WATER FOOTPRINT AND THE VALUE OF WATER USED IN THE LUCERNE-DAIRY VALUE CHAIN

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DECLARATION

I, Morné Erwin Scheepers, hereby declare that this dissertation that is submitted by me for the degree of Master of Science (M.Sc. Agric.) in the Department of Agricultural Economics, Faculty of Natural and Agricultural Sciences, at the University of the Free State, is my own independent work and has not been submitted by me to any other university. Furthermore, I cede the copyright in this dissertation in favour of the University of the Free State.

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***"The glory of the farmer is that in the division of labours, it is his part to create. All trade rests at last on his primitive activity. He stands close to Nature; he obtains from the earth the bread and the meat. The food which was not, he causes to be."* – Ralph Waldo Emerson**

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ABSTRACT

The main objective of this study was to assess the water footprint to produce lucerne under irrigation, which is then used as an important feed input for the production of milk in order to get an understanding of the volume of freshwater that is needed to provide consumers with pasteurised milk. The financial value that was added to the water that was used to produce milk was also explored in order to get an understanding of how the value of the water increase along the milk value chain from the feed producers to the end consumer.

The study was conducted as a case study in the Free State province of South Africa on a dairy farm that makes use of a zero grazing production system. Apart from producing milk, the agribusiness in the case study also processes the raw milk and sells it to retailers. The main feed ingredients fed to the lactating cows consist of lucerne (from the Vaalharts irrigation scheme), high protein concentrate, sorghum silage, oats silage, maize silage and maize meal.

Calculations of the water footprint of milk were based on the method of the Water Footprint Network (WFN). This method considers three different types of water: blue water is all the surface and groundwater consumed along the value chain, green water is rainwater that does not become runoff, and grey water is the volume of freshwater required to assimilate pollutants to ambient levels.

Lucerne production was explored in detail, using *in situ* data from a secondary source, while the water usage of the other crops was estimated with the use of several formulae. The results show that the water footprint indicator of lucerne production at Vaalharts was 456.6 $m^3.ton^{-1}$. Of this, 206.9 $m^3.ton^{-1}$ of water originates from effective rainfall (green water footprint), 171.3 $m^3.ton^{-1}$ from surface and groundwater (blue water footprint) and the remaining 78.4 $m^3.ton^{-1}$ of water was used to assimilate the salts leached during production to acceptable levels (grey water footprint).

The individual water usage of the process steps along the value chain for milk in South Africa was then combined to obtain the total water footprint to produce one kilogram of milk with an average fat content of 4 per cent and 3.3 per cent protein. It was found that 1 025 litres of water are used to produce one kilogram of milk in the case study. Of the total water used, 862 litres was green water and only 97 litres originated from the use of surface and groundwater (blue water footprint). Water required to assimilate the salts to below threshold levels (grey water) accounted for the remaining 66 litres of water per kilogram of milk production.

Essentially, the aim of water footprint assessments is to determine the environmental sustainability of producing the product under consideration in a specific river basin or catchment area. All the production of feeds for the dairy farm in the case study was done within the greater Orange River basin. The main summer crop production months, apart for November which has a moderate blue water scarcity, have low blue water scarcity. The production of lucerne, maize and sorghum under irrigation in the greater Orange River basin is sustainable in the sense that the production thereof does not significantly distort the natural runoff and environmental flow requirements are met. Of all the feeds, only oats produced under irrigation in the Orange River basin is not sustainable from an environmental water flow requirement perspective. Vast quantities of water are used to produce milk, and although the calculated South African milk water footprint is higher than the global average, the production of milk in the case study is sustainable in that the environmental flow requirement is fulfilled.

Although large volumes of water are used for the production of milk, value is also added to the water along the value chain. The value added on the dairy farm was calculated by dividing the gross margin per kilogram of milk by the volume of water used to produce a kilogram of milk. Once the milk is pumped from the dairy to the processing plant, the value added to the water was used instead of the gross margin, owing to the unwillingness of the role players to make information regarding their cost structures available.

The results show that global water footprint averages and country estimates serve as valuable indicators of freshwater use, but studies that are site-specific are needed to investigate the actual impacts on freshwater resources. Milk production in the South African case study uses more water than the global average and slightly less than the country average estimate for South Africa, but remains environmentally sustainable nonetheless. Importantly, water is not simply used as an input for producing milk, but value is added to the water along the milk value chain.

Evaluating the value added along the value chain found that the total value added depend greatly on the volume of the container in which the processed milk is sold. The processing facility in the case study produced milk in two container sizes, one litre and three litres. It was found that by packaging the processed milk in a bottle with a capacity of one litre, a total value of 12.11 ZAR per kilogram of milk (4% fat, 3.3%

protein) was added. In contrast, milk packaged in three litre bottles only added 9.04 ZAR of value per kilogram.

The value added per cubic metre of water once the processed milk reaches the final consumer was evaluated for the two different product volumes. Despite using the same volume of water during production, the value chain of the smaller container added 11.81 ZAR per cubic metre of water as opposed to the 8.82 ZAR added to the water along the value chain of the three litre bottles. A substantial amount of value was added along the value chain of milk and therefore it might not be an inefficient allocation of scarce freshwater to the dairy industry.

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CHAPTER 1

INTRODUCTION

1.1 Background and Motivation

In 1896 William Jennings Bryan wrote: “Burn down your cities and leave the farms, and your cities will spring up again as if by magic; but destroy the farms and the grass will grow in the streets of every city in the country.” The role of commercial agriculture in a modern society cannot be over-emphasised and therefore we need to keep on improving this sector.

South Africa is water scarce and ranked as the 30th driest country in the world (Department of Water Affairs, 2013). The agricultural sector is crucial for the food security of not only South Africa, but also the neighbouring countries and the broader Sub-Saharan Africa (Department of Agriculture, Forestry and Fisheries, 2011). Rapid population growth and increasing variability in rainfall has led to tighter water supply in many parts of South Africa where the water demand often exceeds the supply (Department of Water Affairs, 2012).

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

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

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

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

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

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

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

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

1.2 Problem statement

Currently there is a limited amount of information available to effectively guide South African policymakers to formulate appropriate policies to guide freshwater use and to assist irrigation farmers' water usage behaviour towards becoming more sustainable.

Internationally, the topic has received some attention where the water footprints of animal products were calculated. Of these animal product studies, several dairy water-use-related case studies have been conducted and most of these calculations were conducted from the Life Cycle Assessment (LCA) perspective (De Boer *et al*., 2012; Manazza and Iglesias, 2012; Ridoutt *et al*., 2010). The LCA considers all the inputs, outputs and potential environmental impacts across the complete life cycle of a product system. A life cycle encompasses all the interlinked and consecutive stages of a product system and thus evaluates the product flows from obtaining the raw natural resources to the disposal of the final product (ISO/TC207, 2014).

Mekonnen and Hoekstra (2010c) have also determined the water footprint of dairy cattle, but they followed the methodology described by Hoekstra *et al*. (2011). The study was based on numerous countries with large herds of livestock, together with a global average. No southern African case study was considered in the study. They did, however, estimate the water footprint of South African dairy products and found that it takes about 1 136 litres of water to produce a single litre of milk with a fat content of 1–6 %.

Furthermore, the water footprint assessment reported above focused only on the environmental impact of water use, with no consideration of the economic aspects thereof. Some researchers have linked the economic aspect to the water footprint. Although they focused on economic productivity studies and did not really assess the water footprint, Jordaan and Grové (2012) applied a method to quantify the cumulative value added to the water along the value chain in order to determine where along the value chain the most value was added to the water. Their focus was on small-scale raisin and vegetable farmers, with no similar research being found on the dairy industry.

Even though the water footprint has been widely used internationally, the usage thereof has been very limited in South Africa. There is thus no scientific information on water footprints available to inform sustainable water use in South African dairy production. Given the importance of the dairy industry in the South African economy, the water footprint information of dairy production is vital for sustainable water use.

1.3 Aims and objectives

The aim of the study is to contribute to the limited body of knowledge by assessing the water footprint of lucerne (*Medicago sativa*) produced under irrigation and used as important feedstuff in the production of milk in South Africa. The complete value chain of milk produced in the Free State province of South Africa will be evaluated to obtain the water footprint of milk production. The final value of the water that was originally allocated towards the production of lucerne will also be explored.

Ultimately, this will be the first step towards establishing benchmarks for the economically and environmentally sustainable use of freshwater in the lucerne-dairy value chain.

The aim of the study will be achieved through the following sub-objectives.

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

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

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

1.4 Scope of the study

Due to the sheer size of the South African lucerne and dairy industries, it will not be feasible to conduct the study on the industries as a whole. The study will therefore be based on case studies. The Vaalharts Irrigation Scheme will be used as a case study for the production of lucerne, while the dairy and processing investigation will be based on a case study within the Free State province of South Africa. The water footprint assessment of the case study will be conducted, but the assessment will focus mainly on the calculation of the water footprint and the sustainability thereof.

1.5 Chapter layout

The context and scope of the study was set in the commencement of this chapter. A detailed explanation of the rationale for investigating the water use along the South African lucerne-dairy value chain was given, followed by the aims and objectives of this study.

After setting of the scene for this study, the literature that guided the manner in which the aims and objectives are achieved will be discussed. Chapter Two investigates the relevance of the South African dairy industry from an economic perspective and evaluates the various components of the value chain. The importance of lucerne as feed input in dairy production is also explored.

Following the justification for investigating the water use of the lucerne-dairy value chain, the theoretical framework of the water footprint assessment is discussed in detail. The concept, together with the various methods for calculating the water footprint, is assessed. A concluding section on water footprinting specifically evaluates dairy-related water use research.

In the final portion of Chapter Two, the economic valuation of the water footprint is addressed. The rationale for adding the economic valuation of the water footprint is explained, after which the relevant research findings is weighed against each other.

After evaluating the different methods in the literature review chapter, the methods used to achieve the aims and objectives are selected. Chapter Three explains the chosen methods in detail, followed by an introduction to the data.

The results of the methods and data chapter are calculated and interpreted in Chapter Four. The water footprints of the various steps of the lucerne-milk value chain in the case study is calculated individually before they are added together to get the final water footprint to produce one litre of milk. In the final sections, the sustainability of the relevant freshwater resources is investigated.

Chapter Five is the summary, conclusions and recommendations chapter. A summary of the first chapter is given to set the scene for the research findings. Following the findings is the final section where the recommendations that emanated from the research are discussed.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Chapter Two provides an overview of the relevant literature on water footprint calculations and the economic evaluation of water along value chains. Firstly, the relevance of the dairy industry is investigated before the importance of lucerne in dairy production is explained. After the scene is set, the theory regarding water footprint accounting is discussed, exploring the different approaches to water footprints and the various calculation methods thereof. In the final section of this chapter, the economic valuation of water along value chains, including the rationale for the calculation thereof, is investigated.

2.2 Dairy industry in South Africa

2.2.1 Relevance of the dairy industry to the South African economy

The dairy industry in South Africa may be considered important from an economic perspective. The dairy industry contributes 7 % of the total gross value of agricultural production in South Africa. If only the animal-derived products are considered, the contribution of the dairy industry increases to about 14 % (DAFF, 2014). Figure 2.1 indicates the contribution of the different animal products to the gross value of animal production in South Africa. It is clear from Figure 2.1 that if only the gross value of animal products are compared, dairy products comprise the most important animal derivative, apart from slaughtered chicken and beef.

DAFF (2012) explains that the dairy industry is also an important earner of foreign exchange. The exports of South African dairy products in 2011 totalled about 44 000 tons, amounting to more than R38 million, which is 24 % more exports by quantity and a 53 % increase in value, in comparison with the dairy exports in 2002.

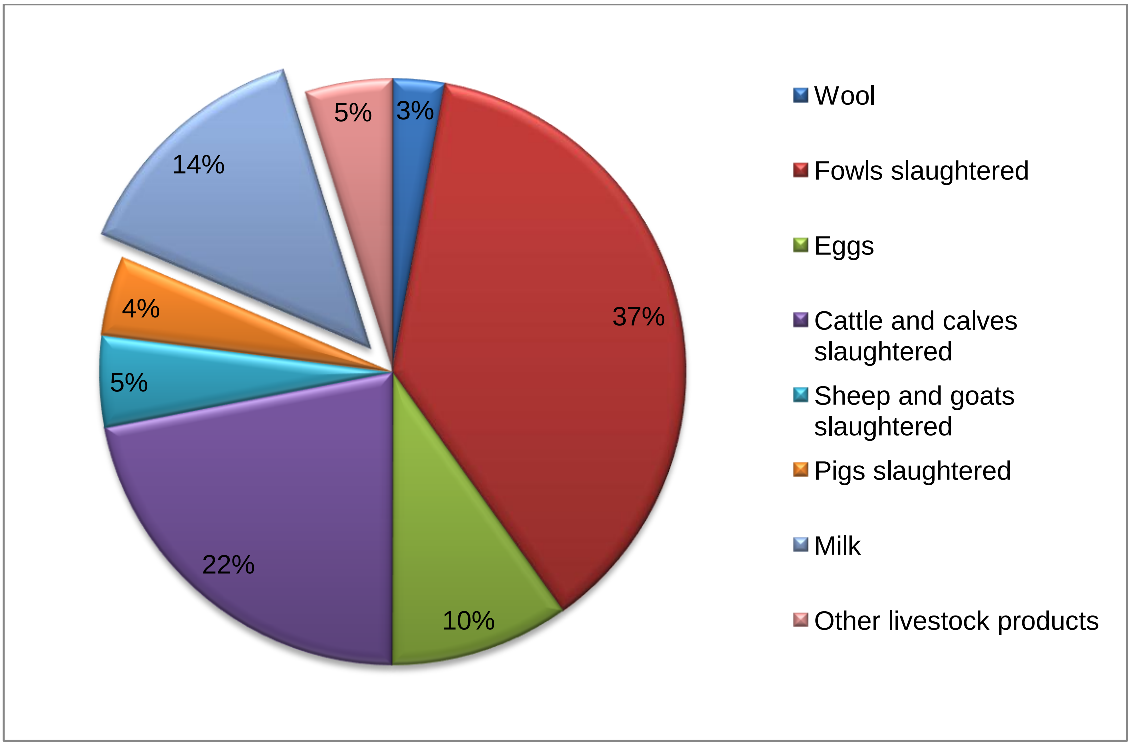


Figure 2.1 The contribution of the different animal products to the total gross value of animal products (Data source: DAFF, 2014)

Dairy consumption has increased over the past decade, with Figure 2.2 indicating the changes in production and consumption during this period. Figure 2.2 shows that the dairy industry has expanded by about 18 % over the past decade, while total consumption of dairy products increased from 1.7 million tons in 2005 to 2.02 million tons in 2013. It is also clear from Figure 2.2 that along with the increase in consumption, the production of dairy products also increased with about 21 % from 2.36 million tons in 2005 to 2.87 million tons in 2013. During the same period, the per capita consumption of dairy products varied between 37 kg and 38.6 kg (DAFF, 2014).

The dairy industry is expected to be one of the fastest growing agricultural industries over the next decade, with the production of fresh milk and dairy products having to increase by an annual average of more than 2.5 % in order to match the sharp increase in consumption (Meyer *et al*., 2013). Meyer *et al*. (2013) continue to explain the demographic changes that are expected to take place over the next decade and predict that by 2020 the annual milk production will have to be around 3.3 million tons in order to meet the demand.

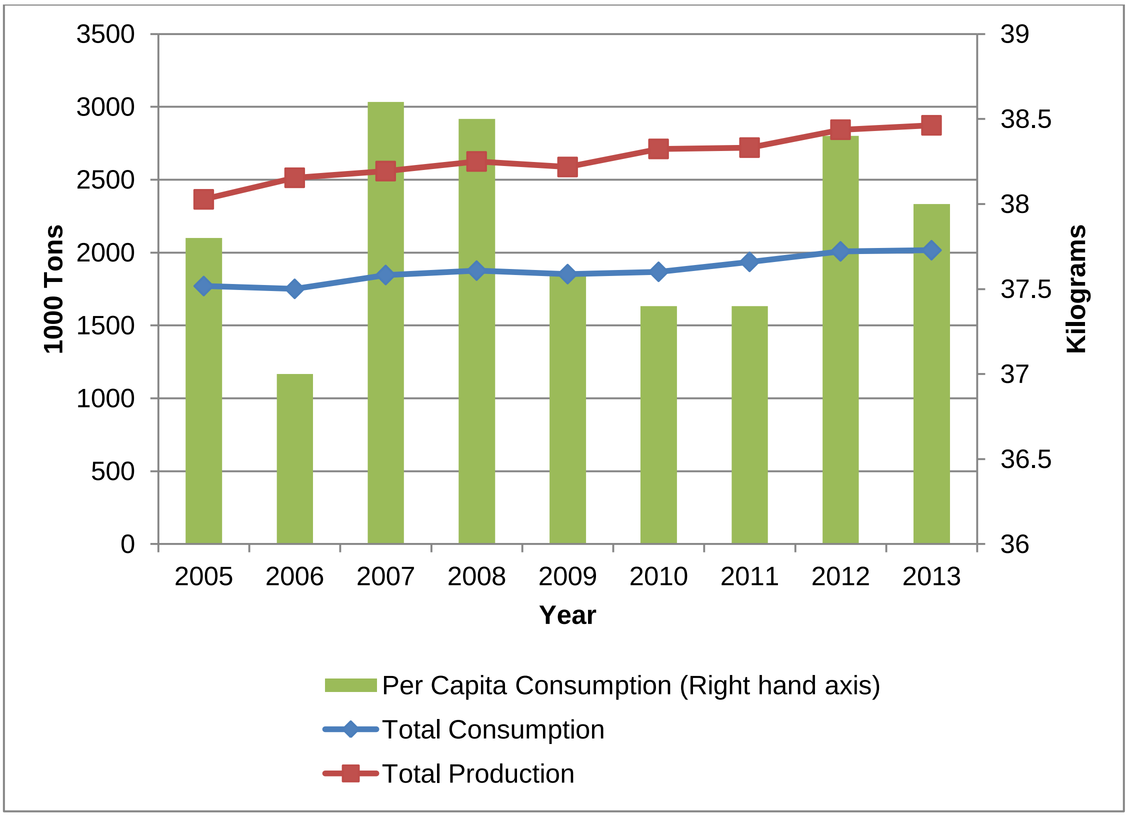


Figure 2.2 Total production, total consumption and per capita consumption of dairy products in South Africa from 2005 to 2013 (Data source: DAFF, 2014)

In addition to its direct contribution to the South African GDP, the dairy industry is also a major source of employment, especially in the rural districts. According to an industry overview of the dairy industry in South Africa, this sector consists of about 4 000 milk producers who in turn provide employment to 60 000 farm workers. A further 40 000 people have indirect employment in the rest of the dairy value chain (DAFF, 2012). Thus, the dairy industry is of major importance in South Africa.

2.2.2 Lucerne-dairy value chain

The dairy value chain is illustrated schematically in Figure 2.3. Figure 2.3 shows that the value chain begins with the input supplies. The most significant of these inputs is the production of field and fodder crops to feed the dairy cows. Lucerne is an important feed source for the dairy cattle. Following the input node is the actual milk production on commercial dairy farms where the cows produce milk after consuming the required feed. The milk is then transported to the milk processors where the raw milk is processed into various different dairy products. In the process, value is added to the milk. These final products are then transported to the retailers where the final consumer buys the dairy product for consumption. Important to note is that at all the different nodes along the value chain water is used and value is added to the raw milk until it reaches the final consumer in the desired form. The input (feed production) stage uses by far the greatest volume of water of all the stages in the value chain, being in excess of 95 % (Hoekstra, 2012; Mekonnen and Hoekstra, 2010b).

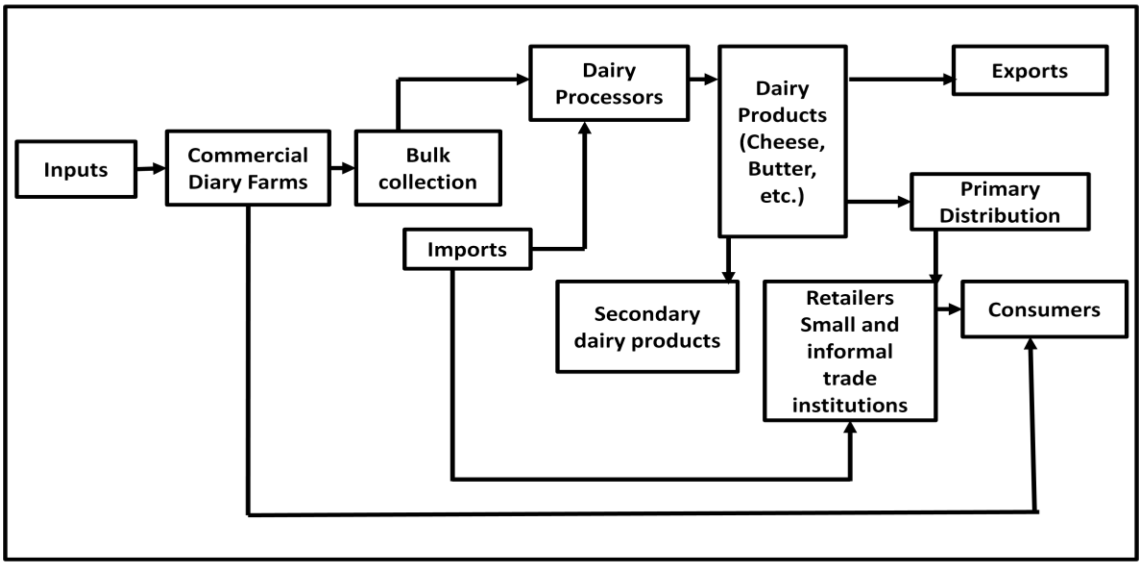


Figure 2.3 Schematic illustration of the dairy value chain (Source: Adapted from DAFF 2012)

For the local dairy industry to supply the increase in demand for dairy products that Meyer *et al*. (2013) predict, they will have to become more efficient. Where the dairy producers are already efficiently using input products to produce dairy consumables, they will inevitably have to use more inputs in order to increase the total output. This then translates into an increase in the amount of feedstuffs required to produce the higher output. Lucerne is an important fodder source for dairy production and the increase in demand for feedstuffs will then also place a greater demand on lucerne stocks. Thus, it is important to consider lucerne when assessing the water footprint of dairy products.

2.3 Theoretical framework

2.3.1 The water footprint concept

The water footprint concept has grown with leaps and bounds since its first introduction by Hoekstra (2003). The water footprint is an indicator of freshwater use that includes both direct and indirect water use of a consumer or product. Hoekstra *et al.* (2011) emphasised that the water footprint can be regarded as a comprehensive indicator of freshwater use and should be used along with the traditional and restricted measures of water withdrawal. Ultimately, the aim of the water footprint is to investigate the sustainability of freshwater use. This is achieved by comparing the water footprint with the freshwater availability (Hoekstra and Mekonnen, 2011; Hoekstra *et al*., 2012).

Internationally there are two general schools of thought with regard to the water footprint concept. They are the concept as described by Hoekstra *et al.* (2011) and that described in the Life Cycle Assessment (LCA).

According to the water footprint concept of Hoekstra *et al.* (2011), the water footprint is divided into three different categories: blue, green, and grey water footprints. Hoekstra *et al.* (2011) defined the blue water footprint as the surface and groundwater that is consumed along the value chain of a product. They explain that consumptive use refers to the loss of surface or groundwater from a catchment. The losses can occur through incorporation into the product, evaporation or when the water returns to a different catchment or the sea. All the green water resources consumed (rainwater that evapotranspired through the vegetation and is incorporated into the product) is considered to be the green water footprint. Polluted water needs vast quantities of freshwater to assimilate the load of pollutants to acceptable standards. The volume of freshwater needed to reduce the pollutants to ambient levels is called the grey water footprint.

The water footprint concept is multidimensional and considers all the water used according to the sources from which the water is extracted and the volumes of freshwater required to assimilate the polluted water to ambient levels.

Hoekstra *et al*. (2011) described different types of water footprints that can be assessed to determine the impact of human behaviour on sustainable water use. Such types include the water footprints of a consumer or a group of consumers; a geographically delineated area; a business; and a product.

- **A consumer or group of consumers –** The water footprint of a consumer or group of consumers is defined as the total volume of water used for the production of goods and services used by the consumer. Both freshwater consumed and the amount of water polluted during the course of production are taken into account. When a group of consumers is considered, one simply sums the water footprints of the individual consumers.

  Once such a water footprint is reported, it is expressed as the volume of water per unit of time, or as the volume of water per monetary unit obtained by dividing the water volume per unit of time by the income. Where a group of consumers are concerned, the water footprint can be expressed as the water volume per unit of time per capita. Ultimately, the aim of calculating the water footprint of a consumer or group of consumers is to evaluate the cumulative impact that these individuals have on water resources.

- **A geographically delineated area** – The water footprint for a geographically delineated area is defined as the total volume of water consumed and polluted within the boundaries of the delineated area. Typical areas include catchments and river basins, states, provinces, nations or any other administrative spatial unit.

  The water footprint for a spatial unit is expressed as the volume of water per unit of time. Alternatively, it can also be expressed in terms of water volume per monetary unit if one takes the water footprint per unit of time and divides it by the income in the area. Calculating the water footprint for a geographically delineated area is usually part of a larger assessment of the sustainability of the water resources in the target area.

- **A business** – One can define a “business water footprint” as the sum of the water footprints of the business outputs. This business water footprint can then be further divided into the direct (operational) and indirect (supply chain) water footprints.

  When the water footprint of a business is considered, it is usually defined as the total volume of water used, both directly and indirectly, in the operation of the business. The direct water footprint is the total volume of water used and polluted in the business’s own operations while the indirect water footprint is the total volume of water used and polluted in order to obtain the inputs required for the business’s operations. A business water footprint aims to assess a specific business’s impact on water resources. Often a business’s water footprint is largely “imported” from elsewhere in the form of water intensive inputs produced in other catchments.

- **A product –** Where a product is considered, the water footprint is the volume of freshwater used to produce the product and is measured along the complete value chain of the product. All the steps along the complete value chain of the specific product are considered.

  A product’s water footprint is always expressed as water volume per product unit. For milk production, it is m^3 of water per litre of milk or litres of water per litre of milk. Another way of expressing the water footprint of milk is m^3 of water per

> kilogram of milk or litres of water per kilogram of milk. Product water footprints are often calculated to enable comparisons between products, often on the basis of volume of water per caloric unit. Ultimately, the aim is to determine the sustainability of water resources.

According to Berger and Finkbeiner (2010), the life cycle assessment (LCA) is a “widely accepted and applied environmental management tool to measure the various environmental interventions caused by products from cradle to grave”. The main focus of the water footprint from the LCA approach is the environmental impacts related to the use of water, and therefore economic and social impacts are typically outside the scope of the LCA. All stages of the life cycle of the product under scrutiny are considered, from the acquisition of the raw materials to the disposal of the final product. Four phases should be included to ensure the completeness of the assessment. These four phases include the definition of the goal and scope of the assessment; the water footprint inventory analysis; water footprint impact assessment; and finally the interpretation of the results.

A water footprint assessment, according to the LCA approach, can be conducted as a stand-alone assessment or it could be included in a wider environmental assessment. The origins of water sources are not accounted for in the same fashion by the LCA as in the Water Footprint Network (WFN) approach. Ridoutt and Pfister (2010) note that the LCA does not directly account for green water use, but because the use of this water is directly related to the occupation of land, it is accounted for elsewhere in a complete LCA. Berger and Finkbeiner (2010) argue that green water is especially important in the production of crops and livestock and neglecting to include such water in the accounting does not give an accurate measure of the true water used. Blue water is accounted for, however, but the deterioration of water quality is dealt with by means of other impact categories such as freshwater ecotoxicity or eutrophication (Jefferies *et al*., 2012).

ISO 14046 (2014) serves as a guideline of what to include in a comprehensive water footprint assessment. The aim of this International Standard is to ensure a form of consistency between the different methodologies. This was done by standardising the terminology used in the calculations and reporting of the various methods. According to this International Standard, the term “water footprint” can only be used when it is the result of a comprehensive impact assessment. The ISO 14046:2014 is based on the LCA approach and identifies potential environmental impacts that are associated with water use. It also monitors changes in water quality and water use over time and across geographical dimensions (ISO/TC207, 2014). Ridoutt (2014) explained that ISO 14046:2014 does not prescribe which methodology one should use for the calculation of a water footprint, but it does serve as a guide for what should be considered in the calculation of a complete water footprint assessment.

According to ISO 14046 (2014), a water footprint is the quantification of potential environmental impacts related to water and is based on the LCA approach to environmental impact. A water footprint assessment conducted according to this International Standard must be compliant with ISO 14044 and should therefore include the four phases of a LCA. These four phases start with the definition of the goals and scope, which is then followed by the water footprint inventory analysis. Once the inventory analysis has been completed, the water footprint impact assessment is conducted. Only then can the results be interpreted.

Although both the LCA and WFN approaches can be used to investigate the water footprint for milk in the South African dairy value chain, the guidelines of the ISO 14046 must also be kept in mind in the reporting of the water footprint indicator of South African milk.

In the following section the various methods available for calculating the water footprint are discussed.

2.4 Methods for water footprint assessment to calculate the water footprint indicator

Several different methods are available to calculate the water footprint, with academics differing on which method is best suited. The available methods include:

- Consumptive water-use based volumetric water footprint proposed by the Water Footprint Network (Hoekstra *et al*., 2011). This method was developed by Hoekstra (2003) and endorsed by the Water Footprint Network (WFN).
- Stress-weighted water Life Cycle Assessment (LCA) as suggested by Pfister *et al*. (2009). The most important difference between the LCA method and the consumptive volumetric-based method is the fact that the LCA shows the region-specific effects of water consumption (Van Der Laan *et al*., 2013).
- an adapted LCA water footprinting methodology that differentiates between the two main impact pathways, as proposed by Milà i Canals *et al.* (2008). These two pathways are Freshwater Ecosystem Impacts (FEI) and Freshwater Depletion (FD).

- the use of a hydrological water balance method loosely based on the method developed and refined by Hoekstra *et al.* (2011), as suggested by Deurer *et al.* (2011). The biggest difference between the methods is that Deurer's method considers all the components of the water balance and not just the water consumption (Van Der Laan *et al*., 2013).

2.4.1.1 Consumptive water-use based volumetric water footprint

The calculations of this method are done according to the three distinct sources of the water, namely blue, green, and grey water. Figure 2.4 is a graphical representation of the different water footprint types according to Hoekstra *et al.* (2011). Figure 2.4 indicates that the total water footprint is divided into three distinct categories in order to indicate the origin of the water. A distinction is made between surface and groundwater; for rainfall that does not become runoff; and for degradation of water quality. It shows that the water footprint concept includes blue, green and grey water, and the indirect water usage. It is also clear from Figure 2.4 that the return flow, which is the non-consumptive part of water withdrawals, is not part of the water footprint. In the following section, the blue, green and grey water footprints are discussed in more detail.

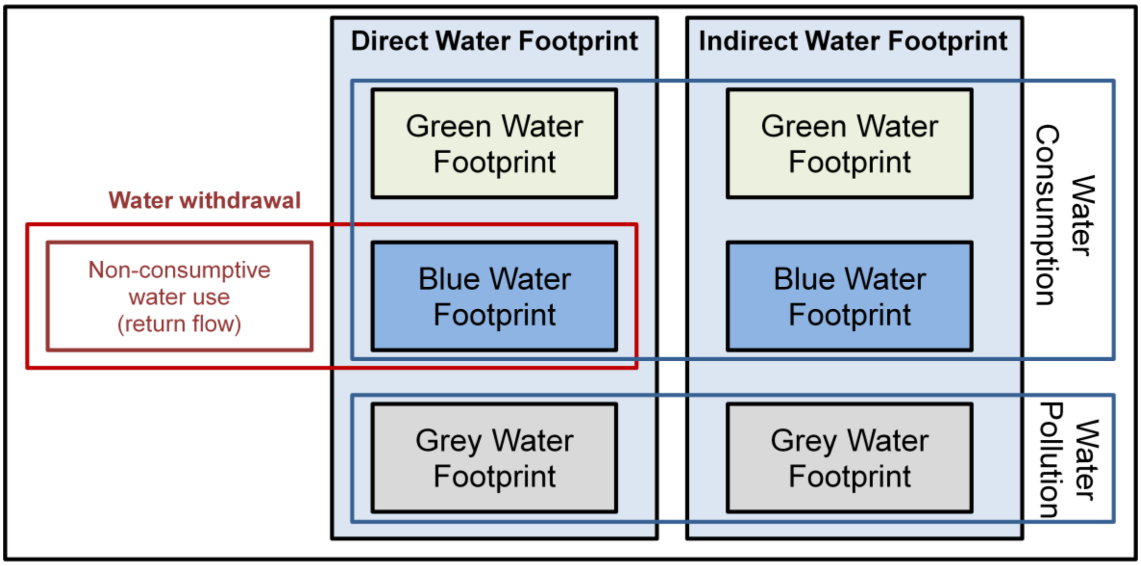


Figure 2.4 Schematic representation of the components of a water footprint (Source: Adapted from Hoekstra *et al*., 2011)

a) **Blue water footprint**: The blue water includes all the surface and groundwater that is consumed along the value chain of a product. Hoekstra *et al.* (2011) elaborate and explain that the blue water footprint is an indicator of fresh surface or groundwater consumed. Such consumptive use of the blue water refers to the following cases:

i. Evaporated water;

ii. Water that is incorporated into the product;

ii. Water that does not return to the same catchment (including water transfers);

iii. Water that does not return to the same catchment during the same period (abstracted during periods of limited supply and returned in times of excess supply).

Most often it is found that evaporation is the most significant component of blue water consumption and therefore consumptive use is often equated to evaporation. The other components, however, should be included in the consumptive use whenever this is relevant (Hoekstra *et al*., 2011). It is noteworthy to state that the consumptive use does not imply that the water disappears from the hydrological cycle, but it does mean that it is not immediately available for alternative use.

The formula to calculate the blue water footprint as suggested by Hoekstra *et al.* (2011) is expressed as volume per unit of output and is as follows:

$$WF_{proc,blue} = \text{Blue Water Evaporation + Blue Water Incorporation + Lost Return Flow}$$

b) **Green water footprint:** All the green water resources consumed (rainwater that evapotranspired or that was incorporated into the product) are considered to comprise the green water footprint. It is further explained that green water is rainwater stored in the soil and is only available for vegetation growth and transpiration. This water will always have a component that will not be able to be used by the plants because there will always be some form of evaporation. Hoekstra *et al.* (2011) conclude that the green water footprint is the total volume of rainwater consumed during the production process. They continue to emphasise the importance of the green water footprint for agricultural and forestry production where the green water footprint refers to the total rainwater evapotranspiration from the fields, together with the water incorporated into the harvested crop. The formula to calculate the green water footprint as suggested by Hoekstra *et al.* (2011) is again expressed as the volume of water per unit of output and is as follows:

$$WF_{proc,green} = \text{Green Water Evapotranspiration + Green Water Incorporation}$$

In an agricultural context, the green water consumption can be physically measured or it can be estimated with a model suitable for estimating the evapotranspiration of a specific crop, based on input data on soil, crop and climate characteristics.

c) **Grey water footprint:** Polluted water needs vast quantities of fresh water to “dilute” the load of pollutants to acceptable standards. This volume of freshwater needed to reduce the pollutants to ambient levels is considered to be the grey water footprint. The volumetric-based grey water footprint does not include an indicator of the severity of the environmental damage of the pollution, but it is simply a method to include the volume of water required to reduce the pollution to acceptable norms. Hoekstra *et al.* (2011) formulated the calculation of the grey water footprint as follows:

$$WF_{proc,grey} = \frac{L}{c_{max} - c_{nat}}$$

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

According to the Water Footprint Network method, a distinction should be made between the direct and indirect water use. Direct water use is the water that is actually used at a specific point in a value chain. A consumer’s direct water footprint is the water that the consumer uses in his or her daily life. The indirect water footprint is usually much larger than the direct water footprint. This is because the indirect water footprint includes all the water used to produce all the products that are consumed by the end consumer. For a business or a product, the greatest portion of the water usage is found in the supply chain (Hoekstra *et al*., 2011), thus, in the value adding activities before the product reaches the business.

2.4.1.2 Total water footprint

In order to evaluate the water used along the value chain, the total production system must be divided into smaller “process steps”. By schematising the production process into a limited number of process steps, one can calculate the water use more accurately. After the different types of water footprints are calculated for a process, they are simply added together to determine the process water footprint (Hoekstra *et al*., 2011):

$$WF_{proc} = WF_{proc,blue} + WF_{proc,green} + WF_{proc,grey}$$

Two alternative approaches could be used to calculate the total water use along the value chain. The two approaches are the chain-summation approach and the stepwise accumulative approach (Hoekstra *et al*., 2011) and are discussed in more detail in the following section.

The chain-summation approach

This approach is the simpler one of the two alternatives, but can only be used in a production process with only one output. Figure 2.5 is a schematic representation of such production systems with only one output. Such cases rarely exist in practice where one can simply divide the total water usage by the production quantity. A more generic method for calculating the water footprint is thus necessary. Only production systems with a single output can be analysed with this method, as is evident from Figure 2.5.

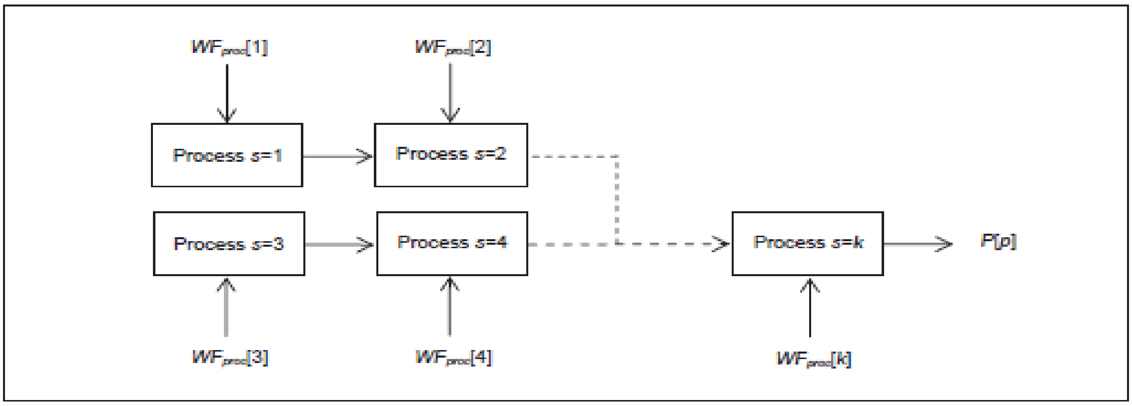


Figure 2.5 Chain-summation approach (Source: Hoekstra *et al*., 2011)

The calculation of the water footprint of a production system with a single output can be explained in terms of the water footprint of product *p* ($WF_{prod}[p]$) (volume/mass). The calculated water footprint is equal to the sum of the relevant process water footprints divided by the production quantity of product *p* ($P[p]$) or:

$$WF_{prod}[p] = \frac{\sum_{s=1}^{k} WF_{proc}[s]}{P[p]} \qquad [volume/mass]$$

Where $WF_{proc}[s]$ is the process water footprint of process step s as indicated in Figure 2.5, and is therefore calculated for each process step along the complete value chain of the product.

The stepwise accumulative approach

A more generic approach to calculate the water footprint of a product is the stepwise accumulative approach that is indicated in Figure 2.6 below. This method accounts for production processes that have more than one input and several outputs. In production systems with complex input and output combinations, the water footprint can only be calculated by using the proportional water footprints of the varying inputs. If the production system depicted in Figure 2.6 is considered, the water footprint of product p can be calculated as follows:

$$WF_{prod}[p] = \left(WF_{proc}[p] + \sum_{i=1}^{y} \frac{WF_{prod}[i]}{f_p[p,i]}\right) \times f_v[p] \qquad [volume/mass]$$

Where $WF_{prod}[p]$ is the water footprint (volume/mass) of output product p and the water footprint of input i is represented by $WF_{prod}[i]$. The process water footprint of the processing step is denoted by $WF_{proc}[p]$ and it transforms the y input products into the z output products. The $f_p[p,i]$ parameter is known as the "product function", while $f_v[p]$ is a "value function". The value function of input p, $f_v[p]$, is defined as the ratio of the market value of the input products in relation to the aggregated market value of all the output products (from p=1 to p=z).

$$f_v[p] = \frac{price[p] \times w[p]}{\sum_{p=1}^{z}(price[p] \times w[p]} \qquad [mass/mass]$$

In the equation, $price[p]$ represents the price of output product p (monetary unit/mass). The summation in the denominator is done over all z the output products that are produced in the considered production process.

Output product p's product function is defined as the quantity of the output product ($w[p]$, mass) that is produced per quantity of input product ($w[i]$, mass)

$$f_p[p,i] = \frac{w[p]}{w[i]} \qquad [mass/mass]$$

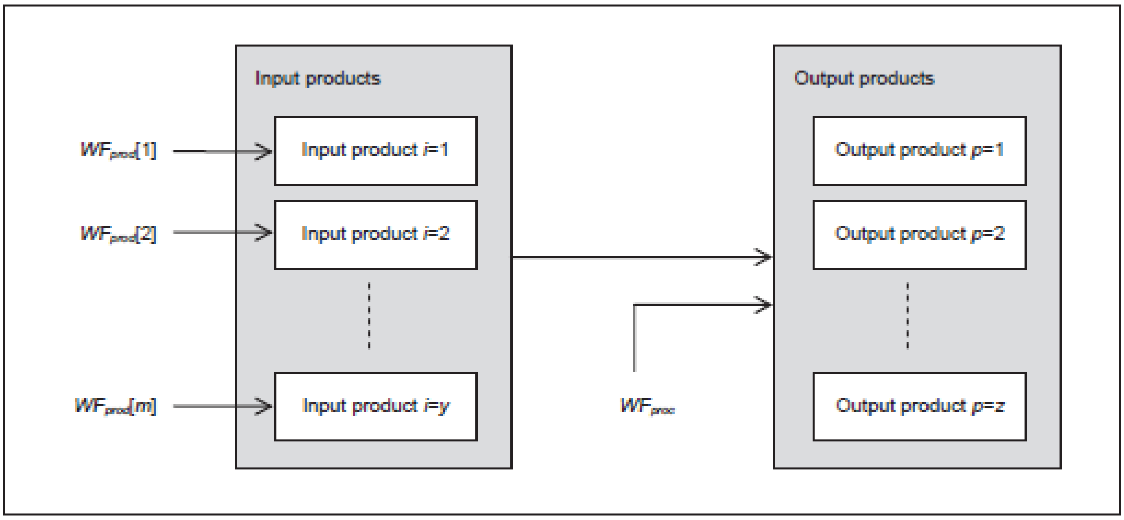


Figure 2.6 The stepwise accumulative approach (Source: Hoekstra *et al*., 2011)

2.4.1.2 Life Cycle Analysis (LCA) by Pfister et al. (2009)

Pfister *et al.* (2009) indicated that the stress-weighted water Life Cycle Assessment (LCA) approach should be used as a base for calculating the water footprint. They continue to explain that in the Life Cycle Inventory (LCI) phase, the quantities of water used are often reported, but the water source and type of use should ideally also be included (Pfister *et al*., 2009). According to the LCA method of Pfister *et al.* (2009), consumptive water use include all the freshwater withdrawals that are transferred into different watersheds, incorporated into the products or the water loss attributable to evaporation. In this method, they use the term “degradative use” to describe the change in water quality that is released back to the original water body (Pfister *et al*., 2009).

Pfister *et al.* (2009) focus on the consumptive water use and hence virtual water is of importance to them. Virtual water consists of all the water evaporated during production and incorporation of products and thus includes both “blue” and “green” water. However, according to the LCA method proposed by Pfister *et al.* (2009), only the blue virtual water footprint is considered. The reason that only the blue virtual water is considered is that green water does not contribute to environmental flows until it becomes blue water. Green water is thus only accessible through the occupation of land. It is comparable to soil and solar radiation that cannot be separated from occupation of land (Van Der Laan *et al*., 2013; Ridoutt and Pfister, 2010).

The LCA method of Pfister *et al*. (2009) makes use of the virtual water database developed by Chapagain and Hoekstra (2004) in order to arrive at the volume of water used to produce the relevant products. Once this is done, the Water Stress Index (WSI) is determined.

The WSI is a measure to determine whether freshwater withdrawal exceeds the water body's replenishment. It is based on the water usage (WU) to water availability (WA) ratio (WTA) (Van Der Laan *et al*., 2013). In order to calculate the WSI, the WaterGAP2 global model is used (Pfister *et al*., 2009). This WaterGAP2 global hydrological water availability model is based on data from 1961 to 1990 and is, therefore, just an average annual water availability average. Such data, however, does not allow for short periods of severe water stresses. This led to the annual data only being used to calculate the WTA, and a variation factor (VF) was introduced to the model in order to provide for monthly variation in precipitation. Storage facilities (dams) reduce the variation in water supply and therefore regulated catchments require a reduced variation factor (Pfister *et al*., 2009).

Pfister *et al.* (2009) suggest the following equations to calculate the WTA in regulated and unregulated catchments:

$$\text{WTA}_{Regulated\ Catchments} = \sqrt{VF} \times \frac{WU}{WA}$$

$$\text{WTA}_{Non-regulated\ Catchments} = VF \times \frac{WU}{WA}$$

$$VF = e^{\sqrt{\ln(S_{Month})^2 + \ln(S_{Year})^2}}$$

VF is defined as the aggregated measure of dispensation of the multiplicative standard deviation of the annual S_{Year} and monthly S_{Month} precipitation (Pfister *et al*., 2009).

Pfister *et al.* (2009) used the WTA to calculate the WSI, but because the WSI is not linear in terms of WTA, they had to modify the WSI to a logistic function. This allowed them to achieve continuous values between 0.01 and 1.

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

From this equation, 0.01 represents the minimum value of the WSI. At this point, any water withdrawal will have, at least, marginal local impact. The maximum value of the WSI is 1 and indicates extreme water stress (Van Der Laan *et al*., 2013; Pfister *et al*., 2009).

The LCA does provide for water quality impacts, but this is not with the grey water method as prescribed by Hoekstra *et al.* (2011). Ridoutt and Pfister (2010) explain that in the LCA context it is more appropriate to include water quality impacts under other impact categories, such as freshwater toxicity or eutrophication, or to apply complex fate and effect models.

2.4.1.3 Life Cycle Analysis (LCA) approach proposed by Milà i Canals et al. (2008)

The method of Pfister *et al.* (2009) involves many assumptions, especially in determining the endpoint impact categories (Goedkoop *et al*., 2013). In the adapted format, this method still distinguishes between blue and green water. Blue water resources comprise the total volume of water in ground or surface bodies that is available for abstraction and is then further classified as flow (such as rain and rivers), fund (such as groundwater) and a deposit or stock (such as fossil water). Different crops and natural vegetation are considered to use a similar amount of soil moisture (green water) and the use of rainwater therefore does not change when crops are produced instead of the natural vegetation. The use of green water is then only of relevance insofar as the calculation of blue water is required (Milà i Canals *et al*., 2008).

Water use is classified as “non-evaporative” and “evaporative”. Non-evaporative water use is experienced when water is returned to the originating water body and becomes available for use by others. Evaporative use is experienced when water is dissipated and is temporarily unavailable for other users (Milà i Canals *et al*., 2008).

An important addition to the model is the factor that land use related to production systems impacts on the availability of freshwater. This addition is incorporated mainly because certain production systems may significantly influence the amount of rainwater available to others. The transformed landscapes can result in increased volume and velocity of runoff, together with infiltration rates much lower than the natural rate. A further consequence is that aquifers are unlikely to be replenished and flooding will increase, which will impact on aquatic ecosystems. These types of land use that increase the runoff will typically have higher water footprints, with the contribution of the land use to the total water footprint calculated as the difference between the water loss of the specific land use and the water loss of a reference land use (Van Der Laan *et al*., 2013; Milà i Canals *et al*., 2008).

A Water Stress Indicator (WSI) is calculated, in the same manner as suggested by Revenga *et al.* (2004).

$$\text{WSI} = \frac{Water\ Use}{(Water\ Resources\ Available - Ecological\ Water\ Requirement\ )}$$

or:

$$\text{WSI} = \frac{WU}{(WR - EWR)}$$

This calculation results in a much more accurate indication of the water available for further human use after allowing for the ecological water requirement (EWR) (Milà i Canals *et al*., 2008).

Estimates of water loss for different land uses were presented by Milà i Canals *et al*. (2008). The volume is then added to the blue water consumption, after which the total is then multiplied with the WSI as the characterisation factor.

Depleted freshwater (FD) is calculated using an Abiotic Depletion Potential (ADP) formula that is adapted to accommodate the possibility of regeneration of water resources (Milà i Canals *et al*., 2008). The adapted ADP model is as follows:

$$ADP_i = \frac{ER_i - RR_i}{\left(R_i{}^2\right)} \times \frac{R_{Sb}{}^2}{DR_{Sb}}$$

or:

$$ADP_i = ER_i - RR_i\left(R_i{}^2\right)^{-1} \times\ R_{sb}{}^2(DR_{sb})^{-1}$$

where:

- i = relevant water resource
- Sb = reference resource
- ER_i = resource i’s Extraction Rate
- RR_i = resource i’s Regeneration Rate
- R_i = resource i’s ultimate reserve
- R_{Sb} = reference resource’s ultimate reserve
- DR_{Sb} = reference resource’s Deaccumulation Rate

2.4.1.4 Hydrological water balance method

This concept acknowledges the same definitions for Blue, Green, and Grey water that was introduced by Hoekstra *et al.* (2011), but the calculations thereof differ slightly (Deurer *et al*., 2011). Contrary to the consumptive water-based volumetric method, this hydrological water-based method allows for both positive and negative water footprints. A positive water footprint means that the total blue water abstraction exceeds the total recharge through precipitation and return flows, while a negative water footprint simply means that the recharge of the blue water resource exceeds the total volume abstracted. It is thus clear that systems that rely on groundwater can only be sustainable if they have negative water footprints according to the hydrological water balance method (Deurer *et al*., 2011; Van Der Laan *et al*., 2013).

The calculation of the water footprint according to this model considers all the components of a water balance. These components include inflows, outflows and storage changes (Deurer *et al*., 2011).

The green water footprint calculation according to the water balance method is as follows:

$$\Delta\, Green\, Water = D^r + ET^r + R^r - RF$$

where:

- ET^r = Evapotranspiration under rain fed conditions
- RF = Effective rain throughfall, being the rainfall minus the water intercepted by the plants
- D^r = Drainage under rain-fed conditions
- R^r = Runoff under rain-fed conditions.

The blue water footprint calculation according to the water balance method is as follows:

$$\Delta\, Blue\, Water = D^r + D^{ir} + R^r + R^{ir} - IR$$

where:

- D^r = Drainage under rain fed conditions
- D^{ir} = Difference between drainage under rain fed and irrigated conditions
- R^r = Runoff under rain fed conditions
- R^{ir} = Difference between runoff under rain fed and irrigated conditions

- IR = Annual amount of blue water irrigation used.

Grey water is calculated according to the method used by Hoekstra *et al*. (2011) and is included into the total water footprint (Deurer *et al*., 2011; Herath *et al*., 2013; Van Der Laan *et al*., 2013).

2.4.1 Discussion of methods

After evaluating the various methods, it is evident that the methods differ significantly in the manner in which the water footprint is calculated. The WFN method accounts for blue, green, and grey water footprints, while the Life Cycle Assessment (LCA) only accounts for the blue water footprint. The LCA neglects green water accounting, based on the notion that green water use cannot be separated from the occupation of land, the impact of which is accounted for elsewhere in LCA. Milà i Canals *et al.* (2008) consider both green and blue water resources and classifies blue water as fund (groundwater), stock (fossil groundwater) and flow (rivers). The hydrological water balance method determines blue, green, and grey water footprints annually on a local scale. The approach characterises the hydrological system by including all in- and outflows and storage changes.

Next, the focus shifts to related research where the water footprints of dairy products were assessed.

2.5 Relevant research on water footprint assessments in dairy

While the Water Footprint Network and others have conducted and published water footprint assessments for a variety of different products, the focus of this discussion will be specifically on dairy-related research.

Research exploring water footprints of dairy products includes that by Mekonnen and Hoekstra (2010b) who carried out a global assessment of water footprint of dairy products; De Boer *et al.* (2012) who conducted a case study in the Netherlands; Ridoutt *et al.* (2010) who explored the water footprint of skimmed milk powder in Australia; and Murphy *et al*. (2013) and Manazza and Iglesias (2012) who explored the water footprint of dairy in Ireland and Argentina, respectively.

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

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

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

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

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

In Argentina, Manazza and Iglesias (2012) conducted a study on the water footprint of the milk agri-food chain. It is interesting to note that they chose to use an adapted version of the LCA method to calculate the water footprint, which is in contrast with the other studies of dairy value chains.

Murphy *et al*. (2013) followed the literature defined by Hoekstra *et al.* (2011) to assess the water footprint of dairy production in Ireland. However, the focus of this study was solely on the dairy production, or from “cradle to farm gate”. Their aim was therefore to only calculate the water used in the physical production of the milk, and not the complete dairy value chain (Murphy *et al*., 2013).

2.5.1 Discussion of relevant research

There has been some interest in the water footprint of dairy value chains, but no such studies have yet been done locally, except for Mekonnen and Hoekstra (2010b) who included South Africa in the estimation of the water footprints of various animal products. Water footprints are accepted as an indicator of water use, but despite the fact that the dairy industry is important for the South African economy and uses vast quantities of water, nobody has yet investigated the water footprint of the South African dairy value chain.

The water footprint indicator is a basic indicator used to determine environmental sustainability. In the next section, emphasis is placed on the economic value of water along the dairy value chain.

2.6 Economic valuation of the water footprint

2.6.1 Rationale for the economic valuation of the water footprint

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

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

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

2.6.2 Research on the economic valuation of the water footprint

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

One study where a significant amount of attention was awarded to economic aspects is that of Chouchane *et al*. (2013). They achieved their goal by assessing the water footprint of Tunisia from an economic perspective (Chouchane *et al*., 2013). In addition to calculating the water footprints of different crops (bio-physical focus), economic water productivity (amongst others) was also calculated for the different crops. The economic water productivity is the value of the marginal product of the agri-food product with respect to water, and is calculated by multiplying the physical productivity with the price of the product. The economic productivity gives an indication of the income that was generated per cubic metre of green, blue, and grey water footprint.

The economic water productivity was calculated in two steps. First, the physical water productivity (in kg/m^3 of water) was calculated for each crop by dividing the crop yield (in kg) by the green, blue, and grey water footprints (in m^3) of the crops. In the second step, the economic productivities (US$/$m^3$ of water) of the crops were calculated by multiplying the physical water productivity (in kg/m^3) of each crop with the product price of the particular crop (in US$/kg). Economic water productivity of the different crops were found to range from 0.03 US$/$m^3$ (olives) to 1.08 US$/$m^3$ (tomatoes). Again, it is noted that the reported economic water productivity refers to the income that is generated per cubic metre of water applied; no costs have been considered.

Zoumides *et al*. (2014), similarly to the approach of Chouchane *et al.* (2013), also included economic water productivity when assessing the water footprint of crop production and supply utilisation in Cyprus. Zoumides *et al*. (2014) calculated the economic water productivity per type of water (green and blue water). The gross value of producing the different crops was calculated by multiplying the total production (i.e. rain fed and irrigated) with the price of the product. The gross value of production then was divided between blue and green water, based on the proportional contribution of blue and green water footprints to the total water footprint of selected crops. The economic value of the green water footprint then was calculated by dividing the gross value of the crops produced from green water by the green water footprint, and the economic value of the blue water footprint by dividing the gross value of the crops produced with blue water by the blue water footprint. The results indicated the income that was earned per cubic metre of green water and blue water, respectively.

Their findings were that irrigated cropland contributed about 80 % to the gross value of agricultural production, while 61 % was attributed to blue water. When considering the economic water productivity in Cyprus, it was found that the blue water economic productivity (in 2009 prices) ranged between 0.89 €/m^3 and 1.15 €/m^3 in the period 1995–2009. In turn, the economic productivity of green water ranged between about 0.22 €/m^3 and about 0.45 €/m^3 for the same period. Thus, more income is generated per cubic metre of blue water used in the production of the selected crops, as compared with a cubic metre of green water.

Changing water use behaviour in Cyprus to decrease the pressure on blue water resources thus may have a significant impact on the economy of Cyprus. Similar to the case described by Chouchane *et al.* (2013), the reported economic water productivity in Zoumides *et al*. (2014) refers to the income that is generated per cubic metre of water applied; no costs have been considered.

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

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

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

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

In another study, Crafford *et al.* (2004) analysed the social, economic and environmental direct and indirect costs and benefits of water use in irrigated agriculture and forestry. More specifically, they considered plantation forestry, irrigated sugarcane, and irrigated subtropical fruit in the Crocodile River Catchment. The direct and indirect economic benefits that were realised in backward and forward sectors linked to the production activities were measured. Value added (difference between proceeds from new production minus the cost of intermediate inputs bought from other sectors) was used as a proxy measure of economic benefit. Comparative analysis was conducted of the efficiency with which water was used by the three sectors under consideration in terms of the economic benefits. Direct and indirect employment and enterprise linkages, as well as external social benefits and costs on households from the three land uses, were assessed to measure the social impact of the respective value chains on households and individuals. For the purpose of the environmental impact analysis, Crafford *et al.* (2004) focused on the environmental aspects of life cycle analysis.

The results from the economic impact analysis showed that the direct value added per cubic metre of water ranged between 1.8 ZAR/m^3 and 2.6 ZAR/m^3 of water for the forest plantations, 1.3 ZAR/m^3 for sugarcane, and 3.2 ZAR/m^3 to 8.7 ZAR/m^3 for subtropical fruit (Crafford *et al*., 2004). However, when considering the indirect linkages, value added per cubic metre of water ranged between 19.9 ZAR/m^3 and 32.1 ZAR/m^3 of water for the forest plantations, 9.9 ZAR/m^3 for sugarcane, and 3.2 ZAR/m^3 to 8.9 ZAR/m^3 for subtropical fruit. Their results also showed that the fruit trees created the most employment benefits per cubic metre of water used. Crafford *et al.* (2004) concluded that their findings showed the impact of the length of the specific value chain on the economic benefits along the value chain, and then the importance of also considering indirect economic impact when making decisions regarding water allocation. For the social impact analysis, the focus was mainly on the direct and indirect employment benefits associated with the different value chains. In the environmental impact assessment, they considered water and energy use (both at farm level and in value adding activities), and the activities' impact on water quality, soil, air, biodiversity, and human health (Crafford *et al*., 2004).

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

2.7 Conclusion

It is evident from the literature that the South African dairy industry is of major significance in terms of its economic contribution to, and employment opportunities in, rural districts. The dairy industry requires vast amounts of the scarce freshwater resources to produce milk, with the feed production stage using by far the greatest share of water along the value chain.

The water footprint concept is well established, with several different institutions working on promoting the concept. Ultimately, the aim of the water footprint is to investigate the sustainability of freshwater resources through comparisons between water footprints and freshwater availability. Water footprint accounting methods differ significantly, with little consensus existing among researchers on which method is best. In order to get clarity on the different terminologies and the definitions thereof, ISO 14046 was developed. ISO 14046 does not prescribe which accounting method to use, but does serve as a guideline for what a water footprint assessment should include.

The method of the WFN accounts for blue, green, and grey water footprints, while the LCA only accounts the blue water used. It is argued that the use of green water cannot be separated from the occupation of land and the impact of land use is already accounted for elsewhere in the LCA. Grey water *per se* is not accounted for, but it is suggested that the deterioration of water quality can be better represented by other impact categories, such as freshwater ecotoxicity and eutrophication (Jefferies *et al*., 2012). The focus of the LCA is on the complete environmental impact related to the use of water, while the WFN method is more concerned with the sustainability of the freshwater use. Milà i Canals *et al*. (2008) suggest the consideration of both blue and green water, and further classify blue water as flow (rivers), fund (groundwater) and stock (fossil groundwater). Deurer *et al.* (2011) suggest that the complete water balance should be considered. These components are then used to determine the blue, green, and grey water footprints at a local level on an annual basis.

Abundant applications of the various approaches to water footprint calculations are available, although there is not sufficient proof to suggest which method is superior. What does emerge from the published reports is that it is crucial to define the goals and scope of the study clearly. Of the all the methods evaluated in this chapter, the consumptive water-use-based volumetric water footprint method of Water Footprint Network (WFN) best suits the goals and scope of this study, in that it emphasises the sustainability of freshwater use. The data available is compatible with the requirements of the WFN method, while the procedures of this model make provision for adding the economic evaluation of the water to the water footprint data.

While the economics aspect has been receiving more attention recently, very little is being done to investigate the value of water along value chains. Although Munro *et al.* (2014) calculated the water footprint and the economic productivity of the water used, this was only done for the production of citrus and did not encompass the complete value chain. The only study found to evaluate the water use along the complete value chain, and then add economic metrics to the water usage, is the study done by Jordaan and Grové (2012). The calculations of the water footprint, together with the value added to the water as it moves through the various stages of the value chain, have the potential to provide more insight in to the way water is allocated in South African agriculture.

Ultimately, the aim of all water footprint assessments is to determine the sustainability of producing the products under consideration. Given that the dairy industry is important from an economic and socio-economic perspective, it is of cardinal importance that the industry be environmentally sustainable.

CHAPTER 3

METHODS AND DATA

3.1 Introduction

In Chapter Three, the methods and data used in order to achieve the aims and objectives outlined in Chapter One will be discussed.

The water footprint methodology that best suits the goals and scope of this study are elaborated. From the literature considered in Chapter Two, it was determined that the Water Footprint Network’s approach is best aligned with the goals and scope of this study. Therefore, in this chapter the application of the method is explained. Once the total water footprint methodology is explained, the method used to quantify the value of the water once it reaches the end consumer will be expanded upon.

The data for the calculations is also explained, together with the management of the data to enable the calculation of the water footprints and the value added to the water.

3.2 Method

After evaluating the different water footprint accounting methods in Chapter Two, it was decided that the consumptive water-use-based volumetric water footprint method of Water Footprint Network (WFN) best fits the scope of this study. The methodology in this chapter and the calculations in the following chapter are therefore based on the guidelines of the WFN approach.

Hoekstra *et al.* (2011) provides a conceptual framework for a complete water footprint assessment. According to this framework, a water footprint assessment consists of four distinct phases which add more transparency to the methodology and help stakeholders to understand the process. The first phase involves setting the scope and goals of the assessment. In phase two, data is collected and the actual calculations are done to calculate the volumetric water footprint indicator. The third phase involves a sustainability assessment in which the water footprint assessment is evaluated from an environmental, social, and economic perspective. The four phases conclude with the final fourth phase, being the formulation of response options and strategies for improving the sustainability of the water footprint.

Phase 1 – Setting goals and scope

With any study, the purpose of the study must be stated at the outset before any further steps can be taken. A water footprint assessment is no different and one must clearly indicate what the purpose of the study is because this has a great impact on the execution of the assessment. The focus of this water footprint assessment is on the calculation of the water footprint indicator and sustainability thereof. The response formulation phase is thus not included.

Firstly, it needs to be stated what type of water footprint is of interest, as this will dictate which methodology to follow in the study. The goal of the study will determine which entity the water footprint will be completed for. Therefore, if the aim of the study is to understand the water usage along a specific supply chain, the water footprint of a particular product or business will be most useful. Some of the more common entities for which water footprints are conducted include process steps, products, consumer groups, markets or geographically delineated areas. Once one has determined the specific entity around which the water footprint will be conducted, several further questions will have to be answered. These questions, for purposes of this study, included examining:

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

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

- Data period: Fluctuations in water supply and availability within and across years is a reality and consequently the water footprint will also vary with the time chosen. Thus, it is important to state clearly whether one is calculating the water footprint in a specific year, an average over several years, or for a number of years.
- Direct or indirect water footprint: Although the focus has traditionally been on the direct water usage, the indirect water usage is often much larger. The recommendation of Hoekstra *et al.* (2011) is therefore to include both the direct and the indirect water footprints.

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

In order to achieve the aims and objectives of this research, it would be sensible to include all the components of the water footprint and to include all the water uses along the lucerne–dairy value chain. The major steps in the value chain of the case study is illustrated in Figure 3.1 and include feed production; milk production; milk processing; and finally the retailing of the milk.

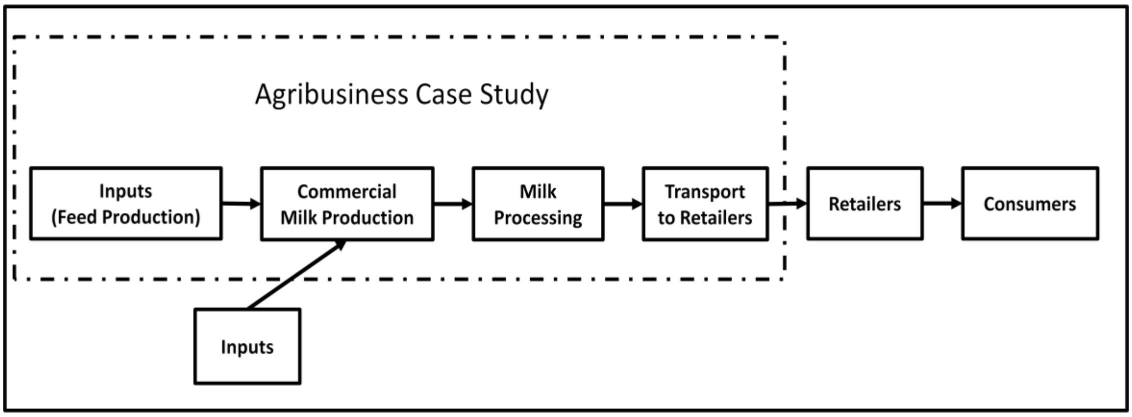


Figure 3.1 Schematic illustration of the lucerne dairy value chain in the case study

After the aims and objectives have been defined, the next step is to calculate the volumetric water footprint indicator.

Phase 2 – Water footprint accounting

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

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

- *Chain-summation approach:* Only production systems with a single output can be analysed with this method and because the processor in the case study only produces milk, this approach will be sufficient for the accounting of the value chain. The various process steps as outlined in Figure 3.1 above are considered individually before the water footprints of these process steps are added together in order to obtain the total water footprint.

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

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

$$WF_{proc} = WF_{proc,blue} + WF_{proc,green} + WF_{proc,grey}$$

$$[volume/mass]$$

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

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

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

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

$$WF_{proc,grey} = \frac{(\alpha \times AR)/(c_{max} - c_{nat})}{Y} \qquad [volume/mass]$$

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

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

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

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

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

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

$$WF_{dairy} = WF_{feed} + WF_{drink} + WF_{service}$$

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

Animal water footprints are usually expressed in terms of m^3/animal/year, but these can also be summed over the entire lifespan of the animal and then given in m^3/animal. Where the water footprint of animals that only provide their products after they have been slaughtered are calculated, it is sensible to calculate the water footprint for the entire lifespan of the animal, as it will be the footprint used to calculate the various product water footprints (meat, leather).

The water footprints of dairy cattle and layer chickens are usually calculated per annum (averaged over their lifetime), as these can then easily be related to annual production or even per unit (litre of milk) water footprint (Mekonnen and Hoekstra 2010a).

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

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

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

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

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

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

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

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

where PO is the product output per head (kg product/y/animal) and FI is the feed intake per head (kg dry mass/y/animal). In the case of dairy production, the amount of dry matter feed intake is divided by the milk produced per cow to obtain the FCE.

Once the FCE and product output have been calculated, one can continue to calculate the total feed per production system for dairy cows as follows:

$$Feed = FCE \times PO$$

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

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

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

Total water footprint

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

The final blue water footprint is then an indicator of the total amount of surface and ground water that evaporated along the lucerne–milk value chain, or that was incorporated into the final product.

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

A detailed calculation was used to determine the grey water footprint of lucerne production, but grey water also arises from other stages along the value chain. Grey water from the production of the feed ration of the lactating cows was estimated as a leaching requirement to maintain the good productive potential of the soil.

No blue water originated from the processing plant, as the fresh water that was used for cleaning the facility was recycled and later used for cleaning the cattle runs and the floor of the dairy parlour. The dairy processing water thus becomes grey water in the effluent pond and was accounted for according to the grey water methodology.

The grey water emanating from the faeces and urine of the lactating cows was estimated with the use of an effluent sample analysis, and the volume measured as the flow into the effluent pond. From the analysis, the electrical conductivity (EC) of the effluent pond was taken and multiplied by the total volume of the effluent, and the salts originating from the abstracted water were then subtracted to obtain the total salts added to the effluent at the facility. The volume of water required to assimilate this load to below the acceptable norm is then the grey water for processing the milk.

Phase 3 – Sustainability assessment

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

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

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

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

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

3.3 Quantifying the value of the water

Although Jordaan and Grové (2012) did not calculate the water footprint of raisins *per se*, their approach to determine the value added to the water along the complete value chain is compatible with the water footprint concept. The value added to the water was therefore calculated in a similar fashion as that done by Jordaan and Grové (2012).

Value is added as the product moves through the stages of the value chain, as explained in Chapter Two, and is expressed in terms of ZAR/m^3 at each stage. This was achieved by taking the value added at each stage and dividing it by the volume of water used at the specific stage.

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

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

3.4 Data

The scope of this study covers a case study of the lucerne–dairy value chain, with a focus on milk, from raw to processed and sold at retail level. Secondary data on water usage for the production of lucerne as a fodder crop was obtained from Van Rensburg *et al.* (2012) who, among other things, explored the management of salinity on lucerne crops.

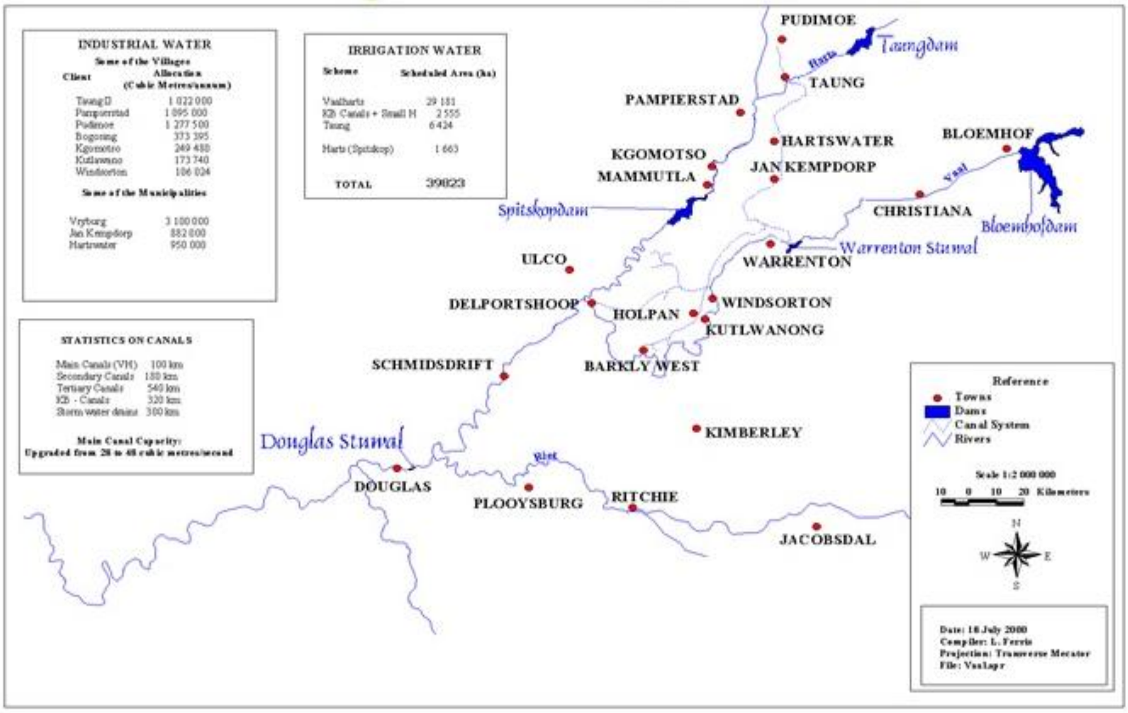
Once the lucerne hay is produced, it becomes an important input for dairy production and the link between the lucerne and dairy value chains is made. Therefore, water data for a commercial dairy farm and a dairy processor is needed. This data was collected through questionnaires and interviews with the managers of the various divisions at the case study agribusiness. The business consists of both a commercial dairy and a processing plant where the milk is processed and bottled.

3.4.1 Water use data on lucerne production

As part of a study to manage the salinity associated with irrigation in the Vaalharts irrigation scheme, Van Rensburg *et al.* (2012) measured the water taken up by lucerne in order to calculate the complete water balance of the crop. Although they used measurements for two irrigation schemes, it would be sensible to focus on their data from the Vaalharts irrigation scheme for the purpose of this study, as lucerne produced in this scheme was used as an important feed ingredient on the case study dairy farm.

Location and layout

The measurements taken by Van Rensburg *et al.* (2012) that are of relevance for this study were noted on farms within the Vaalharts irrigation scheme. This irrigation scheme is situated between the Vaal River and the Harts River in the Northern Cape and falls within the Lower Vaal Water Management Area (WMA). Figure 3.2 is a layout of the Vaalharts Irrigation scheme.



INDUSTRIAL WATER

Some of the Villages

Client	Allocation (Cubic Metres/annum)
Taung D	1 022 000
Pampierstad	1 095 000
Pudimoe	1 277 500
Bogosing	373 395
Kgomotso	249 480
Kutlwano	173 740
Windsorton	106 024
Some of the Municipalities	
Vryburg	3 100 000
Jan Kempdorp	882 000
Hartswater	950 000

IRRIGATION WATER

Scheme	Scheduled Area (ha)
Vaalharts	29 181
KB Canals + Small H	2 555
Taung	6 424
Harts (Spitskop)	1 663
TOTAL	39823

STATISTICS ON CANALS

Main Canals (VH)	100 km
Secondary Canals	180 km
Tertiary Canals	540 km
KB - Canals	320 km
Storm water drains	300 km

Main Canal Capacity:
Upgraded from 28 to 48 cubic metres/second

Date: 18 July 2000
Compiler: L. Ferris
Projection: Transverse Mercator
File: Vaalapr

Figure 3.2 Layout of the Vaalharts Irrigation Scheme (Source: Anon, 2014)

The Vaal River is the main supplier of water to the Vaalharts irrigation scheme, with the Warrenton Weir just upstream of Warrenton diverting water into the Vaalharts main canal. This main canal in turn supplies the North, West, Taung and Klipdam-Barkley canals that convey the water to Vaalharts, Barkley-West, Spitskop and Taung sections. The total licensed areas for irrigation in the sections are 29 181, 2 555, 1 663 and 6 424ha, respectively. In order to convey the irrigation water to the licensed areas, the system comprises 1 176 km of concrete-lined canals, together with 314 km of additional concrete-lined drainage canals to convey storm-water and subsurface drainage water out of the irrigation scheme through to the Harts River (Van Rensburg *et al*., 2012).

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

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

Water Quality

A major focus of the study by Van Rensburg *et al.* (2012) was the quality of the water used for irrigation in the Vaalharts irrigation scheme, among others. They used data provided by the Department of Water Affairs and Forestry to calculate the mean long-term electrical conductivity (EC) and sodium absorption ratio (SAR) of the dams and river water for the period 1970–2006. The measuring stations where the water quality was measured are indicated in Figure 3.3, along with the long-term electrical conductivity of the water at those stations shown in red. Van Rensburg *et al.* (2012) found that the SAR of all the measuring stations within the irrigation scheme remained below 10 and consequently the scheme represents a low sodium hazard (S1).

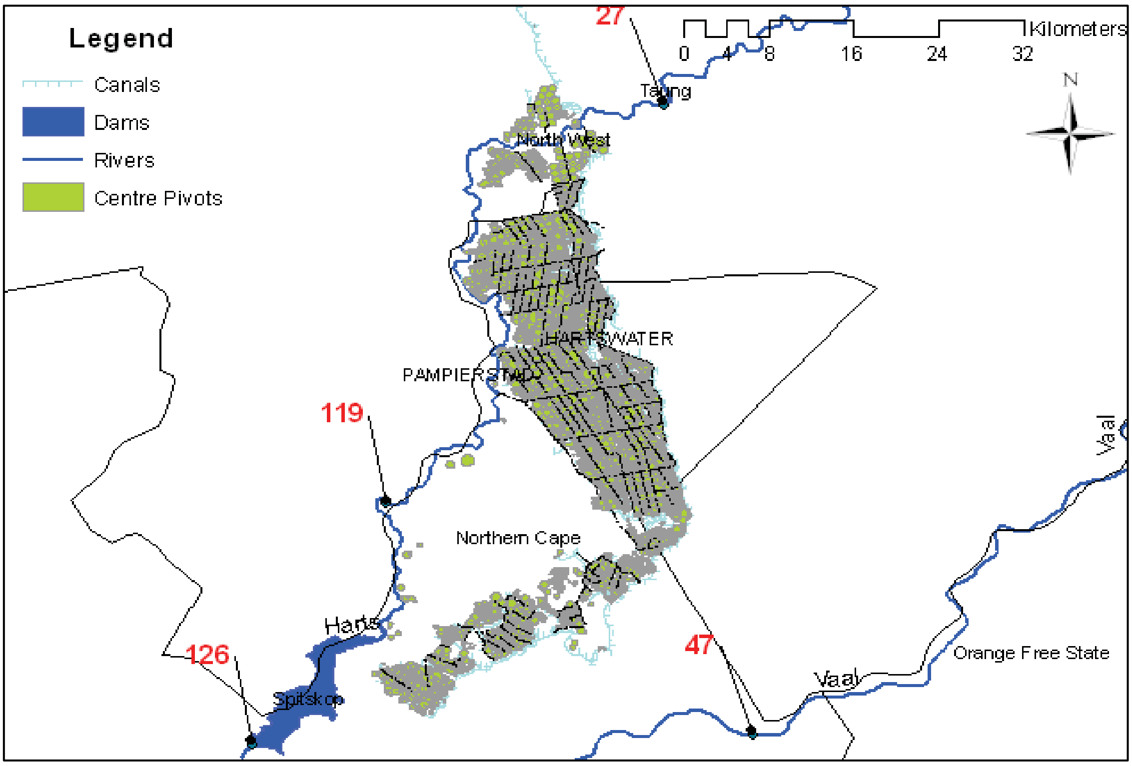


Figure 3.3 Mean long-term electrical conductivity (mSm^{-1}) of dams and rivers at the Vaalharts Irrigation Scheme for the period 1970-2006 (Source: Van Rensburg *et al*., 2012)

In order to see how the irrigation practices at Vaalharts contributed to the deterioration of the water quality, Van Rensburg *et al.* (2012) determined that fairly good quality irrigation water (C2), with a mean long-term EC of 4 mSm^{-1}, is received from the Vaalharts Barrage.

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

Layout of measuring points

The fact that the land used for irrigation was not homogeneous meant that several measuring sites had to be selected in order to get an accurate representation of the irrigation scheme. Thus, no irrigated field is similar and each of the measuring points was seen as a unique opportunity to obtain information on water and salt management practices carried out by farmers at Vaalharts. Measuring points were therefore selected to include a variety of bio-physical conditions at root zone scale as to cover differing irrigation water qualities, soil types, crops, irrigation systems and soils that are artificially drained. This also allowed for the incorporation of different managers. Figure 3.4 below shows the geographical position of the measuring stations at the Vaalharts scheme.

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

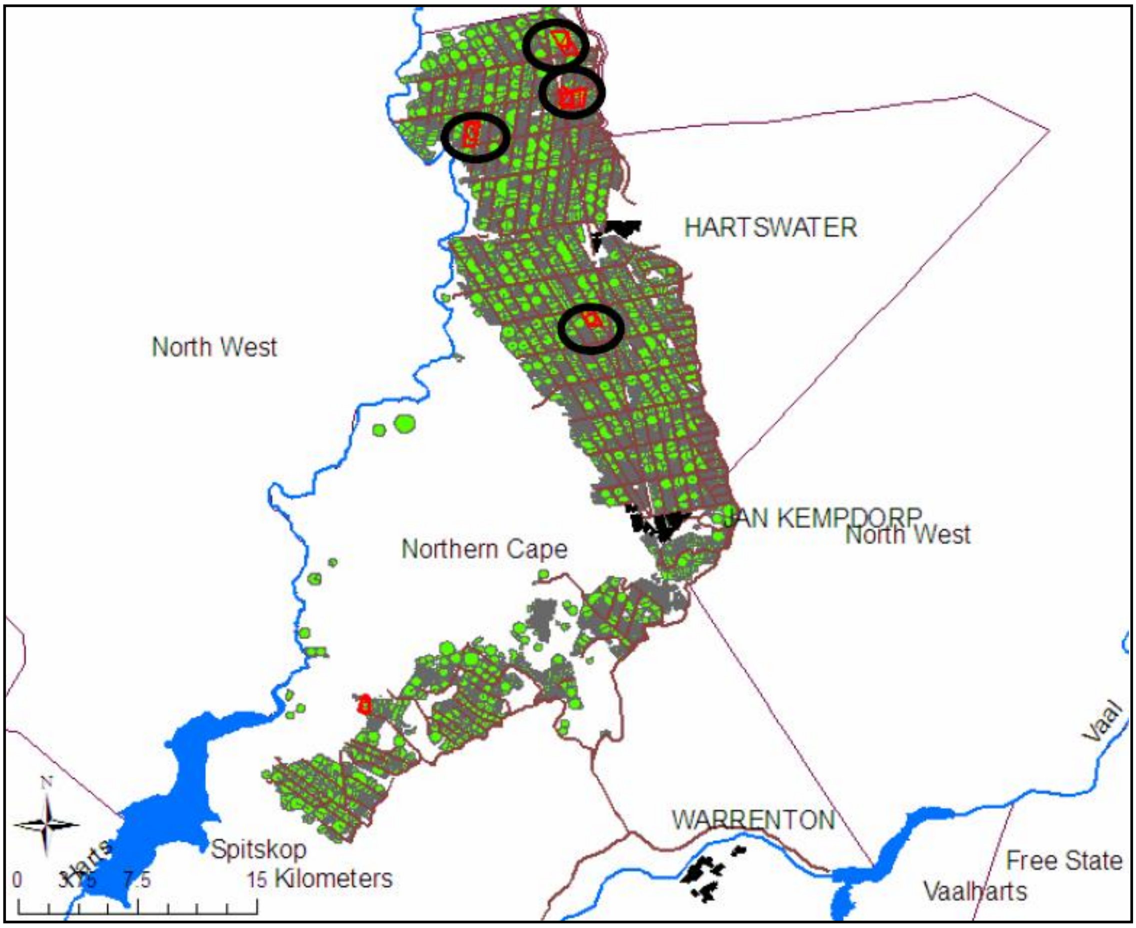


Figure 3.4 Geographical position of the measuring points at the Vaalharts irrigation scheme (Source: Barnard *et al*., 2012)

Data acquisition: Lucerne water usage

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

In order to measure the electrical conductivity of the irrigation water, water table and drainage water, a calibrated handheld Ecoscan (Con6) Electrical Conductivity Meter was used. Water was manually collected with a bailer from the piezometers and with 100 ml bottles from the rain gauge and drainage system.

The principle of conservation of mass, where any change in water or salt of a given volume or depth of soil must be equal to the difference between water or salt added and lost from the same volume, was used to calculate the soil water and salt balances. It is thus crucial to define the boundaries of the relevant system. The soil depth is of relevance for root zone induced salinity, and in the system under consideration the soil depth was taken as 2 000 mm, since this is the potential root zone of the majority of agricultural crops. Figure 3.5 below is a conceptual illustration of the soil and salt water balances. The root zone was then taken as the depth to the restrictive layer, in the cases where such restrictive layers were present.

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

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

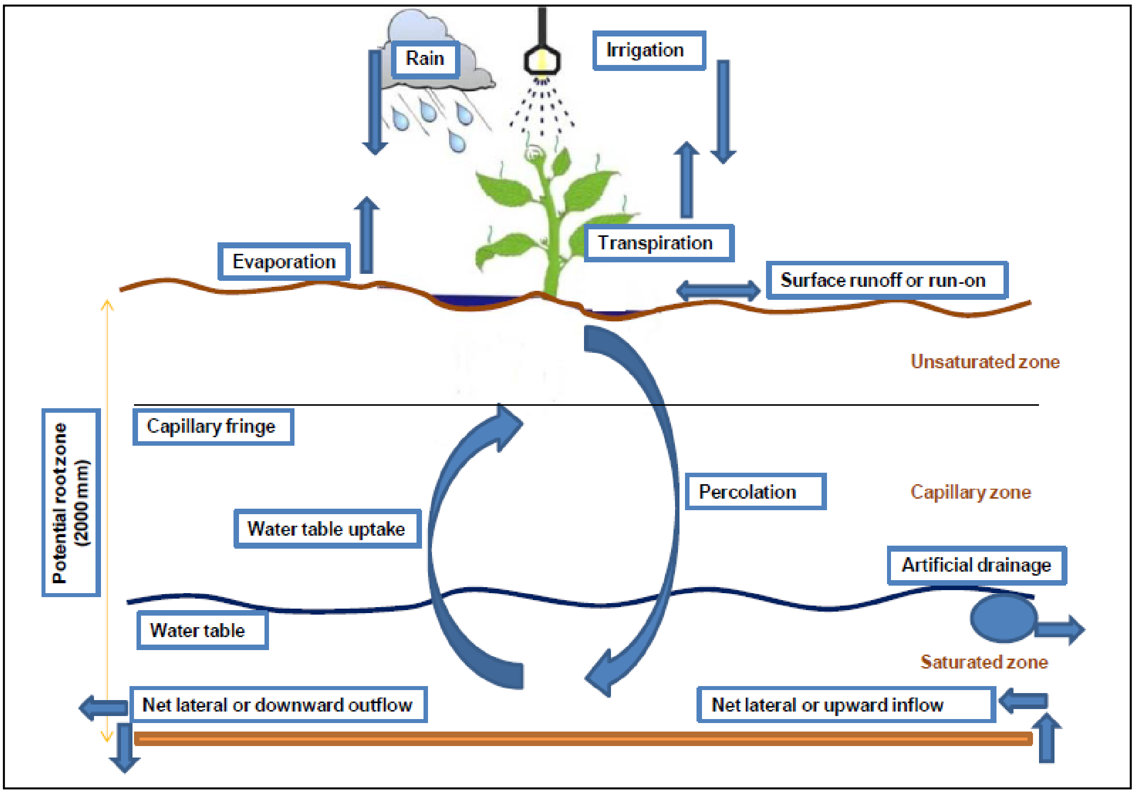


Figure 3.5 Conceptual illustration of the soil water and salt balance for a potential root zone of 2 000 mm of an irrigation field (Source: Van Rensburg *et al*., 2012)

Data acquisition: Lucerne biomass production

Van Rensburg *et al*. (2012) also measured the biomass production of the lucerne *in situ*. In order to get an accurate representation of the true biomass production of the measuring sites, a 4 m x 4 m (16 m^2) plot was measured in each of the fields where the measuring sites were located. Every time the farmer harvested the lucerne from the field, the 16 m^2 plot was manually cut with a sickle and the freshly cut or “wet” lucerne was carefully collected and weighed immediately before any moisture loss occurred. Once the lucerne of the plot had been weighed, a sample was weighed and taken to be dried further in order to obtain the dry matter (DM) production. The representative sample was then placed in a drying oven at 100^{o}C until no further weight loss was observed and this final weight of the sample was then considered to be the DM of the sample. Only once this DM is determined, one can calculate the moisture content of the representative sample, as all the weight loss which can be attributed to the moisture loss.

Assuming that the whole field had the same moisture content prior to cutting, the percentage moisture loss of the sample was used to obtain the DM production of the 16 m^2 plot. This DM production was then multiplied with a factor of 625 in order to obtain the total DM or biomass production of a hectare. This process was duplicated at each measuring site, every time the lucerne producer cut the whole field.

3.4.2 Water used to produce milk

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

Water usage: Feed production

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

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

In the case study it was found that feed ration consists of six main ingredients. The ingredients of the feed ration and the proportion in the final feed mix is summarised in Table 3.1.

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

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

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

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

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

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

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

Once the actual total evapotranspiration (ET_a) was determined, the rainfall during the growing period of the respective crops was used as the green water. The average rainfall data of a measuring station at De Brug (29.18502 S; 25.9756 N) was used in the calculations. It was assumed that all the rain measured by the measuring station was effective rainfall, meaning that all the rain became green water.

Hoekstra *et al.* (2011) explains that the blue water footprint of a growing crop is the minimum of the crop water requirement and the effective irrigation. In the case study, it is assumed that the farmer over irrigated, but for the blue water footprint the over irrigation is not considered. This then means that the blue water is the difference between the ET_a and the effective rainfall.

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

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

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

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

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

The amount of water determined from this method will be greater than the ET_a and the difference between AW and ET_a will be the grey water.

For the maize produced under dry land conditions, it was not possible to determine the grey water without physical measurements, so the grey water listed by Mekonnen and Hoekstra (2010a) for the Free State province of South Africa was used.

Soy cake and sunflower cake, which make up the high protein concentrate, are not produced on the farm and therefore the blue, green, and grey water was taken as that listed by Mekonnen and Hoekstra (2010a) for the country average of South Africa.

Water usage: Pastoral grazing

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

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

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

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

Drinking water of the cattle

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

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

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

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

No *in situ* data was available for the non-lactating animals in the case study and therefore drinking water requirements as prescribed by Ensminger *et al*. (1990) was used as a guideline for the water that the cattle drank. The daily drinking water requirements of the various groups of animals on the case study dairy farm was based on requirement guidelines as suggested by Ensminger *et al*. (1990) (DAEA, 2006; DWAF, 1996b; Ensminger *et al*., 1990). It is then assumed that on this farm a dry cow and a bull drink 45 litres and 50 litres of water per day, respectively. Depending on the ages of the heifers, it was assumed that they drink between 15 litres and 42 litres per day.

It must be noted that these drinking water requirements are based on annual averages and that water excreted through urine and faeces was not taken into account.

Water used in the dairy parlour and processing plant

In the case study, the agribusiness is both a milk producer and dairy processor. The processing plant is adjacent to the dairy parlour, meaning that the milk is simply pumped from the parlour to the processing plant. The processing plant, however, processed more milk than the dairy produced at the time of the research and the agribusiness bought milk from a nearby farm. The grey water from processing will therefore be estimated for the total amount of milk processed and then expressed in terms of cubic metre per kilogram of milk processed. This grey water will then be added to the grey water of dairy production. Besides the economic benefits of having the milk production close to the processing facility, the water usage is also more efficient.

Water used for cleaning and sanitation in the processing plant is reused for cleaning the floors of the parlour. Freshwater used for the cleaning and sanitation of the milking apparatus also becomes part of the effluent. This water then moves to an effluent pond before it is used for irrigation.

No measurement data was available for the volume of effluent, but the volumes of freshwater used for the original cleaning were available. These volumes were then added together to obtain the volume of effluent. Evaporation of the water was not taken into account.

A sample of the freshwater and the effluent was analysed in order to obtain the salt content thereof. It was decided to estimate the grey water of the effluent based on the total dissolvable salt content thereof because the grey water of the crops was also estimated based on the salts that leached.

The method of Hoekstra *et al.* (2011), as applied by Chapagain (2014), was used to determine the grey water of the effluent. The maximum acceptable concentration of salts was taken as 150 mS.m^{-1} as this level of salinity will result in a 90 % relative yield for moderately salt-sensitive crops (DWAF,1996a).

3.5 Orange River Basin Sustainability assessment

Since blue water is used extensively to irrigate the crops considered in the case study, it was decided to base the sustainability assessment on the blue water availability in the basin. The leaching requirement approach used to determine the grey water footprint eventually deposits the leached salts into the river and therefore the environmental flow requirement of the river needs to be satisfied in order for the blue water abstraction from the river to be sustainable.

The Vaalharts Irrigation Scheme falls within the greater Orange River Basin and, faced with the absence of data on a smaller scale, it was decided to do the sustainability assessment based on the data of the basin. Data of the basin was obtained from Hoekstra and Mekonnen (2011).

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

From the methodology of Hoekstra and Mekonnen (2011), blue water scarcity of below 100 % means that the blue water footprint does not exceed the blue water availability (lower than 20 % of natural runoff); moderate blue water scarcity (100–150 %) occurs when the blue water footprint is between 20 and 30 % of the natural runoff and does not meet the environmental flow requirements; and significant blue water scarcity (150–200 %) is when 30 to 40 % of the natural runoff becomes blue water footprint and environmental flow requirements are not satisfied. Finally, if the blue water footprint exceeds 40 % of the natural runoff, environmental flow requirements are not satisfied and it is considered to be severe blue water scarcity (>200 %).

3.6 Value added to the water

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

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

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

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

At the first process step (raw milk production), the directly allocatable cost of producing the raw milk was taken as the purchase price. The gross margin (selling price minus the directly allocatable costs) then represents the value added to the inputs by producing milk. Raw milk produced at the case study dairy farm is not sold to a producer since the agribusiness also process the milk. However, capacity of the processing plant exceed the production capacity of the dairy and consequently raw milk is procured from other farmers. The price paid for this milk varied according to the quality of the milk and the transport distance, so the average price was used as the selling price of the dairy producer and the purchase price of the processor.

Processed milk was contracted for delivery to a premium retail group. At the time the case study was conducted, the processing plant only produced milk packaged in bottles with a capacity of one litre and three litres. The selling price to the retail group was provided by the agribusiness while the retail price was obtained from visiting a retail outlet where the milk was sold.

CHAPTER 4

RESULTS

4.1 Introduction

The calculations of the water footprints of the various components of the total water footprint of the value chain are presented and discussed in Chapter Four. Following the calculation of the water footprints of the individual components, the water footprints are added together in order to obtain the total water footprint to produce one kilogram of milk.

The chapter concludes with the investigation of the value added to the water as the milk moves through the value chain and reaches the final consumer.

4.2 Water footprint of lucerne

For the purpose of this study, it was decided to make use of actual measurements, instead of estimations from water use models, to determine the water footprint of lucerne. Table 4.1 sets out a summary of the aggregated biophysical data collected at the measuring sites over the course of the measuring period. The average cuttings of 7.75 and the 30 594 kg.ha^{-1} yield as indicated in Table 4.1 are discussed in the methods section concerning lucerne biomass measurement.

As the data was collected over a complete growing season, the data at the measuring sites was aggregated in order to obtain average values for all the measuring points over the course of the measuring period. Therefore, the green and the blue crop water footprints will both not be calculated by summing the daily evapotranspiration, but by simply using the average values over the data collection period.

Table 4.1 Biophysical data of the measuring sites at Vaalharts

	Cuttings	**Yield (kg ha^{-1})**	**Silt-plus-clay (%)**	**θs (mm mm^{-1})**	**Soil Depth (mm)**	**W (mm)**	**T (mm)**
Average	**7.75**	30594	23.25	0.383425	2075	793	1089

4.2.1 Blue and Green Water Footprint of lucerne production

According to Hoekstra *et al.* (2011) , the blue water footprint of a growing crop is the minimum of the irrigation requirement and the effective irrigation. Hoekstra *et al.* (2011) continues to explain that the irrigation requirement (IR) is the difference between the crop water requirement and the effective rainfall. Therefore, one has to compare the IR (524 mm) in Table 4.2 with the effective irrigation of 602 mm. The IR of 524 mm is smaller than the effective irrigation and therefore the blue water footprint of producing lucerne in Vaalharts is 524 mm per year.

Table 4.2 Summary of water use data at the measuring points at Vaalharts

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

In order to convert the water footprint into a spatio-temporal dimension, the 524 mm is converted to 5 240 $m^3.ha^{-1}$ which is the blue CWU (crop water use). This conversion of the unit in which the water footprint is expressed is also indicated in Table 4.3. Most often, water footprints are expressed in terms of water per unit of production and therefore it is more sensible to express the blue water footprint in terms of m^3 per ton of output. The blue CWU must thus be divided by the yield per hectare. Table 4.3 shows a blue water footprint of 171.28 $m^3.ton^{-1}$ for the production of lucerne at Vaalharts.

Table 4.3 Summary of the blue- and green water footprint of producing lucerne in Vaalharts

ET crop	ET Green	ET Blue	CWU	CWU Green	CWU Blue	Yield	WF	WF Green	WF Blue
mm/period			m^3/ha			ton/ha	m^3/ton		
1157.2	**633.00**	**524.19**	**11570**	**6330.0**	**5240.0**	**30.59**	**378.18**	**206.90**	**171.28**

Similar to the blue water footprint, the green water footprint will also be calculated using aggregated data collected over a complete growing season of lucerne at Vaalharts. Again, the method supplied by Chapagain (2014) was used to calculate the green water footprint. He suggests that the green water footprint is the minimum between the effective rainfall and the crop water requirement. Using the data from Table 4.2 above, the effective rainfall of 633 mm is far smaller than the crop water requirement of 1 157 mm. The green water footprint of producing lucerne is therefore 633 mm. This ET_{Green} is then converted to $m^3.ha^{-1}$ to get the water footprint of one hectare, which is 6 330 m^3ha^{-1}. Table 4.3 above shows that in order to relate the water footprint to the biomass production of lucerne, the CWU_{Green} must be divided by the average yield over the growing period. The green water footprint to produce lucerne in Vaalharts is then 206.9 $m^3.ton^{-1}$.

4.2.2 Grey Water Footprint of lucerne production

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

The historic data collected at the measuring points in Vaalharts was used to calculate the grey water footprint of lucerne. The Electrical Conductivity (EC) of the soil was measured at the beginning, middle and end of the season at the various measuring points. This, together with the complete salts balance of the soil body, was used to calculate the actual grey water footprint of lucerne production at Vaalharts.

The collected data has a fairly low variance across the various measuring points and therefore the average values of the measuring points will be used. Table 4.4 then represent the average values of the salts balance for producing lucerne at Vaalharts.

Table 4.4 Summary of the Salts Balance and EC of the soil at the end of the production season at the Vaalharts measuring points

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

In order to calculate the grey water footprint of producing lucerne at Vaalharts, the total salts drained per hectare was taken as the load (L). This value was taken, rather than calculating the load through the application and leaching fraction of the fertiliser, because the drained total dissolvable salts already accounts for the fertiliser leaching and deterioration in irrigation water quality. The load was therefore taken as 3 486 $kg.ha^{-1}$.

The c_{max} of the system was taken as the EC_e of the soil at the end of the production season, rather than the salinity threshold of lucerne, in order to get the “true” grey water footprint. It is considered to be the “true” grey water footprint because it reflects the actual occurrences in the soil balance. This measured EC_e was 252.25 $mS.m^{-1}$ but in order to get the total dissolvable salts (TDS) in terms of $kg.l^{-1}$, the EC was multiplied by a conversion factor of (7.5×10^{-6}) (DWAF,1996a).

According to Hoekstra *et al.* (2011), c_{nat} is the natural concentration in the receiving water body, therefore the EC of the irrigation water was taken as the c_{nat}. As with the c_{max}, the c_{nat} of 58.4 $mS.m^{-1}$ was converted to $kg.l^{-1}$ before the calculation of the grey water footprint could be done.

Using the formula suggested by Hoekstra *et al.* (2011), the grey water footprint was calculated in terms of litres per hectare and has to be converted to m^3 per hectare before it can be divided by the yield per hectare to get the final value in terms of cubic metres per ton of biomass production.

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

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

$$\begin{aligned} WF_{grey,Lucerne} &= 2397557.20 \text{ l.ha}^{-1} \\ &= 2397.56 \text{ m}^3\text{.ha}^{-1} \\ &= \mathbf{78.37 \text{ m}^3\text{.ton}^{-1}} \end{aligned}$$

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

Lucerne Water Footprint

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

$$WF_{proc} = WF_{proc,blue} + WF_{proc,green} + WF_{proc,grey}$$

After all the individual components of the water footprint are calculated, the values are added together to obtain the final water footprint of lucerne in terms of m^3 per ton of biomass production. Table 4.5 summarises all the individual components of the lucerne water footprint. It is clear from Table 4.5 that adding the blue, green, and grey water footprints together results in a lucerne water footprint indicator of 456.609 $m^3.ton^{-1}$. Of this water, 206.903 $m^3.ton^{-1}$ originates from effective rainfall, 171.339 $m^3.ton^{-1}$ from surface and groundwater, and the remaining 78.367 $m^3.ton^{-1}$ was used to assimilate the salts leached during production to acceptable levels.

Table 4.5 Summary of lucerne water footprint at Vaalharts

ET_{Crop}	**ET_{Green}**	**ET_{Blue}**	**CWU**	**CWU_{Green}**	**CWU_{Blue}**	**WF_{Grey}**	**Yield**
mm/period			**m^3/ha**				**ton/ha**
1157.19	**633.00**	**524.19**	**11571.93**	**6330.00**	**5241.93**	**3282.32**	**30.59**

$WF_{Lucerne}$	**WF_{Green}**	**WF_{Blue}**	**WF_{Grey}**
m^3/ton			
456.609	**206.903**	**171.339**	**78.367**

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

4.3 Water Footprint of Milk Production

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

Water usage: Feed production

The calculation of the water used to produce the feed for the lactating cows was done by using the equation suggested by Bennie *et al*. (1998). By using this equation, the total seasonal water requirement of the crop was estimated.

A summary of the parameters required for the estimation of this equation is set out in Table 4.6. The parameters in the calculation are: Y_a is the actual total DM yield ($kg.ha^{-1}$); Y_m represents the maximum DM yield ($kg.ha^{-1}$); ET_a is the actual total evapotranspiration (mm); ET_m is the maximum total evapotranspiration (mm); and β is the slope of the ($1- Y_a/ Y_m$) vs ($1-ET_a/ ET_m$) relationship (Bennie *et al*., 1998).

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

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

This equation by Bennie *et al*. (1998) was used to estimate the ET_a of oats, sorghum, maize silage and maize harvested for grain. Table 4.6 gives the values for the various parameters and lists the ET_a of the crops estimated by using the abovementioned equation.

Table 4.6 Summary of the parameters for the equation by Bennie *et al*. (1998), together with the ET_a estimated with the equation.

Product	**DM**	**HI**	**Gr**	**Resi**	**Y_m**	**Y_a**	**ß**	**ET_m**	**ET_a**		
	ton		kg	kg	kg	kg		mm	mm	m^3	**m^3/ton**
Oats Silage	11.5	0.4	3277.1	8192.9	14000.0	8192.9	1.3	684	458.8	4588.3	**400**
Sorghum Silage	16.5	0.5	5120.7	11379.3	17150.0	11379.3	1.5	636	488.4	4884.1	**296**
Maize Silage	19.6	0.6	6954.8	12645.2	25300.0	12645.2	1.4	958	615.7	6157.3	**314.1**
Maize meal	5.4	0.6	5368.0	9760.0	25300.0	9760.0	1.4	958	537.7	5376.9	**1001.7**
HPC	5.4										**1800.5**
Soy		0.5	2.7								**2357**
Sun		0.5	2.7								**1244**

Once the total water usage of the feed crops, apart from lucerne, was estimated, the water usage had to be divided into blue, green, and grey water. The maize milled for maize meal was produced under dry land conditions and therefore all the water used originates from rainfall, meaning that all of the water is green water.

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

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

$$LR = \frac{EC_w}{5(EC_e) - EC_w} = \frac{57.6}{5(170) - 57.6} = 0.072691$$

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

$$AW = \frac{ET_a}{1 - LR} = \frac{458.825}{1 - 0.072691} = 494.792mm$$

After the actual water required to fulfil the requirements of ET_a and leaching was determined, the difference between AW and ET_a was taken as the grey water per hectare. It was found that the grey water for oats was 359.67 m^3, which in turn amounts to 31.36 m^3 per ton of DM. The calculations were replicated for the other crops and it was found that the grey water was 23.20 $m^3.ton^{-1}$ and 24.63 $m^3.ton^{-1}$ for sorghum and maize, respectively.

Maize produced in the Free State province of South Africa has a grey water footprint of 87.00 $m^3.ton^{-1}$, according to Mekonnen and Hoekstra (2010a). The same dataset of Mekonnen and Hoekstra (2010a) was used to obtain the country average values for soy cake and sunflower cake. According to this list, it takes 2 272 m^3 of green water, 73 m^3 of blue water and 12 m^3 of grey water to produce one ton of soy oilcake in South Africa. It also states that the production of sunflower oilcake in South Africa uses 1 162 m^3 of green water, 29 m^3 of blue water and 53 m^3 of grey water. This data was used in Table 4.6 above to determine the water footprint of the high protein concentrate, as the concentrate is made up of equal parts of sunflower and soy oilcake.

After the water footprints all the individual feed ingredients were determined, they were placed in a table to aid the calculation of the total daily dairy feed water footprint. Table 4.7 below contains the quantities of all the feed ingredients and the proportions of all the ingredients in the final feed for the lactating cows. Each cow was fed 24.1 kg of DM every day, with 825 cows being in lactation. The proportion of every ingredient of the 24.1 kg was multiplied by the 825 cows to obtain the volume of each ingredient that was consumed on a daily basis. After the herd total for each ingredient was determined, it was multiplied by the water footprint of each ingredient and expressed in terms of cubic metres per day for the total water footprint, and the blue, green, and grey water footprints. It is clear from Table 4.7 that in order to produce 21 305.625 kg of milk from 825 lactating cows, 17 670.7 m^3 of water was used to produce only the feed.

Table 4.7 Summary of the water to produce feed for the lactating cows per day

Product:	kg DM	%	Herd Total	Ton	m^3/Ton	m3/day	Blue	Green	Grey
Lucerne	4.2	17.5	3484.8	3.5	456.6	1591.2	597.1	721.0	273.1
Oats Silage	1.1	4.4	869.6	0.9	431.4	375.1	283.8	64.1	27.3
Sorghum Silage	2.6	10.7	2128.5	2.1	319.2	679.4	335.4	294.6	49.4
Maize Silage	3.9	16.2	3210.9	3.2	338.8	1087.8	517.7	491.0	79.1
Yellow Maize meal	7.5	31.1	6171.0	6.2	1088.7	6718.1	0.0	6181.3	536.9
HPC	4.9	20.2	4009.5	4.0	1800.5	7219.1	204.5	6884.3	130.3
Soy						4725.2	146.3	4554.8	24.1
Sun						2493.9	58.1	2329.5	106.3
Dairy Feed Total	24.1	100.0	19874.3	19.9		**17670.7**	1938.5	14636.2	1096.0

The total feed water footprint of 17 670.7 m^3 per day relates to 0.829 m^3 per kilogram of milk produced. This figure of 0.829 $m^3.kg^{-1}$ only considers the feed consumed by the lactating cows, and not the complete herd of cattle. The water for the feed of the non-lactating animals is explained in the following section.

Water usage: Pastoral grazing

Mekonnen and Hoekstra (2010a) reported that 385 m^3 of water was required to produce one ton of DM of natural vegetation, under rain-fed conditions, all of which contributes to the total green water footprint. The DMI guidelines of Stalker *et al*. (2012), together with the average body weights set out by Bowling and Putnam (1943), were used to determine the total feed consumption, as indicated in Table 4.8.

Table 4.8 indicates how the daily DMI of all the non-lactating animals were determined. The total DMI was then multiplied by the 385 m^3 reported by Mekonnen and Hoekstra (2010a) in order to calculate the water footprint for the pastoral rangeland. From Table 4.8, it can be seen that the combined total water requirement for all the free range animals is 3 733.76 m^3 per day, all of which contributes to the total green water footprint.

Table 4.8 Summary of the daily feed intake and water required for the production thereof, for the non-lactating animals on the case study farm

		Live Weight	DMI				**m^3/day**
		Kilogram	% of BW	kg	Total	ton	385 m^3/ton
Number of dry cows	**399**	544.31	2.37 %	12.90	5147.2	5.15	1981.66
Number of heifers	**886**						
0-6 months	220	62.14	1.50 %	0.93	205.07	0.21	78.95
6-12 months	206	171.38	2.10 %	3.60	741.39	0.74	285.44
12-18 months	238	259.68	2.15 %	5.58	1328.8	1.33	511.58
18-24 months	156	332.48	2.20 %	7.31	1141.1	1.14	439.32
24+ months	66	479.38	2.30 %	11.03	727.7	0.73	280.17
Number of bulls	**23**	589.67	3.00 %	17.69	406.87	0.41	156.65
						9.70	**3733.76**

Drinking water of the cattle

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

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

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

= 103.456 litre/cow/day.

The guidelines suggested by Ensminger *et al*. (1990) were used to estimate the volume of drinking water for the non-lactating animals on the case study dairy farm (DAEA, 2006; DWAF, 1996b; Ensminger *et al*., 1990). The assumption was made, based on the guidelines of Ensminger *et al*. (1990), that on the case study farm a dry cow and a bull drink 45 litres and 50 litres of water per day, respectively. Depending on the ages of the heifers, it was assumed that they drink between 15 litres and 42 litres per day. The total drinking water of the complete herd is summarised in Table 4.9. From Table 4.9, the amount of water per animal in the various animal groups and the total drinking water of the specific group, as well as the total of the herd, can be seen. The total drinking water of the herd, as indicated in Table 4.9, was 127 972 litres, or 127.97 m^3, per day, which contributes to the total blue water footprint of milk production.

Table 4.9 Summary of total daily drinking water by the complete cattle herd on the case study farm

		Water use		
		l/animal/day	**Total/day**	
Total herd size	**2133**			**85351**
Number of cows in lactation	**825**	103.45		
Average Daily production per cow (kg)	25.825			
Number of dry cows	**399**	45		**17955**
Number of heifers	**886**			**23516**
0-6 months	220	15	3300	
6-12 months	206	22	4532	
12-18 months	238	30	7140	
18-24 months	156	37	5772	
24+ months	66	42	2772	
Number of bulls	**23**	50		**1150**
				127972

4.4 Water Footprint of Milk Processing

All the freshwater used for the cleaning and sanitation of the processing facility is reused to clean the excrement of the dairy cows off the floors of the dairy parlour. It is assumed that all this water becomes effluent (no evaporation is considered). Once the total volume of effluent was determined, the ECe of both the water source and effluent was measured to enable the calculation of the volume of water required to assimilate the effluent to acceptable levels. This measured ECe was expressed in terms of mS.m-1, but in order to get the total dissolvable salts (TDS) in terms of kg.l-1, the EC must be multiplied by a factor of (7.5 x 10-6) (DWAF,1996a). The TDS of the water source was 0.00075 kg.litre-1, while that of the effluent was measured as 0.003465 kg.litre-1.

summarises the use of freshwater in the processing plant. The totals in the second last row of Once the total volume of effluent was determined, the ECe of both the water source and effluent was measured to enable the calculation of the volume of water required to assimilate the effluent to acceptable levels. This measured ECe was expressed in terms of mS.m-1, but in order to get the total dissolvable salts (TDS) in terms of kg.l-1, the EC must be multiplied by a factor of (7.5 x 10-6) (DWAF,1996a). The TDS of the water source was 0.00075 kg.litre-1, while that of the effluent was measured as 0.003465 kg.litre-1.

represent the volume of water used for each clean-up. The plant was cleaned twice a day and therefore the total volume of water is double the volume used at each clean-up.

Once the total volume of effluent was determined, the EC_e of both the water source and effluent was measured to enable the calculation of the volume of water required to assimilate the effluent to acceptable levels. This measured EC_e was expressed in terms of $mS.m^{-1}$, but in order to get the total dissolvable salts (TDS) in terms of $kg.l^{-1}$, the EC must be multiplied by a factor of (7.5×10^{-6}) (DWAF,1996a). The TDS of the water source was 0.00075 $kg.litre^{-1}$, while that of the effluent was measured as 0.003465 $kg.litre^{-1}$.

Table 4.10 Summary of the volume of freshwater used for cleaning the processing plant and dairy parlour

Cleaning and sanitation:	**(m^3)**
Inline Pasturators	**3.0**
Cream Tank	**0.8**
Milk Tanks	**15.0**
Intake	**1.0**
Fillers	**3.0**
Floors	**3.0**
Milking Apparatus	**5.0**
Other uses	**5.0**
Total	**35.8**
Twice Daily	**71.5**

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

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

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

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

$$
\begin{aligned}
WF_{grey,Processing} &= 517\,660 \text{ Litres per day} \\
&= 517.660 \text{ m}^3 \text{ per day} \\
&= \mathbf{0.014\ m^3.kg^{-1}\ milk\ processed}
\end{aligned}
$$

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

4.5 Lucerne-Milk Water Footprint Indicator

After the water footprints of all the different components of the lucerne–milk value chain were determined, they were added together to obtain the complete water footprint. Table 4.11 summarises the water footprint according to the different types of water.

Table 4.11 Lucerne-milk water footprint

		Blue	**Green**	**Grey**	**Total**	
Drinking Water:						
Lactating cows		85.351			85.351	
Non-lactating animals		42.621			42.621	
Feed Production Water:						
Lactating cows		1938.5	14636.2	1096.0	17670.7	
Non-lactating animals			3733.8		3733.8	
Total Daily Water Usage:		2066.5	18370.0	1096.0	**21532.5**	**m^3**
Daily Milk Production	**21305.6**	kg				
		0.097	**0.862**	**0.051**	**1.011**	**m^3/kg**
Processing Water:						
Processing				517.7	517.7	**m^3/day**
Daily Milk Processing	**36155**	kg				
Total Daily Processing Water		**0.000**	**0.000**	**0.014**	**0.014**	**m^3/kg**
Total water Footprint		0.097	0.862	0.066	1.025	**m^3/kg**
		96.99	**862.21**	**65.76**	**1024.97**	**litre/kg**

It is clear from the bottom row of Table 4.11 that in the case study value chain, 1 025 litres of water was used to produce one kilogram of milk with an average fat content of four per cent and a protein content of 3.3 per cent. The 1 025 litres per kilogram compares well with the global average of 1 020 litres per kilogram for milk production estimated by Mekonnen and Hoekstra (2010b).

The weighted average water footprint for producing milk with a fat content between one and six per cent in South Africa was estimated to be 1 136 litres per kilogram (Mekonnen and Hoekstra 2010b). This is somewhat higher than what was found in this case study and can be attributed to a much larger green water footprint than was calculated in the case study.

The total water footprint per kilogram of milk is made up of 97 litres of blue water, 862 litres of green water, and 66 litres of grey water. Figure 4.1 shows the contributions of blue, green, and grey water to the total water footprint indicator. Green water is clearly by far the greatest contributor towards the total water footprint indicator.

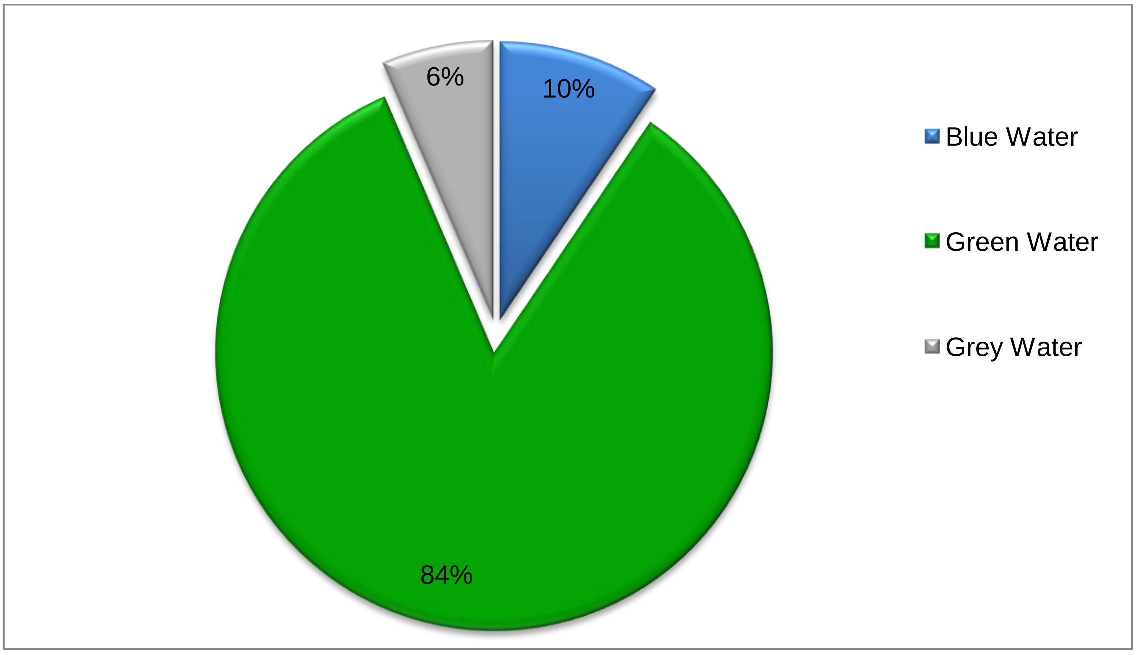


Figure 4.1 Composition of the dairy water footprint in the case study (Source: Own calculations)

Interestingly, the component that contributed the greatest to the total dairy water footprint indicator is the feed for the 825 lactating cows.
From Figure 4.2, it is evident that the water used to produce the feed for the lactating cows is by far the greatest contributor, attracting 81 % of the total water usage.

It is also clear from Figure 4.2 that water used for processing is only marginal and that 98 % of the water usage is taken up in the production of feed for the total herd of cattle (lactating cows, dry cows, heifers and bulls). This is consistent with the findings of Mekonnen and Hoekstra (2010b) and Hoekstra (2012) who also calculated that about 98 % of the water footprints of animal products relates to water used for feed production.

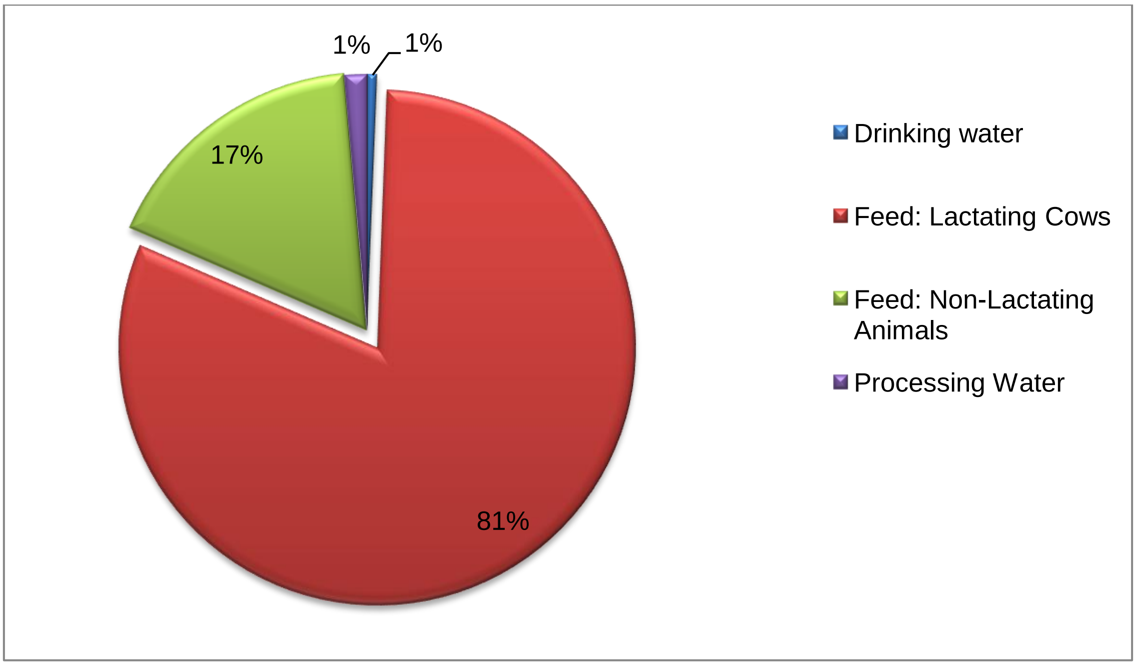


Figure 4.2 Contribution of the various components to the total dairy water footprint (Source: Own calculations)

4.6 Sustainability assessment

The blue water scarcity of the Orange River basin, in which Vaalharts and the dairy farm falls, was determined from the methodology and data of Hoekstra and Mekonnen (2011). The blue water scarcity is calculated as the blue water footprint divided by the blue water availability of the basin on a monthly basis.

Figure 4.3 indicates the monthly blue water footprint (WF), the monthly blue water availability (WA) and the monthly blue water scarcity (WS). It is clear from Figure 4.3 that from January to May, and in December, the blue water availability (WA) exceeds the blue water footprint (WF), resulting in a water scarcity index (WS) of below 100 %. During these months, there is low blue water scarcity with sufficient water available to satisfy the environmental flow requirements. June and November experience moderate blue water scarcity (100-150 %), meaning that the runoff is slightly modified and the environmental flow requirements are not net. July experiences significant blue water scarcity (150-200 %); the runoff is significantly modified and does not meet the environmental flow requirements. August, September and October have water scarcity indices exceeding 300 %. The blue water footprints exceed 40 % of the natural runoff during these months; runoff is thus seriously modified and environmental flow requirements are not met.

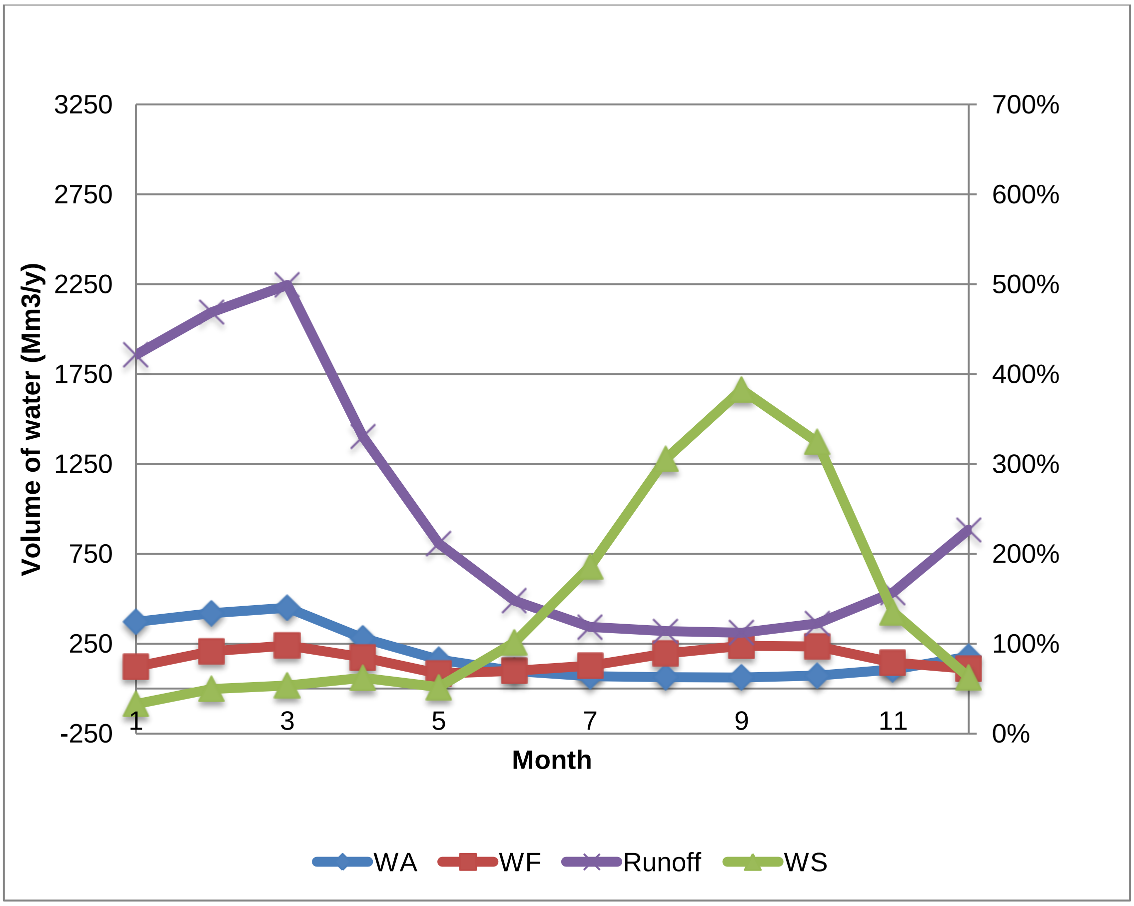


Figure 4.3 Monthly blue water scarcity of the Orange River basin (Source: Hoekstra and Mekonnen 2011)

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

All of the feed crops, apart from oats, used at the dairy require the majority of water usage from November to February. The growing period of maize produced under irrigation was between November and February, while sorghum was planted in December and harvested at the end of February. Although lucerne is a perennial crop, the ET_a was significantly higher during the warmer months of November, December, January and February.

Apart for November that has moderate blue water scarcity, the main production months of December, January and February have low blue water scarcity. The production of lucerne, maize and sorghum under irrigation in the greater Orange River basin is sustainable in the sense that the production thereof does not distort the natural runoff significantly and environmental flow requirements are met.

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

4.7 Value added to the water

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

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

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

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

The parameters of the equation are as follows:

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

Unlike the other stages along the value chain, milk production does not have a purchase price so the directly allocatable costs per litre of milk produced was used as the purchase price. In the case study, these costs was provided by the farmer and amount to R3.23 per litre of milk produced. The gross margin is then used as a proxy for the value added on farm level.

Although the price that the processor paid for raw milk varied with the quality of the milk and the distance it had to be transported, the average price paid for milk with 3.3 per cent protein and four per cent fat was R 4.75. Since the processing facility had two output products that has distinctly different values, the value added from processing to retail also differ. Therefore the value added to the two product categories was explored individually.

The one litre bottles were sold to the retailer at R10.40 per unit while R25.90 was the price the processor received for a three litre bottle of processed milk. At retail level the milk was sold at R14.95 for a one litre unit and R35.95 for a three litre bottle. Figure 4.4 summarises the distribution of value along the value chain of producing milk and packaging it in one litre bottles. From the results of the equations explained in the beginning this section it was found that by packaging the processed milk in a bottle with a capacity of one litre, a total value of R11.72 was added per litre of milk, which is indicated at the bottom of Figure 4.4. To see how much value is added per kilogram, the value per litre is multiplied with the weight of one litre of milk which was explained earlier as 1.033 kilogram. The value added per kilogram of milk (4% fat, 3.3% protein) is then R12.11.

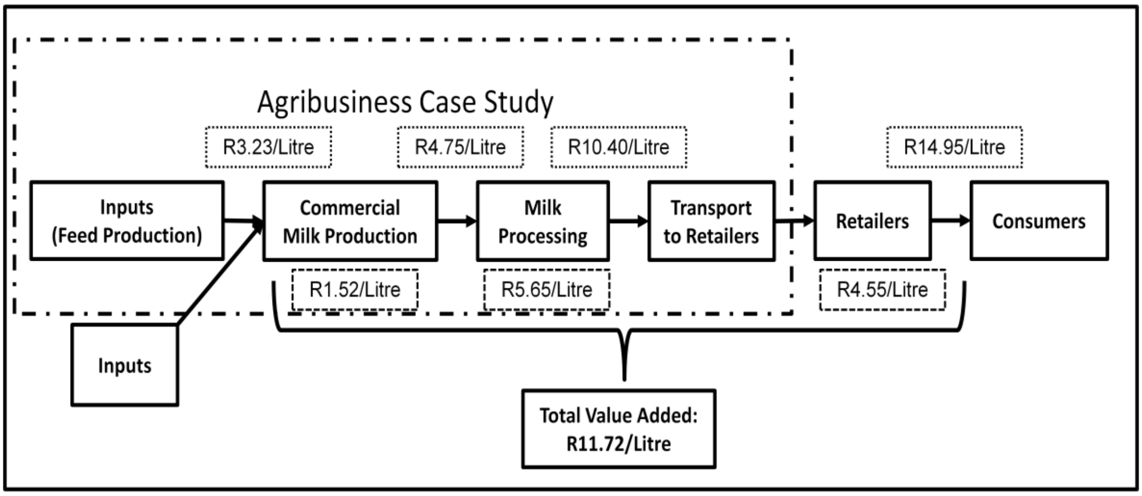


Figure 4.4 Distribution of value added (in 2014 prices) to milk produced in the Free State and sold in one litre bottles (Source: Own calculations)

It is clear from Figure 4.4 that the greatest value is added to the milk during processing where R5.65 is added per litre. Retailers added a further R4.55 per litre with farmers adding only R1.52 per litre of milk.

Exploring the value added along the value chain of the milk packaged in three litre bottles shows that only R8.75 of value was added per litre in comparison with the R11.72 added to the smaller containers. Figure 4.5 indicates the distribution of value along the value chain of processed milk packaged in bottles with a capacity of three litres is again concentrated between the processor and the retailer. The dairy farmer receives the same price for the raw milk regardless of the value added to the milk further along the value chain, so the value added to the milk by the farmer is again R1.52 per litre. Converting the value added per litre of milk to value added per kilogram reveals that the three litre containers only add value of R9.04 while the one litre bottles add R12.11 per kilogram of milk.

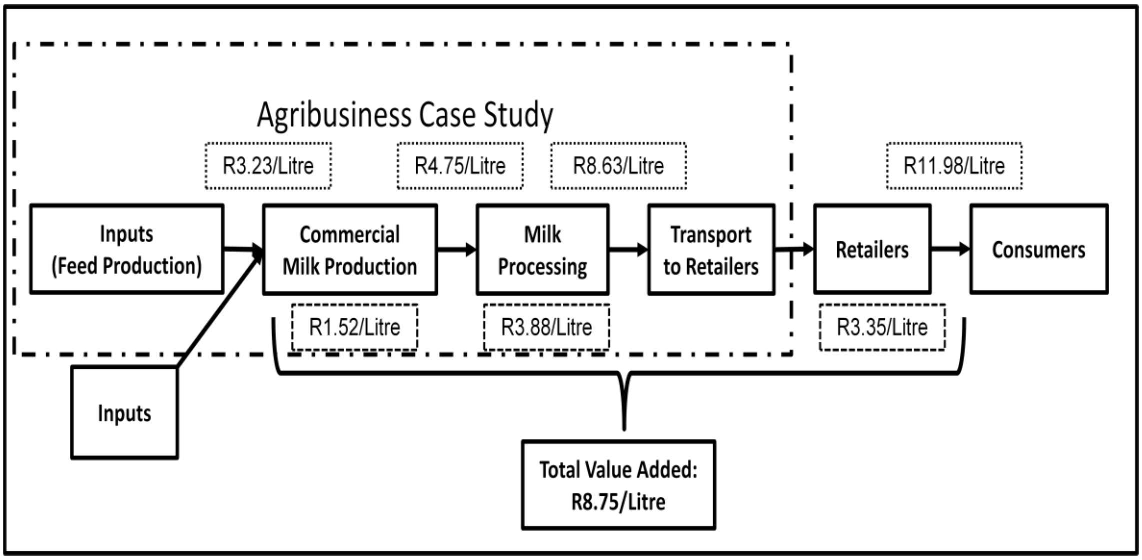


Figure 4.5 Distribution of value added (in 2014 prices) to milk produced in the Free State and sold in bottles with a capacity of three litres (Source: Own calculations)

The value added approach neglects the costs incurred and only considers the value added. It is clear from both Figure 4.4 and Figure 4.5 that the greatest value is added to the milk when it is bottled in smaller containers rather than larger containers.

The same volume of water is used to produce one litre of milk, regardless of the container in which it is packaged. Value added from processing to retail varied with the different packaging sizes, resulting in significantly different total value added. Table 4.12 lists the value added at the nodes along the value chain of milk. The total value added to the milk is then divided by the water footprint calculated earlier to obtain the value added per cubic metre of water once the processed milk reaches the final consumer.

Table 4.12 Value added (in 2014 prices) to the milk as it moves along the value chain from the primary producer to the final consumer

	1Litre	**3Litre**	
Dairy Value Added	R 1.57	R 1.57	R/kg
Processing Value Added	R 5.84	R 4.01	R/kg
Retail Value Added	R 4.70	R 3.46	R/kg
Total Value Added	R 12.11	R 9.04	R/kg
Water Used for Production	1.0250		m^3/kg
Value Added to the Water	**R 11.81**	**R 8.82**	**R/m^3**

Milk sold in the one litre bottle added the greatest value per litre of milk (thus also per kilogram) while the same quantity of water was used in the production thereof. It therefore makes sense that the value chain of milk packaged in bottles with a volume of one litre, add significantly more value to the water than the larger container's value chain. Table 4.12 confirms that the smaller container's value chain add R11.81 per cubic metre of water used during production as opposed to the R8.82 added to the water along the value chain of the three litre bottles.

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

4.8 Discussion

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

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

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

Despite using 1 024.965 litres of water to produce one kilogram of milk, the milk value chain in the case study does not significantly disrupt the natural runoff and remains environmentally sustainable. The water used in the production of milk is used to create a product that consumers demand and in the process, value is added to the water allocated to the production of milk. By adding value to the scarce resource, progress is made towards ensuring environmental sustainability, resource efficiency and social equity.

Value added to the milk differed notably depending on the packaging volume of the processed milk. The results showed that if the milk was bottled in a container with a capacity of one litre, the total value added to the milk was R3.06 per kilogram more than when it was bottled in a container with a three litre capacity. Despite using in excess of 98% of the total water for milk production on farm level, only between 13% and 17% of the value (depending on the packaging volume) was added on the farm level.

The total value added to the water used to produce one kilogram of milk (4% fat; 3.3% protein) and sold in one litre bottles amounted to R12.11. This relates to R11.81 per cubic metre of water used. In contrast, milk sold in bottles with a capacity of three litres only added a total of R9.04 per kilogram of milk and R8.82 per cubic metre of water used.

The results of this study show that allocating scarce freshwater to agriculture and more specifically to milk production is not only sustainable from an environmental flow requirement perspective, but using the water for the production of milk also adds significant value to the water.

CHAPTER 5

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

5.1.1 Background and motivation

Agriculture is the single largest user of freshwater in water-scarce South Africa and is currently an inefficient user of freshwater (Nieuwoudt *et al*., 2004; DWA, 2013). Backeberg and Reinders (2009) have stated that irrigated agriculture in South Africa uses roughly 40 % of the exploitable runoff, while other estimates suggest that up to 60 % of the available freshwater is used by the agricultural sector (DWA, 2013).

Despite agriculture's high water use, it directly contributes less than three per cent to the South African GDP (DAFF, 2014). The agricultural sector thus only generates a small portion of the income, while using the largest share of the available freshwater, meaning that it might be an inefficient allocation of scarce freshwater resources to agriculture (Nieuwoudt *et al*., 2004).

The scarce freshwater in South Africa is not only important to irrigated agriculture, but also for the production of animal products. Mekonnen and Hoekstra (2010b) and Hoekstra (2012) found that in excess of 95 % of animal water footprints relate to the water used in the production of feed.

The dairy industry is no different and also uses large volumes of water to produce milk. The sector is relatively important from an economic perspective in that the dairy industry contributes 14 % to the gross value of animal production and 7 % of the gross value of agricultural production in South Africa (DAFF, 2014). It is thus clear that the dairy industry is of economic importance, but its impacts as an employer in the rural areas are of much more significance. According to an industry overview of the dairy industry in South Africa, the sector consists of about 4 000 milk producers who in turn provide employment to 60 000 farm workers. A further 40 000 people have indirect employment in the rest of the dairy value chain (DAFF, 2012), spreading the benefits of the industry much farther. It is thus undeniable that the dairy industry is of significant socio-economic importance.

The complete dairy value chain is made up of several process steps, starting with the production of fodder and ending with the processed dairy product on the table of the final consumer. All the stages of production use water in the process of adding value to the product. Both De Boer *et al*. (2012) and Mekonnen and Hoekstra (2010b) have reported that the water use related to feed production comprised the majority of the total water usage. Faced with the dairy industry using vast quantities of freshwater in the production of milk, the focus on the sustainable use of the scarce resource from both an economic and environmental perspective is of paramount importance. Ridoutt *et al*. (2010) state that water footprints are emerging as an important indicator of sustainability in agriculture and have good prospects for contributing towards the sustainable use of freshwater.

5.2 Problem Statement and Objectives

In the wake of the inefficiency with which the agricultural sector uses water, policymakers have limited information available to guide the formulation of appropriate policies to guide the use of freshwater. These policies should also encourage irrigation farmers to adopt water use behaviour which tends to be more sustainable.

A reasonable amount of research has been done internationally on the water usage for the production of animal products, but in South Africa such research has been rather sparse. Most of the reported water footprint assessments focus on the environmental impact of water use only, neglecting the economic aspects of the water use.

In South Africa, the use of water footprints has been very limited, resulting in a lack of local scientific information to inform sustainable water use in South African dairy production. In consideration of the importance of the dairy industry in the South African economy, water footprint information is vital for moving towards the sustainable use of water.

The main objective of this study was to explore the water footprint of lucerne (*Medicago sativa*) produced under irrigation in South Africa and used as an important fodder crop for milk production. The value added to the water as the dairy product moves through the value chain was also investigated in order to take the first step towards establishing benchmarks for the economically and environmentally sustainable use of freshwater in the lucerne–dairy value chain. Two sub-objectives were used to achieve the main objective. Firstly, the water footprint of lucerne produced under irrigation in South Africa was investigated, after which the dairy value chain was used to determine the water footprint for milk. Secondly, the value of the water by the time it reached the final consumer in the form of milk was quantified in order to see how much value was added to the water along the lucerne–dairy value chain. This value added is expressed in terms of South African Rand (ZAR) per cubic metre of water used.

5.3 Results and Discussion

Lucerne Water Footprint Indicator

The results show that 456.609 cubic metres of water were used to produce one ton of lucerne under irrigation in the Vaalharts irrigation scheme in South Africa. Of that, 206.9 cubic metres of water was effective rainfall that contributed to the evapotranspiration of the crop, while the remainder of the evapotranspiration of 171.34 cubic metres was supplied by irrigation. A further 78.37 cubic metres of water was required to assimilate the salts from the production process to the natural levels in the receiving water body.

Evaporation of water during transport (via canals and diversions) and storage (from dams and reservoirs) was not considered in the calculation of the water used in the production of lucerne. Water usage in the supply chain of inputs for the production of lucerne was also not considered in the calculations.

Rainwater evapotranspired, or green water, accounted for of 45.3 per cent of the lucerne water footprint. Abstracted surface and groundwater used to irrigate the lucerne contributed a further 37.5 per cent of the water footprint, with the remaining 17.2 per cent being attributed to grey water. The blue and green water footprints can be reduced by improving the efficiency with which the lucerne uses the water, thus the use of cultivars that produce more dry matter from the same volume of water will decrease the water footprint per ton. Excessive salt leaching in the lucerne production case study can be attributed to the over-irrigation that was recorded. The average evapotranspiration over the course of the growing season was 1 157.19 mm, while the sum of the effective rainfall and applied irrigation over the same period was 1 238 mm. This difference is the total surplus irrigation that was responsible for leaching the salts and resulting in an unnecessarily high grey water footprint. Better irrigation scheduling could, therefore, reduce the grey water footprint.

Water Footprint Indicator of Processed Milk

Results showed that feed production accounted for the greatest portion of the water usage for milk production. Water related to feed production accounted for 1 004 litres of water for one kilogram of milk with a fat content of four per cent and 3.3 per cent protein. This relates to 98.02 % of the total water usage of 1 025 litres. Drinking water thus only contributes 0.59 % of the total water usage, while the remaining 1.41 % originated from the cleaning and sanitation procedures used at the dairy parlour and processing plant.

The total water usage can be divided into the different types of water. Investigating the origin of the total water use reveals that only 96 litres of water per kilogram of milk produced is from blue water (surface and groundwater). The majority of the water use, 862 litres, originates from rainwater that does not become runoff (i.e. used by the vegetation) and is considered to be green water. Grey water of 66 litres make up the remainder of the 1 025 litres of water used to produce one kilogram of milk. This grey water is the water required to assimilate the salts originating from the production processes to below the acceptable norms prescribed by the DWAF (1996a).

Since the greatest portion of the total water footprint is for the production of feed, it is important to investigate the type of water footprint of the feed. Blue water only accounts for 9 % of the total feed water, and grey water accounts for a further 5 %. The greatest portion of water used for the production of feed is therefore attributed to effective rainfall or green water. Reducing the irrigation requirement of the irrigated crops can decrease the consumptive water use of milk production. However, by eliminating irrigation altogether, the water footprint of the feed production could only be decreased by 9 %. Measures to decrease the water footprint indicator of milk production in South Africa include using crop hybrids that use the water more efficiently with better harvest indices and increasing the feed conversion efficiencies of the cows (more milk from the same feed).

Sustainability Assessment

Ultimately, the aim of all water footprint assessments is to determine the environmental sustainability of producing the product under consideration in a specific river basin of a catchment area. All the production of feeds for the dairy farm in the case study was done within the greater Orange River basin. The sustainability assessment was conducted by evaluating the monthly blue water scarcity according to the methodology and dataset of Hoekstra and Mekonnen (2011).

The feed consumed to produce milk on the farm in the case study came from irrigated crops that required the majority of water during the warmer months, from November to February. This is indeed the case for all the crops, apart from oats that were produced during the cooler months. Sorghum was planted in December and cut at the end of February for silage, while the maize planted in early November was also cut for silage in February. The ET_a of lucerne, which is a perennial crop, was much higher during the warm months, from November to February.

The main summer crop production months, apart for November that has moderate blue water scarcity, have low blue water scarcity. The production of lucerne, maize and sorghum under irrigation in the greater Orange River basin is sustainable in the sense that the production thereof does not distort the natural runoff significantly and environmental flow requirements are met.

Oats under irrigation are produced for silage between June and October, depending on the planting date. June has moderate blue water scarcity and significant blue water scarcity in occurs in July, while August, September and October experience severe water scarcity. Therefore, oats produced under irrigation in the Orange River basin are not sustainable from an environmental water flow requirement perspective. The production of oats in this basin should be strongly reconsidered.

The water footprint indicator as a stand-alone measure of freshwater use may be misleading. Therefore, the focus should be on the impact and sustainability of freshwater use, and not solely on the volumetric indicator. Despite the fairly large water footprint of milk production, the results of the case study show that this water footprint remains sustainable.

Value Added to the Water

The water used in the production of milk is used to create a product that consumers demand and in the process, value is added to the water allocated to the production of milk. By adding value to the scarce resource, progress is made towards ensuring environmental sustainability, resource efficiency and social equity.

Evaluating the value added along the value chain found that the total value added depends greatly on the volume of the container in which the processed milk is sold. The processing facility in the case study produced milk in two container sizes, one litre and three litres. The results showed that by packaging the processed milk in a bottle with a capacity of one litre, a total value of R11.72 was added per litre of milk. The value added per kilogram of milk (4% fat, 3.3% protein) is then R12.11. The greatest value is added to the milk during processing where R5.84 is added per kilogram. Retailers added a further R4.70 per kilogram with farmers adding only R1.57 per kilogram of milk.

Comparing the total value added to the milk packaged in three litre bottles shows that only R9.04 of value was added per kilogram in comparison with the R12.11 added to the smaller containers. The dairy farmer receives the same price for the raw milk regardless of the value added to the milk further along the value chain, so the value added to the milk by the farmer is again R1.57 per kilogram. It is thus clear that the greatest value is added to the milk when it is bottled in smaller rather than large containers.

The volume of water used along the value chain is the constant, regardless of the size of the container in which the milk is sold. The value added from processing to retail varied did, however, differ with the packaging sizes.

The value added per cubic metre of water once the processed milk reaches the final consumer was evaluated for the two different product volumes. Milk sold in the one litre bottle added the greatest value per kilogram of milk while the same quantity of water was used in the production thereof. It therefore makes sense that the value chain of milk packaged in bottles with a volume of one litre adds significantly more value to the water than the larger container's value chain. The value chain of the smaller container added R11.81 per cubic metre of water as opposed to the R8.82 added to the water along the value chain of the three litre bottles. One can then draw the conclusion that selling milk in smaller containers result in higher returns per cubic metre of water used.

Despite only 13% (17% for the 3l bottle) of the total value was added to the water on the farm, in excess of 98% of the all the water along the value chain was on the farm. This heavily skewed distribution of water used and value added emphasises the importance of focusing on the farm level to optimise the water used and value added to the water in the production of milk.

5.4 Recommendations

It is important to note that the focus of this South African case study of water footprint assessments is on the freshwater impacts of milk production, and that the study does not serve as a complete environmental sustainability indicator. Neither is this research representative of the South African dairy industry at large. It is acknowledged that not all production systems are alike, and that variability in the water footprints can be attributed to the differences in the production systems.

In the light of the results from this study, the following implications can be drawn for water users in the production of processed milk policy implications:

- Milk production in the greater Orange River basin does not disrupt the natural runoff significantly and satisfies the environmental flow requirements. Milk production in this basin is thus environmentally sustainable. However, oats and other crops produced under irrigation from July to October in this basin result in severe blue water scarcity and should be reconsidered.

- The distribution of water use in the milk value chain is heavily skewed with the production node accounting for more than 98% of the total water footprint. Emphasis should therefore be placed upon optimising water use on farm level in order to improve the water use efficiency of the value chain.
- Inefficient irrigation scheduling that result in over-irrigation is not reflected in the blue and green water footprints and only influences the leaching of salts from the soils. Better irrigation scheduling will result in lower grey water footprints.
- Grey water from the dairy parlour should be properly treated before leaving the effluent pond.

The following policy implications can be drawn from the study:

- Despite using vast quantities of water, significant value is added to the water along the milk value chain. Allocating water to this sector is not an inefficient allocation of freshwater. Therefore instead of just taking the primary production into account, the complete value chain of agricultural products should be considered before policy recommendations are made.
- The dairy industry is important from a socio-economic perspective and since the most value is added to the water during processing, incentives should be put in place to move the milk processing facilities to the rural production areas.
- The deterioration of irrigation water quality should be carefully monitored to ensure the sustainability of irrigated agriculture. Better guidelines and regulations for the timely evaluation of irrigation water quality should be established. More importantly, these guidelines and regulations should be implemented and action plans should be developed to manage the deterioration of water quality.
- Promote the research and development of irrigated field and fodder crops that have improved water use efficiencies. New varieties with better water use efficiencies will reduce the water footprints per unit of output.

The following recommendations for further research arise from the study:

- Further research to explore the water usage of different dairy production systems is of cardinal importance to enable comparisons to be made between different production systems.
- Ideally, all the information required to determine the water footprint of the milk value chain in South Africa should be obtained from actual measurements collected from various farms over a period exceeding one production season. Accurate *in situ* data will eliminate the need for estimations and ultimately result in more accurate water use related findings. Furthermore, such data will facilitate the making of comparisons of water footprints and contribute to the sustainability thereof over time. It will also be possible to formulate more accurate monthly blue water scarcities estimates for more localised areas.
- Research can also be extended to include pollutants other than just salts in the calculation of the grey water footprint.
- Research into the better management of dairy effluent might result in less pollutants originating from the dairy effluent.
- Explore the value added to water along the value chains of more processed dairy products (cheese, yogurt, butter, etc.). It is expected that such value chains will have substantially higher returns per cubic metre of water.
- The value of the meat at the end of the dairy cow's productive lifetime should be explored to determine the effect that the value of the meat will have on the water footprint of milk and meat.

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