer & Waldner, 2002; Meyer et al., 2004; Gordon & Robert, 2007; Cardot et al., 2008). The book entitled *Nutrient requirements of dairy cattle*, compared various methods used to calculate the FWI of lactating dairy cows. Of the methods addressed, it was found that the method prescribed by Murphy et al. (1983) was the most accurate equation in representing the biological components of dairy cattle, and thus the most effective method to predict FWI (Subcommittee on Dairy Cattle Nutrition et al., 2001). The following FWI equation is suggested by Murphy et al. (1983):

$$FWI = 15.99 + 1.58 * DMI, kg. day^{-1} + 0.05 * Na intake, g. day^{-1} + 1.2 * \min temp C$$

.....[11]

Murphy et al. (1983) state that FWI is determined by dry matter intake (DMI), sodium (Na) intake and minimum temperature. From the above (equation 11) it was estimated that for milk production per cow ranging between 33-35kg milk/day, total free water intake equated to 2.7 litres of water per kg milk produced (Subcommittee on Dairy Cattle Nutrition et al., 2001). However, due to the limited availability of specific nutrient data per cow, and the minor contribution of the WF of drinking water in comparison to the WF of pasture (Drastig et al., 2010; Zonderland-Thomassen & Ledgard, 2012; Huang et al., 2014; Bosire et al., 2015; Palhares & Pezzopane, 2015; Scheepers, 2015; Owusu-Sekyere et al., 2016), this thesis followed the FWI method created by Little & Shaw (1978) as performed by Scheepers (2015), which simply requires information regarding dry matter intake and milk yield. Thus the Little

& Shaw (1978) equation which was then used to calculate the water footprint of drinking water for lactating cows is as follows:

$$FWI = 12.3 + 2.15 * DMI, kg. day^{-1} + 0.73 * Milk yield, kg. day^{-1}$$

.....[12]

Where free water intake (FWI) is determined by dry matter intake (DMI) and milk yield.

In order to calculate the amount of milk produced per cow per day, mean estimates were retrieved from literature, as farmers were unable to provide daily milk production values per cow breed. Cunha et al. (2010) undertook a desktop study which calculated various mean milk production values (litres milk per day) for both Jersey and Holstein cows according to the results of other authors. Through the use of the desktop study values, the calculated average milk production for lactating Holstein and Jersey dairy cows were 31.6 litres (32.548kg) and 21.7 litres (21.351kg) per cow per day respectively.

Thus, the total milk yield according to cow breed was calculated using the ratio of annual Friesland and Jersey lactating cow numbers, obtained from on farm records, weighted according to the ratio of average milk production values per respective cow, using the assumed average values from Cunha et al. (2010) (See Appendix E).

4.2.2.4.2 Non-lactating cows drinking water footprint

Gordon & Robert (2007) suggest various prescribed free water intake (FWI) values for Jersey and Friesland cows in a technical report for reasonable stock water requirements. These values were based on FWI values for both breeds found in literature. The literature estimates found by Gordon & Robert (2007) were averaged according to cow type and lifecycle stage, providing the mean FWI values for lactating and non-lactating cows in table 4.5.

Due to the similarities between calculated drinking water for lactating cows (see results chapter) and the mean value estimates for lactating cows presented by Gordon & Robert (2007) in table 4.5, the mean values from Gordon & Robert (2007) for the calculation of the drinking water footprint for calves, heifers and dry cows were used. Gordon & Robert (2007) did not provide drinking water estimates for bulls, as a result, the drinking water footprint for bulls is assumed to be the same as the value provided by Scheepers (2015).

Table 4.5: *The mean values of free water intake requirements (FWI) for lactating and non-lactating dairy cows*

	Friesland FWI (Litres per cow per day)	Jersey FWI (Litres per cow per day)
Calves*	18,72	16,75
Heifers (<2)*	29,22	23,90
Lactating cows*	60,34	54,86
Dry cows*	42,10	36,10
Bulls**	50,00	50,00

*Source: Gordon & Robert (2007); **Source: Scheepers (2015)

Using the values found in table 4.5, the drinking water footprint for non-lactating cow type a in year i is equal to the estimated free water intake of cow type a (FWI_a) multiplied by the number of cow(s) a (n), converted into cubic meters:

$$NonLactating\ WF_{drinking,i,a} = (FWI_a * n_a) * 0.001 \quad \dots\dots\dots[13]$$

From equations 12 and 13 the total drinking WF in year i was thus calculated as the sum of the water footprints for lactating and non-lactating dryland dairy cows:

$$WF_{drinking,i} = \sum FWI_{lactating,i} + \left(\sum_{a=1}^4 NonLactating\ WF_{drinking,i,a} \right) \quad \dots\dots\dots[14]$$

4.2.2.5 Water footprint of servicing water

Throughout the milking process cows release urine and manure deposits within the parlour, which then needs to be cleaned. For hygiene purposes milking equipment also requires cleaning after each cow is milked (Milk SA, 2013; Esterhuizen et al., 2015). Milk tanks are used to store milk once cows have been milked. These tanks must be cleaned with soap, acid and sanitizer as well as large quantities of water, after each milk collection (Milk SA, 2013), further contributing to the freshwater requirements during the milk production process. Often pond systems or settling dams are used to manage wastewater from the cleaning of the dairy pits and equipment, as this water is loaded with micro-organisms, cleaning materials, solids and fat (Torr, 2009; Milk SA, 2013; Esterhuizen et al., 2015).

Effluent discharged from cleaning and processing activities during milk production have major pollution potential. Meissner et al. (2013) suggest that between 75% and 95% of water

consumed by dairy production in South Africa is discharged as effluent (Meissner et al., 2013). In South Africa, most of the effluent produced by dairy is deposited back onto land and pastures, providing the role of fertilizer at the risk of ground water pollution (Esterhuizen et al., 2015).

The WF of servicing water was calculated using the estimated water use (litres) for cleaning the farm's dairy parlour and milk tanks. Based on these values, the blue water footprint of servicing water was calculated by converting litres of blue servicing water into cubic meters. After cleaning, used servicing water is washed into a slurry pit where it is recycled and distributed over the pastures once every two months. The calculation of the grey water footprint for the used cleaning water was thus ignored, as the grey water footprint of slurry is accounted for in the water footprint of pastures.

4.2.3 Phase 3- Sustainability Assessment

The scope of the sustainability assessment is based on the goals and scope phase of the water footprint assessment. As a volumetric value, the WF has no significant meaning in terms of sustainability, and thus this value needs to be put within a local context in order to derive a valuable comparison, and a view on the sustainability of local fresh water consumption. Thus, the WF sustainability assessment's primary function is to perform a comparison between human consumption to the earth's water requirements to support its functions (Hoekstra et al., 2011).

Sustainability has environmental, social and economic dimensions, with impacts either being primary or secondary. For the purpose of this study, the economic and environmental sustainability of the WF of pasture fed dairy enterprises was assessed within the individual farm's local context. As an alternative to calculating the blue and green water scarcity values as stipulated in the water footprint assessment manual, this thesis utilises the water risk filter tool created by the WWF (WWF, 2016)³, which provides insight into physical, regulatory and reputational risk of the dryland farm. The tool does this by addressing both the geographical context of the WF for the farm, and the characteristics of the water consuming processes themselves.

³ The water scarcity index utilised in the WFA was not appropriate for this study as the case study farm was not situated in a river basin and only utilised groundwater rather than surface water.

This thesis used the framework of the sustainability assessment in order to identify the specific processes within the production of dairy, from crop-to-farm gate, which contribute most significantly to the WF of the enterprise, and have the largest impact on the economic and environmental sustainability related to the farm's WF.

4.2.3.1 Environmental sustainability guidelines for research

- Water quality within a farm's area should remain within national standards along with freshwater flow requirements and limits. This includes groundwater and natural runoff.
- Analysing the grey water footprint goes beyond the scope of this research, and thus this paper will only perform a narrative on farm practices which contribute to the grey water footprint through fertilizer and slurry application, as well as the handling of effluent.
- The Water Risk Filter provides environmental sustainability guidelines which can be found on the Water Risk Filter website ⁴.

4.2.3.2 Economic sustainability

Water should be allocated in a way that is economically efficient, with fresh water consumption benefits outweighing the costs associated with the water footprint. These costs include opportunity costs, externalities and scarcity rent.

In order to assess the economic sustainability of pasture based dairy production enterprises, the gross value of green crop water use, as performed in the study by Zoumides et al. (2014) was required. This gross value assesses the green (EV_{green}) economic water values of crop yield (Y) at producer prices (P_{base}) in base year terms for dryland (dry) pastures.

$$EV_{green[dry]} = \sum (Y_{dry} * P_{base})$$

.....[15]

Economic water productivity is also a significant indicator of economic sustainability (see 2.3.1). This indicator is calculated for the total water footprint (Chouchane et al., 2015). The value of economic water productivity (EWP) (ZAR/m^3) for dryland (dry) pasture systems was

⁴ The full criteria for the Water Risk Filter can be found online in the Water Risk Filter guidelines available at: <http://waterriskfilter.panda.org/>.

calculated by dividing the total value of milk produced (ZAR/ton) by the total water footprint of the given system (Schyns & Hoekstra, 2014; Chouchane et al., 2015; Pahlow et al., 2015). This calculation is illustrated below:

$$EWP_{milk\ prod} = \frac{Y * P_{base}}{WF_{green} + WF_{blue}} \dots\dots\dots[16]$$

In a similar vein, land productivity is considered as an indicator of economic sustainability. This was calculated by multiplying the base producer price for the pasture crop (P_{base}) by annual crop yield (Y) (ton/ha), in order to provide a land value per hectare (ZAR/ha). This calculation is illustrated in equation 17.

$$ELP = Y * P_{base} \dots\dots\dots[17]$$

Another indicator which may prove beneficial in the economic analysis of a dairy enterprise is the milk:feed price ratio (MFR) (ton/ZAR) (IFCN Dairy Network 2014). This ratio compares quantities of milk produced per farm (Y_{milk}) to the feed price ($P_{feed[base]}$) which has been standardised to a base year. This ratio is not able to assess the value of pasture grown feed on a dryland pasture without exact pasture production costs. As a result, the milk:feed price ratio was adjusted to the value of milk:cost ratio. This new ratio served as an indicator of the value gained from milk production to cover the overall production costs of the dryland dairy enterprise, indicated in equation 18.

$$Milk\ value:cost = \frac{Value\ milk}{Total\ costs} \dots\dots\dots[18]$$

The water productivity along with production theory provides valuable insights into the economic value of water under dryland systems in terms of rainfall, milk production, employment and water use. This is assumed as the ratio of farm process to water use (m^3).

Through the sustainability assessment, with primary focus on economic relevance, this research addressed issues of water productivity, milk production efficiency and water scarcity in the response formulation phase of the assessment.

This research employed the Water Risk Filter in order to assess the economic and environmental sustainability results in terms of water related risk. The Water Risk Filter's goal is to provide all information and aspects required for individuals and businesses to address their water risk in terms of physical, regulatory and reputational risk. The Water Risk Filter (WRF) does this by utilising data from nationally available datasets within South Africa, including datasets from the DWS, CSIR and the WRC, in order to estimate and assess ground and surface water scarcity across South Africa. The Water Risk Filter addresses the need for companies to understand, manage and assess their water risk with the use of an effective platform. In doing this, companies are able to consider their water related risk within a set of structured water risk sets, without the need of an expert, through tools such as the provision of automatic basin risk indicators, along with a business risk calculator via a user questionnaire. The various water risk levels are designed according to water risk scores and their corresponding weighting (estimated by the WRF), and are provided a risk indicator between 1 and 5 (1 indicating no or limited risk, and 5 indicating very high risk). Through the water risk filter tool, this thesis highlights the various water risks associated with dryland farm production, which fall under both environmental and economic sustainability consideration under the guidelines provided in the water footprint assessment manual and those provided by the water risk filter (WWF, 2016).

4.2.4 Phase 4- Response formulation

The response formulation phase of the water footprint assessment is the final phase according to the water footprint assessment manual. The purpose of response formulation is to determine a response to the outcomes of the water footprint accounting and sustainability assessment phases. The WFA manual suggests various responses. Examples of these responses include shared responsibility of consumers, addressing possible areas in which water footprints can be reduced, addressing consumer behaviour, water footprint offsetting, water footprint reduction targets, and government policy and regulation (Hoekstra et al., 2011).

Water is a scarce good because it carries opportunity costs, where the benefits have been forgone towards alternative uses. This scarcity highlights the importance of addressing the imbalances between the supply and demand for freshwater resources under prevailing institutional arrangements and infrastructural conditions (Hoekstra et al., 2012; Schyns et al.,

2015). Certain socio-economic questions need to be addressed when formulating a response to the values calculated in the WFA. These questions include: what water resource is being used? How is the water resource being used? When is the water being used? What other uses are there regarding this freshwater? Is the water being used sustainably? How are the potential risks between blue and green water ratios being managed? (Jefferies et al., 2012). Response formulation can be formulated on various levels as a response to the aforementioned questions, i.e. through policy, government regulation, catchment management, company business strategy (in this case Woodlands Dairy), and on farm management (Hoekstra et al., 2012; Meissner et al., 2013; Mekonnen & Hoekstra, 2014a).

Poor animal management along with cropping practices play a significant role in the depletion and pollution of water sources (Peden et al., 2009). Suggested reasons, by Schyns & Hoekstra (2014) and Zonderland-Thomassen & Ledgard (2012), for poor water footprint practices within agriculture include:

- Evaporation from storage reservoirs (the second largest form of blue water consumption globally after irrigated crop production)
- Evapotranspiration rates of green water on and off farm
- The production of low value cereals and crops with high water footprints
- Pasture leaching
- Severe blue water scarcity which hinders freshwater resources' ability to assimilate pollutants
- Crop production in water scarce river basins and catchments

General responses to the large water footprint of dairy involve the relocation of dairy production from water scarce regions to water rich areas (Huang et al., 2014), however, this is not necessarily a feasible option in reality. Other responses tend to be more drastic, with suggestions of changing consumer eating habits away from animal products such as dairy, towards plant-based products. In developing countries these are not a feasible options due to the secondary impacts a change in dairy demand and supply would have along the dairy value chain, as well as the direct and indirect effects this would have on socio-economic development and employment within South Africa (Meissner et al., 2013). Thus, Peden et al. (2009) suggests that the promotion of the better integration of livestock and water

development within sub-Saharan Africa as an alternative. Such an alternative has the potential to reduce poverty, improve and increase food production, and reduce the existing pressures on scarce freshwater resources (Peden et al., 2009).

Research studies on the water footprint of dairy have suggested various responses to water footprint study outcomes. The majority of these responses fall under farm management techniques, and the address of water productivity values (Meissner et al., 2013). These responses address various aspects of animal production including feed sourcing, animal productivity, drinking water provisions and water conservation techniques (Peden et al., 2009). Suggestions include the improvement of feed conversion efficiency through the rehabilitation of degraded pastures, and the adoption of improved breeding practices and feed compositions (Peden et al., 2009; Meissner et al., 2013; Bosire et al., 2015). Through improved feed conversion efficiency, the water footprint per ton of milk produced has the potential to be reduced within the production system (Bosire et al., 2015). Hoekstra et al. (2012) suggest that the import of feed from water rich areas instead of producing feed in water scarce areas is another valuable method in the attempt to mitigate water scarcity, alongside improved feed conversion efficiency (Hoekstra et al., 2012).

4.3 Data sources

In estimating the volumetric water footprint, specifically when addressing the blue and green water footprint of crop production, as well as the various sustainability indicators, many data sources are required. Ideally, the majority of data acquired is accessed from local data (Hoekstra et al., 2011). Table 4.6 describes the individual components, and their respective data sources, which were required in order to determine the water footprint of dryland pasture based dairy enterprises, by contributing to the calculation of the individual water footprint components and the overall water footprint assessment.

The majority of data required for the determination of the water footprint for pasture fed dairy enterprises on dryland pastures was gathered from interview and questionnaire questions (refer to Appendix F), put forward to the farm owner and manager. These data variables primarily relate to the animal husbandry practices on farm, as well as geographical water source information and other general farm and economic variables, such as

employment values. In the instances where data could be collected on farm, global averages were used along with online data sources.

Where farm data was not available, climate data and meteorological data was required for the determination of the annual rainfall and water availability indicators within farm regions. This data was obtained from the ARC-ISCW.

Table 4.6: *Data input and sources table*

Data required	Input	Source
Climate	Weather Rainfall	ARC-ISCW On-farm data
Crop characteristics	ET _c values P _{eff}	SAPWAT 3.0
Grey WF	C _{max} and C _{min} Slurry	DWAF (1996) Woodlands dairy- Galloway (2016)
Bought in feed	Quantity of bought in feed WF of Lucerne	On-farm data Scheepers (2015)
Bought in concentrates	Quantity of bought in concentrates WF of high protein concentrates	On-farm data and own extrapolation Owusu-Sekyere et al. (2016)
Drinking water	Drinking water of lactating cows Drinking water of non-lactating cows Milk production ratios	Little & Shaw (1978) Gordon & Robert (2007); Scheepers (2015) Cunha et al. (2010)
Servicing water	Amount of water used to clean milk tanks Amount of water used to clean dairy parlour	Farm estimates
Farm Characteristics	Economic variables Herd characteristics Farm management systems	On-farm data
Producer prices	Milk price Average value of kikuyu Market price of Lucerne	On-farm data Derived from on farm economic data DAFF (2016)

4.4 Synopsis

This chapter addressed the various water-consuming components related to dryland on-farm milk production systems. From this, and chapter two of this theses, it was determined that the focal processes to be addressed in order to measure the water footprint of dryland pasture based dairy enterprises in the Eastern Cape were pasture, bought in feed and

concentrates, drinking water and servicing water. These processes were addressed in the water footprint assessment phases of the WFA method, where the goals and scope were defined, the WF accounting and sustainability assessment phase methods provided the relevant equations for the calculation of the WF, and sustainability indicators related to the WF of dairy production. The response formulation phase of the method provided examples of WF recommendations, and the data sources section used the information from the previous sections of the chapter in order to determine what data is required for the completion of the WFA in order to answer the research question of this thesis. Chapter five presents the results of this thesis based on the method as set out in this chapter.

CHAPTER 5
RESULTS

Following the methods chapter, this succeeding chapter captures the results of the method stipulated in chapter 4 for the three phases of the water footprint assessment, being water footprint accounting, sustainability assessment and response formulation. In utilising the results established in the water footprint accounting phase, the sustainability assessment will assess these results in environmental and economic terms, after which the response formulation phase will provide recommendations subject to the findings in the water footprint accounting and sustainability phases.

5.1 Water footprint accounting

As stipulated in the methods chapter, the following section will calculate the total water footprint of a dryland dairy enterprise by assessing the total water footprints for pastures, bought in feed and concentrates, drinking water and servicing water processes. These results will be presented under their respective process and discussed at the end of the water footprint accounting phase.

5.1.1 The water footprint of pasture

5.1.1.1 Green water footprint

The green water footprint for dryland pastures was calculated according to the water footprint assessment, through the use of the SAPWAT 3.0 program (see 4.2.2.1), with the intention of determining the values for crop evapotranspiration (ET_c) and effective rainfall (P_{eff}). Using the values gathered by SAPWAT, the minimum of ET_c and effective rainfall per month was used to calculate the green water footprint of dryland pastures per month, and per annum (see Appendix G). The results of the green water footprint calculations for dryland pastures are provided in table 5.1, and the total water footprints per annum are illustrated in figure 5.1.

Table 5.1: *The total monthly and annual green water footprints (m³) of 210ha dryland pasture (2011-2015)*

	Year				
	2011	2012	2013	2014	2015
January	33 600	54 600	31 500	40 950	68 880
February	96 600	119 700	54 600	115 500	60 900
March	44 100	56 700	6 300	37 800	52 500
April	90 300	86 100	92 400	79 800	44 100
May	138 600	33 600	90 300	91 350	19 320
June	126 000	75 600	28 350	60 900	52 500
July	98 700	136 500	92 400	68 250	73 500
August	135 450	100 800	54 600	77 700	105 000
September	58 800	96 600	63 000	52 500	102 480
October	60 900	128 100	139 650	27 300	94 080
November	73 500	45 150	77 700	42 000	31 500
December	84 000	50 400	88 200	94 500	31 500
Total	1 040 550	983 850	819 000	788 550	736 260

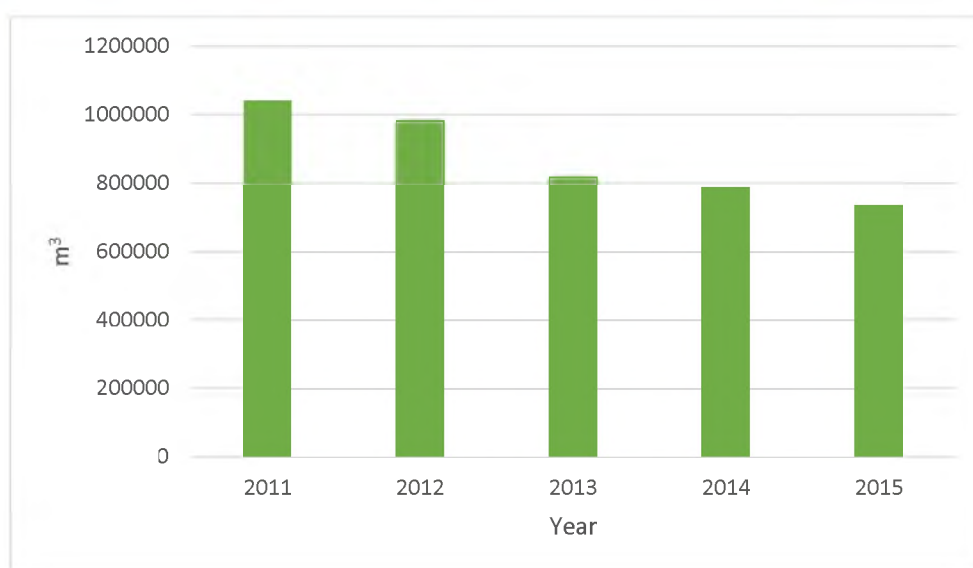


Figure 5.1: *The total green water footprint for 210ha dryland pasture for Glen Dye dairy farm (2011-2015)*

Based on the results presented in table 5.1 and figure 5.1, it is evident that the green water footprint for the dryland pastures was highest in 2011 and lowest in 2015. This result may be considered unusual, as annual rainfall was lowest in 2013 (refer to 3.7.2.1). Thus, the implied assumption that the green water footprint of dryland pastures is directly correlated to the total amount of rainfall (mm) (see 2.2), does not necessarily hold. Where green water is defined as rainwater absorbed by the crop plant (Mekonnen and Hoekstra, 2014b). This is

due to the nature of the green evapotranspiration (ET_{green}) calculation which is taken as the minimum of crop evapotranspiration (ET_c) and effective rainfall (P_{eff}) (see 4.2.2.1). By illustrating the differences between the ET_c and P_{eff} for 2015 in figure 5.2, the reasoning for a lower green water footprint in the year 2015 is shown to be as the result of lower ET_c values, and can thus explain why wetter years such as 2015 have lower water footprints.

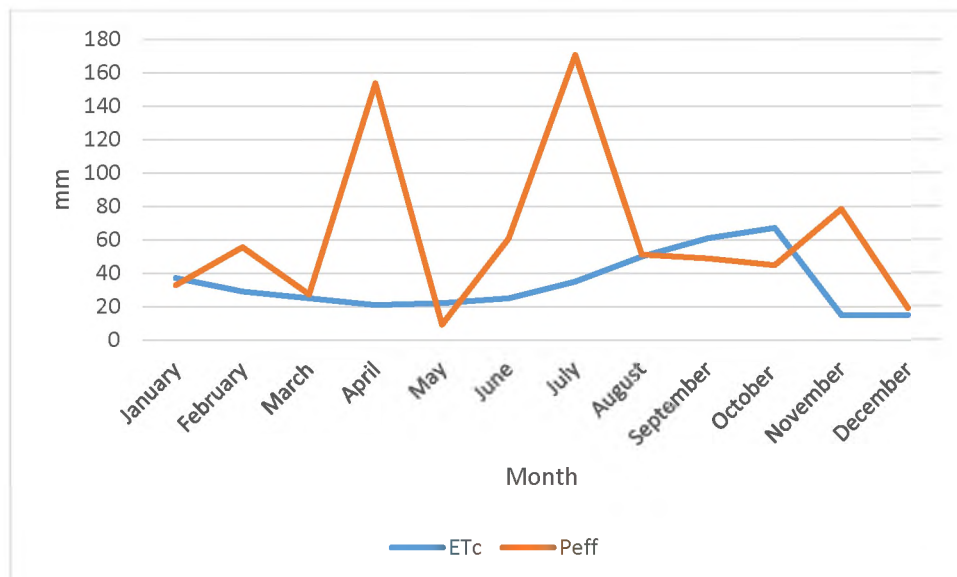


Figure 5.2: The difference between ET_c and effective rainfall for the year 2015

5.1.1.2 Grey

5.1.1.2.1 Fertilizer

Glen Dye fertilizes its pastures with 46% nitrogen fertilizer, five times a year. Based on the pasture area of 210 hectares, and the qualitative information provided on farm and from Woodland's dairy representatives, the grey WF was calculated as prescribed by Franke et al. (2013) (see 4.2.2.1.2.1). The leaching-runoff fraction of nitrogen fertilizer application was calculated in table 5.2 using the qualitative methods stipulated in Franke et al. (2013). This was then used to calculate the total grey water footprint in table 5.3.

5.1.1.2.2 Slurry

The grey water aspect of the farm's servicing water is found in the collection of effluent into a slurry pit, which is then distributed over pastures as a form of natural fertilization every 2 months. Woodlands Dairy reports on farm slurry water quality based on standards set by Woodlands dairy (see Appendix C for slurry report), as the values presented do not meet the

water quality standards as stipulated by the Department of Water and Sanitation (DWS) (Republic of South Africa, 2013).

Table 5.2: The nitrogen fertilizer leaching-runoff fraction for Glen Dye dairy farm

Category	Factor	Leaching runoff potential	Very low	Low	High	Very high		
		Score (s)	0	0,33	0,67	1		
		Weight (w) alpha					Wi*Si	
Environmental factors	Atmospheric input	N-deposition (g N m ⁻² year ⁻¹)	10	<0,5	>0,5	<1,5	>1,5	5
	Soil	Texture (relevant for leaching)	15	Clay	Silt	Loam	Sand	1
		Texture (relevant for run-off)	10	Sand	Loam	Silt	Clay	0
		Natural drainage (relevant for leaching)	10	Poorly-very poorly drained	Moderately-imperfectly drained	Well drained	Excessively-extremely drained	6,7
		Natural drainage (relevant for run-off)	5	Excessively-extremely drained	Well drained	Moderately-imperfectly drained	Poorly-very poorly drained	1,65
	Climate	Precipitation (mm)	15	0-600	600-1200	1200-1800	>1800	4,95
Agricultural practice	N-fixation (kg/ha)		10	0	>0	<60	>60	6,7
	Application rate		10	Very low	Low	High	Very high	3,3
	Plant uptake (crop yield)		5	Very high	High	Low	Very low	1,65
	Management practices		10	Best	Good	Average	Worst	0
							$(\alpha)=\sum S_i * W_i$	30,95

Source: Franke et al. (2013); Galloway (2016a); Own extrapolation

Table 5.3: Grey water footprint of nitrogen fertilizer applied five times per year on dryland pastures

	AR	A (ha)	α	C_{max} (kg/m ³)	C_{nat} (kg/m ³)	WF _{grey} (m ³) per application	WF _{grey} (m ³) total
Nitrogen	0,46	210	0,3095	0,01	0,0005	3 147,126	15 735,632

On interviewing Craig Galloway from Woodlands dairy, he stated that “with regards to DWS (Department of Water and Sanitation) standards for the use of waste water for beneficial disposal, the slurry [of the farm] does not fall within the [water] quality standards they [DWS] require for a general authorisation”. He also noted that Woodlands Dairy does not perform the required analysis proposed by the DWS because certain aspects of the water quality of slurry, of all Woodlands dairy farms, fall outside of the DWS water quality parameters. Thus, Woodlands prefers to focus on the “beneficial nutrients in the slurry for pasture growth and

soil health”, which if not redistributed onto pastures could otherwise become water source pollutants (Galloway, 2016b). Due to the slurry report inconsistencies, the sustainability assessment and response formulation of the water footprint assessment for slurry collection and pasture distribution, will be centred around the slurry report and recommendations provided by Woodlands dairy for Glen Dye dairy farm.

5.1.2 The water footprint of bought in feed

Founded on the WF values established in Scheepers & Jordaan (2016) (see 4.2.2.2), this thesis calculated the WF of bought in feed by multiplying the total amount of bought in Lucerne (tonnes) by the blue and green water footprints of Lucerne per tonne as illustrated in table 5.4.

Table 5.4: *WF of bought in feed (m³) for Glen Dye dairy farm per year*

Tonnes Lucerne	Blue WF (m ³)	Green WF (m ³)	Total WF (m ³)
200	3 4256	41 380	75 636

Source: Scheepers & Jordaan (2016); Own extrapolation

5.1.3 The water footprint of bought in concentrates

Utilising the WF values estimated by Owusu-Sekyere et al. (2016) for high protein concentrates (HPC), in order to calculate the water footprint of dryland bought in concentrates (see 4.2.2.3), the total water footprints for concentrates (2011-2015) for Glen Dye farm are illustrated in table 5.5.

Table 5.5: *The WF of bought in concentrates (2011-2015)*

Year	Total concentrates (tonnes per year)	Blue WF (m ³ /year)	Green WF (m ³ /year)	Grey WF (m ³ /year)	Total WF (m ³ /year)
2011	2 289	115 758	77 057	43	192 858
2012	2 388	120 753	80 382	45	201 180
2013	2 133	107 849	71 792	40	179 682
2014	2 052	103 778	69 082	39	172 900
2015	2 150	108 728	72 377	41	181 146

Source: Owusu-Sekyere et al. (2016); Own extrapolation

5.1.4 The water footprint of drinking water

The water footprint of drinking water varies for different cow breeds and cow stages within the breeding cycle (Subcommittee on Dairy Cattle Nutrition et al., 2001). Thus, WF calculations were made according to cow type and the number of lactating cows, dry cows,

heifers, bulls and calves (See Appendix H for dairy herd characteristics). The following section divides drinking water footprint calculations per lactating and non-lactating dairy cow.

5.1.4.1 Lactating cows

As discussed in the research methods chapter, the water footprint of drinking water for lactating cows can be expressed in the simplified Little & Shaw (1978) equation, which stipulates that free water intake (FWI) is dependent on dry matter intake (kg per day) and milk yield (kg per day). Using this equation, along with the weighted average ratio of milk production (see research methods) and the dry matter intake (DMI) values provided by the farm manager, the water footprint for lactating Friesland and Jersey cows is as follows.

Table 5.6: *The water footprint of drinking water for lactating cows (2011-2015) based in the FWI estimation equation by Little & Shaw (1978)*

Year	Friesland					Jersey				
	Number	DMI (kg per day)	Average milk yield per cow per day (kg)	FWI (litres per cow per day)	WF (m ³ per day)	Number	DMI (Kg per day)	Average milk yield per cow per day	FWI (litres per cow per day)	WF (m ³ per day)
2011	514	20	18,985	60,330	31,010	343	16	12,454	55,791	19,136
2012	523	20	17,875	68,349	35,746	379	16	11,726	55,260	20,943
2013	452	20	17,976	68,422	30,927	355	16	11,792	55,308	19,634
2014	420	20	19,547	69,569	29,219	358	16	12,822	56,060	20,070
2015	412	20	19,915	69,838	28,773	412	16	13,064	56,237	23,170

5.1.4.2 Non-lactating cows

Due to the similarities between calculated drinking water for lactating cows using the Little & Shaw (1978) equation, and the mean value estimates for lactating cows presented by Gordon & Robert (2007) (refer to 4.2.2.4.2), mean values offered by Gordon & Robert (2007) for calves, heifers and dry cows for the drinking water calculation of non-lactating Jersey and Friesland cows were used. For bulls, it was assumed that the drinking water value equivalent to those used by Scheepers (2015). Thus, the calculations for non-lactating cows are as follows in table 5.7.

Table 5.7: Drinking WF calculations for dry cows (2011-2015)

Year	Friesland				Jersey			
	Number	FWI per cow per day	Total FWI per day (L)	WF (m ³) per day	Number	FWI per cow per day	Total FWI per day (L)	WF (m ³) per day
2011	99	42,1	4 167,9	4,2	66	36,1	2 382,6	2,4
2012	89	42,1	3 746,9	3,7	65	36,1	2 346,5	2,3
2013	77	42,1	3 241,7	3,2	61	36,1	2 202,1	2,2
2014	72	42,1	3 031,2	3,0	61	36,1	2 202,1	2,2
2015	62	42,1	2 610,2	2,6	61	36,1	2 202,1	2,2

Source: Gordon & Robert (2007); Own extrapolation

Table 5.8: Drinking WF calculations for calves, bulls and heifers (2011-2015)

		Friesland				Jersey			
		Number	Drinking water per cow (L)	Daily free water intake (Litres per day)	WF drinking water (m ³ per day)	Number	Drinking water per cow (L)	Daily free water intake (Litres per day)	WF drinking water (m ³ per day)
2011					11,4				6,3
	Calves	92	18,7	1 721,9		62	16,8	1 038,5	
	Heifers (<2)	313	29,2	9 144,8		208	23,9	4 971,2	
	Bulls	10	50,0	500,0		6	50,0	300,0	
2012					12,7				7,8
	Calves	166	18,7	3 107,0		120	16,8	2 010,0	
	Heifers (<2)	313	29,2	9 144,8		227	23,9	5 425,3	
	Bulls	9	50,0	450,0		7	50,0	350,0	
2013					11,5				7,6
	Calves	124	18,7	2 320,9		97	16,8	1 624,8	
	Heifers (<2)	298	29,2	8 706,6		235	23,9	5 616,5	
	Bulls	9	50,0	450,0		7	50,0	350,0	
2014					10,2				7,2
	Calves	80	18,7	1 497,3		68	16,8	1 139,0	
	Heifers (<2)	281	29,2	8 209,9		239	23,9	5 712,1	
	Bulls	9	50,0	450,0		7	50,0	350,0	
2015					10,3				8,8
	Calves	175	18,7	3 275,4		175	16,8	2 931,3	
	Heifers (<2)	227	29,2	6 632,2		227	23,9	5 425,3	
	Bulls	8	50,0	400,0		8	50,0	400	

Source: Gordon & Robert (2007); Own extrapolation

5.1.4.3 Total drinking water water footprint

Thus, based on the water footprints of drinking water calculated for lactating and non-lactating cows per breed per day, the total WF of drinking water per day is presented in table 5.9.

Table 5.9: *The average total drinking water footprint for dryland Friesland and Jersey cows per day per year (2011-2015)*

	Average Friesland WF drinking water (m ³ per day)	Average Jersey WF drinking water (m ³ per day)	Total average WF (m ³ per day)
2011	47	28	74
2012	52	31	83
2013	46	29	75
2014	42	29	72
2015	42	34	76

5.1.5 The water footprint of servicing water

As noted in section 4.2.2.5 of the research methods chapter, the grey water aspect of servicing water is in the collection of slurry into slurry pits which is then distributed over the field as a form of natural fertilization, contributing to the grey water footprint of pasture. Thus, the calculation of the total water footprint of servicing water only accounts for blue water to avoid double counting, and is calculated in table 5.10.

Table 5.10: *The water footprint of servicing water*

	Litres per day	Litres per annum	Total blue WF (m ³)
<i>Milk Tanks</i>	800	292 000	292
<i>Dairy parlour</i>	8 000	2 920 000	2 920
			3 212

5.1.6 Total water footprint

Using the water footprint values calculated above for pastures, drinking water, bought in feed and concentrates, and servicing water, the total water footprint for a dryland pasture based dairy enterprise (2011-2015) is presented in table 5.11, and figures 5.3 and 5.4.

Table 5.11: *The total water footprint for a dryland pasture based dairy enterprise (m³) (2011-2015)*

	2011			2012			2013			2014			2015		
	Blue WF	Green WF	Grey WF	Blue WF	Green WF	Grey WF	Blue WF	Green WF	Grey WF	Blue WF	Green WF	Grey WF	Blue WF	Green WF	Grey WF
Drinking water	27 146			30 394			27 402			26 236			27 674		
Servicing water	3 212			3 212			3 212			3 212			3 212		
Bought in feed	34 256	41 380		34 256	41 380		34 256	41 380		34 256	41380		34 256	41 380	
Bought in Concentrates	115 758	77 057	43	120 753	80 382	45	107 849	71 792	40	103 778	69 082	39	108 728	72 377	41
Pasture		10 40 550	1 5736		983 850	15 736		819 000	15 736		788 550	15 736		736 260	15 736
Total	180 372	1 158 987	1 5779	188 615	1 105 612	15 781	172 719	932 172	15 776	167 483	899 012	15 774	173 870	850 017	15 776
Percentage of total WF	13,5%	86,5%	1,2%	14,4%	84,4%	1,2%	15,4%	83,2%	1,4%	15,5%	83,1%	1,5%	16,7%	81,8%	1,5%

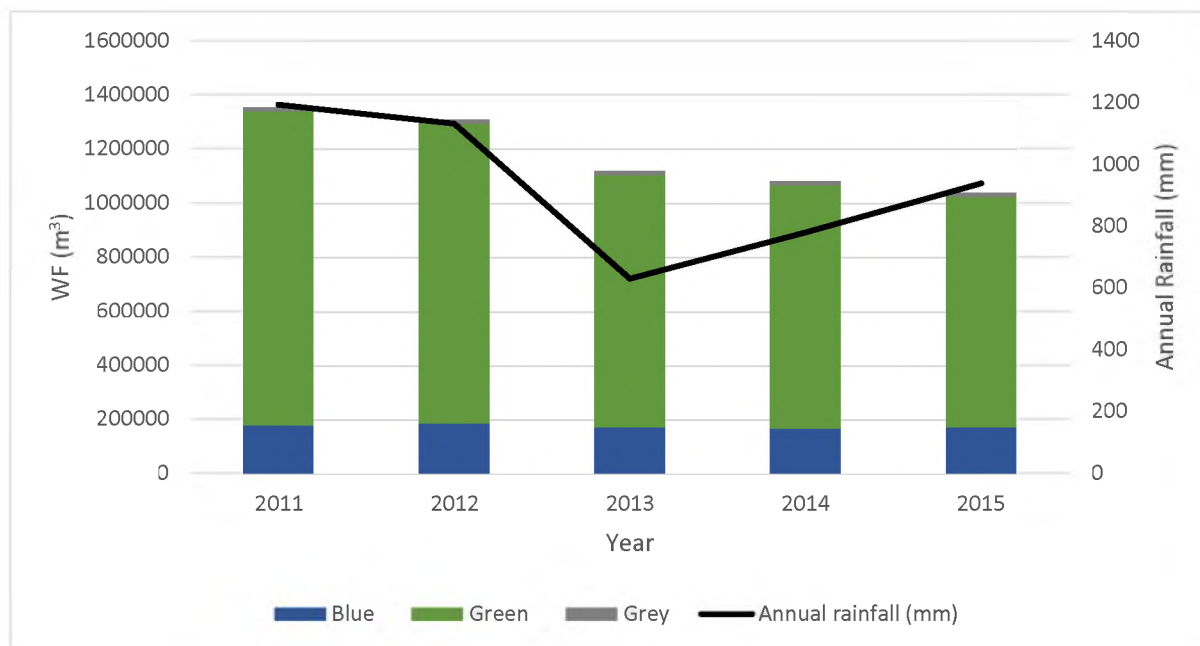


Figure 5.3: The total water footprint (m³) for a dryland pasture based dairy enterprise (2011-2015)

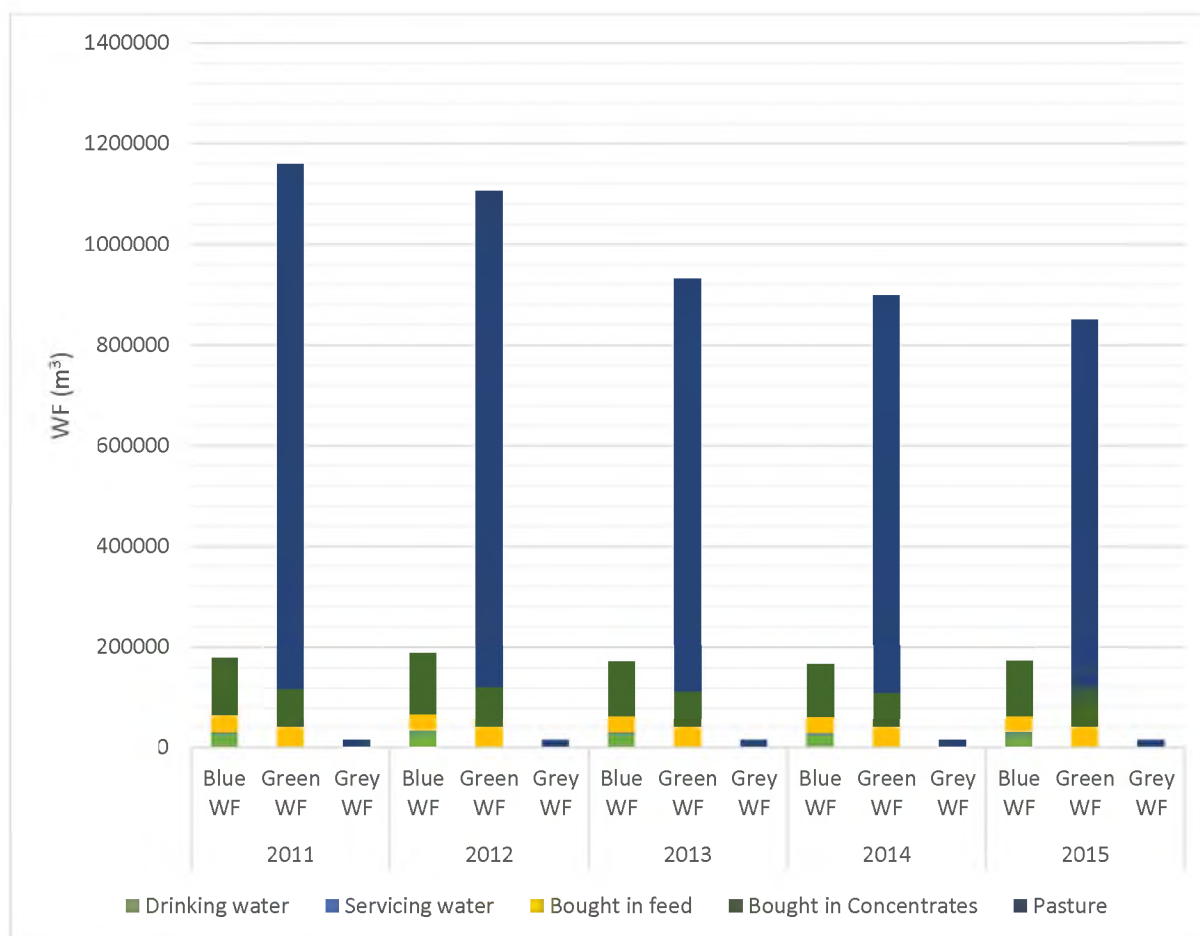


Figure 5.4: The blue green and grey water footprints (m³) for a dryland pasture based dairy enterprise according to water consuming processes (2011-2015)

5.1.7 Discussion

The purpose of the water footprint accounting section of the results chapter was to calculate the blue, green and grey water footprint values for pasture based dairy enterprises, characterised by the water consuming processes of pasture, bought in feed and concentrates, drinking water and servicing water. Through analysis of the overall water footprint accounting results, one observes that the green water footprint makes up the majority of the overall water footprint for dryland dairy pastures (between 82% and 87%), blue water contributes between 13% and 17% of the overall water footprint and the grey water footprint accounts for approximately 1% of the overall water footprint per annum. This result is as expected, based on the literature reviewed in chapter 2, where the water footprint of agriculture, animal products and the water footprint of dairy products is made up predominantly of green water (see 2.2) . Of the total water footprint per annum, pasture production processes account for most of the overall water footprint per annum. Of total blue water per annum, servicing water contributes the least to the overall blue water footprint, with bought in feed and concentrates contributing most significantly. The grey water footprint is minimal in comparison to both the blue and green water footprints. However, this is due to lack of data regarding the grey water footprint of bought in feed, and the fact that the in-depth calculation of the grey water footprint falls outside of the goals and scope of this thesis. Of the blue, green and grey water footprints, the green water footprint is the least consistent per annum. This is due to the fluctuating green water footprint of pasture, which varies similar due to the approximations, made for these figures, based on literature values for the water footprints of bought in feed and concentrates (see 4.2.2.2 and 4.2.2.3).

5.2 Sustainability assessment

According to the results determined in the water footprint accounting phase, the following section addresses the environmental and economic sustainability aspects of the water footprint assessment, after which the Water Risk Filter tool will be used to assess the overall water related risk of the dryland pasture enterprise.

5.2.1 Environmental sustainability

For the purposes of this research, a narrative of the grey water footprint and the slurry report provided by Woodlands Dairy will be used to assess the environmental sustainability of the

dryland pasture based dairy enterprise. Further analysis will be provided in the water risk filter analysis which will follow. In accordance with the environmental sustainability criteria set out in the methods chapter, the environmental sustainability of the dryland enterprise will be assessed according to the national water quality standards set out by the National Water Act.

5.2.1.1 Grey water footprint

The grey water footprint was calculated as per the water quality guidelines presented by the Department of Water Affairs (1996), and thus serves as an indicator for pollution caused by pasture fertilization. The total grey water footprint per annum, as illustrated in figure 5.3, makes a minor contribution to the overall water footprint. Thus pollution caused by fertilizer application can be considered negligible.

5.2.1.2 Slurry

An on-farm slurry dam is categorised as a waste management facility which discharges or disposes of waste-water onto or to a “land based facility”. This disposal is regulated by section 20 of the Environment Conservation Act 73 of 1989 (Bieldt, 2016). One can assume that all used cleaning water equates to the value of effluent water collected in the slurry pit. Thus, using the cleaning water values calculated in the water footprint accounting phase of the water footprint assessment, cleaning water per month is approximately 300m³ of water. Slurry is distributed once every two months, thus on average, on any given day, the slurry pit will contain between 8,8m³ and 600m³ of effluent water.

The National Water Act provides agricultural effluent guidelines for effluent standards on any given day of the year, given different categories for total cubic metres of effluent water (Republic of South Africa, 2013). These water quality standards are presented in table 5.12.

The values provided in table 5.12 do not include values for faecal coliforms, free chlorine, fluoride, phosphates, suspended solids, and soaps, oil and grease, as Woodlands Dairy does not report on these water quality values. Craig Galloway from Woodlands Dairy highlighted that Woodlands Dairy does not calculate these values as slurry pit values fall outside of the specified national parameters for all farms belonging to Woodlands Dairy.

Table 5.12: *Water quality standards for effluent water*

	pH	Electro conductivity (EC) (mS/m)	Chemical Oxygen demand (COD) (mg/l)	Sodium Absorption Ratio (SAR)	Ammonia as Nitrogen (NH ₄ -N) (mg/l)	Nitrate/Nitrite as Nitrogen (NO ₃ -N) (mg/l)
<50m ³ /day	6-9	< 200	< 5 000	< 5		
50-500m ³ /day	6-9	< 200	< 400	< 5		
500-2000m ³ /day	6-9	< 150	< 75		< 3	< 15

Source: Republic of South Africa (2013); Trace and Save (2016)

Woodlands Dairy does however provide nutrient values, for which no national water quality standards have been set for waste-water (Republic of South Africa, 2013; Galloway, 2016a, 2016b). Comparing the values in table 5.12 to those found in the Glen Dye slurry report, there are variables which fall outside of the stipulated national quality standards, particularly the variable Ammonia (NH₄-N) which is “way too high” (Galloway 2016b). According to the National Water Act, any waste water which does not fall within the water quality guidelines requires the application for a waste water licence, presenting a problem for all Woodlands Dairy farms, as the effluent on all farms which supply Woodlands Dairy does not fall entirely within the water quality parameters presented by the National Water Act (Republic of South Africa, 2013; Galloway, 2016b; Bieldt, 2016)

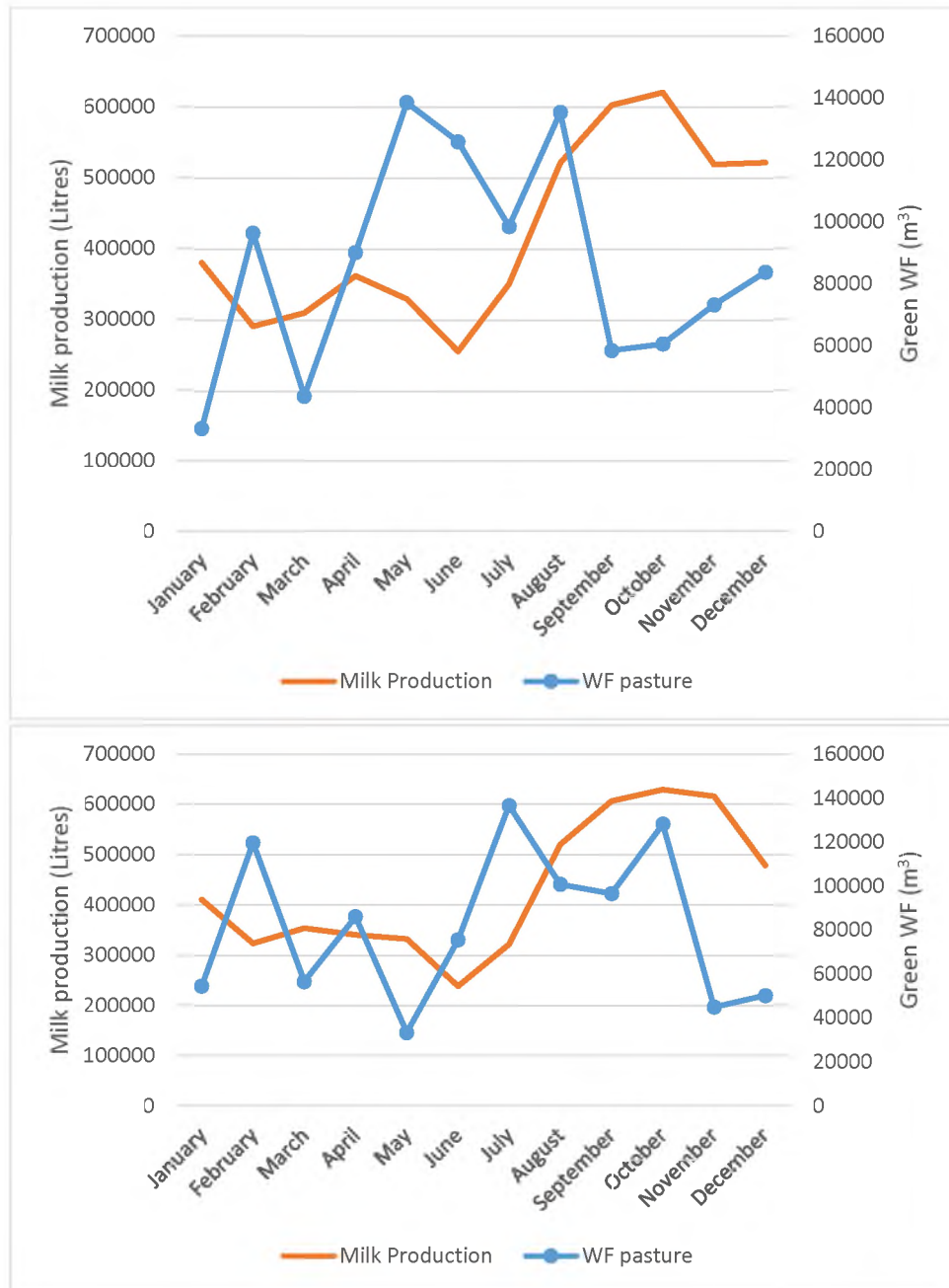
Although the waste water quality requirements present a risk to the environmental sustainability of the dryland farm, and other farms belonging to Woodlands dairy, the company chooses to take an approach which assesses the beneficial nutrients (K, Na, Ca, Mg, Fe, Mn, B, Cu, Zn) of effluent water (Galloway, 2016a), which would otherwise become pollutants if left to be incorporated into run-off. Woodlands Dairy believes that the best method, as a response to identification of these beneficial nutrients, is to redistribute slurry over pastures to promote soil health and pasture growth (Galloway, 2016b).

5.2.2 Economic sustainability

5.2.2.1 Production

Milk production tends to be somewhat independent of the monthly green water footprint, with the majority of milk production, on this specific case study farm, occurring towards the end of each year. This is predominantly due to the two breeding seasons established by the

farm as a form of herd and milk production management, where cows produce the most milk after calving down within these seasons. This is reflected in figure 5.5, which compares monthly milk production to the monthly green water footprint of the dryland dairy enterprise for the years 2011 to 2015.



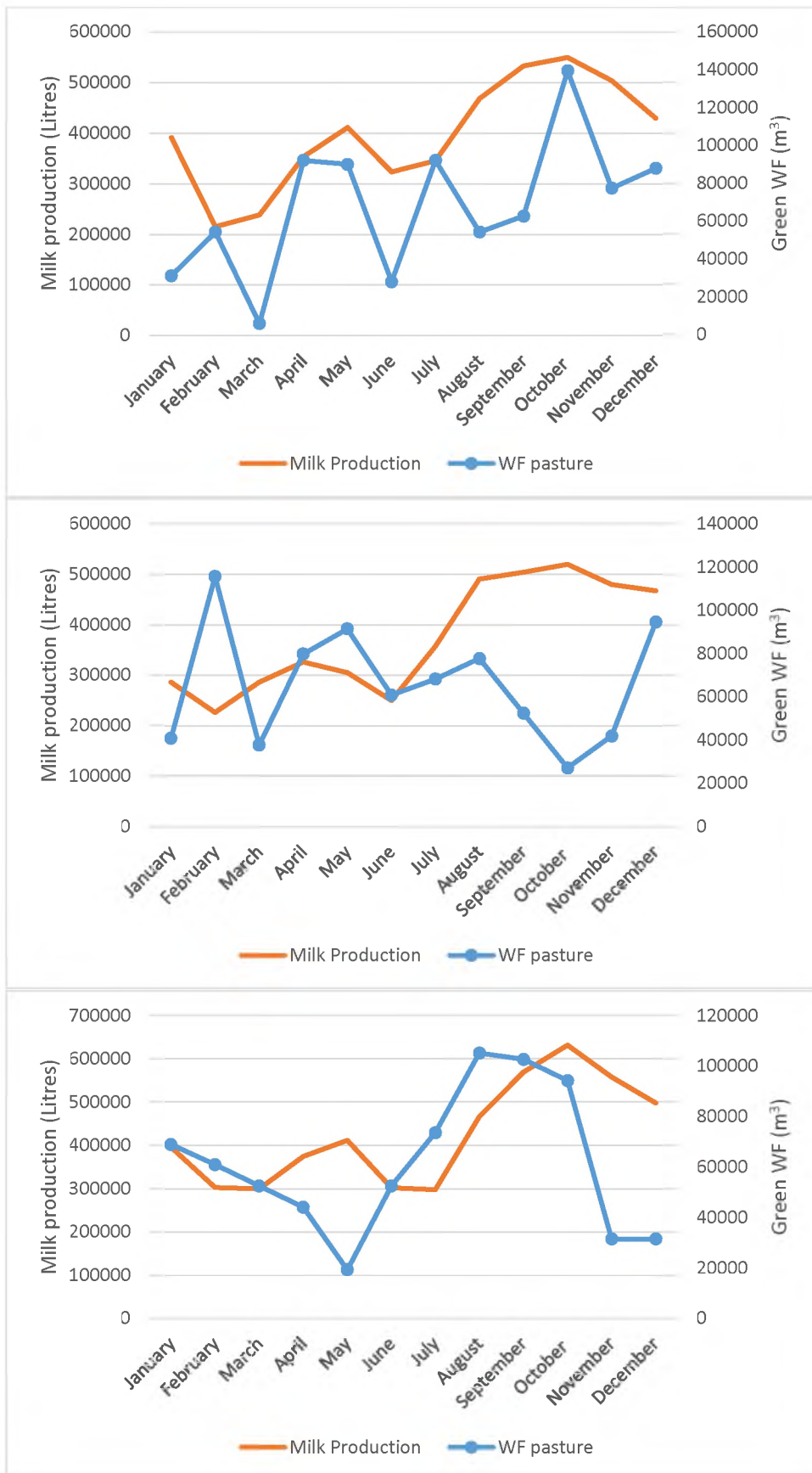


Figure 5.5: The water footprint of dryland pasture versus monthly milk production (2011-2015)

Thus, due to the reasons presented above regarding breeding seasons, the monthly green water footprint values are not the best indicators to use when investigating the relationship between the water footprint and milk production. However, more insight regarding dryland milk production and water use may be gathered by assessing annual data values. Such values include the relationship between milk production and annual rainfall, and annual economic water productivity.

Dryland farm milk production is highly correlated with annual rainfall as illustrated in figure 5.6. In years where there is low rainfall annual milk production decreases as a result of decreased pasture quality. Greater water availability allows for a better quality grass, which allows for higher milk production yields per cow (Ball et al., 2001). This suggests that dryland farms face high risks in terms of production due to reliance on rainfall, which is often unpredictable and variable from year to year.

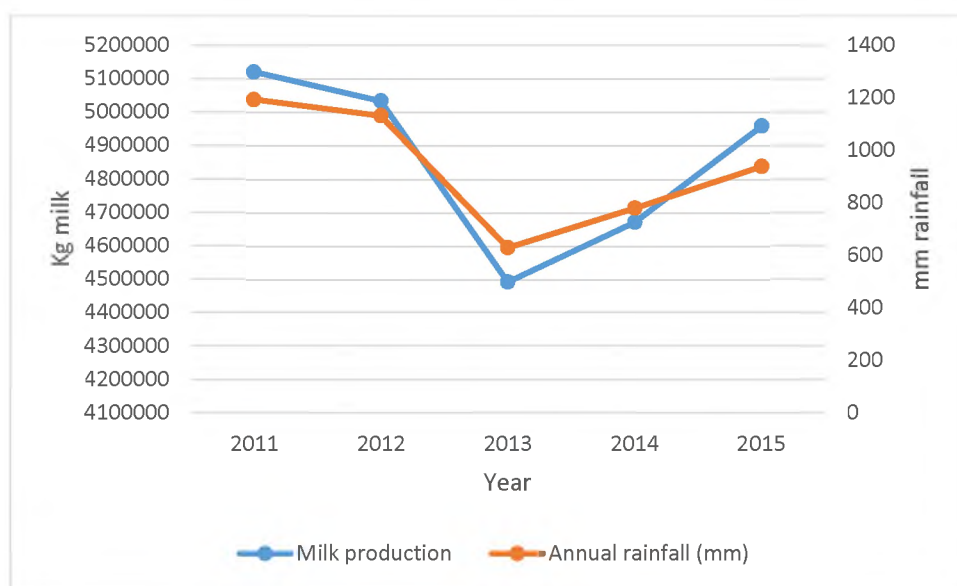


Figure 5.6: Annual milk production versus water availability

Using the price of milk estimates worked back per litre of milk (provided by the case study farm and indicated in table 5.13), the average value of water per cubic metre of water used to produce milk was calculated using the milk price per litre of milk in conjunction with the yearly water footprint totals, as found in tables 5.13 and 5.14.

To calculate the value of the water footprint per litre of milk produced (m^3/l) the total value of milk produced in kilograms is converted into litres by dividing the production value by the conversion metric of 1.04. These new production values are illustrated in table 5.13 below.

Table 5.13: *Litres of milk produced per annum (2011-2015)*

Year	Litres milk produced
2011	4924042
2012	4840688
2013	4320738
2014	4492356
2015	4768649

Using the values found in table 5.13 above, the total water footprint per litre (m^3/l), as provided in table 5.13 of the original thesis, is calculated by dividing the total water footprint (m^3) (see table 5.11) by its respective milk production (litres) for that year.

Table 5.14: *The water, costs and milk price (base 2010) for Glen Dye dairy farm per litre of milk (2011-2015)*

	$m^3/litre\ milk$	Variable Costs R/l milk	Fixed Costs R/l milk	Milk price R/l milk
2011	0,28	R1,66	R0,50	R2,99
2012	0,27	R1,76	R0,53	R3,13
2013	0,26	R2,04	R0,56	R3,28
2014	0,24	R2,02	R0,55	R3,62
2015	0,22	R1,85	R0,60	R3,16

Source: On-farm data; Own extrapolation

*base 2010 prices

Table 5.15: *Average value of water per m^3 water footprint*

	R/ m^3
2011	R10,87
2012	R11,56
2013	R12,66
2014	R15,05
2015	R14,49

*base 2010 prices

Due to the risks associated with dryland farming, dryland enterprises tend to be cost minimisers (Galloway, 2016b). Hence, as a cost minimiser, the dryland farm attempts to minimise its costs through any means possible. Such means include reducing fertilisation costs or variable costs associated with the hiring of contractors etc. (Galloway, 2016b). Figure 5.7 indicates the costs which the case study farm was willing to share, per annum. The figure indicates that costs per annum tend to stay level, with 2011 and 2013 experiencing the lowest

total costs at base 2010 prices. The cost minimising behaviour of the farm is illustrated in the cost composition of the farm's driest year (2013), where fertilizer costs were reduced in order to compensate for the decrease in milk production.

Table 5.15 expresses annual costs in terms of a percentage of total annual costs. In doing this, as a percentage of total costs found in figure 5.6, in the dry year (2013) fertilizer costs were approximately 28.15% lower than in 2012. The cost composition shown in table 5.16 indicates that fertilizer costs contributed least in 2013 to overall costs when compared to previous years and the years which followed. One would assume that feed and concentrate costs would make up a larger proportion of total costs in dryer years, however 2012 utilises the highest proportion of feed and concentrate costs. On further investigation this can be explained for two reasons.

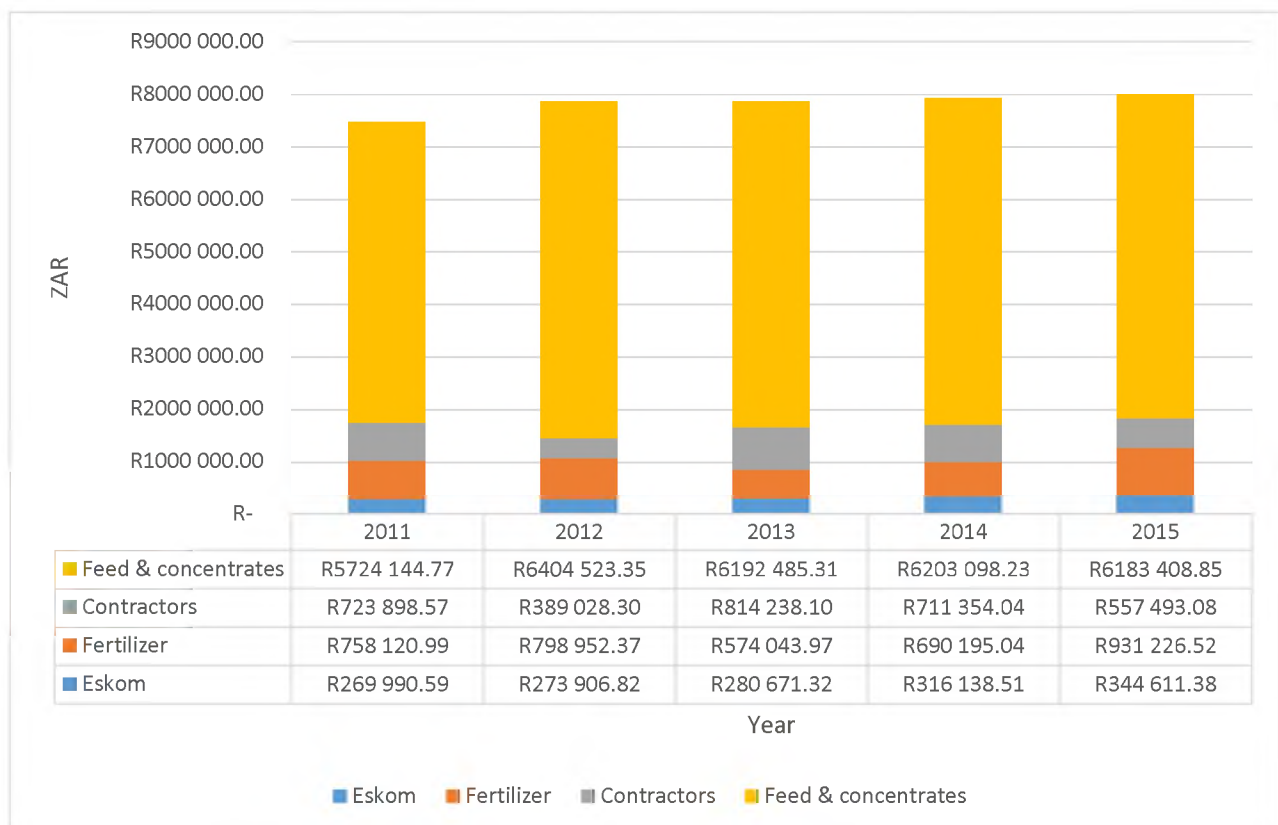


Figure 5.7: Costs per annum at base 2010 prices (2011-2015)

**base 2010 prices*

Firstly, contractor costs were significantly lower in 2012, resulting in the feed and concentrates price compensating for this as a percentage of total costs. Secondly, an analysis was performed to compare annual rainfall for the years 2012 and 2013 in figure 5.8. This

figure highlights that most of the rainfall in 2012 occurred in the last quarter. This figure indicates that the months January through to June are considered dry. Further, this dry spell falls over the farm's calving season (where good quality feed is most vital), thus providing explanation for a higher feed and concentrates cost percentage in 2012 in comparison to 2013.

Table 5.16: Individual costs as a percentage of annual total costs

	2011	2012	2013	2014	2015
Eskom	3,6%	3,5%	3,6%	4,0%	4,3%
Fertilizer	10,1%	10,2%	7,3%	8,7%	11,6%
Contractors	9,7%	4,9%	10,4%	9,0%	7,0%
Feed & concentrates	76,6%	81,4%	78,8%	78,3%	77,1%
Total	100,0%	100,0%	100,0%	100,0%	100,0%

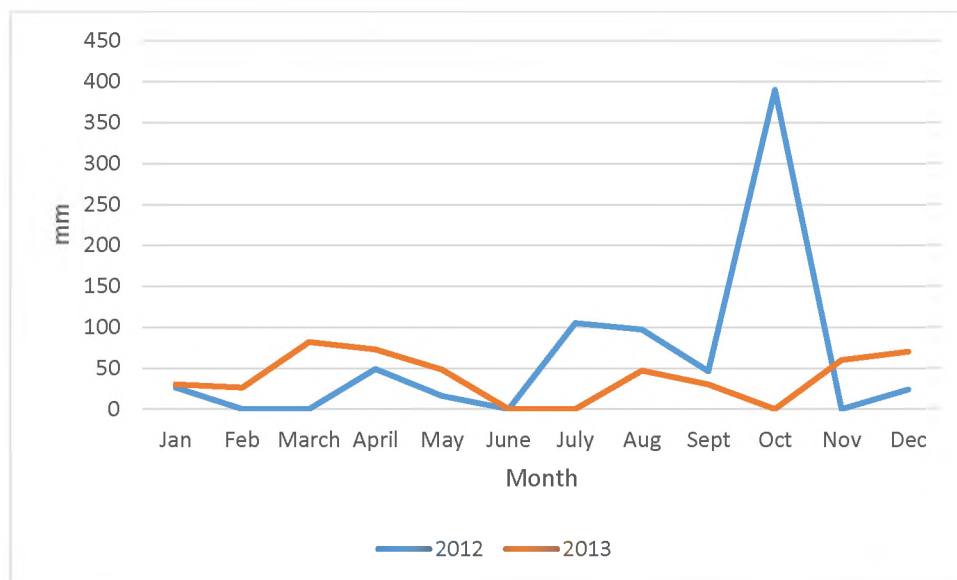


Figure 5.8: Annual rainfall for 2012 and 2013

5.2.2.2 Value of water

The average value of water per m³ of water utilises the entire water footprint value per year, as seen in table 5.15. However, a value per water footprint indicator can also be investigated per annum. The following section provides the average values of green water for pastures and the grey water footprint of fertilizer.

The average cost of pasture grey water per m³ of water, as calculated in table 5.17, utilises fertilizer costs as a proxy for the total cost of grey water per annum. From these results, the costs of pasture grey water per cubic metre were calculated fall between R36.00 and R59.00

per m³ grey water. This measure is beneficial as it can quantify the cost of pollution per cubic meter.

Table 5.17: *The average cost of pasture grey water per m³ (2011-2015)*

	2011	2012	2013	2014	2015
WF (m ³)	15 779	15 781	15 776	15 774	15 776
Fertilizer costs	R758 120,99	R798 952,37	R574 043,97	R690 195,04	R931 226,52
R/m ³	R48,05	R50,63	R36,39	R43,75	R59,03

**base 2010 prices*

No explicit costs were made available regarding pasture. Thus, the average value of pasture green water per cubic metre was calculated in table 5.18 by using the average value of water per m³ of water calculated in table 5.15. This is also known as the economic land productivity of dryland pasture (ELP). Through this calculation, the suggested average value of green water lies between R3 000 and R3 500 per tonne of pasture. The values found in table 5.18 can thus be used to determine the overall economic value of the dryland pastures (see section 4.2.3.2), as found in table 5.19.

Table 5.18: *The Economic Land Productivity of pasture m³*

	Pasture green WF (m ³ /ha)	Average value of water (R/m ³)	Average value of the green WF of pasture (R/ha)	Average value of the Green WF of pasture (ELP) (R/tonne)
2011	4 955	R10,87	R53 844,45	R3 365,28
2012	4 685	R11,56	R54 152,38	R3 384,52
2013	3 900	R12,66	R49 362,24	R3 085,14
2014	3 755	R15,05	R56 494,01	R3 530,88
2015	3 506	R14,49	R50 786,77	R3 174,17

**base 2010 prices*

Table 5.19: *The economic value of green water on dryland pastures*

	Average value of the green WF of pasture (R/ha)	Economic value of 210ha dryland pasture green water
2011	R53 844,45	R11 307 334,93
2012	R54 152,38	R11 371 999,02
2013	R49 362,24	R10 366 070,34
2014	R56 494,01	R11 863 743,15
2015	R50 786,77	R10 665 220,92

**base 2010 prices*

Founded on the above calculations, the value of green water for pasture production alone has an economic value of approximately R11 million per annum for dryland pasture with the lowest economic land productivity occurring in the driest year (2013).

5.2.2.3 Water productivity

In a similar vein to the calculations utilised in table 5.18, to calculate the total economic land productivity for dryland pasture per hectare in table 5.19, and the economic water productivity of milk production is presented in table 5.20. The EWP of milk production was calculated by utilising the producer price of milk and milk production for the years 2011 to 2015, at base 2010 prices. Economic water productivity (EWP) of dairy production is illustrated in table 5.20 and calculated as the ratio of the value of milk yield (litres) at base 2010 prices, to the total water footprint (blue and green water) (m³) of the dryland dairy enterprise.

Results of the total EWP per annum highlight the inverse relationship which exists between water productivity and the water footprint (Mekonnen and Hoekstra 2014b). This relationship is illustrated in table 5.20, indicating that the years experiencing higher water footprints express lower EWP and vice versa with those experiencing lower water footprints. These values provide insight into the economic benefit of water use within the dryland dairy industry. As illustrated, 2015 has both the lowest total (blue + green) water footprint and the highest EWP. By assessing variables contributing to the enterprise this result is assumed to be due to favourable rainfall along with good milk production yields, and a favourable combination of bought in concentrates and dryland pasture grazing.

Table 5.20: *The economic water productivity of dryland milk production (2011-2015)*

	Milk production (litres)	Price milk (R/Litre)	Total WF (m ³)	EWP (R/m ³)
2011	4 924 042	R2,99	1 339 359	R10,99
2012	4 840 688	R3,13	1 294 227	R11,70
2013	4 320 738	R3,28	1 104 891	R12,84
2014	4 492 356	R3,62	1 066 495	R15,27
2015	4 768 649	R3,16	1 023 887	R14,71

**base 2010 prices*

5.2.2.4 Value of milk-to-costs ratio

An alternative measure to EWP is the use of the value of milk-to-costs ratio (see equation 18 of section 4.3.3.2) in order to compare the value of milk output for R1.00 worth of costs. The profit potential of the dryland enterprise. Table 5.21 expresses the value of milk-to-costs ratio

and indicates that on average, approximately R1.00 worth of costs generates between R1.80 and R2.06 value of milk. This outcome indicates that the enterprise is able to cover a significant proportion of its major costs.

Table 5.21: The value of milk-to-costs ratio (2011-2015)

	2011	2012	2013	2014	2015
Value of milk production	R14 725 860,96	R15 141 944,50	R14 184 270,55	R16 282 757,46	R15 060 225,27
Total costs	R7 476 154,92	R7 866 410,84	R7 861 438,71	R7 920 785,82	R8 016 739,84
Milk value:cost Ratio	1,97	1,92	1,80	2,06	1,88

**base 2010 prices*

5.2.3 Water risk assessment

Through the water risk procedure dictated by the Water Risk Filter tool, the following section will assess the physical, regulatory and reputational risk for the basin and company related risk of Glen Dye dairy farm.

The overall portfolio risk of the dryland enterprise is illustrated in figure 5.9. This figure suggests that the enterprise faces higher basin related risk than company related risk, with an overall low to moderate portfolio risk. In conjunction with the results found in figure 5.10, the dryland farm experiences low physical water risk, and moderate to high regulatory and supply chain risk. The basin in which the farm resides faces a few water risks of its own, particularly in terms of water quality and governmental regulation (see Appendix I for full report).

5.2.3.1 Basin related risk

Basin related risk was calculated by the Water Risk Filter according to the farm's location. As stated by the report provided by the WRF, the basin in which Glen Dye is situated, experiences physical water risks such as a very high risk of predicted climate change impact on sea levels, along with a potential water resource shortage in the medium term, moderate risk of surface water contamination, and moderate vulnerability of water ecosystems. Regulatory risk varies between some and very high risk. The high regulatory risk of this basin is characterised by deficient water strategy in terms of local, national or upstream governance, the basin resides

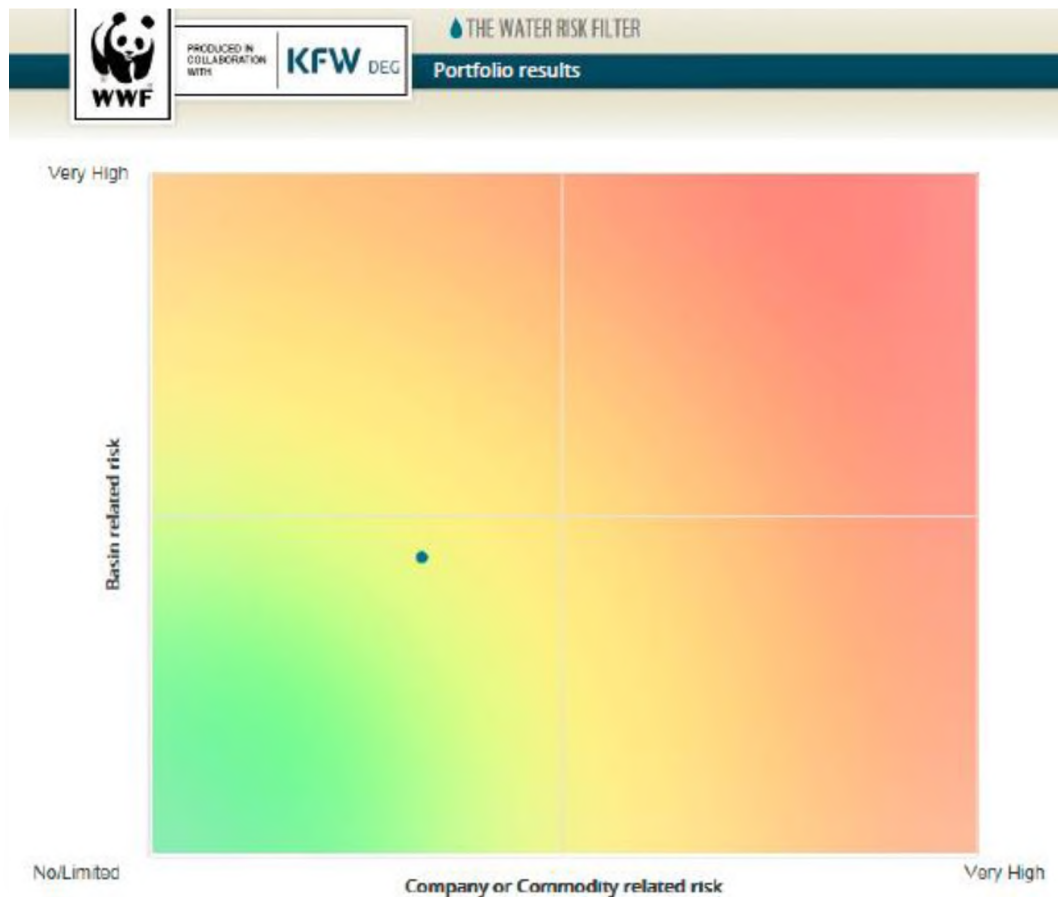


Figure 5.9: Overall portfolio risk for Glen Dye dairy farm
Source: WWF (2016)



Figure 5.10: Company versus basin related risk according to the Water Risk Filter
Source: WWF (2016)

in a municipal area where the municipal functionality is considered non-functioning, and no catchment management agency (CMA) has been established within the area. However, the basin is also characterised by limited threats to biodiversity, limited risk of protest and adequate access to safe drinking water and sanitation.

5.2.3.2 Company related risk

The company related risk values provided in the WRF report were calculated according to a questionnaire filled in on behalf of the dryland dairy enterprise (see Appendix J). Based on the answers provided in the questionnaire, a score and a weighting were attached to the relevant water risk categories. There were issues in the issuing of the final WRF report, as the website was having technical difficulties with the questionnaire. Thus, where results are not accurate due to questionnaire errors, narrative will be provided based on the WRF response recommendations. The results indicate that the farm faces very limited physical risk all round, with no issues in acquiring groundwater for drinking and servicing water purposes, negligible farm pollution values (as per this study), with farm slurry and soil quality being monitored frequently by Woodlands Dairy. However, the farm faces potential risk in the reliance that the farm has on clean freshwater for drinking and servicing water required within the milk production processes. The farm itself faces minimal physical water risk, however, the physical water risk of its suppliers cannot be ignored, where supplying industries for feed and concentrates tend to be water intensive and involve some level of pollution as a result of irrigation practices. This risk may be mitigated using alternative suppliers should the need arise to attain feed ingredients from areas which face lower water scarcity.

In terms of regulatory risk, although the farm has not been penalised for any significant breaches of discharge within the last five years, the enterprise is at risk with regards to its slurry pit compliance and recent requirements for the application of a waste water licence within the near future. As the farm falls under Woodlands Dairy, the farm itself has little reputational risk, rather Woodlands Dairy carries this risk. As a result, all farms which belong to Woodlands Dairy are considered water stewardship stakeholders, illustrating potential water use efficiency and improvement through water stewardship programs under the Woodlands Dairy banner.

5.3 Response formulation

Various research on dairy production and water use efficiency provide recommendations primarily focussed at farm management techniques and water productivity values (Meissner et al., 2013), such as feed sourcing, drinking water provision and water conservation techniques (Peden et al., 2009). The following responses and suggestions have been made according to the values found in the accounting phase and the sustainability assessment. These pertain to the values of the accounting results, and economic and environmental sustainability of the dryland pasture based enterprise, with respect to the Q20A catchment and Woodlands Dairy.

The values determined in the accounting phase follow those which were found in the case studies assessed in section 2.2. The results highlight that the green water footprint is the largest water footprint contributor, as stipulated by Mekonnen & Hoekstra (2010b) for the water footprint of grazing animal product production systems. Other water footprint assessments of dairy production support this finding (Drastig et al., 2010; Palhares and Pezzopane 2015; Scheepers and Jordaan 2016), where these studies all found that the green water footprint contributed most significantly, and the grey water footprint contributed least significantly to the overall water footprint of dairy production.

The results found in the water footprint accounting phase did not match those expected. The research predicted that the water footprint of dryland pastures would be higher in wetter years, and lower in dryer years. However, due to the nature of the green water footprint calculation for pasture production, the overall water footprint for the driest year (2013) was higher than the wetter years which followed. Based on the WFA values in the water footprint accounting phase, the values for EWP followed the theory stipulated in the literature, indicating an inverse relationship to the water footprint. Furthermore, the economic land productivity indicated a direct relationship between the value of pasture and the water footprint, where wetter years had a higher valued pasture compared to dryer years. These results comply with the correlation between milk production and annual rainfall, which indicate a direct correlation between milk production values and the total rainfall per annum.

The values found in the water footprint accounting phase can also be used to provide recommendations as to freshwater allocation within the various enterprise processes.

Through inference of the final water footprint calculation per production process, per annum, the areas in which water use efficiency could be promoted, and have a significant impact, would be through the alternative sourcing of feed and concentrates, as drinking and servicing water make up a small proportion of the overall water footprint. However, both bought in variables would not change their water footprint values, but rather their water scarcity indices according to the area in which these variables are sourced. In terms of on-farm water conservation, the dryland farm relies primarily on rainfall, with ground water abstraction contributing minimally to the overall water footprint, within a quaternary catchment which faces little water scarcity risk. This suggests that water conserving techniques are not necessary, but should be encouraged where possible.

In terms of grey water, and the pollution of surface and groundwater resources, as it stands currently, the effluent captured on farm within the slurry pit does not meet acceptable standards in terms of the effluent quality standards stipulated in the National Water Act. As a result, the farm should try to improve the quality of their slurry pit in order to meet national waste water requirements. According to Woodlands Dairy, the company has taken to informing its suppliers regarding the company's engagement with the DWS, and has recommended to the respective farmers to begin the process of registering their waste water. This issue is both a challenge and time-consuming process for farmers, and as of yet has not been enforced or regulated, and so most farmers are waiting for enforcement from the DWS before taking action to this regard (Galloway, 2016b).

South Africa has one of the most progressive water Acts in the world (Seago, 2016), however, as made evident from the sustainability assessment, the predominant water risk associated with Glen Dye dryland dairy enterprise, basin and business related, is the risk associated with governance and regulation. As made evident in the water risk assessment, there is no CMA present within the catchment area, there is little to no water governance within the area, and the Ndlambe municipality is considered non-functioning. This poses the question "who should be responsible for the implementation and the regulation of water resources if local governance is not performing its mandate as according to the National Water Act (Act 36 of 1997)?" The answer, as suggested by the WWF, is water stewardship.

According to the Water Risk Filter, there is no agreed definition for water stewardship, however, it is a term which is being used increasingly by businesses and non-governmental

organisations. This term is used to describe the actions taken by private entities to promote efficient and sustainable water use along supply chains, and within the bounds of internal operations. The term water stewardship recognises that the management of water resources requires the input of both internal and external entities for the management of public resources, which historically has been left to governmental organisations. Business risk of poor quality and scarce freshwater resources is a fundamental risk which is thus recognised through the incorporation of water stewardship as part of a business' strategy. Through water stewardship actions, starting from water awareness, stewardship may result in influence on freshwater governance, as depicted in figure 5.11. (WWF, 2016). Once a farmer is able to look at his/her own water use in agricultural production, they can then become involved in the broader catchment issues and engage in the management of freshwater resources within that catchment (WWF, 2014).

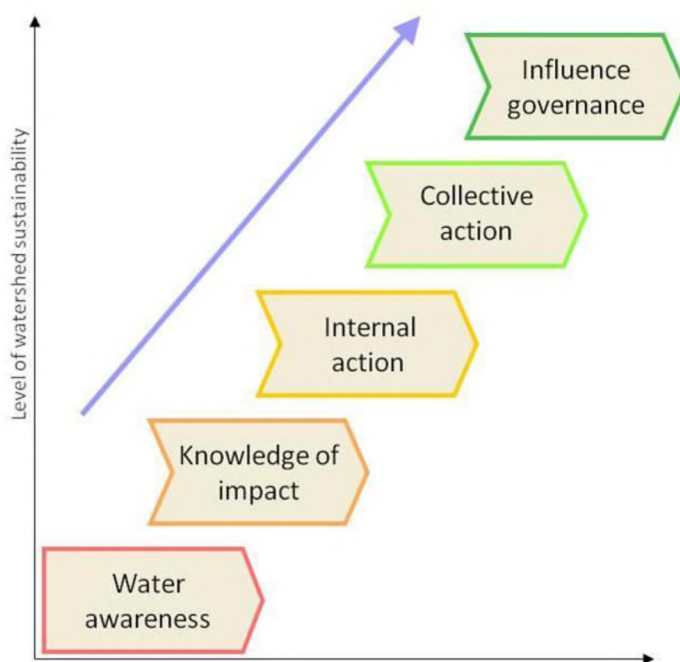


Figure 5.11: Levels of water stewardship

Source: WWF (2016)

Woodlands Dairy, to which Glen Dye produces, promotes environmental sustainability. The company has introduced carbon footprint assessments to all of the company's suppliers, and is in the process of developing water use strategies. This can be seen as a positive attempt by the company to instil a water stewardship network with all respective dairy farms which produce milk for the company (Galloway, 2016b). Thus, a recommendation to Woodlands

Dairy would be to implement water awareness campaigns among its suppliers, and build a water stewardship network under the guidance of the company. In doing this, both dryland and irrigated farming systems may become more water efficient, fall within the regulation standards as stipulated by the National Water Act, and promote equitable and sustainable allocation of freshwater resources.

In terms of the quaternary catchment in which Glen Dye resides, one could recommend the development of a water stewardship group or organisation among farmers in the area. However, as stipulated by the WWF (2014), the first step is for individual farms and stakeholders to become water aware. The promotion of this initial awareness may require external promotion from researchers, non-governmental organisations, or fellow farmers within the area.

CHAPTER 6
CONCLUSION

The objective of this research was to determine the water footprint of dryland pasture based dairy enterprise in the Eastern Cape, with reference to a specific case study, whilst focusing on the economic implications of the water footprint. To address this objective, this research assessed the respective water footprint theory within the literature review, assessed the environmental and market related context of dairy in South Africa, following which, performed a water footprint assessment on the case study dairy enterprise with focus on environmental and economic sustainability.

The aims of the literature review (chapter one) were to address the theoretical frameworks of the water footprint, various case studies which incorporated the water footprint methodologies, and the economic application of the water footprint. The water footprint provides insights into water use and management through the use of quantitative water indicators, which prove beneficial in evaluating the impact of freshwater use and abstraction within the hydrological cycle. This thesis assessed the two primary water footprint methodologies, the water footprint assessment and the life cycle assessment, within the theoretical frameworks section 2.1. Through analysis, the water footprint assessment was determined to be the most suitable methodology for assessing the water footprint of dryland pasture based dairy enterprises, due to the methodology's inclusion of a green water indicator. Further benefits of utilising this methodology included the relevance the WFA places on the context of water consumption, and the sustainability and response formulation phases' ability to interpret the value of the volumetric water footprint. These benefits were further emphasised in terms of the context of research within the case studies segment of the literature review (2.2), where it was found that green water is considered an integral component of all agriculture. Dairy production was found to require a green water footprint indicator, as blue water only contributed minimally to the overall water footprint of milk production in many studies focussing on the water footprint of dairy production. Following both the theoretical framework (2.1) and the case studies (2.2), section 2.3 assessed the economic application possibilities of the water footprint. Such applications included water productivity, the value of virtual water, business related water risk, and water scarcity.

Dairy production is economically important in South Africa. The industry contributes R15bn towards the annual agriculture GDP and provides both direct and indirect employment throughout the dairy value chain. However, there are many environmental risks associated with dairy production, particularly the water use within the industry. For various socio-economic reasons, this research determined that targeting consumers to reduce this water use through consumer behaviour, is not a viable option within South Africa. Rather water use strategies should focus on the development of water use efficiency measures by farmers. This, however, comes with its challenges as the dairy industry faces other socio-political challenges such as trade liberalization externalities, price uncertainty and the pressures of labour costs.

South Africa has one of the best national water acts in the world, however as made evident in the background and results chapter, the issues of water scarcity and water quality lie in the implementation of the National Water Act. Water is a scarce good because it carries opportunity costs, where the benefits have been forgone towards alternative uses. This scarcity highlights the importance of addressing the imbalances between the supply and demand for freshwater resources under prevailing institutional arrangements and infrastructural conditions (Hoekstra et al., 2012; Schyns et al., 2015).

The Eastern Cape faces many water quality issues, providing grounds for the necessity to address water pollution contributors, particularly within the agricultural sector. Within the agricultural sector of the Eastern Cape, milk production dominates the coast line of the province. It was on this basis, and the information found on the literature review, that this thesis aimed to perform a water footprint assessment of dryland pasture based dairy enterprise in the Eastern Cape.

The topic of this thesis was approached by implementing the four phases of the WFA based on a dryland dairy enterprise as a case study. The specifics of this farm were addressed throughout the study area (section 3.7) and later the methods and results chapters.

The accounting phase of the WFA approached the overall WF of pasture based dairy enterprises by utilising the chain summation approach through the summation of the water footprints of contributing water consuming processes within the enterprise. These processes included pasture production, bought in feed and concentrates, drinking water and servicing

water. Overall observations of the water footprint accounting results included a high green water footprint which contributed approximately 80% per annum towards the overall dryland WF for the period 2011-2015, and the largest contributing factors to the blue water footprint of the enterprise were bought in feed and concentrates. The grey water was found to have minimal contribution towards the overall water footprint with approximately 1% contributed to the overall water footprint per annum. Other interesting results found in the water footprint accounting phase included the values found in the WF of pasture production. The research provided in the literature review implied that the water footprint of dryland pastures would be higher in wetter years and lower in the dryer years, however due to the nature of the water footprint calculation this was not the case. Through inference of the final water footprint calculations per production process, the only areas in which water use efficiency could be promoted and have a significant impact, would be through alternative sourcing of feed and concentrates. However, both of these bought in variables would not change their water footprint values, but rather their water scarcity indices according to the area in which these variables are sourced.

The sustainability assessment phase of the WFA addressed the values found in the accounting phase by highlighting both environmental and economic sustainability implications of the water footprint of dryland pasture based dairy enterprises. In doing so, the sustainability assessment assessed the grey water footprint, production theory, the economic values of pasture, as set out in the methods chapter 4. Both the economic land and economic water productivity indicators highlighted the relationship between the water footprint and economic value. The economic land productivity of the pastures was found to be higher in wetter years, and lower in dryer years, and the economic water productivity values found in the assessment reflected the inverse relationship between the water footprint and economic water productivity, both water productivity indicators in line with the literature findings.

The environmental sustainability assessment, of the sustainability assessment phase, indicated that water quality standards, particularly of on-farm effluent, serve as the largest threat to the environment. This not only presents risk to the catchment, but regulatory risk to the farm, should the farm's effluent be investigated. Thus, the recommendations provided in the response formulation phase suggested that the respective farmers begin the process of registering their waste water. However, this issue is both a challenge and time-consuming

process for farmers, and yet has not been enforced or regulated, and so most farmers are waiting for enforcement from the Department of Water and Sanitation before taking action.

The water footprint is not the only water efficiency measure utilised day to day. This water measurement tool allows for the measurement of water consumption within local context. The WF is a relatively new method, with its establishment in the early 2000s and thus is still facing teething problems. One such weakness includes the measurement's applicability on a small scale. This is because the methods primary focus is on catchment level sustainability. The blue and green water sustainability indicators fail to show significant environmental impacts of individual water users, such as the dryland dairy enterprise in this case study, and so other sustainability indicators need to be included to formulate a small-scale sustainability profile. Such a profile incorporates the company related risk associated with water use. There are no methods as of yet which do this within the Water Footprint Assessment system, however, the need to consider business related risk has been highlighted in the water footprint's economic application to business (see 2.3.4).

The Water Risk Filter tool is the ideal tool to utilise in conjunction with the WFA to formulate an overall sustainability profile for an individual enterprise. This tool enables any user to calculate their company relate water risk within South Africa, and map this risk according to water risk guidelines for physical, reputational and regulatory risk. This tool serves both individual water users and large companies with multiple operational sites, allowing for a detailed overview of the respective catchments as well as the individual enterprise.

South Africa has one of the most progressive national water acts in the world, however water scarcity within agriculture is being perpetuated by poor regulation. With reference to the case study, a catchment management agency has not been put in place, the Ndlambe municipality is non-functioning, and effluent dam requirements are not being enforced. This signals that the responsibility for water scarcity management lies with the water user. This has possible negative implications such as furthering the pre-national water act agenda of many farmers based on riparian rights. Such a scenario could result in the perpetuation of the Eastern Cape's current water scarcity problem along with issues of accessibility of water for small scale emerging farmers. The alternative possibility requires the cooperation of individual water users to manage water availability within catchment areas through water stewardship programs.

This research focussed solely on compiling a case study report for one dryland pasture based dairy enterprise in the Eastern Cape. This limits the study's overall contribution to the water footprint beyond providing an example of its application within the dairy industry and in South Africa. Recommendations for future research include the application of the methods developed in this thesis to compare multiple dryland pastures, after which water use efficiency recommendations can be made through the comparison of different dryland farms. The farm which was assessed in this research is considered to run efficiently under a well-structured system, and as such could be used as a reference case study for other dryland studies as a benchmark for water use efficiency within dryland pasture based dairy enterprises. Government regulation and intervention seem to be lacking within water scarcity management, and so it is recommended that future research focusses on water stewardship practices as an alternative form of water resource management with respect to its efficiency outcomes as well as cost-benefit analysis.

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APPENDICES

APPENDIX A

A1: Carbon footprint assessment 2013

Glen Dye (2013)	
Scope 1: Mechanical Sources	
Mobile Sources	32.1
Stationary Fuels	0.3
Fugitive Emissions	0.0
Scope 1: Non-Mechanical Sources	
Enteric Fermentation	4187.9
Manure Management (CH ₄)	1298.4
Direct N ₂ O (Manure Management)	703.6
Indirect N ₂ O (Manure Management)	12.5
Crop Production	229.9
Crop Residue Management	0.0
Waste (Onsite Incineration)	TM 1.7
SUB TOTAL (Scope 1)	6466.4
Other Direct	
Fugitive Emissions (Non-Kyoto Ga	36.2
Scope 2	
Electricity	340.1
SUB TOTAL (Scope 1, 2 & Other)	
	6842.7
Scope 3	
Feed (Outsourced)	1652.2
Outsourced Freight Transport - In	44.9
Fertilizer Production	78.1
Pesticide Production	4.7
Contractors (Indirect Energy)	1.1
SUB TOTAL (Scope 3)	1781.0
TOTAL	
	8623.7

APPENDIX A

A2: Carbon footprint assessment 2014

Glen Dye (2014)	
Scope 1: Mechanical Sources	
Mobile Sources	26.8
Stationary Fuels	0.5
Fugitive Emissions	0.0
Scope 1: Non-Mechanical Sources	
Enteric Fermentation	3766.1
Manure Management (CH ₄)	554.1
Direct N ₂ O (Manure Management)	613.5
Indirect N ₂ O (Manure Management)	4.6
Crop Production	216.5
Crop Residue Management	0.0
Waste (Onsite Incineration)	1.7
SUB TOTAL (Scope 1)	5183.9
Other Direct	
Fugitive Emissions (Non-Kyoto Gases)	0.0
Scope 2	
Electricity	346.8
SUB TOTAL (Scope 1, 2 & Other)	
	5530.7
Scope 3	
Feed (Outsourced)	1498.8
Outsourced Freight Transport - In	23.6
Fertilizer Production	73.5
Pesticide Production	0.0
Contractors (Indirect Energy)	5.9
SUB TOTAL (Scope 3)	1601.8
TOTAL	
	7132.6

APPENDIX A

A3: Carbon footprint assessment 2015

Glen Dye (2015)	
Scope 1: Mechanical Sources	
Mobile Sources	26.8
Stationary Fuels	3.2
Fugitive Emissions	0.0
Scope 1: Non-Mechanical Sources	
Enteric Fermentation	4197.1
Manure Management (CH ₄)	593.5
Direct N ₂ O (Manure Management)	631.8
Indirect N ₂ O (Manure Management)	4.7
Crop Production	159.2
Crop Residue Management	39.8
Waste (Onsite Incineration)	1.7
SUB TOTAL (Scope 1)	5657.7
Other Direct	
Fugitive Emissions (Non-Kyoto Gases)	18.1
Scope 2	
Electricity	389.7
SUB TOTAL (Scope 1, 2 & Other)	
	6065.5
Scope 3	
Feed (Outsourced)	1793.9
Outsourced Freight Transport - In	31.9
Fertilizer Production	62.6
Pesticide Production	0.0
Contractors (Indirect Energy)	5.9
SUB TOTAL (Scope 3)	1894.3
TOTAL	
	7959.8

APPENDIX B

APPENDIX B:

The following table illustrates the qualitative method used in the Tier 1 grey WF accounting in order to calculate the leaching-runoff fraction of nitrogen. Factors which influence this calculation include environmental factors and agricultural practices. These factors are weighted (W_i), according to factor importance, against a score (S_i) (between 1 and 0) for leaching run-off potential and summed together to form a leaching-runoff percentage. Where values are unknown this method assumes the related score of 0.5.

Table D1: Leaching-runoff potential of nitrogen calculation for the grey water footprint of dryland pastures

Category	Factor		Leaching runoff potential	Very low	Low	High	Very high
			Score (s_i)	0	0,33	0,67	1
			Weight (w_i)				
			Leaching-runoff fraction (α)= $\sum S_i * W_i$				
Environmental factors	Atmospheric input	N-deposition (g N m ⁻² year ⁻¹)	10	<0,5	>0,5	<1,5	>1,5
	Soil	Texture (relevant for leaching)	15	Clay	Silt	Loam	Sand
		Texture (relevant for run-off)	10	Sand	Loam	Silt	Clay
		Natural drainage (relevant for leaching)	10	Poorly-very poorly drained	Moderately-imperfectly drained	Well drained	Excessively-extremely drained
		Natural drainage (relevant for run-off)	5	Excessively-extremely drained	Well drained	Moderately-imperfectly drained	Poorly-very poorly drained
	Climate	Precipitation (mm)	15	0-600	600-1200	1200-1800	>1800
Agricultural practice	N-fixation (kg/ha)		10	0	>0	<60	>60
	Application rate		10	Very low	Low	High	Very high
	Plant uptake (crop yield)		5	Very high	High	Low	Very low
	Management practices		10	Best	Good	Average	Worst

Source: Franke et al. (2013)

APPENDIX C

APPENDIX C:

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P O Box 684
Somerset Mall,
7137

Vat Reg. Nr. 4200161414

Certificate of Analyses

Report No.: WT3317

Craig Galloway
Woodlands Dairy
PO Box 4
Humansdorp
6300

Water Analyses Report

Date received: 15/03/2016

Date tested: 16/03/2016

Reference No.	Lab. No.	Na mg/l	K mg/l	Ca mg/l	Mg mg/l	Fe mg/l	B mg/l	Mn mg/l	Cu mg/l	Zn mg/l	NH ₄ -N mg/l	NO ₃ -N mg/l	Temperature at reception (°C)	Date Sampled
Glen Dye Solids	3317	672.48	347.56	211.82	125.04	0.26	0.38	0.199	0.152	0.053	379.800	0.186	21.6	10/03/2016
Glen Dye Liquids	3318	719.10	309.82	233.68	144.85	0.46	0.48	0.209	0.184	0.146	346.700	0.145	21.7	10/03/2016

Order no.: 173244

Statement: The reported results may be applied only to samples received. Any recommendations included with this report are based on the assumption that the samples were representative of the source from which they were taken.

Sample temperature at reception is stipulated in the results table. Ideally the sample(s) should reach the laboratory within 6 hours, or be kept at <10°C and delivered within 24 hours. If these conditions are not maintained, analysis will proceed but interpretation of the results generated is at the clients own discretion.

Samples received in good condition.

23-03-2016
Date Reported


Dr. Pieter Raath
PhD/Agric. (Soil Science)
General Manager

APPENDIX D

APPENDIX D:

Concentrate value calculations

$$2150t = \sum_{a=1}^3 \frac{\text{Ratio value}_{a,2015} * \text{kg Concentrates}_a}{WT_{2015}}$$

.....[H1]

We can also find the total concentrates in tonnes per cow type a by dividing the product of the ratio value for cow type a and its estimated kg concentrates by the total weighted value (2015), and further divided by the number of cow type a in year 2015 as expressed in equation []

$$\text{Concentrates (tonnes)}_a = \left(\frac{\frac{\text{Ratio value}_{a,2015} * \text{kg Concentrates}_a}{WT_{2015}}}{\text{No cows}_{a,2015}} \right)$$

.....[H2]

Using the values calculated in equation [], the total concentrate per cow type a for year i is calculated by multiplying the calculated concentrates per cow type a by the number of cow type a in year i. This is illustrated in equation, and the resultant values are found in table (?).

$$\text{Total Concentrates (tonnes)}_{a,i} = \text{Concentrates (tonnes)}_a * \text{No cows}_a$$

.....[H3]

Table H1: Weighted average ratio calculations for kg concentrates per lactating Jersey and Friesland cow, and dry cows (2015)

	Lactating fries	Lactating Jersey	Dry cow
Kg concentrate per cow type	7,5	6,8	2,5
No cows	412	412	123
Cow ratio	3,349593	3,349593	1
Total weighted value			50,39919

Source: Own extrapolation

APPENDIX E

APPENDIX E:**Table H1: Weighted average ratio calculations for milk production per lactating cow type**

Year	Ratio of lactating cows		Weighted percentage			Annual average Milk produced per cow type (kg)		Average weighted milk produced per day (kg)		Average weighted milk produced per cow per day (kg)	
	<i>Friesland</i>	<i>Jersey</i>	<i>Weighted total</i>	<i>Friesland</i>	<i>Jersey</i>	<i>Friesland</i>	<i>Jersey</i>	<i>Friesland</i>	<i>Jersey</i>	<i>Friesland</i>	<i>Jersey</i>
2011	1,499	1	70,126	0,696	0,304	3 561 821	1 559 183	9 758,414	4 271,734	18,985	12,454
2012	1,380	1	66,266	0,678	0,322	3 412 240	1 622 076	9 348,604	4 444,042	17,875	11,726
2013	1,273	1	62,792	0,660	0,340	2 965 641	1 527 926	8 125,043	4 186,099	17,976	11,792
2014	1,173	1	59,536	0,641	0,359	2 996 538	1 675 512	8 209,694	4 590,443	19,547	12,822
015	1	1	53,899	0,604	0,396	2 994 831	1 964 564	8 205,016	5 382,368	19,915	13,064

Source: Own extrapolation

APPENDIX F

APPENDIX F:

Questionnaire

Dear participant,

Please answer all questions. Where certain measurements are not applicable please provide the closest or available values. For example: where annual values are not available as asked in the questionnaire please provide monthly, daily or hourly values and indicate the unit of time used.

Respondent variables

Please fill out the following personal information (this information is for researcher reference only, and will not be published):

Farm name: _____

What type of pasture does the farm consist of? Rain-fed/irrigated and rain-fed: Choose an item.

Participant's name: _____

Participant's association to the dairy farm in question: _____

How long have you (participant) been involved with the dairy farm in question? _____

Date of questionnaire completion: _____

General farm characteristics

The questions below are required in order to capture general information regarding the farm in question. This information include the farm's historical background and its economic standing. These variables are important for this research project as the answers will provide both research area context and provide economic variables, which will be associated and compared with water consumption and milk production statistics.

General variables

What is the area (hectares) of the farm? _____

Where is the farm located? (If you have the exact longitude and latitude geographical points of the farm, please provide these).

Please provide a brief description of the farm's history. (This should include the year of farm establishment, any change in ownership, any changes in farm area, and any other farm product production which occurred before the farm became a dairy farm).

APPENDIX F

What type of milking parlour system has the farm used over the last five years (2011-2015)?

What is the farms association to Woodlands dairy? (Please provide a brief description as well as the number of years the farm has been in association with Woodlands dairy).

Has the farm undergone and carbon footprint assessment? (If yes, please provide the carbon footprint report).

What are the predominant water sources which supply the farm?

Economic variables

Please fill in the following information regarding the farm’s economic variables over the last five years:

	2011	2012	2013	2014	2015
Number of full time workers					

APPENDIX F

Number of part time /seasonal workers					
Farm annual turnover					
Farm annual expenses					
Farm annual profit					

Milk production variables

The water footprint of dairy is dependent on the farm management techniques, livestock numbers, and animal husbandry variables. This includes calving strategies and milk yields. The questions below relate to these variables.

Please provide a brief description of the calving strategies which the farm undertakes.

Please indicate the average number of cows per year, over the last five years, which relate to the tabulated dairy herd characteristics, for both Friesland and jersey cow farm populations. (Where actual values are not available please provide estimates):

	Characteristic	Friesland	Jersey
2011	Calves		
	Heifers (<2 years old)		
	Lactating cows		
	Dry cows		
	Bull(s)		

APPENDIX F

	Total milk produced (Kg milk per year)		
	Milk fat content (%)		
	Milk protein content (%)		
2012	Calves		
	Heifers (<2 years old)		
	Lactating cows		
	Dry cows		
	Bull(s)		
	Total milk produced (Kg milk per year)		
	Milk fat content (%)		
	Milk protein content (%)		
2013	Calves		
	Heifers (<2 years old)		
	Lactating cows		
	Dry cows		
	Bull(s)		
	Total milk produced (Kg milk per year)		
	Milk fat content (%)		
	Milk protein content (%)		
2014	Calves		
	Heifers (<2 years old)		
	Lactating cows		
	Dry cows		
	Bull(s)		
	Total milk produced (Kg milk per year)		
	Milk fat content (%)		
	Milk protein content (%)		
2015	Calves		
	Heifers (<2 years old)		
	Lactating cows		
	Dry cows		
	Bull(s)		
	Total milk produced (Kg milk per year)		
	Milk fat content (%)		
	Milk protein content (%)		

Overhead water use variables

The following questions address all overhead water uses which are not direct water inputs into the production of milk. These variables require approximate averages over the last five years (Please provide estimates where exact data is not available).

Energy

APPENDIX F

What is the farm's average annual petrol/diesel use (Litres per year)? (Please note that if litres per annum are not available please indicate litres in terms of another time frame or petrol/diesel costs rather than quantities).

What is the farm's average annual electricity use (Kilowatts per year)? (Please note that if KWh per annum are not available please indicate KWh in terms of another time frame or electricity costs rather than quantities).

Cleaning

What is the water source utilised for cleaning water?

On average how often is the dairy parlour cleaned per day?

On average how much water is used per dairy parlour cleaning (Litres per cleaning)?

On average how many times per day are the farm's milk tanks cleaned?

On average how much water is used per milk tank cleaning (Litres per cleaning)?

How is cleaning water disposed of once used? (Please write a brief description of water disposal practices).

Pasture production and feed variables

One of the largest contributors to the water footprint of pasture based dairy enterprises is the production and consumption of animal feed. The following questions address these variables from on farm feed production to feeding practices.

APPENDIX F

Feed

Pastoral grazing dry matter intake (Kg per cow)

Dry matter intake (Kg per cow)

Feed ratio of concentrates to roughages

Concentrates (Kg per cow), and concentrates composition

Region of concentrates origin

Bought in feed (Tonnes per year), and feed composition

Region of bought in feed origin

Crop/pasture on farm production

Please answer the following for each type of pasture grass/ crop produced on farm:

Pasture grass/ crop type: _____

Grass/crop area (hectares): _____

Planting dates: _____

Harvesting dates: _____

Annual yield: _____

APPENDIX F

Water variables

What was the average monthly and annual rainfall (mm) for the last five years? (Please provide/attach detailed rainfall data for the last five years (2011-2015)):

	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual Rainfall
2011													
2012													
2013													
2014													
2015													

Farmer perceptions

This segment of the questionnaire is in place in order to gauge the attitudes of dairy farmers on irrigated and dryland pastures as to water scarcity, regulation and the impact of water related variables on the dairy farm in question.

***Instructions:** The following questions are open ended questions. Please answer these questions as honestly as possible.*

Do you feel that climate change has a significant impact on water scarcity? Why?

In your personal opinion, is water scarcity is a major issue in the Eastern Cape?

Is water scarcity is a major issue in the area in which this farm is located? Please elaborate.

How does water scarcity impact the amount of milk produced by your dairy cows?

APPENDIX F

Do you think you need to reduce the amount of water your dairy farm consumes? Why?

Do certain government regulations prevent you from consuming large quantities of water? Which regulations?

Do certain government regulations prevents you from using as much water as your farm needs? Please elaborate.

In your opinion, which is more important to address, the carbon footprint or the water footprint? Why?

On farm milk production has a small water footprint, yes or no?

What farm management techniques could you implement in order to reduce your water footprint?

APPENDIX F

Would you be willing to reduce your water footprint, even if it meant reducing your annual turnover? Why?

Would you purchase water footprint credits (similar to carbon credits) in order to continue as business as usual?

APPENDIX G

APPENDIX G:**Table C1: SAPWAT values and resultant green water footprint of dryland pastures for 2011**

	ET _c	Rainfall	Rain loss	P _{eff}	ET _{green}	CWU _{green}	WF _{green} (tonne)	WF _{green} pasture
January	53	26	10	16	16	160	10	33600
February	46	53,5	0	53,5	46	460	28,75	96600
March	56	94	73	21	21	210	13,125	44100
April	43	58,5	0	58,5	43	430	26,875	90300
May	73	120	54	66	66	660	41,25	138600
June	60	317	254	63	60	600	37,5	126000
July	47	187,5	58	129,5	47	470	29,375	98700
August	65	92,5	28	64,5	64,5	645	40,3125	135450
September	28	29	0	29	28	280	17,5	58800
October	35	29	0	29	29	290	18,125	60900
November	35	127	57	70	35	350	21,875	73500
December	40	60,5	0	60,5	40	400	25	84000

Table C2: SAPWAT values and resultant green water footprint of dryland pastures for 2012

	ET _c	Rainfall	Rain loss	P _{eff}	ET _{green}	CWU _{green}	WF _{green} (tonne)	WF _{green} pasture
January	58	26	0	26	26	260	16,25	54600
February	57	174,5	110	64,5	57	570	35,625	119700
March	27	59,5	0	59,5	27	270	16,875	56700
April	62	49	8	41	41	410	25,625	86100
May	52	16	0	16	16	160	10	33600
June	36	124,5	56	68,5	36	360	22,5	75600
July	78	105	40	65	65	650	40,625	136500
August	48	97	4	93	48	480	30	100800
September	65	46	0	46	46	460	28,75	96600
October	61	390	320	70	61	610	38,125	128100
November	25	21,5	0	21,5	21,5	215	13,4375	45150
December	26	24	0	24	24	240	15	50400

APPENDIX G

Table C3: SAPWAT values and resultant green water footprint of dryland pastures for 2013

	ET _c	Rainfall	Rain loss	P _{eff}	ET _{green}	CWU _{green}	WF _{green} (tonne)	WF _{green} pasture
January	46	30	15	15	15	150	9,375	31500
February	39	26	0	26	26	260	16,25	54600
March	3	82	45	37	3	30	1,875	6300
April	44	73	24	49	44	440	27,5	92400
May	43	48	0	48	43	430	26,875	90300
June	44	13,5	0	13,5	13,5	135	8,4375	28350
July	44	46,5	0	46,5	44	440	27,5	92400
August	26	47	0	47	26	260	16,25	54600
September	42	30	0	30	30	300	18,75	63000
October	67	105,5	39	66,5	66,5	665	41,5625	139650
November	37	60	0	60	37	370	23,125	77700
December	42	70	15	55	42	420	26,25	88200

Table C4: SAPWAT values and resultant green water footprint of dryland pastures for 2012

	ET _c	Rainfall	Rain loss	P _{eff}	ET _{green}	CWU _{green}	WF _{green} (tonne)	WF _{green} pasture
January	64	19,5	0	19,5	19,5	195	12,1875	40950
February	55	136	69	67	55	550	34,375	115500
March	49	71	53	18	18	180	11,25	37800
April	38	124	57	67	38	380	23,75	79800
May	46	44,5	1	43,5	43,5	435	27,1875	91350
June	33	29	0	29	29	290	18,125	60900
July	34	32,5	0	32,5	32,5	325	20,3125	68250
August	37	52	3	49	37	370	23,125	77700
September	33	98	73	25	25	250	15,625	52500
October	56	13	0	13	13	130	8,125	27300
November	20	83	0	83	20	200	12,5	42000
December	45	79	9	70	45	450	28,125	94500

APPENDIX G

Table C5: SAPWAT values and resultant green water footprint of dryland pastures for 2015

	ET _c	Rainfall	Rain loss	P _{eff}	ET _{green}	CWU _{green}	WF _{green} (tonne)	WF _{green} pasture
January	37	41	7	32,8	32,8	328	20,5	68880
February	29	69,5	54	55,6	29	290	18,125	60900
March	25	34	0	27,2	25	250	15,625	52500
April	21	192	178	153,6	21	210	13,125	44100
May	22	11,5	0	9,2	9,2	92	5,75	19320
June	25	76	28	60,8	25	250	15,625	52500
July	35	213	182	170,4	35	350	21,875	73500
August	50	64	47	51,2	50	500	31,25	105000
September	61	61	3	48,8	48,8	488	30,5	102480
October	67	56	0	44,8	44,8	448	28	94080
November	15	98	0	78,4	15	150	9,375	31500
December	15	24	0	19,2	15	150	9,375	31500

APPENDIX H

APPENDIX H:**Table G1: Dairy cow herd characteristics for Glen Dye dairy farm**

	Characteristic	Friesland	Jersey
2011	Calves	92	62
	Heifers (<2 years old)	313	208
	Lactating cows	514	343
	Dry cows	99	66
	Bull(s)	10	6
2012	Calves	166	120
	Heifers (<2 years old)	313	227
	Lactating cows	523	379
	Dry cows	89	65
	Bull(s)	9	7
2013	Calves	124	97
	Heifers (<2 years old)	298	235
	Lactating cows	452	355
	Dry cows	77	61
	Bull(s)	9	7
2014	Calves	80	68
	Heifers (<2 years old)	281	239
	Lactating cows	420	358
	Dry cows	72	61
	Bull(s)	9	7
2015	Calves	175	175
	Heifers (<2 years old)	227	227
	Lactating cows	412	412
	Dry cows	62	61
	Bull(s)	8	8

APPENDIX I

APPENDIX I:



Basin related risk

Risk	№	Score	Indicator	Answer
Physical Risk Scarcity (Quantity)	1	3 Some risk	Water Scarcity and maximum net water depletion	Water resource shortage medium term
	2	1 Very limited risk	Groundwater Scarcity	No shortage
	3	1 Very limited risk	Climate change temperature impact	Very low risk
	4	No data available	Climate change rainfall impact	
	5	5 Very high risk	Climate change sea level change	Predicted sea level impact
	6	2 Limited risk	Meteorological drought index	Moderate risk over a period of 30 years
	7	2 Limited risk	Flood risk index	5 - 10 days with streamflow greater than 2mm/day
Physical Risk Pollution (Quality)	8	3 Some risk	Present ecological status around the facility	Moderate risk of surface water contamination
Physical Risk Ecosystem health	9	1 Very limited risk	Threat to freshwater biodiversity threat around the facility	No river conservation features
	9a	No data available	WWF priority basin	NO
	10	3 Some risk	Vulnerability of water ecosystems in the country	Vulnerable
Physical Risk Dependency on hydropower	11	1 Very limited risk	Dependency on hydropower	No hydropower dependency

APPENDIX I

Risk	N#	Score	Indicator	Answer
Regulatory Risk	12	5 Very high risk	Water strategy of local, national and upstream governments, including drought and flood management plans where appropriate	No strategy
	13	3 Some risk	Sophistication and clarity of water related legal framework	Somewhat sophisticated, strict and subjective
	14	5 Very high risk	Municipal functionality	Not functioning
	15	3 Some risk	Enforcement of water related legal framework	Moderate compliance
	16	5 Very high risk	Establishment of a catchment management agency (CMA)	No CMA established
	Reputational Risk	17	4 High risk	Cultural and/or religious importance of local water sources
18		1 Very limited risk	History of protests	No service delivery Protests
19		1 Very limited risk	Access to safe drinking water	Adequate access
20		2 Limited risk	Access to improved sanitation	Intermediate access

Company related risk

Risk	N#	Score	Indicator	Answer
Physical Risk Scarcity (Quantity)	1	1 Very limited risk	Importance of having sufficient amounts of clean fresh water available for the production/ operational site's operations	Not important at all
	2	1 Very limited risk	Problems the company has/had withdrawing/obtaining the required amount of water for its operations	No
	2a		If yes, please explain:	
	3	3 Some risk	Total annual amount of freshwater withdrawn either directly from a water source or through the municipal supply (m ³ /year)	31035
	3a		Surface (e.g. River/ Lake)	0
	3b		Ground-water	1-10%
	3c		Municipal Supply	0
	3d		Rainwater	91-100%
	3e		Non-freshwater (e.g. saltwater)	0
	3f		Unknown Source	1-10%

APPENDIX I

Risk	N#	Score	Indicator	Answer
	4	1 Very limited risk	Percentage of the total amount of withdrawn water that is recycled or reused (used more than once). Maximum answer for this indicator is 100%	>90%
	4a	-1	Total amount of waste water discharged? (m ³ /year)	16600
	4b		Ocean	0
	4c		Surface (e.g. River/ Lake)	0
	4d		Subsurface/ Well	0
	4e		Off-Site Water Treatment	0
	4f		Other or unknown	91-100%
Physical Risk Pollution (Quality)	5	3 Some risk	Typical level of water pollution caused by this industry	Some pollution
	5a		Average ecotoxicity	1.78
	5b		Average eutrophication	0
	5c		Average acidification	0.0000237
	6	1 Very limited risk	Requirement of treatment/ purification of the water the company withdraws before use in operations	No filtering or purification is required
	7	1 Very limited risk	Percentage of the withdrawn freshwater that is discharged with some level of pollution	<10%
	8	1 Very limited risk	Quality measurements of the water the company withdraws and discharges by the company itself or an external company	Water withdrawal and waste water quality is being measured on at least a weekly basis, and include CO ₂ /BOD, PH and temperature measurements
	8a		If no, please explain:	Farm does not pollute, but rather uses slurry to fertilize fields. Farm looks at soil quality.
Physical Risk Physical risk of suppliers	9	4 High risk	Average water intensity of suppliers to this industry	Supplying industries to the industry are dependent on large amounts of water
	9a		Country of origin of the main supplier(s) to the company	South Africa
	9b		Average direct operations % of total value chain water withdrawals of this industry	27.8%
	9c		Average supply chain % of total value chain water withdrawals of this industry	72.2%
	10	2 Limited risk	Estimated total annual amount of freshwater withdrawn by suppliers to this specific company or facility (m ³ /year)	10.000-100.000 m ³ /year
	11	3 Some risk	Average level of water pollution caused by suppliers to this industry	Some pollution from supplying industries, based on the three pollution indicators

APPENDIX I

Risk	N#	Score	Indicator	Answer
	11a		Average ecotoxicity	2016
	11b		Average eutrophication	0.0000373
	11c		Average acidification	0.0272
	12	1 Very limited risk	Flexibility of the company to change its main supplier(s)	Many alternative suppliers exist and switching is not difficult
Regulatory Risk	13	4 High risk	Compliance of the company to legal waste water quality standards	The company is planning to meet the existing standards within next 5 years
	13a		If company does not meet discharge quality requirements, please explain which elements do not comply (e.g. COD/ BOD/ TSS/ Chemicals/ Temperature/ Metals/ etc.).	NH4-N
	14	1 Very limited risk	Has the company paid any penalties or fines for significant breaches of discharge regulations within the last 5 years?	No
	14a		If yes, please describe the incident(s):	
	15	3 Some risk	Is the company exposed to planned or potential significant regulatory changes?	Changes in water rights or licenses to operate are being discussed
	15a		Other (please specify):	
	15b		Is there a strong enforcement of water related regulations in the area your company operates in?	Strong enforcement in the whole basin
	16	1 Very limited risk	Exposure of this specific facility to local/national media coverage criticizing for a possible water issue	Never
Reputational Risk	17	1 Very limited risk	Exposure of this specific facility to global media coverage criticizing for a possible water issue	Never
	18	2 Limited risk	Does the company know who the other key stakeholders (e.g. communities, other industries, agriculture etc.) are who are dependent on the water supply and quality within the water basin the company operates in?	Yes, company knows some key stakeholders
	19	1 Very limited risk	Importance of the company as a water consumer in comparison to other stakeholders within the river basin (within 50km).	One of the smallest users
	20	3 Some risk	Engagement with other local basin stakeholders like municipalities, governments, companies, farmers and NGOs to solve water-related conflicts and to manage local water resources	Yes, company is reactively engaging with other stakeholders
	20a		If yes, please specify	Farmer community, Woodlands Dairy
	20b		Does an official forum or platform exist in which stakeholders come together to discuss water-related issues of the basin?	Yes, an active forum exists, which is actively engaging all stakeholders to sustainably manage the basin
	20c		If yes, please state the name	All Woodlands Dairy farmers

APPENDIX I

Risk	N#	Score	Indicator	Answer
	21	1 Very limited risk	Involvement in any water-related disputes with other stakeholders in the basin within the last 3 years	No dispute in the last 3 years
	22	3 Some risk	Water policy, strategy and/or management plan of the company	Yes, the company has a very high level water policy, strategy and/or management plan, with no specific measurements or targets
	23	1 Very limited risk	Highest level of responsibility within the company for the policy, strategy and/or plan	CEO and/or Board of Directors
	24	2 Limited risk	Discussions of monitoring of (waste) water quantities and quality within top management	Yes, at least once per quarter
	25	2 Limited risk	Contingency planning to be prepared to respond to water risks, such as supply disruptions, price increases and more stringent regulations	Yes, high level contingency plans have been prepared for all known potential scenarios
	25a		If yes, please specify	Cost reduction strategy
	26	3 Some risk	Water-related actions taken at the operational/ production site in regard of improving its own operations	High level consumption metering and/or discharge metering
	26a		Other (please specify):	
	27	3 Some risk	Significant investments planned within the next 3 years which are related to water issues (e.g. water treatment plant, water recovery, water efficiency)	Yes, minor investments planned
	27a		If yes, please specify	Attainment of waste water licencing
For anonymous bench marking purposes	28		The annual (production) volume of output of this facility	4836055
	28a		Unit	other
	28a		Average amount of withdrawn freshwater needed to deliver or produce 1 unit of product	6.35
	29		The annual (production) volume of output of this facility	
	29a		Average amount of withdrawn freshwater per full time equivalent employee (FTE) per year	
Final comments (for internal use only)	30		If you have any final comments, please add them here	

APPENDIX J

APPENDIX J:



Scores can be generated at a facility specific level by filling in the questionnaire. All answers to the questionnaire can be saved to allow the user to return to complete the questionnaire at another time. You can also send the questionnaire - fully secured - to another user, for example a plant manager, who will be able to enter information on your behalf.

The questions with water drops are direct risk indicators. Other questions do not influence the risk scores, but may help to better understand the water situation of your company. This may be helpful when defining what your company can do to respond to water issues and mitigate some of the risks.

Company related risk

Physical Risk

Risk Indicator

Scarcity (Quantity)

1. Importance of having sufficient amounts of clean freshwater available for the production/ operational site's operations
 Not important at all, Very Important / Vital for operations

2. Problems the company has/had withdrawing/sustaining the required amount of water for its operations
 No

2a. If yes, please explain:
 No data available

3. Total annual amount of freshwater withdrawn either directly from a water source or through the municipal supply (m³/year)
 32,035.47

Please indicate the percentage of the total amount of freshwater that your company withdraws for its production/ operational site per water source:

	0	1-10%	11-50%	51-90%	91-100%
3a. Surface (e.g. River/ Lake)	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
3b. Ground-water	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
3c. Municipal Supply	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
3d. Rainwater	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>
3e. Non-freshwater (e.g. seawater)	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
3f. Unknown Source	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

4. Percentage of the total amount of withdrawn water that is recycled or reused (used more than once). Maximum answer for this indicator is 100%
 >90%

4a. Total amount of waste water discharged? (m³/year)
 16,598.9

Please indicate the percentage of the total amount of waste water that your company discharges into the different receiving



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KFW DEG

THE WATER RISK FILTER

Company related risk results

bodies:

	0	1-10%	11-30%	31-50%	51-100%
4b. Ocean	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
4c. Surface (e.g. River/ Lake)	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
4d. Subsurface/ Well	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
4e. Off-Site Water Treatment	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
4f. Other or unknown	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>

Pollution (Quality)

5. Typical level of water pollution caused by this industry

Some pollution

5a. Average ecotoxicity

1.7785930779

5b. Average eutrophication

0

5c. Average acidification

0.0000237278

6. Requirement of treatment/ purification of the water the company withdraws before use in operations

No filtering or purification is required

7. Percentage of the withdrawn freshwater that is discharged with some level of pollution

<10%

8. Quality measurements of the water the company withdraws and discharges by the company itself or an external company

Water withdrawal and waste water quality is being measured on at least a weekly basis, and include COD/BOD, PH and temperature measurements

8a. If no, please explain:

Farm does not pollute, but rather uses slurry to fertilize fields. Farm looks at soil quality.

Physical risk of suppliers

9. Average water intensity of suppliers to this industry

Supplying industries to the industry are dependent on large amounts of water

9a. Country of origin of the main supplier(s) to the company

South Africa

10. Estimated total annual amount of freshwater withdrawn by suppliers to this specific company or facility (m³/year)

APPENDIX J

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Company related risk results			

10.000-100.000 m3/year

11. Average level of water pollution caused by suppliers to this industry
Some pollution from supplying industries, based on the three pollution indicators

11a. Average ecotoxicity
2,016.1228790673

11b. Average eutrophication
0.0000372755

11c. Average acidification
0.0272259513

12. Flexibility of the company to change its main supplier(s)
Many alternative suppliers exist and switching is not difficult

Regulatory Risk

13. Compliance of the company to legal waste water quality standards
The company is planning to meet the existing standards within next 5 years

13a. If company does not meet discharge quality requirements, please explain which elements do not comply (e.g. COD/ BOD/ TSS/ Chemicals/ Temperature/ Metals/ etc.).
NH4-N

14. Has the company paid any penalties or fines for significant breaches of discharge regulations within the last 5 years?
No

14a. If yes, please describe the incident(s):
No data available

15. Is the company exposed to planned or potential significant regulatory changes?
Changes in water rights or licenses to operate are being discussed

15a. Other (please specify):
No data available

15b. Is there a strong enforcement of water related regulations in the area your company operates in?
Strong enforcement in the whole basin

Reputational Risk

16. Exposure of this specific facility to local/national media coverage criticizing for a possible water issue

APPENDIX J

WWF	PRODUCED IN COLLABORATION WITH	KFW DEG	THE WATERSHED REPORT	Company related risk results
Never				
.....				
17. Exposure of this specific facility to global media coverage criticizing for a possible water issue				
Never				
.....				
18. Does the company know who the other key stakeholders (e.g. communities, other industries, agriculture etc.) are who are dependent on the water supply and quality within the water basin the company operates in?				
Yes, company knows some key stakeholders				
.....				
19. Importance of the company as a water consumer in comparison to other stakeholders within the river basin (within 50km).				
One of the smallest users				
.....				
20. Engagement with other local basin stakeholders like municipalities, governments, companies, farmers and NGOs to solve water-related conflicts and to manage local water resources				
Yes, company is reactively engaging with other stakeholders				
.....				
20a. If yes, please specify				
Farmer community, Woodlands Dairy				
.....				
20b. Does an official forum or platform exist in which stakeholders come together to discuss water-related issues of the basin?				
Yes, an active forum exists, which is actively engaging all stakeholders to sustainably manage the basin				
.....				
20c. If yes, please state the name				
All Woodlands Dairy farmers				
.....				
21. Involvement in any water-related disputes with other stakeholders in the basin within the last 5 years				
No dispute in the last 5 years				
.....				
22. Water policy, strategy and/or management plan of the company				
Yes, the company has a very high level water policy, strategy and/or management plan, with no specific measurements or targets				
.....				
23. Highest level of responsibility within the company for the policy, strategy and/or plan				
CEO and/or Board of Directors				
.....				
24. Discussions of monitoring of (waste) water quantities and quality within top management				
Yes, at least once per quarter				
.....				
25. Contingency planning to be prepared to respond to water risks, such as supply disruptions, price increases and more stringent regulations				
Yes, high level contingency plans have been prepared for all known potential scenarios				
.....				
25a. If yes, please specify				

APPENDIX J



PRODUCED IN COLLABORATION WITH



THE WATER RISK FILTER

Company related risk results

Cost reduction strategy

26. Water-related actions taken at the operational/ production site in regard of improving its own operations

High level consumption metering and/or discharge metering

26a. Other (please specify):

No data available

27. Significant investments planned within the next 3 years which are related to water issues (e.g. water treatment plant, water recovery, water efficiency)

Yes, minor investments planned

27a. If yes, please specify

Attainment of waste water licensing

For anonymous bench marking purposes

28. The annual (production) volume of output of this facility

4,856,066

28a. Unit

other

28b. Average amount of withdrawn freshwater needed to deliver or produce 1 unit of product

6.3910725266

29. The annual (production) volume of output of this facility

No data available

29a. Average amount of withdrawn freshwater per full time equivalent employee (FTE) per year

No data available

Final comments (for internal use only)

30. If you have any final comments, please add them here

No data available