THE WATER-ECONOMY NEXUS OF BEEF PRODUCED FROM DIFFERENT BREEDS OF CATTLE

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SUBMITTED IN ACCORDANCE WITH THE REQUIREMENTS FOR THE DEGREE
DOCTOR OF PHILOSOPHY

IN THE

FACULTY OF NATURAL AND AGRICULTURAL SCIENCES
DEPARTMENT OF AGRICULTURAL ECONOMICS
UNIVERSITY OF THE FREE STATE
BLOEMFONTEIN
2018

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DECLARATION

I, Frikkie Alberts Maré, hereby declare that:

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DEDICATION

This thesis is dedicated to my wife,
Ansori Maré,
who always stands behind me, encourages me,
and whose love carried me
through the compilation of the thesis.

ACKNOWLEDGEMENTS

"Money, if you use it, comes to an end. Learning, if you use it, increases."

- Swahili proverb -

I specifically want to thank my wife (Ansori Maré), my parents (Petrus and Christine Maré), my parents-in-law (Zol and Annelie du Plessis), and the rest of my family for their support, motivation, encouragement, and the sacrifices they had to make to enable me to complete this thesis. My greatest appreciation goes to our Heavenly Father who gave me the insight, guidance, and perseverance to complete this research.

I would also like to express my sincere gratitude to the following people and organisations for their contributions to this study:

- Dr Henry Jordaan, my promoter, colleague, and friend, for the significant role that he played in this study.
- Dr Mesfin Mekonnen, my co-promoter, for always willingly and very quickly assisting me with technical questions regarding the water footprint concept.
- Prof Bennie Grové, my colleague, friend, and previous co-supervisor of my MSc. I strongly believe that this thesis is largely based on the skills he taught me during my MSc.
- Profs Frikkie Neser and Hennie Snyman from the Department of Animal, Wildlife and Grassland Sciences, for the valuable information and guidance you supplied.
- Mr Nick Serfontein, chairman of the Sernick Group, for supplying the necessary data and hosting the feedlot experiment.
- Mr Carel Serfontein, CEO of the Sernick Group, and Mr Christo Faasen, MD of the Sernick Group, for the data you supplied.
- Mr Phillip Oosthuizen, my former MSc student, for his hard work with the feedlot experiment.
- Mr W.A. Lombard, Mr Walter van Niekerk, and Ms Marcill Venter, my colleagues and friends at the Department of Agricultural Economics, for your continued support.
- My other colleagues at the Department of Agricultural Economics for always helping out where needed.
- Mrs Chrizna van der Merwe and Ms Ina Combrinck, secretaries of the Department of Agricultural Economics, for providing me with so much more than administrative assistance.
- All the breeders' societies of the cattle breeds involved in this study for the data supplied by them.
- The Sernick Group and the Water Research Commission (WRC Project K5/2397//4) for their financial and other contributions. The views expressed in this thesis do not necessarily reflect those of the Sernick Group or the WRC.

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LIST OF ACRONYMS AND ABBREVIATIONS

ADG	Average daily gain
ARC	Agricultural Research Council
BFW	Body fluids weight
BOD	Biological oxygen demand
BPW	By-products weight
CIA	Central Intelligence Agency
COD	Chemical oxygen demand
CU	Cattle unit
CW	Carcass weight
DAFF	Department of Agriculture, Forestry and Fisheries
DARD	Department of Agriculture and Rural Development
DM	Dry matter
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
ET	Evapotranspiration
EWC	Economic water consumption
EWP	Economic water productivity
FCR	Feed conversion ratio
GDP	Gross domestic product
ha	Hectare
ISO	International Organization for Standardization
kg	Kilogram
LCA	Life-cycle assessment
LSU	Large stock unit
LW	Live weight
m^3	Cubic metre
MFC	Marginal factor cost
OECD	Organization for Economic Co-operation and Development
PMFP	Profit-maximising feeding period
R	South African rand
SAFA	South African Feedlot Association

SCU	Slaughtered cattle unit
SS	Suspended solids
Stats SA	Statistics South Africa
TBL	Triple bottom line
TSS	Total suspended solids
TV	Total value
UFS	University of the Free State
USA	Unites States of America
USD	United States dollar
VA	Value added
VAT	Value-added tax
VCA	Value chain analysis
VF	Value factor
VMP	Value of the marginal product
WF	Water footprint
WFA	Water footprint assessment
WFN	Water Footprint Network
WF_{VA}	Water footprint of the value added (economic water consumption)
WRC	Water Research Commission
wrcu	Water-related cattle unit
WSI	Water stress index
WUE	Water use efficiency

ABSTRACT

Beef production is well documented to have a very high water footprint (WF), leading to recommendations that consumers should eat less beef in order to decrease the pressure on the scarce freshwater resource. Given the importance of beef production to the South African economy, in the context of severe freshwater scarcity, it is important to understand the water-economy nexus of beef production in order to ensure the ecological stewardship and economic prosperity of the sector. The primary objective of this research was to analyse the WF and economic value added (VA) of different breeds of beef cattle, produced through the same production method, with the aim of identifying the breed with the best economic water consumption (EWC) figures in terms of beef production. A bottom-up approach was followed to analyse the WF and economic VA for the different links along the value chain. Seven different cattle breeds (Afrikaner, Brahman, Bonsmara, Simbra, Angus, Simmentaler, and Limousin) were used for the analyses to determine the EWC for each breed for an extensive cow-calf production system, a feedlot, and an abattoir, representing the complete value chain of beef production.

The WF approach was followed to estimate the green, blue, and grey WF of each breed for every step in the value chain in order to quantify the freshwater consumption. Economic VA, as the difference between the total revenue and the cost of those intermediate production factors, of which the WF was not included in the total WF of the production process, was used as the economic indicator for every step in the value chain. The EWC of the different breeds was then expressed as the total WF per unit of economic VA in litre/R. The EWC for a kilogram (kg) of beef for different beef cuts was then estimated according to the value factor (VF) of each cut in relation to the total value (TV) of the slaughtered animal. In order to treat all the breeds the same, a simulation model was used for the extensive cow-calf enterprise that simulated the feed intake and reproduction data of each breed according to the breed's average performance data. The feedlot data were gathered through an experiment whereby 35 bull calves from each breed (245 in total) were fed according to their profit-maximising feeding period (PMFP), while the processing (slaughter and deboning) data were collected when the fattened calves from the feedlot were slaughtered and processed.

The results show notable differences between the different breeds in terms of their WF, economic VA, and EWC. It was interesting to note that while the Angus had the lowest overall EWC for the whole value chain, it was not the breed with the lowest EWC for any of the individual stages in the value chain. The Bonsmara revealed the lowest EWC in terms of the extensive cow-calf enterprise, while the Limousin and Simmentaler exhibited the lowest EWC in terms of feedlot fattening and abattoir processing respectively. Similar contradicting results were also found when comparing only the WF or the economic VA of the different breeds for the whole value chain to that of the separate links along the value chain. These contradicting results showed the benefit of a bottom-up approach compared to a top-down approach when estimating the WF, economic VA, and EWC of beef.

The results further showed that there is a large difference in the WF of different cuts of beef, with the high-value cuts having a much larger WF than the lower-value cuts. As such, the results show that a consumer can decrease his/her overall WF by consuming lower-value beef cuts.

The conclusion from this research is that the calculation and reporting of the WF, economic VA, and EWC, especially for products with more than one value chain link, is much more complicated than a top-down analysis based on the whole value chain. By estimating only one value for each of the abovementioned factors for the whole value chain and then making recommendations on that value, one could easily be guilty of the fallacy of division since the recommendations may have a negative influence on some links in the value chain. Each link in the value chain should therefore be assessed individually to identify problem areas in the WF and economic VA context that can be improved by recommendations for the specific value chain link. It is further important to keep the water-economy nexus in mind and analyse the WF and economic VA in a holistic framework as recommendations to decrease the WF of a product may lead to a less desired economic situation and *vice versa.* The estimated WFs of the different beef cuts provide new knowledge and can be used to create awareness among consumers, but even if consumers switch to cheaper beef cuts with a lower WF, it will not help to improve the overall WF of beef. It is thus concluded that the optimisation of production from the available freshwater sources for each link in the value chain should be prioritised as it will decrease the overall WF of the product, increase the economic VA, and improve the EWC.

CHAPTER 1

INTRODUCTION

"Water is life. It's vital. It supports the immense diversity of life on earth. It's a source of food, health and energy. Fresh water makes civilization possible. But fresh water, in turn, isn't possible without a healthy planet – and human actions are putting a healthy planet at risk."

- Conservation International (2016) -

1.1 BACKGROUND AND MOTIVATION

Water conservation theory has existed since the beginning of time as any society that deals with a limited resource quickly learns to use it wisely. During the 1900s, the governments of various countries realised the need for legislation on water use in order to allocate this precious resource more effectively among an unlimited number of uses. In order to attempt to get society to save water, various initiatives have been introduced in different countries, such as the National Water Week in South Africa (Department of Water Affairs [DWA], 2016). The focus of initiatives like South African National Water Week is to make consumers of water aware of the value of water and the need for sustainable management of this scarce resource by encouraging them to save on their physical water use in and around the home and workplace. Although people use large amounts of water for drinking, cooking, washing, and other activities at home, the Water Footprint Network (WFN, 2016) argues that even more water is used for growing food and producing items like clothing, cars, and computers.

According to the WFN (2016), the water footprint (WF) measures the amount of water used to produce each of the foods and services people use. It can be measured for a process, product, company, country, or even globally. By using the WF method to calculate one's total water use, the focus of saving water for sustainable use shifts from the physical consumption of freshwater (such as a shower instead of a bath because a shower uses less water) towards saving water through the food that one consumes or the products one uses. One kilogram of beef, according to the WFN (2016), has a global average WF of 15 415 litres, while a kilogram of sheep meat and chicken meat have WFs of respectively 10 412 litres and 4 325 litres. One can thus lower one's WF by consuming sheep or chicken meat instead of beef.

Although the suggestion that people should change their diets in order to save water does hold some truth, it is, however, not that simple as there are factors other than water use that will also be influenced by such an action. The influence of changing diets in order to save water will have a different impact on different continents, countries, provinces, regions, and even farms as the availability and source of freshwater, the climate, the type of products produced, the production systems of these products, and the socio-economic circumstances of the population differ.

Another factor that should be kept in mind is the issue regarding food security and the growing population figures that accompany it. Malthus (1798) stated,

> "*Yet in all societies, even those that are most vicious, the tendency to a virtuous attachment is so strong, that there is a constant effort towards an increase of population. This increases the number of people before the means of subsistence are increased. The food therefore which before supported seven millions must now be divided among seven millions and a half or eight millions.*"

The fact that water is a scarce resource and should be used wisely will always be true, but the fact that we are dealing with an increasing population cannot be ignored. To date, the production of food and fibre was able to keep up with the growing demand from society, but will this tendency continue indefinitely? Available agricultural land should thus be used to its optimal potential to produce food and fibre, without harming the natural resources required to do so.

In South Africa, 79.4% of the total available land surface is suitable for agricultural production (Central Intelligence Agency [CIA], 2016). Of the total agricultural land, only 12.5% is arable, with a further 0.4% planted with permanent crops. The rest, or 87.1%, of the total agricultural land is covered with permanent natural pasture that can only be used for livestock production or game ranching. Animal production is the largest agricultural sector in South Africa and contributed 47.6% to the total gross income from agricultural production for the year 2016. The gross income from slaughtered cattle amounted to R33 004 million (1 USD = R14.70), which equals 26.7% of the gross income of animal production and 12.7% of agriculture as a whole (Department of Agriculture, Forestry and Fisheries [DAFF], 2017). Apart from the direct contribution by the primary beef production sector, the indirect contribution through the secondary and tertiary economic sectors in terms of elements such as input suppliers and job creation should also be taken into account. The livestock sector, especially the beef production sector, is thus a very large and important sector in terms of the South African economy and care should be taken to ensure its future existence.

In the event where members of society heed the recommendation from the WFN (2016) and change their diet from products like beef to products that use less water to produce, such as chicken meat, a large part of the total available agricultural land in South Africa may become unproductive. This will not only affect the food security of the country, but will also negatively influence a sector that largely contributes to the total gross domestic product (GDP), export market, and employment in the country. Instead of discouraging the consumption of beef, there should rather be a search for ways to produce beef with a lower WF that will improve the environmental stewardship of beef production.

Another way for consumers to decrease their WF, according to Hoekstra (2010), is to maintain their consumption patterns but select products with a relatively lower WF from other regions or production systems. The problem, however, is that it is easier said than done due to three reasons. The first is the fact that some regions are, for example, only suitable for extensive beef production. The region, product, and production method are thus rather fixed, as no other viable option exists to keep the specific area of land in production. The second issue with selecting products from another region or production system with a relatively lower WF is the fact that the WF information in many instances does not exist and the consumer thus has no way to compare and select the preferred option. The third reason is the fact that the region that produces products with a lower WF may not necessarily be more sustainable in terms of freshwater use as the water scarcity of the specific region is not always taken into account in the WF analysis. Ways should thus rather be determined to reduce the WF of beef in areas where only one production method can be applied in order to increase the environmental stewardship of beef production, while balancing the economic viability at the same time.

The WF of a kilogram of beef comprises various sources of water throughout the value chain. Spies (2011) conducted a detailed analysis of the red meat value chain in South Africa, and the complexity of the value chain with the various factors that can influence each link of the chain was clearly demonstrated. Due to the complexity of the value chain, one should be very cautious to make assumptions regarding the value chain and the estimation of the WF of beef. The WF for cattle production can, for example, differ significantly between two regions and even though each region may have the same reproduction statistics, the total WF of the beef produced from the two regions can differ. Harding, Courtney and Russo (2017) proved this point when they investigated the influence of geographical location of primary cattle production, feed production, feedlots, and abattoirs in South Africa on the blue WF of beef. They found that the blue WF for beef varied between 3 583 litres/kg carcass weight (CW) in the worst-case scenario to 353 litres/kg CW in the best-case scenario. The estimation of the WF of beef should thus further be done according to a detailed value chain analysis (VCA) for a specific region and production system so that the WF is not over- or underestimated based on certain assumptions.

1.2 PROBLEM STATEMENT AND OBJECTIVES

Large parts of agricultural land in South Africa and the rest of the world are only suitable for extensive cow-calf beef production. It will thus be very difficult to use another production method or to produce another agricultural commodity with a lower WF in these regions. It is, however, documented that different breeds of cattle have different feed and water requirements. One way to address the issue of the large WF of beef, while keeping the economic consequences of proposed changes in mind, is to estimate the WF of different breeds of beef cattle for every link in the value chain to identify the beef breed that best optimises freshwater consumption in terms of production (volume water / kg beef) and economic value added (VA) (volume water / monetary unit VA).

Traditionally, the focus of water requirements for beef cattle was more on the amount of drinking water (direct water use) that the animals require (Ittner, Kelly & Guilbert, 1951; Winchester & Morris, 1956; Parker *et al*., 1998; Gaughan *et al*., 2001; Davis, Watts & Tucker, 2006). The focus of these studies was on the influence that factors such as the ambient temperature, dry matter (DM) intake, and other meteorological variables, such as humidity, rainfall, and radiation, had on the water intake of cattle. Although most of the studies focused on beef cattle under feedlot conditions, there is very little reference to the types of cattle that were used in the particular studies. Winchester and Morris (1956) distinguished between *Bos indicus* and *Bos taurus* types of breeds and found that the *Bos indicus* cattle drank significantly less water than the *Bos taurus*. The problem, however, is that there are many breeds that can be classified under either *Bos indicus* or *Bos taurus* and other sub-genetic classifications as well. Apart from the need for better distinction between different breeds in terms of water utilisation, the focus of water consumption research has also shifted to the indirect water use.

Since recognising the importance of accounting for the indirect water use to produce products or deliver services, various authors investigated the total water use (total WF) to produce beef (Mekonnen & Hoekstra, 2010; Ercin, Aldaya & Hoekstra, 2012; Hoekstra, 2012; Mekonnen & Hoekstra, 2012; Ridoutt *et al*., 2012; Gerbens-Leenes, Mekonnen & Hoekstra, 2013; Bosire *et al*., 2015). The specific focus of the abovementioned studies differed in many ways. Mekonnen and Hoekstra (2010) compared the WF of beef in a global analysis for three different farming (production) systems, without any reference to the type (breed) of cattle. Ridoutt *et al.* (2012) compared the WF of six geographically defined beef cattle production systems in Australia, with the only reference to the type of cattle for two of the systems in the broad definitions of "Japanese ox" and "EU cattle". Gerbens-Leenes *et al.* (2013) and Bosire *et al.* (2015) focused more on comparing the WF of different types of meat (poultry, pork, beef, shoats, and camels) to one another. Whether the specific study included multiple countries (Gerbens-Leenes *et al.*, 2013) or one country (Bosire *et al.*, 2015), no reference was made to types of cattle in the various countries. Authors comparing different production systems such as grazing, mixed, and industrial systems (Gerbens-Leenes *et al.,* 2013), and arid, semi-arid, and humid systems (Bosire *et al.,* 2015) also focused solely on the production system and not on different types of cattle.

In light of the literature referred to above, it is clear that little attention has been paid to the variation in the WF of different breeds of beef cattle. This is quite an interesting fact, as the studies by Mekonnen and Hoekstra (2010), Hoekstra (2012), Mekonnen and Hoekstra (2012), Ridoutt *et al.* (2012), Gerbens-Leenes *et al.* (2013), and Bosire *et al.* (2015) all referred to the fact that the feed that the cattle (animal) consumed contributed the largest part to the WF of beef (meat), and that the feed conversion ratio (FCR) or feed efficiency (kilogram feed required per kilogram live weight

[LW] gained) was an important factor to consider in the total WF of beef. The fact that the FCR of beef cattle differs between breeds, as well as within a certain breed, has already been proven by various studies and it was found that the FCR should be considered an important variable when a producer decides on a certain breed to farm with or when the selection criteria for the breed are determined (Koch *et al*., 1963; Archer & Bergh, 2000; Bosman, 2002; Strydom *et al*., 2008; Crowley *et al*., 2010). Except for the difference in FCR between cattle breeds, other biological traits, like cow productivity, also differ between breeds and will ultimately affect the breed's freshwater consumption and must be investigated. Neglecting the different breeds in previous research means that one of the factors that participants in the beef value chain can consider to reduce the WF of their activities, has not been investigated before.

Another interesting observation made from the research that was previously conducted on the WF of beef is the fact that many of the studies applied a top-down approach, with many assumptions to estimate the WF of beef at country level. Although some of the studies, such as Ridoutt *et al.*'s (2012) study, compared geographical regions within a country, and other studies, such as those by Gerbens-Leenes *et al.* (2013) and Bosire *et al.* (2015), referred to different production systems, none of the studies distinguished between the different value chain links within the beef value chain. Feng *et al.* (2011) found that although a top-down approach can provide relatively detailed WFs of industrial products, the bottom-up approach should be used for agricultural products to allow for detailed information of the individual processes in the value chain in order to make policy recommendations. In order to really grasp the WF of beef, it is thus necessary to analyse the different value chain links (primary production, feedlot fattening, and abattoir processing) in order to determine how the various links contribute to the total WF. The WF of beef (or other agricultural products) should thus be determined according to a detailed VCA. One study that did not only compare different regions but also the different links in the value chain is by Harding *et al.* (2017). However, they only estimated the blue WF to use it in a life-cycle assessment (LCA) where the water equivalent footprint of the various links in the beef value chain was estimated for different regions. Since Harding *et al.*'s (2017) study did not include the green and grey WFs, the total WF of the various value chain links was not estimated.

The need for considering the environmental (water) and economic impacts of agricultural production has been identified in the past and various authors have estimated the economic productivity of water (monetary unit / volume of water) (Crafford *et al*., 2004; Sraïri *et al.,* 2009; Aldaya, Munoz & Hoekstra, 2010; Jordaan, 2012; Chouchane *et al*., 2013; Zoumides *et al*., 2014; Scheepers, 2015), or the economic consumption of water (volume of water / monetary unit) (Mekonnen & Hoekstra, 2011; Rudenko *et al*., 2013). Although both reporting methods can certainly be used as indicators of the water-economy nexus, the differences in reporting make it difficult to compare the results of the different studies. The other problem with the mentioned literature is that the estimation methods of the economic impact differed between studies. The different methodology of studies implies that in some instances the results of studies that have used the same reporting method cannot be compared. In order to compare the water and economic impacts (water-economy nexus) of different studies, products, or production methods, it is necessary to find a uniform method to estimate and report these impacts.

Various gaps in the existing knowledge on the WF and economic VA of beef were discovered during the literature review. The first gap is the differences between cattle breeds in terms of their reproduction, production, and input demand factors that were ignored in the past. Secondly, very little attention has been paid in the past to the various links in the value chain and how each of these links influences the WF and VA of beef production. Thirdly, although the importance of considering environmental (water) and economic impacts in conjunction had been identified in the past, the methods used to analyse these impacts differed between studies as some expressed it as economic water productivity (EWP), while others preferred economic water consumption (EWC). In order to contribute to knowledge of the WF of beef, and WF research in general, **the primary objective of this study is to analyse different breeds of beef cattle, following the same production method, on their WF and economic VA for different links in the value chain through a bottom-up approach to identify the breed with the best EWC figures in terms of beef production.** It is of crucial importance that beef production enterprises must be environmentally and economically viable in order to ensure their longevity and for them to contribute to social sustainability at large by providing employment in the region and food for an ever-growing population. The estimated WF and VA results for different links in the value chain will provide valuable information for policy recommendations to address the specific problem areas.

In order to achieve the primary objective, the following secondary objectives must be reached:

- **Estimate the water-economy nexus of the different cattle breeds under the same extensive farming conditions for a cow-calf enterprise.**

  In order to treat all the cattle breeds the same in terms of the extensive farming conditions for a cow-calf enterprise, it is necessary to make use of a farm simulation model where it is assumed that all the breeds are reared on the same farm. Sufficient information about each breed exists, in terms of their genetic and production potential, to make very accurate assumptions in this simulation model. The WF and economic VA of breeds will differ as the grazing utilisation, need for supplement feed, inter-calf periods, and weaning weights of breeds differ.

- **Estimate the water-economy nexus of the different cattle breeds in an intensive feedlot at the profit-maximising feeding period (PMFP).**

  Thirty-five calves of each of the chosen breeds were fed in a commercial feedlot until the feeding period where each breed realised the maximum profit or minimum loss was reached. This was done by weighing the animals on a weekly basis to determine the value of the extra LW they have gained (value of the marginal product [VMP]) and comparing it to the feeding cost for that week (marginal factor cost [MFC]). Once the calves reached the point where the VMP was equal to the MFC, they were slaughtered.

- **Estimate the water-economy nexus of the different cattle breeds at the abattoir and deboning plant.**
  Abattoirs use approximately the same quantity of water per beef carcass, not depending on the relative size (weight) of the carcass. The slaughter and deboning statistics of the calves that were slaughtered from the feedlot were used to estimate the WF and VA of the different breeds. The WF and VA of the abattoir and processing plant vary between the breeds, as the CW, bone-meat ratios, and value of the by-products differ between the breeds.

The achievement of the abovementioned primary and secondary objectives contributes knowledge to the fields of WF research and agricultural economics as:

- the WF of beef produced from a specific region through the widest utilised production system in South Africa is estimated;
- the WF of different cattle breeds following the same production system is estimated at every step of the value chain;
- the economic contribution of the various breeds in terms of VA is estimated at every step of the value chain; and
- the water-economy nexus for beef production is addressed as the quantity of water to produce a unit of VA (EWC) is estimated for each cattle breed.

1.3 THE SOUTH AFRICAN BEEF INDUSTRY

In order to gain a better understanding of the South African beef industry, it is necessary to provide an overview of the industry in terms of the different segments and their roles within the beef value chain. The relevance of the beef industry to the South African economy must also be reviewed in order to emphasise the importance of the future sustainability of this industry.

1.3.1 Relevance of the beef industry to the South African economy

The value of primary South African agricultural production was R263.2 billion in 2016, while the estimated contribution to the GDP was R72.2 billion in 2015 (DAFF, 2017). Although primary agricultural production contributes only 2% to the total GDP of the country, the other linkages in terms of the value chain, which include the processing and retail sectors, should also be kept in mind as more than 70% of primary agricultural output consists of intermediate products. Greyling (2012) found that when primary agricultural production is considered with only the sectors with which it has the strongest linkages, agriculture represents around 7% of the economy.

The total gross income of agricultural producers amounted to R259 620 million for 2016, of which animal products contributed 47.6%. Slaughtered cattle contributed the most to the total gross income, with a share of 26.7% in terms of animal products and 12.7% in terms of the total gross income of agriculture (DAFF, 2017).

In addition to its direct economic contribution, the red meat industry is also a major employer in the agricultural sector. The primary agricultural sector employs approximately 810 000 people in South Africa (Statistics South Africa [Stats SA], 2017). Livestock producers create about a quarter (200 000) of the available jobs in agriculture, while the mixed-farming producers (crops and livestock) create a further 50 000 jobs. Jobs created by agriculture through secondary and tertiary linkages are not included in these statistics and should further increase the importance of the red meat value chain as a contributor to employment.

The livestock industry, including the beef value chain, is a very important sector for South Africa in terms of its contribution to the economy. Red meat, and especially beef, has, however, been identified as one of the food products with the largest WF and consumers are therefore encouraged to consume less beef (Hoekstra, 2010). The availability of freshwater for the production of products, however, differs between countries and it is therefore necessary to evaluate the availability of freshwater in South Africa in order to determine whether the WF of beef production should be considered.

1.3.2 The beef value chain

The South African beef value chain is illustrated in Figure 1.1. Although some parts of the value chain may not have been included in the figure, this version was simplified to focus more specifically on the commercial production and processing of cattle into beef and the WF and VA of these sectors.

The black areas and linkages in Figure 1.1 are those that form part of this study, while the grey areas were omitted from the study. The main role players in the South African beef value chain are as follows:

- **National cattle herd:** According to Stats SA (2016), the national cattle herd consist of almost 14 million head of cattle.
- **Farmers (producers):** There are approximately 31 567 households farming with 51 or more cattle and 556 800 households farming with between 1 and 50 head of cattle (Stats SA, 2016). Although Stats SA (2016) only defines the households in terms of the number of cattle kept, for the purposes of this study it is assumed that the first group of households (51 or more cattle) are commercial producers, while the rest are either emerging or subsistence farmers. The breeds and production methods differ between farms and production regions.

Primary producers farm with a large variety of cattle breeds and the most common production system is the cow-calf production system, where weaned calves of approximately seven months of age are sold to a feedlot for finishing.

- **Feedlot sector:** Between 65% and 70% of all cattle that are slaughtered in South Africa are from the feedlot sector (DAFF, 2014). The majority of feedlots buy weaned calves at an approximate LW of 235 kg and then increase the LW to 450 kg over a period of approximately 112 days before they are slaughtered (Ford, 2011). Feedlots with different standing capacities, from a few animals to 130 000 animals, exist in South Africa (Oosthuizen, 2016). The total standing capacity of the feedlot industry is about 580 000 animals at any given point in time, delivering approximately 1.5 million animals annually (Oosthuizen, 2016).

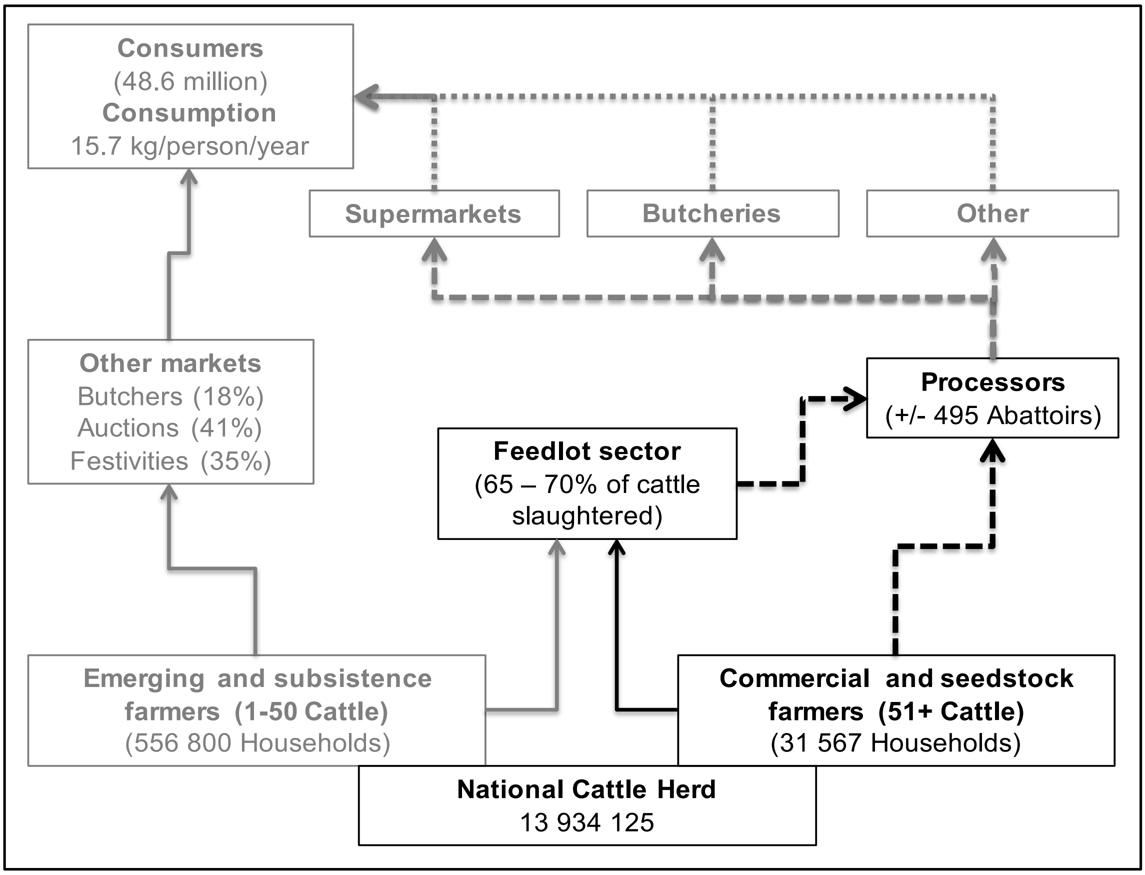

Figure 1.1: South African beef value chain
Source: Compiled from Spies (2011), DAFF (2014), and Stats SA (2016)

- **Other markets:** The other markets in the beef value chain include, but are not limited to, informal butchers (18%), auctions (41%), and festivities (35%) (DAFF, 2014). Most of the cattle from the emerging or small-scale sector enter these markets but some animals from commercial farmers may also be sent through these channels.
- **Abattoirs (commodity processors):** The abattoir sector plays a very important role in the beef value chain as it transforms live animals to meat. Throughout South Africa there are approximately 495 red meat abattoirs slaughtering from two to 1 500 units per abattoir per day

(DAFF, 2014). Many of the large feedlots own their own abattoirs and are thus vertically integrated.

- **Retailers (food product processors):** Retailers are considered as all outlets selling red meat products and include, but are not limited to, supermarkets and butcheries. There are four large supermarket chains in South Africa and numerous independent butcheries and other outlets of beef. The supermarkets usually have a butchery that processes the carcasses to different cuts of meat and other products. The consumer buys the final product directly from one of the retailers.
- **Consumers:** In South Africa, there are approximately 48.6 million consumers of beef with an average per capita consumption of 15.7 kg/year (DAFF, 2014).

The South African beef value chain is large and complex and has many linkages. It must, however, be seen in the context of the rest of the South African economy to realise the importance of this sector.

1.4 DESCRIPTION OF THE STUDY AREA

The Sernick Group provided the data used in this research. This specific group of companies was chosen as it owns all the relevant links in the beef value chain, from a cow-calf enterprise to the abattoir and deboning facility.

Sernick was founded in 1982 and is a diversified organisation that focuses on agriculture and agricultural processing activities. Sernick is based in Kroonstad and Edenville in the Free State province of South Africa and consists of six business entities that each adds value to the group. The group employs approximately 400 people and has an annual turnover of approximately R1 billion (Sernick, 2017). Figure 1.2 provides a graphic representation of the Sernick Group, with the red blocks representing the business units of the group and the grey blocks representing the group’s dealings with other parties.

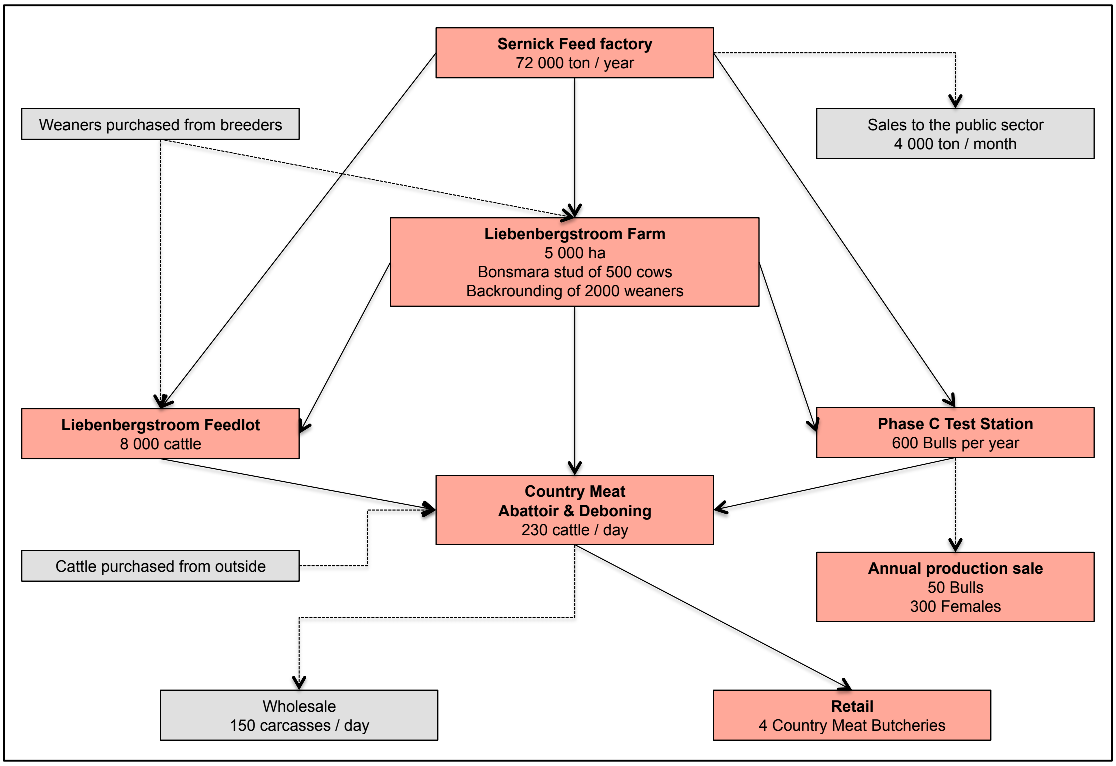

Figure 1.2: The Sernick Group
Source: Adapted from Sernick (2017)

Since this study focuses on beef production, the following business units within the Sernick Group were used to generate the necessary data by either conducting actual experiments or through simulation:

- **Liebenbergstroom Farm:** The farmland was used as the basis to simulate the cow-calf production system of seven different cattle breeds.
- **Liebenbergstroom Feedlot:** The commercial feedlot was used to conduct a feeding experiment with weaned calves from seven different cattle breeds in order to determine their feed intake and profit-maximising slaughter point.
- **Sernick Feed Factory:** All the supplementary feed that was used in the cow-calf production simulation, as well as the different feed rations used in the feedlot to fatten the weaned calves, was provided by the Sernick Feed Factory.
- **Country Meat Abattoir and Deboning:** The feedlot-fattened calves were slaughtered and deboned at the abattoir to determine the carcass composition and economic value, as well as the value of the by-products of the seven different cattle breeds.

The Sernick Group is known for its production of stud Bonsmara cattle, which is a very prominent and renowned breed in South Africa. The farmlands of the Sernick Group can, however, also be used to farm with other cattle breeds. The purpose of this study is to evaluate the different breeds in terms of their WF and economic contribution.

1.5 LAYOUT OF THE THESIS

The thesis is presented in seven chapters, of which the first chapter provides an introduction and background to study. The problem statement and objectives are also set in Chapter 1 and some literature is reviewed to show how the study relates to the existing literature.

Chapter 2 entails a literature review on various topics to allow for meeting the objectives of the study. The different approaches to WF analysis are reviewed, with special attention to the WF analysis method of the WFN, the WF in LCA, and the International Organization for Standardization (ISO) standard for water footprint assessment (WFA), in order to identify the most suitable methodology for the purposes of the study. Studies that estimated both water and economic impacts are also reviewed to determine the methodology that should be followed in the estimation of the water-economy nexus for beef, before the last part of Chapter 2 provides the differences between cattle breeds as a justification of the study.

Chapters 3, 4, and 5 deal with the water-economy nexus of the different links in the beef value chain according to the objectives. In Chapter 3, the WF and VA of a cow-calf production system are quantified, while the same is done for the feedlot in Chapter 4, and for the abattoir and deboning plant in Chapter 5. The main purpose of these three chapters is to estimate the water-economy nexus for each of the seven identified cattle breeds according to the value chain link.

In Chapter 6, the findings of the previous three chapters are used to estimate the total WF, economic VA, and EWC of different beef cuts produced from the different cattle breeds.

Finally, Chapter 7 provides a short summary of the thesis and the conclusion on the water-economy nexus of beef produced from different breeds of cattle. Some recommendations for beef cattle farmers, feedlots, and abattoirs regarding the improvement of their EWC are provided, and recommendations are also made for policy formulation and possible future research topics are proposed.

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CHAPTER 2

LITERATURE REVIEW

"We forget that the water cycle and the life cycle are one."

- Jacques-Yves Cousteau (1910 – 1997) -

2.1 INTRODUCTION

The first part of the literature review sets out to determine whether South Africa can be considered a water-stressed country, to justify the need for water consumption or water footprint (WF) research. The different approaches to WF analysis are reviewed thereafter with specific focus on the water footprint assessment (WFA), water footprinting in the life-cycle assessment (LCA), the International Organization for Standardization (ISO) standard for WFA, and the approaches that were previously used to estimate the WF of beef in order to determine which approach should be used in this study. Without previous research specifically focusing on the water-economy nexus, the literature review sets out to determine how economic impacts have been linked with water footprinting in the past and how the economic impact should be reported. The last part of the review focuses on the differences between beef cattle breeds in order to justify the estimation of the water-economy nexus for different breeds.

2.2 SOUTH AFRICA AS A WATER-STRESSED COUNTRY

In terms of the availability of freshwater, it is important to distinguish between water scarcity and water stress. According to Schulte (2014), the term "water scarcity" refers to the "volumetric abundance, or lack thereof, of water supply", while "water stress" refers to the "ability, or lack thereof, to meet human and ecological demand for water". Water scarcity is thus an aspect that contributes to water stress. A certain area, or country, can thus be water stressed, but not water scarce.

In terms of water stress, South Africa is ranked the 65th most water-stressed country in the world (Gassert *et al.*, 2013). According to Gassert *et al.* (2013), South Africa has an average water stress score of 3.04, while agriculture has an average score of 3.19; where a score of [4-5] indicates extremely high stress (>80%), [3-4] is an indication of high stress (40-80%), and [2-3] indicates medium-high stress (20-40%). Figure 2.1 provides an overview of the exposure to water stress in areas of agricultural production.

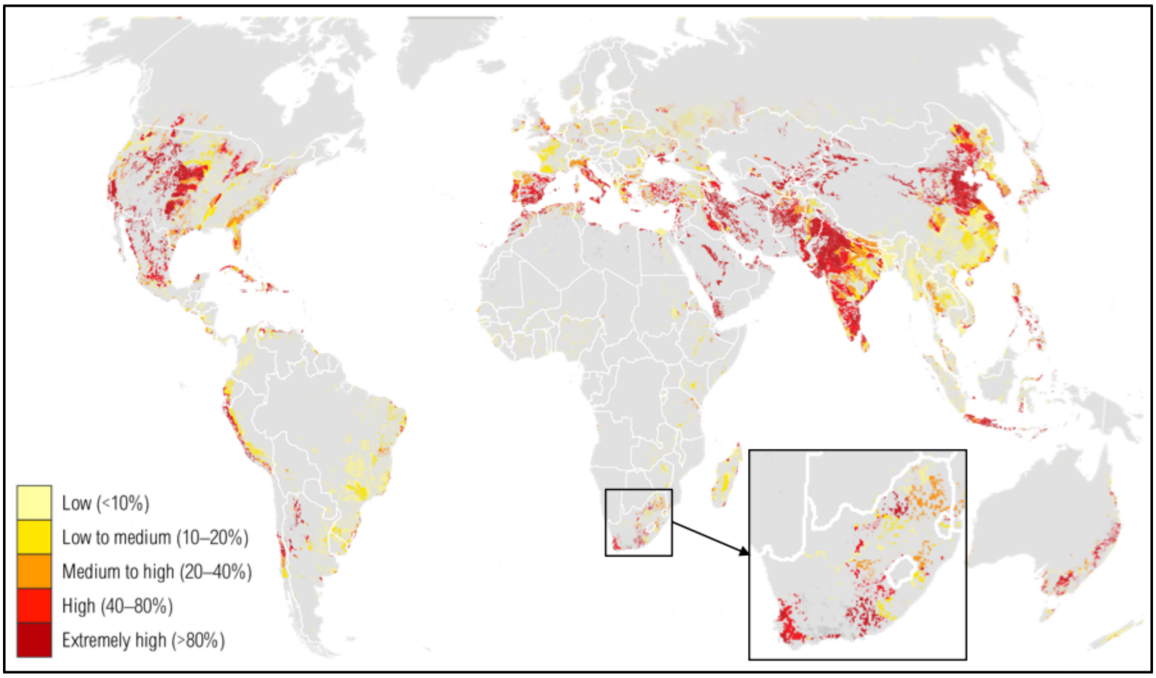

Figure 2.1: Exposure to water stress in areas of agricultural production
Source: Gassert *et al.* (2013)

It is clear from Figure 2.1 that although the average water stress for South Africa is considered as “high stress”, the water stress in the country varies from “low” to “extremely high”. The variability in water stress across South Africa is also presented in Figure 2.2, which shows the water stress index (WSI) (Pfister, Koehler & Hellweg, 2009) at watershed level for South Africa.

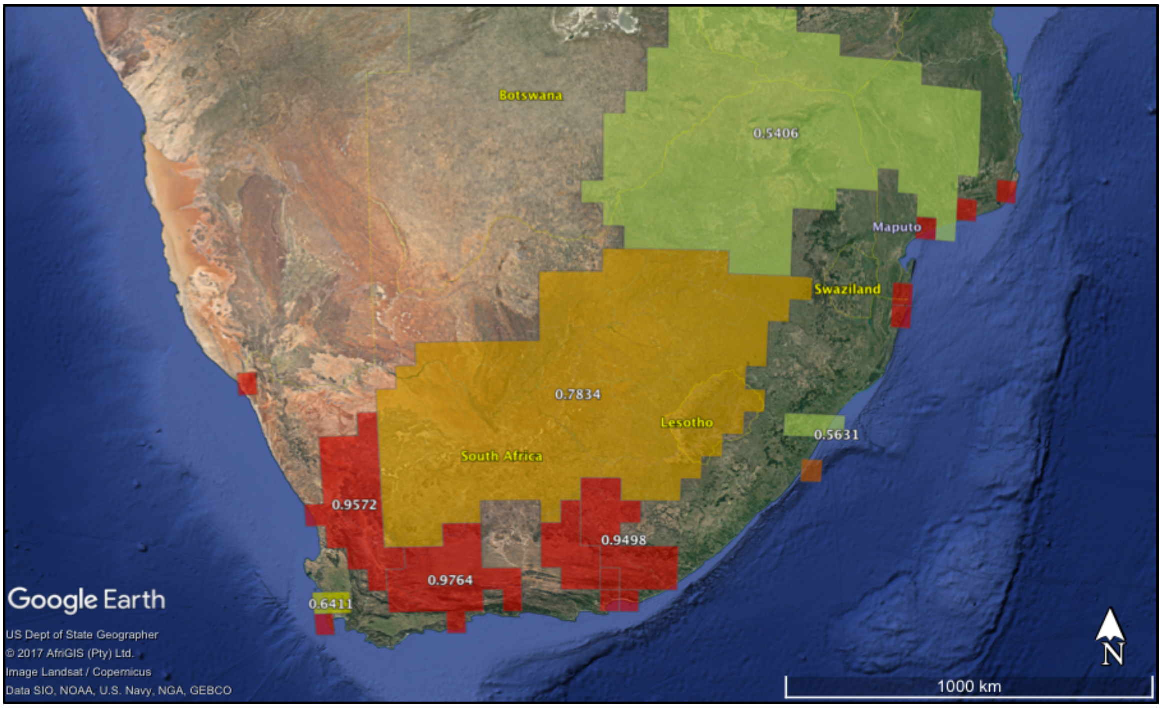

Figure 2.2: Water stress index map of South Africa for watersheds with a water stress index of >0.5
Source: Compiled from Pfister *et al.* (2009) and Google Earth (2017)

According to Pfister *et al.* (2009), the WSI follows a logistic function ranging from 0.01 to 1 (where "1" is an indication of severe water stress) and is based on the local freshwater withdrawal-to-availability ratio. It is evident from Figure 2.2 that the largest parts of South Africa have a WSI at watershed level of more than 0.5, while some areas of the country have a WSI of almost 1.

As such, South Africa can definitely be considered a water-stressed country, based on the work by Pfister *et al.* (2009) and Gassert *et al.* (2013). The demand for freshwater thus often exceeds the supply (withdrawal-to-availability ratio) and therefore the usage patterns of freshwater in South Africa should be investigated in order to find solutions that will improve the water-stress level of the country. One approach to investigate the water use of current and alternative agricultural production methods is the estimation of the WF of products and processes.

2.3 DIFFERENT APPROACHES TO WATER FOOTPRINT ASSESSMENT

Two general schools of thought exist regarding the calculation of a WF, namely the WF approach by Hoekstra (2003), which developed into the WFA concept (Hoekstra *et al*., 2011), and the water LCA, which was introduced by authors such as Pfister and Hellweg (2009) and Pfister *et al*. (2009).

Apart from the differences between the WFA and LCA, there are also different calculation methods for each. The water LCA can, for example, be conducted following the stress-weighted water LCA as proposed by Pfister *et al.* (2009), or the adapted LCA water footprinting methodology as proposed by Milà i Canals *et al*. (2009). The WFA, on the other hand, can be conducted by either following the consumptive water-use-based volumetric WF approach (Hoekstra *et al.*, 2011) or Deurer *et al*.'s (2011) hydrological water balance method.

The different WF communities also do not always agree with the methods the other party uses. This is quite clear from a published exchange of letters between the LCA and WFA communities. In the first letter, Pfister and Hellweg (2009), from the LCA community, disagreed with the WFA community's definition of the WF, as the definition does not reflect the environmental impact. Pfister and Hellweg (2009) further proposed that a spatially varying WSI should be used to weigh the water consumption as a function of water scarcity. Hoekstra, Gerbens-Leenes and Van der Meer's (2009) replied that the WF, as defined by them, could best be used in its original form, which excludes impact. According to them, the introduction of the WSI would transform the WF into an aggregated, weighed WF impact index.

Ridoutt and Huang (2012), from the LCA community, wrote another letter in which they argued that environmental relevance was the key to understanding WFs and that it must be considered when WFs are used for decision making and policy development. They argued that the need to reduce humanity's WF is not caused by an absolute shortage of freshwater, but due to the fact that freshwater use is skewed towards highly stressed watersheds. Hoekstra and Mekonnen (2012) replied by agreeing that reduction targets regarding WFs within catchments should be formulated on the basis of relative water scarcity per catchment, but then stated that it should be kept in mind that the local environmental impact is only one of a range of factors to be considered when prioritising options for WF reduction. The reduction of WFs (increasing water productivity) in non-stressed basins can be an instrument to reduce the aggregate WF in stressed basins due to the competition over the globe's freshwater resources.

Despite some authors, such as Boulay, Hoekstra and Vionnet (2013), indicating that there are indeed complementarities between the two schools of thought, the Water Footprint Network (WFN) and the LCA community never really moved closer to each other. This is evident from Pfister and Ridoutt's (2014) letter where they pointed out pitfalls in Boulay *et al.*'s (2013) paper and advised the water resource community to update the WFA methodology in order to align it with the LCA framework and the, then forthcoming, ISO 14046 standards. Hoekstra (2016) replied to Pfister and Ridoutt's (2014) letter with a paper titled "A critique on the water-scarcity weighted water footprint in LCA", where he concluded the paper by stating that the critique was not against LCA in itself, but rather against the way that some authors have proposed to account for water consumption and water scarcity within an LCA.

During recent history, various researchers conducted literature reviews on the differences between the WFA and LCA approaches in order to choose the most valid approach for the specific scenario in question, to suggest improved methods on how to calculate the WF, and to clarify the objectives of both approaches to develop them further (Chapagain & Orr, 2009; Jefferies *et al*., 2012; Boulay *et al*., 2013; Ridoutt & Pfister, 2013; Chenoweth, Hadjikakou & Zoumides, 2014; Sabli *et al*., 2017). Although the abovementioned studies usually favoured one approach over another, or made suggestions on how both approaches can be used in conjunction, there is not really an indication why there should be moved forward with only one of the approaches. Boulay *et al.* (2013) simplified the differences between the two approaches, and attempted to provide each approach with its place in research, by stating that the LCA approach is more product focused and the WFA approach is more water management focused.

In order to attempt to set a form of consistency between the different methodologies, the ISO published ISO 14046:2014, which serves as a guideline of what to include in a comprehensive WFA. Whether the WFA or LCA concept is used to calculate a WF, the ISO 14046 guidelines must thus also be kept in mind and followed in the reporting of the WF.

The problem is that although it certainly may be argued that the outcomes of the WFA and LCA approaches should focus on the same direction, the differences between the assumptions and calculations of the schools are just too diverse to simply decide on either one when a WF must be calculated for a product or process. The aim of this section is to assess the different WF protocols, while following the ISO 14046 guidelines, and to evaluate the usefulness of their outcomes to the stakeholders in the beef value chain.

2.3.1 The water footprint assessment methodology

According to the WFN (2016), the document *Water Footprint Assessment Manual – Setting the Global Standard* (Hoekstra *et al.*, 2011) was founded on a decade of research and application and lays out the internationally accepted methodology for conducting a WFA. The goal of a WFA is to measure the volume of freshwater required for a product, process, or organisation over the full supply chain.

The WF of a product, process, or organisation does not only account for the direct water use, but also for the indirect water use and is thus equal to the total consumptive water use (Hoekstra *et al.*, 2011) (see Figure 2.3).

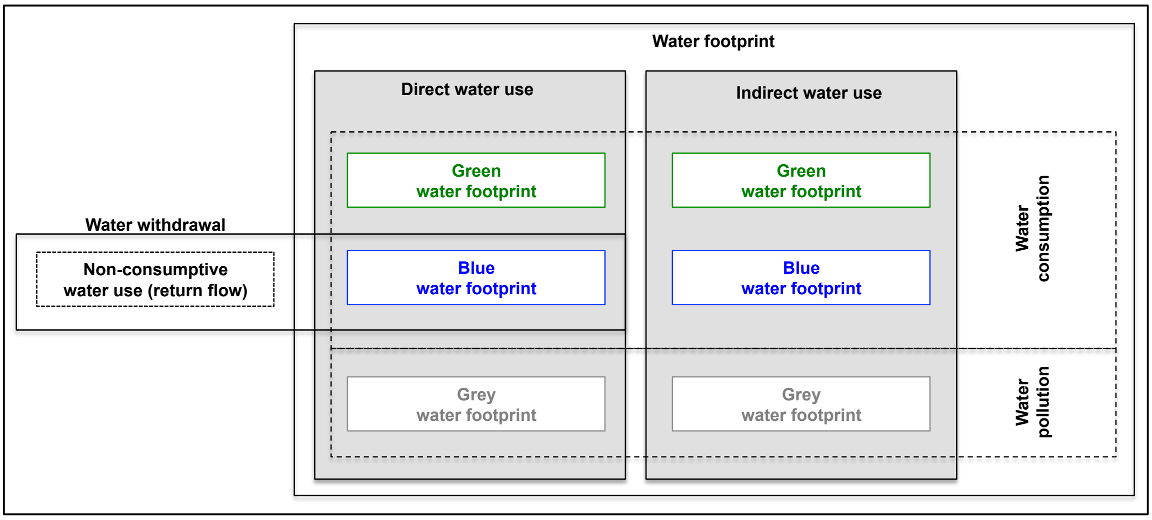

Figure 2.3: Schematic representation of the components of a water footprint
Source: Adapted from Hoekstra *et al.* (2011)

This multidimensional indicator shows water consumption volumes by source and polluted volumes by type of pollution, while all components of a total WF are geographically and temporally specified. The WF differs from the classical “water withdrawal” measure since:

- it does not include blue (surface or soil) water insofar as this water is returned to where it came from;
- it is not restricted to blue water use, but also green water (rain that does not become runoff) and grey water (polluted); and
- it is not restricted to direct water use, but also includes indirect water use (Hoekstra *et al.*, 2011).

It is evident from Figure 2.3 that the WF offers a wider perspective than the concept of water withdrawal of how a consumer or producer relates to the use of freshwater. It should, however, be kept in mind that the WF is only a volumetric measure of water consumption and pollution and is not a measure of the severity of the environmental impact (Hoekstra *et al.*, 2011).

2.3.1.1 Calculation of a water footprint according to the water footprint assessment methodology

Since this thesis is on the WF of a product (beef), the focus will be on the calculation of the WF for a product, which, according to Hoekstra *et al.* (2011), is equal to "the sum of the water footprints of the process steps taken to produce the product (considering the whole production and supply chain)". In each of the process steps it is necessary to calculate the blue, green, and/or grey WFs, where the sum of the three will be the WF of the process step in volume per product:

$$WF_{proc} = WF_{proc,blue} + WF_{proc,green} + WF_{proc,grey} \tag{2.1}$$

The blue WF refers to the consumptive use of fresh surface or groundwater and includes water evaporation, water incorporated in the product, water that does not return to the same catchment area, and water that returns to the same catchment area but not in the same period (Hoekstra *et al.*, 2011). The blue WF in a process step in volume per product is calculated as:

$$WF_{proc,blue} = BlueWaterEvaporation + BlueWaterIncorporation + LostReturnflow \tag{2.2}$$

The green WF refers to the precipitation that is stored in the soil or temporarily stays on top of the soil or vegetation and eventually evaporates or transpires through the plants (Hoekstra *et al.*, 2011). The green WF, as the volume of rainwater consumed during the production process step, in volume per product, is calculated as:

$$WF_{proc,green} = GreenWaterEvaporation + GreenWaterIncorporation \tag{2.3}$$

The grey WF is an indication of the degree of pollution that can be associated with a process step and is defined by Hoekstra *et al.* (2011) as "the volume of freshwater that is required to assimilate the load of pollutants based on natural background concentrations and existing ambient water quality standards". The grey WF in volume per product is calculated as:

Where L is the pollutant load in mass per product, C_{max} is the ambient water quality standard (maximum concentration) for that pollutant in mass per volume, and C_{nat} is the natural concentration of that pollutant in the receiving water body in mass per volume.

2.3.2 The life-cycle assessment

The paper "Assessing the environmental impacts of freshwater consumption in LCA" by Pfister *et al.* (2009) laid down the foundation for the LCA methodology of WF accounting. According to Pfister *et al.* (2009), it is a method for assessing the environmental impacts of freshwater consumption that considers damages to three areas of protection: human health, ecosystem quality, and resources, and can be used within most of the existing life-cycle impact assessment methods.

The LCA approach makes use of a WSI to characterise local water use impacts, and this method is therefore useful in showing the region-specific effects of water consumption (Ridoutt & Pfister, 2010). The WSI is calculated from the WaterGAP2 global model, which shows the annual average global hydrological water availability, and is based on the water-use-to-availability ratio. The WSI is a logistic function that achieves continuous values between 0.01 and 1 (Pfister *et al.*, 2009):

The minimum water stress, according to the WSI, is then equal to 0.01, as any water use does have an impact, while the maximum is equal to 1 (Pfister *et al.*, 2009).

2.3.2.1 Calculation of a water footprint according to the life-cycle assessment methodology

The LCA method to calculate product WFs incorporating the WSI is set out in Figure 2.4. Apart from using a WSI to incorporate the regional water stress into the WF, the LCA also differs from the WFA as the green WF does not form part of the analysis.

According to Ridoutt and Pfister (2010), the consumption of green water *per se* does not contribute to water scarcity as it is not part of the environmental flows and is not accessible for human consumption. It is only when green water becomes runoff and basically turns to blue water that the consumption thereof can contribute to water scarcity.

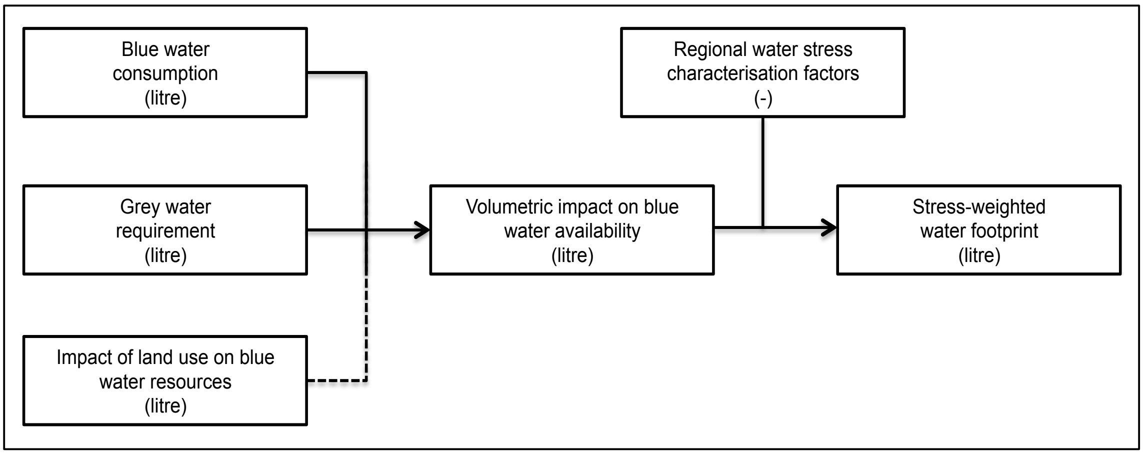

Figure 2.4: Method for calculating product water footprints incorporating water stress characterisation factors
Source: Ridoutt and Pfister (2010)

It is also important to note that although the LCA method accounts for grey water, it is not done in the same way that Hoekstra *et al.* (2011) proposed. Ridoutt and Pfister (2010) explain that, although it is considered beneficial to include the grey water calculation, in terms of the LCA method emissions to freshwater are usually considered under "other impact" categories such as eutrophication or freshwater eco-toxicity.

2.3.3 The international standard: ISO 14046:2014

The WF of a product, process, or organisation is determined by different metrics that quantify the potential environmental impact. The ISO 14046:2014 (Environmental management – Water footprint – Principles, requirements and guidelines) standard was created to set a standard for measuring the impact of water use and promoting efficiency in water management.

In order to ensure a form of consistency between the different methodologies, the ISO standardised the terminology used in the calculation and reporting of the different WF methodologies. The ISO does not set out a specific methodology that must be followed for the calculation of a WF but it is based on the LCA approach and a WF should, according to the ISO, include the four phases of an LCA, namely the definition of the goals and scope, the WF inventory analysis, the WF impact assessment, and the interpretation of the results.

Either the WFN or LCA approaches can thus be used to calculate the WF of a product, providing that the guidelines, as set out by the ISO 14046:2014, are kept in mind for what should be considered in the calculation of a complete WFA.

2.3.4 Previous applications of the Water Footprint Network and life-cycle assessment approaches to assess the water footprint of beef

Various studies using different approaches have been conducted in the past to assess the WF of beef (Mekonnen & Hoekstra, 2010a; Hoekstra, 2012; Mekonnen & Hoekstra, 2012; Ridoutt *et al*., 2012; Gerbens-Leenes *et al*., 2013; Zonderland-Thomassen, Lieffering & Ledgard, 2014; Bosire *et al*., 2015; Pearce, 2016; Harding *et al*., 2017). In order to distinguish between the differences in the objectives and outcomes of these and other studies according to the specific methodology that was applied, it is necessary to compare them with one another.

The studies based on the WFA approach that focused on beef (or meat including beef) include those by Mekonnen and Hoekstra (2012), Gerbens-Leenes *et al.* (2013), Bosire *et al.* (2015), and Pearce (2016). Although all the abovementioned studies calculated the WF for beef and other types of animal products, the specific objective of each study was different. Mekonnen and Hoekstra's (2012) objective was to estimate the WF of animal products per country and production system, while Gerbens-Leenes *et al.* (2013) wanted to determine what factors contributed to differences in the WF for different production methods of the same meat type, as well as between different meat types. Gerbens-Leenes *et al.*'s study (2013) was based on the same global data used by Mekonnen and Hoekstra (2012). The objective of Bosire *et al.*'s (2015) study was to use the WF indicator in order to explore spatial and temporal changes in the use of freshwater for meat and milk production in Kenya, while Pearce (2016) estimated the WF of beef produced in a South African feedlot.

The mentioned studies all succeeded in the quantification of the WF for different meat types, production systems, and even countries. The results, providing the green, blue, and grey WFs, can thus successfully be utilised to compare the meat types, production systems, and countries on their water use efficiency (WUE) to produce beef, but no conclusion can really be drawn regarding the sustainability of the freshwater use as the water availability of the specific region is not quantified and compared to the freshwater use.

The LCA-based studies that focused on the blue WF of beef (and other meat) include studies by Ridoutt *et al.* (2012), Zonderland-Thomassen *et al.* (2014), and Harding *et al.* (2017). Ridoutt *et al.* (2012) compared the WF of beef produced in six geographically defined production systems in Australia, while Zonderland-Thomassen *et al.* (2014) compared the WF of seven classes of beef and sheep farms in New Zealand. Both studies found that both the consumptive water use and the WF of beef cattle varied between the different geographically defined production systems and classes of farms. Harding *et al.* (2017) estimated the WF and WF equivalent of beef produced in, and with feed from, various geographical regions in South Africa. These studies made use of the WSI to determine the WF and therefore they also incorporated the sustainability of the water use in the different regions.

The conclusion drawn from the literature on the two approaches is that the WSI incorporates the availability of freshwater in a certain region into the LCA, while the WFA sums the total water use for a product, process, or country. When the WF of beef for two different geographical locations, with different freshwater availability (WSI) but where the WF (cubic metre [m^3]/tonne) of the produced feed is the same, is estimated using the WFA and LCA approach, the WFA will result in the same WF for both regions, while the LCA will estimate a higher blue WF in the region with the higher WSI. In the event where two different production systems in the same geographical location are compared on their WF, the WSI for both the production systems will be the same and will thus not influence the WF of the two production systems.

It is thus concluded that when the WFs of the same product or process from different geographical locations are compared, the LCA approach should be used. Even though the LCA approach does not include the green and grey WFs and the incorporation of the WSI makes it difficult to distinguish whether the difference in the blue WF between two regions is due to a difference in water use or water scarcity, the approach does suggest the more suitable region for more sustainable production practices. In the event where the products or processes are based in the same geographical location, the WFA approach should be used as the inclusion of green, blue, and grey WFs provides a better distinction between the water use of the products/processes. However, this does not imply that the WFA approach cannot be used to compare different regions, or that the LCA approach cannot be used to compare products from the same region.

2.4 THE WATER-ECONOMY NEXUS

WF research originally set out to quantify water use and to make recommendations regarding the sustainability of water use. The sustainable use of water, or any other natural resource for that matter, is, however, not the only factor that should be considered in the overall sustainability of businesses, sectors, or a country in order to preserve it for future generations. Elkington (1994) coined the term “triple bottom line” (TBL), which refers to a sustainability framework that considers three parts, namely social, ecological, and financial. According to the TBL, a business will only be sustainable when it considers social equity (people), environmental stewardship (planet), and economic prosperity (profit).

The problem with improving more than one sustainability indicator is that these indicators are often negatively correlated. Although some research has shown that social sustainability practices directly reduce costs (Brown, 1996; Brown, Willis & Prussia, 2000; Carter, Kale & Grimm, 2000), Pullman, Maloni and Carter (2009) contradicted these findings. According to Pullman *et al.* (2009), environmental efforts may reduce some costs, but these savings are negated by related cost increases or reduced income levels. The improvement of environmental stewardship in terms of the WF of a business should thus be done in such a manner that it does not ruin the economic prosperity of the business and the water-economy nexus should therefore be considered.

2.4.1 Estimating the economic impact for water footprint research

In order to consider both environmental (water) and economic impacts, various authors have estimated economic water productivity (EWP), which is expressed as a monetary unit per unit of water use, for example, in their research, as US\$/m^3 (Crafford *et al.*, 2004; Aldaya *et al.*, 2010; Jordaan, 2012; Chouchane *et al.*, 2013; Zoumides *et al.*, 2014; Scheepers, 2015). The problem with the estimated EWP of the mentioned authors is that almost all the studies estimated the economic contribution differently and therefore it is difficult to compare the results. The water use in the studies also varied from the total WF, to a blue WF only, and in one instance direct water use was estimated.

Aldaya *et al.* (2010), Chouchane *et al.* (2013), and Zoumides *et al.* (2014) respectively used the market price of the product, the value of the marginal product (VMP), and the gross value of the output as the economic contribution. Although all of these certainly can be seen as indicators of economic productivity, none of them truly grasps the total value added (VA) through the value chain as, for example, the value of by-products may not be included. Another problem is that some stages of production may have been omitted from the water use or WF estimation and the estimated EWP may then be very high for the included production stages. None of these estimations can further be compared with one another as they all estimated the economic contribution differently.

Crafford *et al.* (2004), Jordaan (2012), and Scheepers (2015) estimated EWP by expressing the VA per m^3 of water. Jordaan (2012) and Scheepers (2015) estimated the VA per m^3 of water for every step in the value chain. The problem with their approach was that the VA was calculated differently for primary agricultural production and processing. At the primary product level, VA was considered as the difference between the total revenue and the variable cost, while at the processing level, VA was considered as the difference between the revenue of the processor and the price paid for the intermediate product, with no deduction of other costs. Crafford *et al.* (2004) considered VA as the difference between proceeds from production and the cost of the intermediate products used for production.

The various estimations of the VA do not only make it difficult to compare the various studies' results in terms of EWP, but one also wonders which of the studies applied the correct procedure to estimate VA. According to the *MacMillan Dictionary* (2017), VA can be defined as "the amount by which the value of a product increases as it goes through the different stages of being made and sold". Two important factors stand out from the definition, namely the increase of the value of the product, and the different stages of being made and sold (production stages). The increase in value, from the beginning to the stage of final analysis, of the product should thus be determined according to the various stages of production. A value chain analysis (VCA) should thus be conducted in order to estimate the VA by each production stage.

According to Bockel and Tallec (2006), VA represents the value that the agent has added during the accounting period to the value of the inputs in the process of production or processing and can be defined as:

$$VA = Y - II \qquad [2.6]$$

Where Y is the value of the output and II is the value of the intermediate inputs used.

VA is a measure of the creation of wealth, which is the contribution of the production process to the growth of the economy.

Rudenko *et al.* (2013) stated that VA includes the contributions of the production factors and although it corresponds to the income received by the owners of these factors, it is not just an element of income. VA also represents the distribution of income among the four fundamental agents of the economy, namely households, financial institutions, government administration, and non-financial enterprises. Rudenko *et al.* (2013) further explained that VA can also be estimated as the difference between the sale price of a given product and the total production costs incurred to produce the product.

The calculation of VA, as proposed by Bockel and Tallec (2006) and Rudenko *et al.* (2013), in terms of VCA certainly holds water. It also does not propose a problem when used in conjunction with direct water use (Jordaan, 2012), but when VA is linked to the concept of WFA, it presents a problem. Since the WF of a product or process also includes the indirect use of water, it basically includes the water embedded in the production inputs used to produce the product. When estimating the EWP or the WF of the VA (economic water consumption [EWC]), the total WF of the product (including the WF of the production inputs) is used in conjunction with the VA of only the specific process or product. This results in an under- or overestimation of the EWP. For example, when the WF of feedlot-finished calves is estimated, the WF of the feed (which is a production input) is included in the total WF of the finished calves. If the VA is calculated by subtracting the cost of the production inputs (feed), it means that only the VA by the feedlot in the feeding process is considered as the total VA, while the total WF includes the WF of the production inputs. In order to correctly estimate the EWP or EWC for the feedlot, the cost of the production inputs should either be included in the total VA of the feedlot (in the event where the WF of the production inputs is included in the total WF), or the WF of these production inputs should be excluded from the total WF (in the event where the cost of the production inputs is subtracted from the total VA).

For the purpose of this research, and as a proposal for future research, the VA for each stage of production will be taken as the total revenue from the produced products minus the cost of the intermediate production inputs of which their WF is not included in the WF of the specific production stage or product, while the definition is based on the assumption that the revenue is more than the cost of intermediate production inputs. In the case of the beef value chain, the VA by the primary cow-calf producer will thus be equal to the total revenue from the weaned calves and the culled cows, while the WF will be distributed among the weaned calves and culled cows based on the value factor (VF) of each. The next production stage is the feedlot, and here the VA is equal to the difference between the revenue of the finished calves that are sold to the feedlot and the cost of the weaned calves that were purchased, while the total WF of only the feedlot will be estimated. The final production stage is the abattoir and deboning plant, where the VA will be equal to the total revenue minus the cost of the live finished calves, while the WF of only the processing will be estimated. The VA of beef is then equal to the sum of the VA by the primary producer, feedlot, and processer, while the WF of beef will be equal to the sum of the WF of the primary producer of the calves, the WF of the feedlot, and the WF of the processing plant.

2.4.2 Economic productivity of water versus economic consumption of water

Previous studies that reported both water and economic impacts utilised either the EWP in monetary unit per volume (Crafford *et al.*, 2004; Aldaya *et al.*, 2010; Jordaan, 2012; Chouchane *et al.*, 2013; Zoumides *et al.*, 2014; Scheepers, 2015), or the economic consumption of water (EWC) in volume per monetary unit (Mekonnen & Hoekstra, 2011; Rudenko *et al.*, 2013).

Both ways of reporting revealed the correlation between freshwater use and the economic impact of the water use, and therefore, in principle, both reporting methods show exactly the same thing in opposite directions. The question then remains: Which one of the two available reporting methods should be used?

It is impossible to discredit the one method in favour of the other, as both are correct. The argument for and against the two reporting methods should thus be based on the applicability of the preferred method in terms of the specific research it is used for. For the application of this research, and as a proposal for future research (assuming VA as measurement of economic impact), the economic impact in terms of WF research will be reported as the EWC in litre or m^3 per one unit of monetary VA (in the case of South Africa it will be South African rand). The reason for choosing EWC above EWP is quite simple. WF research is basically always reported as product/process water consumption per unit of output (m^3 or litre WF/kg or tonne) and not as product/process water productivity (kg or tonne/m^3 or litre WF). It is thus proposed that the economic impact is reported in the same way as the water impact. In this research, the product/process water consumption will also be used as the WF reporting method (m^3 or litre WF/kg or tonne) and therefore the reporting of EWC (m^3 or litre WF/R VA).

Estimating the water and economic impacts of beef produced from a certain production system seems quite straightforward once the estimation methods and reporting options have been decided on. However, when the goal is to compare different beef cattle breeds from the same production system, there must be underlying differences between the breeds to justify the study.

2.5 DIFFERENCES BETWEEN BEEF CATTLE BREEDS

Previous studies that estimated the WF of beef found that the largest part of the WF of beef is contributed by the feed that the cattle consume and therefore the feed conversion ratio (FCR) is an important determinant in the total WF of beef (Mekonnen & Hoekstra, 2010a; Hoekstra, 2012; Mekonnen & Hoekstra, 2012; Ridoutt *et al.*, 2012; Gerbens-Leenes *et al.*, 2013; Bosire *et al.,* 2015; Pearce, 2016). In the quest to search for cattle with lower FCRs in order to improve the profitability of a feedlot, many authors have compared animals as well as breeds and breed types and found that although the FCR differs between individual animals, there are also significant differences between breeds and breed types (Koch *et al.*, 1963; Archer & Bergh, 2000; Strydom *et al.*, 2008; Crowley *et al.*, 2010).

FCR might be one of the most important traits in terms of feedlot finishing, but it is not the only biological trait that must be kept in mind regarding the influence of traits on the WF and VA of different breeds in the beef value chain. The first link in the beef value chain is the primary producer who, in the case of South Africa, produces weaned calves in a cow-calf production system. In terms of primary production, other factors like the reproduction and production traits should also influence the WF and VA as they determine the amount of product (total weight of weaned calves) produced from a certain quantity of production inputs. Another important factor that must be kept in mind is the dressing percentage of the animal at the day of slaughter. The higher the dressing percentage, the more beef is produced from a certain live weight (LW) and the lower the WF of the produced beef will be.

Evidence of the differences between breeds in terms of primary production in South Africa is provided by publications such as Scholtz (2010) and SA Stud Book (2017). Scholtz (2010) compared the growth and reproductive data of various breeds in South Africa from the year 1999 to 2008 and found distinctive differences between the breeds. SA Stud Book (2017) published the data of 28 different breeds as captured on 1 March 2017 and reported that the average weaning weight per breed varied between 144.7 kg and 243.6 kg, the average cow weight varied between 273 kg and 596 kg, and the average inter-calf period of breeds varied between 380.2 days and 494.9 days.

Bosman (2002) compared the average daily gain (ADG), feed intake, and FCR of 22 different breeds from six breed types (see Table 2.1) over a feeding period of 112 days in the feedlot. The results indicated distinct differences between the average breed type values for all three factors, with the differences between the minimum and maximum ADG, feed intake, and FCR being 0.5 kg/day, 3.03 kg/day, and 0.48 kg respectively.

Table 2.1: Average daily gain, feed intake, and feed conversion ratio for different breed types

Breed type	ADG (kg/day)	Feed intake (kg/day)	FCR kg feed : 1 kg weight gain
Bos indicus	1.35	9.17	6.79
Bos taurus africanus	1.37	9.43	6.88
Bos taurus indicus	1.66	10.66	6.42
Bos taurus British breeds	1.73	11.54	6.67
Bos taurus dual purpose	1.85	12.19	6.59
Bos taurus lean meat	1.81	11.58	6.4

Source: Bosman (2002)

The differences between the various breeds in terms of ADG and FCR in Bosman's (2002) study are presented in Table 2.2. It is evident from Table 2.2 that the differences between the individual breeds are even larger than in the case of the breed type averages. The ADG of the different breeds varied between 1.12 kg and 1.93 kg, while the FCR varied between 6.09 kg and 7.31 kg.

Table 2.2: The average daily gain and feed conversion ratio of different cattle breeds

Type	Breed	Number of animals	ADG (g)	FCR
Bos indicus	Brahman	411	1 345	6.79
Bos taurus africanus	Afrikaner	327	1 220	7.12
	Bonsmara	2 371	1 680	6.58
	Drakensberger	240	1 550	6.84
	Nguni	134	1 120	6.7
	Tuli	10	1 270	7.16
Bos taurus indicus	Beefmaster	37	1 725	6.48
	Brangus	20	1 580	6.47
	Santa Gertrudis	587	1 730	6.35
	Simbra	174	1 590	6.35
Bos taurus – British breeds	Hereford	149	1 815	6.22
	Red Poll	31	1 630	7.31
	SA Angus	396	1 805	6.49
	Shorthorn	52	1 765	6.81
	Sussex	240	1 635	6.51
Bos taurus – Dual purpose	Braunvieh	46	1 725	7.03
	Gelbvieh	116	1 880	6.68
	Simmentaler	1 471	1 915	6.46
	South Devon	57	1 895	6.18
Bos taurus – Lean meat	Charolais	141	1 925	6.09
	Limousin	189	1 710	6.44
	Pinzgauer	295	1 790	6.68

Source: Bosman (2002)

The proven differences in the genetic potential of the different breeds provide the scope to compare the breeds in terms of WF and VA. With approximately 39 highly diversified beef cattle breeds in South Africa, ranging from indigenous to foreign breeds (Scholtz, 2010), producers are spoiled for choice when it comes to selecting a breed to farm with. It is not practically possible to compare the WF and VA of all the breeds at the same time and therefore only seven breeds from seven different breed types were included in this study.

2.6 CONCLUSION

South Africa can be considered a water-stressed country since the demand for freshwater exceeds the supply in large parts of the country. WFA is one way to determine the consumption of water by different products or processes and to make recommendations to decrease the consumption of freshwater. However, there are quite a few accounting frameworks to determine the WF of a product or process and the most suitable framework should be chosen for the specific research.

The most popular WFA frameworks are the WFA and the LCA. According to the ISO standard, any of these approaches can be used, providing that it adheres to the principles set out in the standard. After reviewing the different approaches, it can be concluded that the WFA (Hoekstra *et al.*, 2011) should be used when products or processes, which occur in the same geographical region, are compared as the WF of the WFA is more comprehensive since it includes the green and grey WFs. The LCA approach may be the more appropriate choice when products or processes of different geographical regions are compared since the WF of the LCA incorporates the water stress of a specific region through the WSI. The WFA approach will be used in this study since the beef produced for the different breeds of beef cattle will be from the same geographical area.

The reviewed literature indicated that although the economic impact had been estimated in conjunction with environmental (water) impacts before, almost none of the studies followed the same estimation or reporting framework. It is thus proposed that VA should be used as the economic impact, where the VA for each production process is equal to the total revenue from the sold produce minus the cost of the intermediate production inputs, which are not accounted for in the WFA. It is further proposed that the water-economy nexus should be reported as the EWC (WF/monetary unit) rather than EWP (monetary value/WF unit) since the WF of the produced product is also expressed as a consumptive value.

The revision of the differences between beef cattle breeds revealed that there are distinctive differences between the breeds in terms of production and reproduction traits. These mentioned differences should have an impact on both the WF and VA of the different breeds and therefore justify the principle of comparing beef produced from different breeds on their WF and VA.

The literature review, in terms of the objective of the study, proved that the differences between breeds should be acknowledged in terms of WF research. The literature further exposed the differences between previous applied methods to estimate the WF and VA of beef and provided pointers on which the argument to reach the objective of this study can be based.

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CHAPTER 3

THE WATER-ECONOMY NEXUS OF WEANED CALVES

“No water, no life. No blue, no green.”

- Sylvia Earle (1935 – present) -

3.1 BACKGROUND AND INTRODUCTION

In terms of freshwater use, various authors identified beef as the farm animal product with the largest total water footprint (WF) (Mekonnen & Hoekstra, 2012; Gerbens-Leenes *et al*., 2013). Although the bulk of the total WF of beef comprises the green WF, the high total WF data are still used to convince consumers to move away from diets containing beef or to select beef from other regions or production systems with a lower WF (Hoekstra, 2010). International studies by authors such as Mekonnen and Hoekstra (2012), Gerbens-Leenes *et al.* (2013), and Bosire *et al.* (2015), as well as South African studies by Pearce (2016) and Harding *et al.* (2017), all estimated the WF of beef. All of the mentioned studies, except Pearce (2016), used a top-down approach with country-level data to estimate the WF for different production systems; Pearce (2016) calculated the WF of beef produced in a feedlot with a bottom-up approach. A top-down approach is a typical input-output approach that is often done on country level, while a bottom-up approach refers to a process analysis that includes more detail of individual production processes (Feng *et al*., 2011). Almost all the abovementioned authors estimated the WF in terms of green, blue, and grey water, but Harding *et al.* (2017) focused only on the blue WF and linked the results with the water stress index (WSI) to differentiate between production regions.

The studies by Mekonnen and Hoekstra (2012) and Gerbens-Leenes *et al.* (2013) admitted that there are concerns regarding the assumptions that were made in the country-specific top-down approach as not all the needed data were available. Specific concerns were raised regarding the assumptions of animal numbers, the feed intake by the animals, and the composition of feed. The concerns were further specifically about the distribution of the assumed data over the production systems and especially in the case of the Organization for Economic Co-operation and Development (OECD) and developing countries. Apart from Pearce’s (2016) study, which was a bottom-up approach for a feedlot, very little information exists on the WF of beef based on a specific farm, feedlot, or abattoir and which was determined using the primary data from the mentioned facilities.

Another factor that was not mentioned by authors such as Mekonnen and Hoekstra (2012), but which is of concern in developing countries, is the existence of the informal market for beef.

The animals of communal farmers are often not included in the formal animal number statistics of a country, while much of the offtake does, however, reach the formal market and is included in the statistics. This may cause the assumed offtake rate in the studies such as the one by Mekonnen and Hoekstra (2012) to be higher than it should be.

Although Mekonnen and Hoekstra (2012), Gerbens-Leenes *et al.* (2013), and Bosire *et al.* (2015) found notable differences among the different production systems, it is not always possible for a producer to switch from one to another. In South Africa, for example, there are basically only two types of production systems for beef, namely a mixed system where weaned calves are produced from a cow-calf production system on natural grazing before the weaned calf is sold to the feedlot for industrialised fattening, and a grazing-only system where calves are kept on natural grazing until they are ready for slaughter. About 65% to 75% of the beef produced in the country originates from the first option (Department of Agriculture, Forestry and Fisheries [DAFF], 2014). The reason for this is the fact that the marginal land that is used for extensive cow-calf production systems cannot sustain a grazing-only system and these producers can thus not switch to another production system. Their only option to decrease the WF of the cow-calf production system is by farming with another breed of cattle.

Even though South African cattle producers are spoiled for choice in terms of different breeds of beef cattle, they are not able to test various breeds on their available farmland in order to attempt to identify the breed that will be the most suitable for their specific conditions. Such an exercise is costly and will set the producer back many years in terms of his/her breeding objectives. Producers thus tend to farm with the breed that they like the most, which they are familiar with, which is readily available in their region, and/or which delivers good results on neighbouring farms.

The primary objective of this chapter is to estimate the WF per kilogram of weaned calf and the economic value added (VA) of different cattle breeds on the same extensive farming conditions for a cow-calf enterprise. In order to treat all the cattle breeds the same in terms of the extensive farming conditions for a cow-calf enterprise, it is necessary to make use of a farm simulation model where it is assumed that all the breeds are raised on the same farm. Sufficient information about each breed is available, in terms of their genetic and production potential, to make very accurate assumptions in this simulation model. The WF and VA of breeds will differ as the grazing capacity, need for supplements, inter-calf periods, and weaning weights of breeds differ.

3.2 PROCEDURES AND DATA

This study was conducted through a simulation model based on the production data of the farmland owned by Sernick, which is situated close to the town of Edenville in the Free State province of South Africa. The farm consists of 5 013 hectares (ha) of natural vegetation, which is made up from 11 different title deeds. The farmland is divided into 220 camps with an average size of 23 ha each. A six-camp rotational grazing system is followed, where a group of 40 to 50 cattle are rotated between the six camps for optimal grazing management. Water for the farm is supplied in the form of underground water sourced from 38 boreholes that are scattered over the property (Sernick, 2017).

Being spoiled for choice in terms of available cattle breeds, it is no easy task to select only seven breeds to work with. In order to make the best possible selection in terms of the breeds to be used, seven different breed types that differ biologically from one another were first decided on. The selected breed types were then used to identify specific breeds, one breed from each breed type, available within a 150-km radius from the Sernick Feedlot, in order to minimise the impact of animals originating from different areas. The seven chosen breeds naturally represented the most preferred breed in each breed type for South African cattle producers in that region and therefore sufficient numbers of these animals were available in the selected region.

The final selection in terms of breed types, as well as breeds, is presented in Table 3.1. It is interesting to note that although some of the breeds belong to the same species, they are different in terms of breed type and frame size. This difference causes the maturity and other biological factors to differ between the breeds and finally influence reproduction and production figures that will have an impact on the WF, as well as on the economic contribution of each breed.

Table 3.1: Selected breeds for this study

Breed type	**Breed**	**Species**	**Frame size**
Sanga	Afrikaner	*Bos taurus africanus*	Small
Sanga derived	Bonsmara	*Bos taurus africanus*	Medium
Zebu	Brahman	*Bos indicus*	Medium
Zebu derived	Simbra	*Bos taurus indicus*	Medium
British	Angus	*Bos taurus*	Medium
European – Dual purpose	Simmentaler	*Bos taurus*	Large
European – Lean meat	Limousin	*Bos taurus*	Large

Source: Oosthuizen (2016)

Sernick currently farms with Bonsmara cattle on the property, but for the sake of the analysis for the different breeds, only the supplementary feed intake, drinking water intake, and water used for servicing the Bonsmara herd were used to derive the data per large stock unit (LSU), which was used to simulate the data for the other breeds. The cow weights, inter-calf periods, and weaned calf weights were determined by using data from seven different breeders in a radius of 150 km around Sernick for each of the seven cattle breeds.

In order to determine the WF and VA per kilogram of live weaned calf produced, a decision must be made whether the calf is considered a final product or a process step in the production of meat. The problem, however, is that when one considers a farming operation, the live weaned calf can be considered as both. The primary producer of weaned calves considers the calf as his/her final product, but in the larger value chain, the production of the calf is only a process step. The fact of the matter, however, remains that the WF and VA per kilogram of live calf at the day of weaning will be the same, regardless whether one considers the calf a final product or a process step.

Since there are many factors that influence the production and reproduction of cattle, the most uniform way to calculate the WF and VA of a kilogram of live weaned calf is to do the calculation over a fixed term of one year. The total WF of the cattle herd for the year is then divided by the total kilograms of live weaned calves produced, while the VA is the combined income received for the weaned calves and culled cows.

3.2.1 Cow-calf herd data for the different breeds

The first step in simulating the data for different breeds of beef cattle in a cow-calf enterprise is to determine the number of animals of each breed that can be kept sustainably on the natural grazing at Sernick. The natural grazing is dominated by three species of grass, of which the composition is described in Table 3.2.

Table 3.2: Natural grazing composition at Sernick

Species of grass	Quantity (ha)	Stocking rate (ha/LSU)	Grazing capacity (number of LSUs)
Digitaria eriantha	1 300	1.5	867
Themeda triandra	3 383	5	677
Eragrostis curvula	330	1.5	220
Total	**5 013**	**2.8**	**1 790**

Source: Serfontein (2015)

According to the natural grazing composition, the farm has an average weighted stocking rate of 2.8 ha/LSU and can accommodate 1 763 LSUs. An LSU has, however, a very specific description and is defined as “the equivalent of an ox with a live weight [LW] of 450 kg which gains 500 g per day on grass pasture having a mean digestible energy of 55% and to maintain this, 75 MJ/day is required” (Meissner *et al.*, 1983). In order to determine how lactating cows of the different breeds compare to an LSU, the frame size regression equations that were developed by Mokolobate (2015) are used where:

Small frame: $Y = 0.2871428571 + 0.0025542857x - 0.0000005714x^2$ [3.1]

Medium frame: $Y = 0.220714286 + 0.0030978571x - 0.0000010714x^2$ [3.2]

Large frame $Y = 0.3239285714 + 0.0036535717x - 0.0000015x^2$ [3.3]

Where Y represents LSU and x the cow weight.

By substituting the average cow weights of the different breeds into the abovementioned equations, making assumptions regarding the replacement rate of cows (15%), number of bulls (3%), mortality rates of cows and calves (1% and 2% respectively), and calculating the national average calving percentage from the inter-calf period (Scholtz, 2010) of each respective breed, the herd compositions of the various breeds that can be kept on the farm can be simulated. The simulated herd composition for the different breeds is presented in Table 3.3.

It is evident from Table 3.3 that the frame size and cow weight of the different breeds have an effect on the maximum number of cow-calf units that the farm may be stocked with as 1 285 Afrikaner cow-calf units but only 909 units of Limousin can be kept. A beef cattle farming operation does, however, not consist of cow-calf units only and therefore the number of bulls, young replacement heifers, and heifers ready for mating must also be taken into account.

Since the LSUs of these animals are less than that of a cow-calf unit, the total number of animals on the farm is more than the maximum number of cow-calf units. The simulated reproduction data in Table 3.3 show that the total weight (in kilogram) of calves sold differ greatly between the breeds, with the Bonsmara producing 162 197 kg of sellable calves, while the Limousin produces only 96 931 kg.

The simulated herd composition of the various breeds will be used to calculate the required amount of supplementary feed for each breed that will be used in combination with the utilised amount of natural grazing in order to calculate the WF per kilogram of weaned calf sold from each breed. The VA for the cow-calf enterprise per kilogram of calf is equal to the price of a kilogram calf plus the income derived from the culled cows divided by the kilograms of calf produced.

3.2.2 Feed requirements of the different breeds

Since the same farm is used for the analyses, and the stocking rate for the different breeds of cattle is calculated accordingly, it means that all the breeds will consume the same amount of natural vegetation. The consumed amount of natural vegetation in relation to the total production must, however, still be calculated in order to determine the WF of the feed. In terms of supplementary feed requirements for the different breeds, the supplementary feed was also provided based on the LSU/animal of the breed.

According to Meissner *et al.* (1983), an LSU (as defined in Section 3.2.1) willingly consumes approximately 10 kg of dry matter (DM) per day. Since the farm can accommodate 1 790 LSUs and the total LSUs of each of the different breed also calculates to 1 790 LSUs, it means that each breed will consume approximately 6 533 tonnes of DM per year. Smit (2017) stated that the utilisation factor of natural grazing ranges between 0.2 and 0.5, while a utilisation factor of 0.4 can be used for good-quality natural grazing. The total annual natural grazing DM production at Sernick, given a utilisation factor of 0.4, is then equal to 3.26 tonnes/ha, of which 1.3 tonnes/ha are consumed.

Table 3.3: Simulated herd composition of the different cattle breeds

	Afrikaner	Brahman	Angus	Bonsmara	Simbra	Simmentaler	Limousin
Stocking rate calculation							
Frame size	Small	Medium	Medium	Medium	Medium	Large	Large
Cow weight (kg)	476	520	541	552	546	549	582
LSU/cow-calf unit	1.37	1.54	1.58	1.60	1.59	1.88	1.94
Maximum cow-calf units	1285	1145	1115	1100	1108	940	909
Herd composition							
Young heifers	151	138	136	134	135	118	115
Heifers at bull	151	138	136	134	135	118	115
Cows with calves	1004	922	904	895	899	790	768
Bulls	30	28	27	27	27	24	23
Total animals	1336	1226	1202	1190	1196	1051	1022
Reproduction data							
Weaning %	80%	76%	88%	89%	78%	72%	68%
No. of calves weaned	790	688	779	783	688	558	516
No. of weaned calves sold	640	550	643	649	553	439	401
Weaning weight (kg)	210	232	227	250	231	222	242
Kg of calves sold	134 296	127 582	146 033	162 197	127 830	97 521	96 931
Cows culled	151	138	136	134	135	118	115

Source: Compiled from Scholtz (2010), data from various breeders, and own calculations

The supplementary feed requirements of the different breeds were based on the amount of lick that Sernick supplies to its current Bonsmara herd. Table 3.4 provides the three types of lick requirements of female Bonsmara cattle in different stages of their reproduction cycle for the different months of the year. These requirements were then divided by 1.6 (the LSU for the Bonsmara) to calculate the lick requirements for a standard LSU.

Table 3.4: Supplementary feed requirements of the Bonsmara and a large stock unit

Bonsmara kg/day (LSU = 1.6)												
	Jan.	**Feb.**	**Mar.**	**Apr.**	**May**	**June**	**Jul.**	**Aug.**	**Sep.**	**Oct.**	**Nov.**	**Dec.**
Production lick												
Cow with calf	2.5	2.5	2.5	2.5							2.5	2.5
Heifer	2	2	0.5	0.5	0.5	1.5	1.5	1.5	2	2	2	2
Winter lick												
Pregnant cow					0.5	0.5	0.5	0.5	0.5	0.5		
Summer lick												
Dry cow											0.5	0.5
Pregnant cow	0.4	0.4	0.4	0.4								
LSU kg/day (LSU = 1)												
	Jan.	**Feb.**	**Mar.**	**Apr.**	**May**	**June**	**Jul.**	**Aug.**	**Sep.**	**Oct.**	**Nov.**	**Dec.**
Production lick												
Cow with calf	1.6	1.6	1.6	1.6							1.6	1.6
Heifer	1.2	1.2	0.3	0.3	0.3	0.9	0.9	0.9	1.2	1.2	1.2	1.2
Winter lick												
Pregnant cow					0.3	0.3	0.3	0.3	0.3	0.3		
Summer lick												
Dry cow											0.3	0.3
Pregnant cow	0.2	0.2	0.2	0.2								

Source: Compiled from Serfontein (2015) and own calculations

Table 3.5 summarises the annual supplementary feed requirements of the different breeds in terms of production lick, summer lick, and winter lick.

Table 3.5: Annual lick requirements of the different breeds

	Afrikaner	**Brahman**	**Angus**	**Bonsmara**	**Simbra**	**Simmentaler**	**Limousin**
Production lick (kg)	382 801	378 003	427 917	434 784	388 668	377 139	364 530
Winter lick (kg)	93 357	96 206	96 810	97 109	96 948	100 361	100 996
Summer lick (kg)	25 468	29 104	21 040	20 143	27 984	33 343	36 155
Total (kg)	**501 625**	**503 312**	**545 767**	**552 036**	**513 599**	**510 844**	**501 682**
Total (tonne)	**502**	**503**	**546**	**552**	**514**	**511**	**502**

Source: Own calculations

It is interesting to note that the total lick requirements of the breeds differ, as one would expect all the herds to utilise the same amount of lick since it was calculated according to the LSU of each breed. The difference in lick utilisation is, however, caused by the differences in the inter-calf periods and thus the weaning percentage of the breeds that cause the number of animals in a specific phase of reproduction as a fraction of the herd to differ between the breeds.

3.2.3 Procedure to determine the water footprint

The WF of weaned calves produced from a cow-calf enterprise is basically based on three main components of water use, namely the drinking water of the animal, the water embedded in the feed that the animal consumes, and the water used for cleaning (service water) (Chapagain & Hoekstra, 2003). Mekonnen and Hoekstra's (2010a) and Mekonnen and Hoekstra's (2012) calculation frameworks were followed to determine the total WF of weaned calves. A distinction was made between the blue WF (consumption of water from surface and groundwater), green WF (evapotranspiration [ET] of rainwater), and the grey WF (the volume of freshwater to assimilate the pollution load).

According to Mekonnen and Hoekstra (2012), the WF of an animal, in terms of a year (m^3/y/animal) or over the lifetime of the animal (m^3/animal), is expressed as:

$$WF_{Animal} = WF_{feed} + WF_{drink} + WF_{service} \qquad [3.4]$$

Where WF_{feed}, WF_{drink}, and $WF_{service}$ represent the total WF related to feed, drinking water, and service water respectively.

Although the same calculation framework was used for the purpose of this research, there are some fundamental differences. Mekonnen and Hoekstra (2012) calculated the WF for a single animal using a top-down approach with a country perspective. Although this is certainly the route to follow when one wants to calculate the WF of beef from a country perspective, there are many assumptions that may skew the results. In order to calculate the WF for beef, one must divide the WF of the entire breeding herd by the amount of beef that is produced from that herd. In this case, the WF per kilogram of weaned calf (LW) will be calculated through a bottom-up approach with a farm perspective. A weaned calf is the final product of the beef cattle producer, but when one takes into account the entire beef value chain, the calculation will be for a process step in the determination of the WF for beef. The estimated WF is thus not the WF over the lifetime of the animal or of a year but the WF required to raise a calf up to the age of weaning (approximately seven months). In order to calculate the WF for beef, one must divide the WF of the entire breeding herd by the amount of beef that is produced from that herd. The total WF of the herd can, however, not only be allocated to the weaned calves produced, as a by-product in the form of culled cows is also produced. The WF of the herd should thus be split between the weaned calves (as primary product) and the culled cows (as by-product) according to the value factor (VF) of each.

The WF per kilogram LW of the weaned calves can then be expressed as:

> Where WF_{feed}, WF_{drink}, and $WF_{service}$ represent the WF of the entire herd, VF_{Calves} is the VF of the calves, and W_{Calves} is the total LW of the calves.

The VF_{Calves} is calculated as:

> Where V_{Calves} and $V_{Culled\ cows}$ represent the total value (TV) of the weaned calves and culled cows respectively.

The second difference in the case of this research is that no water is used in the mixing of supplementary feed and therefore the WF_{feed} differs slightly from that of Mekonnen and Hoekstra (2012) and is expressed as:

$$WF_{feed} = \sum_{p=1}^{n}\left(Feed[p] \times WF_{prod}[p]\right) \qquad [3.7]$$

> Where $Feed[p]$ represents the total amount of feed ingredient p consumed by the herd and $WF_{prod}[p]$ the WF of feed ingredient p.

Mekonnen and Hoekstra's (2010b) WF data for South Africa were used for the different feed ingredients in the supplementary feed. The WF for the natural grazing at Sernick was, however, not available and was estimated using ET data from earth observation/satellite imagery.[1] Since the natural grazing is only rain fed and not fertilised, there are no blue and grey WFs and the green WF of the grazing will be equal to the ET of the consumed grazing. The ET for the farm, according to the satellite imagery data, is 703.87 mm/annum, which calculates to 1.92 mm/day, while the water use efficiency (WUE) of the grazing with a total DM production of 3.5 tonnes/ha/year is 4.97 kg/ha/mm. When one compares the production efficiency of the grazing in terms of water use with international data, it is very low. At Sernick, 2 012 litres of green water are used to produce

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[1] ET data were made available from the "Wide-scale Modelling of Water and Water Availability with Earth Observation/Satellite Imagery" project co-funded by the Water Research Commission (WRC) (Project no. K5/2401//4) and the DAFF. The project is being carried out by Stellenbosch University, in partnership with eLEAF ®, Agricultural Research Council (ARC), GeoTerra Image ®, and independent consultants.

one kilogram of DM, while Kannan *et al.* (2017) found that native grasses (natural grazing) in the United States of America (USA) consumes on average between 431 and 705 litres of green water to produce a kilogram of DM. The Sernick data, however, compare very well to work done by Snyman (1989) in a similar region, where the average daily ET for different natural grass species in the Free State province of South Africa ranged between 1.66 and 2.39 mm/ha/day, while the WUE ranged between 4.72 and 6.01 kg/ha/mm. The production efficiency of the work done by Snyman (1989) ranged between 1 664 and 2 119 litres of green water per kilogram of DM.

3.2.4 Procedures to determine economic water consumption

Many products undergo various stages before they can be considered a final product. The final product of one producer/business can further be an intermediate product or production input in the production process of another producer/business. In the beef production chain, the primary producer of weaned calves uses different resources to produce the final product. The weaned calf is, however, considered by the feedlot as a production input in order to produce a final product in the form of fattened or finished calves. These fattened calves are then considered a production input by the abattoir and deboning plant that produce final products in the form of different meat cuts and by-products.

In order to determine the TV that is contributed to the economy and at the same time avoiding any double counting, the VA at each production phase must be accounted for. Since the production of weaned calves is the first production step in the beef value chain, the VA is equal to the sum of the TV of the weaned calves (primary product) and the culled cows (by-product), with no other deductions being made and based on the assumption that the total revenue of the enterprise exceeds the total costs. This is equal to the value that value-added tax (VAT) is calculated from. The VA by the cow-calf production unit of a herd is thus equal to the sum of the V_{Calves} and $V_{Culled\ cows}$ and the WF per unit of VA (economic water consumption or WF_{VA}) for a breed is then calculated by dividing the WF of the herd (WF_{Herd}) by the total VA (VA_{Herd}):

3.3 RESULTS

3.3.1 The water footprint of weaned calves from the different cattle breeds

The WF of the different cattle breeds is exhibited in Table 3.6. The WFs of the feed, drinking, and service water are presented in m^3 per breed. The reason for the WFs of the natural grazing, drinking, and service water being the same is the fact that although the total animal numbers of all the breeds differ due to their different LSU values, the total LSUs taken up by each breed is the same and the data are calculated accordingly.

Table 3.6: The water footprint of weaned calves and culled cows for the different breeds

	Afrikaner	Brahman	Angus	Bonsmara	Simbra	Simmentaler	Limousin
WF OF FEED							
Grazing							
Green WF (m^3 for herd)	13 105 823	13 105 823	13 105 823	13 105 823	13 105 823	13 105 823	13 105 823
Supplementary feed							
Green WF (m^3 for herd)	202 469	202 146	222 172	225 046	206 763	204 095	199 470
Blue WF (m^3 for herd)	10 926	10 927	11 954	12 103	11 168	11 053	10 820
Grey WF (m^3 for herd)	15 604	15 586	17 109	17 328	15 938	15 744	15 394
WF OF DRINKING WATER							
Blue WF (m^3 for herd)	25 740	25 740	25 740	25 740	25 740	25 740	25 740
WF OF SERVICE WATER							
Blue WF (m^3 for herd)	1 287	1 287	1 287	1 287	1 287	1 287	1 287
TOTAL WF OF HERD	**13 361 849**	**13 361 509**	**13 384 085**	**13 387 326**	**13 366 719**	**13 363 742**	**13 358 535**
Green WF (m^3 for herd)	13 308 293	13 307 969	13 327 995	13 330 869	13 312 586	13 309 919	13 305 294
Blue WF (m^3 for herd)	37 953	37 954	38 981	39 129	38 194	38 079	37 847
Grey WF (m^3 for herd)	15 604	15 586	17 109	17 328	15 938	15 744	15 394
VF of culled cows	0.243	0.251	0.236	0.220	0.256	0.281	0.286
WF OF CULLED COWS (m^3)	**3 249 766**	**3 352 409**	**3 154 973**	**2 939 634**	**3 425 165**	**3 753 829**	**3 814 208**
VF of weaned calves	0.757	0.749	0.764	0.780	0.744	0.719	0.714
WF OF WEANED CALVES (m^3)	**10 112 083**	**10 009 100**	**10 229 111**	**10 447 692**	**9 941 554**	**9 609 913**	**9 544 327**
WF PER KG OF WEANED CALF (Litre)	**60 940**	**62 687**	**57 856**	**53 375**	**62 526**	**77 609**	**76 462**
Green WF (litre/kg)	60 695.45	62 435.32	57 613.18	53 149.91	62 273.26	77 296.86	76 156.81
Blue WF (litre/kg)	172.40	177.35	167.80	155.35	177.94	220.25	215.77
Grey WF (litre/kg)	0.20	0.21	0.21	0.20	0.21	0.26	0.25

Source: Own calculations

The specific quantities of especially drinking and service water may differ between the breeds in a real-life scenario, but as the drinking and service water only make up 0.2% and 0.01% of the total WF respectively, any differences are considered negligibly small. It is thus assumed that every herd consumes the same amount of natural grazing, drinks the same amount of water, and requires the same amount of service water.

The only part of the total WF that differs between the respective breeds is the WF of the supplementary feed. Although the supplementary feed is also provided according to the LSU values, the differences in the reproductive data of the breeds (see Table 3.3) cause the breeds to have different supplementary feed needs. The Limousin, for example, is the heaviest breed of the seven and one may expect its use of supplementary feed, and thus the WF of the supplementary feed, to be the highest. The truth, however, is that the total supplementary feed WF of the Bonsmara herd, which is a lighter breed than the Limousin, is 28 791 m^3/herd more than that of the Limousin herd due to its much higher reproductive rate and associated higher supplementary feed needs.

It is interesting to note that when the total WFs of the different herds are compared, the WF of the Limousin herd, as the herd with the lowest WF, is only 0.22% less than that of the Bonsmara herd, as the herd with the highest WF. Another important aspect of the total WF of the different herds is the proportions of green, blue, and grey WFs. The average green WF across all the breeds is 99.59% of the average total WF across all the breeds, while the blue and grey WFs are equal to only 0.29% and 0.12% respectively of the total.

The second part of Table 3.6 divides the total WF of each herd between the culled cows, as the by-product of the cow-calf production system, and the weaned calves according to the VF of each group. Although it is assumed that 15% of the cows of every breed are culled per year, the VF of the culled cows and weaned calves differs between the breeds as the reproductive statistics of the breeds differ (see Table 3.3). The allocated WF of the weaned calves is then divided by the total LW of the calves to calculate the WF per kilogram of live calf sold.

It is clear from Table 3.6 that the WF per kilogram of weaned calf differed greatly between the various breeds. The Bonsmara had the lowest WF of 53.4 m^3/kg calf, while the Simmentaler had the highest WF of 77.6 m^3/kg calf. When all the breeds are compared to the Bonsmara, the WF/kg calf of the Angus was 8% higher, while the Afrikaner's, Simbra's, and Brahman's WF/kg calf were respectively 14%, 17%, and 17% more than that of the Bonsmara. The WF/kg calf of the Limousin and Simmentaler were respectively 43% and 45% more based on the same calculation.

The respective average green, blue, and grey WFs in the case of the WF/kg calf for the different breeds show almost the same proportions as in the case of the average total WF per herd. The green WF/kg calf is 99.715% of the total WF, while the blue and green WF/kg calf are respectively equal to only 0.285% and 0.0003% of the total WF. When only the blue WF/kg calf of the different breeds are compared, it is found that the differences here are also large, as in the case of the total WF/kg calf. The blue WF/kg calf of the Angus, Afrikaner, Simbra, Brahman, Simmentaler, and Limousin are respectively 8%, 11%, 14%, 15%, 39%, and 42% higher than that of the Bonsmara.

It is evident from the WF results of the cow-calf production system for the different breeds that there are large differences between the WF/kg calf of the different breeds. Switching from Simmentaler to Bonsmara cattle can lower the total WF/kg calf of the cow-calf production system with as much as 45% in the case of a specific farm. Improving the environmental stewardship of the cow-calf production system is, however, not the only indicator that must be considered in deciding which breed will be the most sustainable as the economic sustainability of each breed should also be considered.

3.3.2 The economic value added by the cow-calf production system

The economic VA in the case of a cow-calf production system stems from two sources, namely the income from the weaned calves sold as the primary product, and the income from the culled cows sold as the by-product.

In the model it was assumed that 15% of the cows are culled or replaced yearly since the average reproduction period of a cow is taken as seven years. These cows are slaughtered, have a dressing percentage of 50%, and receive a price of R29.00/kg carcass. The actual cow weights of the different breeds are used to calculate the VA. The weaned calves are sold to the feedlot for fattening and while the actual weaning weights of different breeds are used, the price for which all the calves are sold is taken as R19.50/kg LW. The VA by the different breeds are presented in Table 3.7.

Table 3.7: Value added by the cow-calf production system for the different breeds

	Afrikaner	Brahman	Angus	Bonsmara	Simbra	Simmentaler	Limousin
No. of calves weaned	790	688	779	783	688	558	516
Weaning weight (kg)	210	232	227	250	231	222	242
VA	**R3 235 749**	**R3 113 548**	**R3 447 679**	**R3 816 955**	**R3 100 451**	**R2 414 569**	**R2 434 091**
No. of cows culled	151	138	136	134	135	118	115
Cow LW (kg)	476	520	541	552	546	549	582
VA	**R1 039 887**	**R1 042 840**	**R1 063 371**	**R1 073 965**	**R1 068 199**	**R943 180**	**R972 738**
Total VA	**R4 275 637**	**R4 156 388**	**R4 511 049**	**R4 890 920**	**R4 168 650**	**R3 357 749**	**R3 406 829**

Source: Own calculations

When the total VA of the breeds is compared, the Bonsmara adds the most value of all the breeds, while the Simmentaler adds the least. A comparison of the breeds with the Bonsmara showed that the Angus added 8% less value, while the Afrikaner, Simbra, and Brahman added 13%, 15%, and

15% less value respectively. The Limousin and the Simmentaler respectively added 30% and 31% less value than the Bonsmara.

The reason for the large variation in VA between the breeds also stems from the large variation in the reproduction data of the breeds (see Table 3.3). The low reproduction rate of the Limousin, for example, in comparison to a breed like the Bonsmara, is also evident in Table 3.6 when the share of the VA from the culled cows in relation to the total VA is compared. The VA of the culled cows of the Bonsmara is 22% of the total VA, while the figure is 29% for the Limousin. This means that in the case of the Limousin, almost a third of the total VA stems from the by-product and not the primary product. The share of the VA from the culled cows in relation to the total VA for the other breeds is 24%, 24%, 26%, 25%, and 28% for the Angus, Afrikaner, Simbra, Brahman, and Simmentaler respectively.

It is interesting to note that the order of VA between the breeds has a negative relationship with the order of the WF/kg calf between the breeds. The breed with the highest VA, the Bonsmara, also had the lowest WF/kg calf, while the breed with the lowest VA, the Simmentaler, also exhibited the highest WF/kg calf. In order to determine what effect this will have on the water-economy nexus of the different cattle breeds, the WF_{VA} of the breeds must be compared.

3.3.3 The economic water consumption of the cow-calf production system

The WFs of every unit VA (WF_{VA}) for the different breeds are presented in Table 3.8, and indicate the WF (litre) of R1 VA. The pattern of results in Table 3.8 could have been expected, based on the outcome of the WF and VA of the different breeds in the previous sections. It is, however, still interesting to see that while a breed like the Bonsmara has a WF_{VA} of 2 737 litres/R, the WF_{VA} of the Simmentaler is 1 243 litres/R more at 3 980 litres/R.

Table 3.8: The economic water consumption of the different breeds

	Afrikaner	**Brahman**	**Angus**	**Bonsmara**	**Simbra**	**Simmen-taler**	**Limousin**
WF_{VA} (Litre/R)	**3 125**	**3 215**	**2 967**	**2 737**	**3 206**	**3 980**	**3 921**
Green WF_{VA} (Litre/R)	3 112.6	3 201.8	2 954.5	2 725.6	3 193.5	3 963.9	3 905.5
Blue WF_{VA} (Litre/R)	8.9	9.1	8.6	8.0	9.2	11.3	11.1
Grey WF_{VA} (Litre/R)	3.6	3.7	3.8	3.5	3.8	4.7	4.5

Source: Own calculations

When the WF_{VA} of all the breeds is compared to the Bonsmara, it was found that the Angus, Afrikaner, Simbra, Brahman, Limousin, and Simmentaler respectively had a WF_{VA} of 8%, 14%, 17%, 17%, 43%, and 45% more. The total WF_{VA} of all the breeds is, however, very high and may come as a concern if the WF in terms of green, blue, and grey water is not considered separately. The bulk, or 99.6%, of the total WF_{VA} consists of the green WF_{VA}, while the blue and grey WF_{VA}

only contributed 0.3% and 0.1% respectively to the total WF_{VA} of the cow-calf production system. Even though the Simmentaler had blue and grey WFs of approximately 41% and 34% more than that of the Bonsmara, the specific quantities of water used to add R1 value is very small for both breeds.

The WF_{VA} of the different breeds proves that a cow-calf producer can improve both the environmental stewardship and economic contribution of the enterprise through the selection of the most suitable breed for a specific farm.

3.4 DISCUSSION

This chapter set out to determine the WF per kilogram of a weaned calf and the VA of the different cattle breeds under the same extensive farming conditions for a cow-calf enterprise. In order to reach the objective, a simulation model was used to generate the production data and feed requirements of the different breeds before the WF, the VA, and the WF_{VA} were estimated.

The results of Chapter 3 are summarised in Figure 3.1, in which the WF/kg calf, the total VA, and the WFVA of the different breeds are presented. The results clearly show that there are large differences between the seven breeds in terms of these factors. It was also found that the breeds that exhibited the higher WF/kg calf had a lower amount of VA and thus revealed a negative correlation between the two factors. Although the total WF per herd for each breed revealed little variation between the breeds, the difference in the VA between the breeds caused the WFVA to increase in the same way as the WF/kg calf.

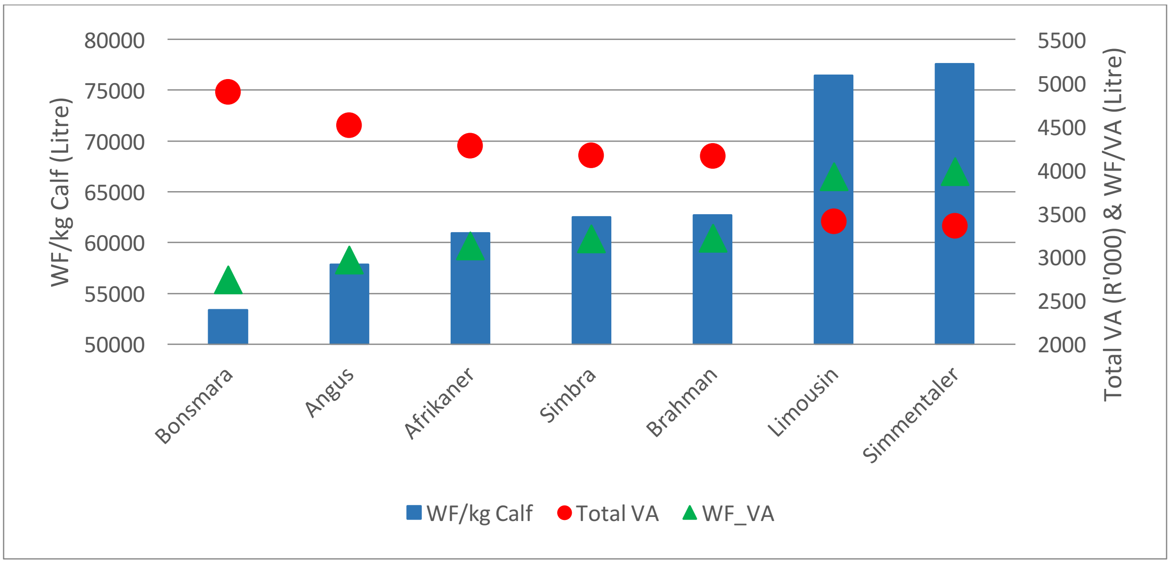

Figure 3.1: The water footprint per calf, total value added, and water footprint of the value added of the different cattle breeds
Source: Own calculations

According to the results, the Bonsmara herd, as the herd with lowest WF/kg calf, the highest VA, and the lowest WF_{VA}, provides the producer with 31% more VA than the Simmentaler, while, at the same time, having a 45% lower WF/kg calf than the Simmentaler. Farming with Bonsmara rather than the Simmentaler in this specific study would thus provide the producer the opportunity to lower the economic water consumption (EWC) of the operation with 45%.

The very high total WF/kg calf may give reason for concern, especially when the outcomes of this study – where the average WF/kg calf ranges between 53 375 litre/kg and 77 609 litre/kg – are compared with other beef WF study results, such as the work done by Mekonnen and Hoekstra (2012), who found the global WF of a kilogram boneless beef to be 15 415 litre/kg and that of South Africa to be 17 387 litre/kg (Mekonnen & Hoekstra, 2010c). By comparing a kilogram of live weaned calf and a kilogram of boneless beef, one is not comparing apples with apples, but the difference in the WF of the two is still too large for comfort and one would expect the WF of the weaned calf to become even larger as it continues through the feedlot and abattoir.

Some factors should be kept in mind when one wants to compare the findings of this study with others. The first is the fact that a bottom-up approach from the perspective of a single producer (farm) was used to calculate the WF/kg calf by dividing the total WF of the herd by the sellable offtake classes (weaned calves and culled cows) according to the VF of each. The data used in this study were thus more exact than the national average data that were used by authors such as Mekonnen and Hoekstra (2012).

The second factor is that country-perspective studies by authors such as Mekonnen and Hoekstra (2012) and Gerbens-Leenes *et al.* (2012) made no distinction between the different classes or grades of cattle and meat. The total WF was thus divided by the total offtake of beef. In the case of this study, a distinction was made between the weaned calves and culled cows and the total WF was allocated according to the VF of each. Since the VF of the weaned calves was more than that of the culled cows, the WF allocated to the weaned calves was more.

The third factor that must be kept in mind is that although the WF of the calf will increase as it moves through the feedlot and abattoir, the WF/kg boneless beef is calculated according to its VF in relation to the whole animal. Part of the total WF of the calf must thus be allocated to by-products, such as the hide, head, and offal, which will reduce the WF/kg boneless beef.

The results from this chapter provided valuable new knowledge on the differences between different cattle breeds in terms of their WF and VA. This information and the calculation framework can be used by beef producers to determine which breed of beef cattle will simultaneously improve their environmental stewardship and economic VA.

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CHAPTER 4

THE WATER-ECONOMY NEXUS OF FEEDLOT-FINISHED CALVES

"We never know the worth of water till the well is dry."

- Thomas Fuller (1608 – 1661) -

4.1 BACKGROUND AND INTRODUCTION

The feedlot sector plays a very important role in the South African beef industry, with approximately 65% to 75% of all cattle being marketed through feedlots (Department of Agriculture, Forestry and Fisheries [DAFF], 2014). The aim of cattle feedlots is to achieve the highest possible weight increase during the shortest period of time by feeding the weaned calves balanced rations containing energy, proteins, minerals, and vitamins, while also administering antibiotics for optimal health and growth hormones to further increase weight gain (Spies, 2011). South Africa had an average feedlot standing capacity of 584 324 head of cattle in 2015, with the five largest feedlots holding approximately 68% of the total standing capacity (South African Feedlot Association [SAFA], 2015). The single largest feedlot has a standing capacity of 120 000 head of cattle (Karan Beef, 2016).

Significant differences were found between grazing, mixed, and industrial production systems in terms of water footprint (WF) of a kilogram of beef, and the global weighted average ranged from 10 244 litres/kg for industrial systems (of which feedlots form part) to 15 712 litres/kg for mixed systems and 21 829 litres/kg for grazing systems (Mekonnen & Hoekstra, 2012). Gerbens-Leenes *et al*. (2013) set out to determine which factors influenced the WFs of production systems for the same meat type and found that, in the case of beef, although the fractions of concentrates in the feed increased from grazing to industrial systems, the industrial systems used 3.7 times less feed than the grazing systems to produce the same amount of beef. This means that the feed conversion ratio (FCR) of an industrial system is better. The combined effect of the increase in concentrate fractions and the decrease in the amount of feed causes the green WF to decrease from grazing to industrial systems, while the blue and grey WFs increase. Mekonnen and Hoekstra (2010a), Hoekstra (2012), Mekonnen and Hoekstra (2012), Ridoutt *et al.* (2012), Gerbens-Leenes *et al.* (2013), and Bosire *et al.* (2015) all agree that the largest part of the WF of beef is contributed by the feed that the animal consumes and that the FCR is an important factor in the determination of the WF of beef.

Given the importance of the FCR as a determinant in the WF of beef, and the fact that the FCR differs between cattle breeds (Koch *et al*., 1963; Archer & Bergh, 2000; Strydom *et al*., 2008;

Crowley *et al*., 2010), one method of reducing the WF of beef might be to determine and select the breed with the lowest FCR. It is interesting to note that although various authors investigated and estimated the WF of beef and made recommendations regarding the importance of feed composition and FCR between the different production systems, very little attention was paid to different breed types (Mekonnen & Hoekstra, 2010a; Ercin *et al*., 2012; Hoekstra, 2012; Mekonnen & Hoekstra, 2012; Ridoutt *et al*., 2012; Gerbens-Leenes *et al*., 2013; Bosire *et al*., 2015; Pearce, 2016; Harding *et al*., 2017). The results of the abovementioned studies provided estimates on mostly country-level data, but the studies did not account for different value chain links and certain variables, such as genetic differences between breeds, included in beef production and therefore cannot be used for policy recommendations.

Although the possible reduction of the WF through breed selection will contribute to the environmental stewardship of beef production, the economic side of beef production should also be sustained. The objective of this chapter is to estimate the WF per kilogram weight gain of feedlot-finished calves and the economic value added (VA) of the different cattle breeds. The WF and the VA of each breed will differ since the FCR and growth curves of each breed differ.

4.2 PROCEDURES AND DATA

The study was conducted through an actual feeding experiment where 35 calves of each of the seven breeds were fed in the Liebenbergstroom feedlot owned by the Sernick Group. The experiment is discussed in detail in Oosthuizen (2016). The feedlot is situated close to the town of Edenville in the Free State province of South Africa and has a standing capacity of 8 000 head of cattle. The drinking water for the cattle is supplied from a dam as well as underground water sourced from boreholes, while the feedstuff to make up the feed rations are bought from various suppliers.

Weaned calves that are being fed in a feedlot and then sold to an abattoir can be considered a process step in the value chain to produce beef, or can be considered a final product for the feedlot. In the event where a cow-calf producer sells the calf to the feedlot, the same scenario presents itself as the calf is a process step in the value chain for beef but also the final product for the producer. Since the calf that is sold to the feedlot remains a live calf for the producer and the feedlot, it does not really matter if the calf is considered a final product or a process step as the WF and VA estimation will remain the same. In the case of the feedlot-abattoir link, it is more complicated as the feedlot delivers a live animal as a final product but only gets paid for the cold carcass of that animal, while the abattoir takes and sells the fifth quarter (hide, head, and offal), or by-products, as its slaughter fee.

The question now is how the estimated feedlot WF should be allocated. Since the feedlot only gets paid according to the cold carcass weight (CW) of each animal, it does make some sense to allocate the feedlot WF according to the value factor (VF) of the carcass and by-products and then only allocate the carcass WF to the feedlot. In practice, however, the feedlot must deliver the live animal, and the price received, even though calculated according to the CW, is the price the abattoir pays for the live animal. For the sake of this chapter, the feedlot-finished calf was considered as the final product of the feedlot and the WF was allocated to the amount of live weight (LW) gained in the feedlot. The VA was taken as the difference between the price received for the finished animal and the price paid for the weaned calve.

4.2.1 Feedlot data for the different breeds

In order to generate the data, 35 calves from seven different cattle producers (245 calves in total) were collected in a 150 km-radius around the feedlot in order to minimise the climate, grazing, and adjustment effects (Oosthuizen, 2016). All the animals were treated homogeneously in terms of vaccinations, growth stimulants, and handling. Each breed was fed separately in its own pen on three different feed rations, namely starter, grower, and finisher. The calves were fed from 50-kg feed bags and at the end of each day the remaining feed was cleaned from the troughs and weighed in order to determine the breed's daily feed intake. All the animals were weighed once a week, on the same day and time, to determine the average daily gain (ADG) and to calculate the FCR for each breed. Water meters were used to measure the water flow to the water troughs in the pens. The water used for cleaning the troughs was subtracted from the total flow and the remainder, which included drinking water and evaporation, was used as the amount of drinking water.

In order to maximise the profit or minimise the loss for each breed, the profit-maximising feeding period (PMFP) was estimated with the production economic principles (Oosthuizen, 2016). According to production economics theory, profit is maximised (loss is minimised) at the stage in production where the value of the marginal product (VMP) is equal to the marginal factor cost (MFC). In order to estimate the PMFP, the VMP was taken as the weekly growth (in kg LW) of the animal multiplied by the dressing percentage and carcass price, while the MFC was equal to the total variable cost of the feedlot expressed as a price per kilogram of feed.

The growth and feed intake data that were generated through the feedlot experiment are presented in Table 4.1. The PMFP, as estimated by Oosthuizen (2016), was based on a carcass price of R35.00/kg and dressing percentages of 59%, 57%, 60%, 60%, 59%, 62%, and 63% respectively for the Brahman, Afrikaner, Bonsmara, Simbra, Angus, Simmentaler, and Limousin to estimate the VMP. A feed price of R2.55/kg, R2.80/kg, and R2.90/kg for Weeks 1-5, 6-14, and 15-30 respectively was used as the MFC. The reason for the different feed prices is due to the fact that the animals received three different feed rations, known as a starter, grower, and finisher.

It is interesting to note, as seen in in Table 4.1, that although the ADG and FCR of the different breeds seem to be very close to each other, the PMFP varied tremendously between breeds. The Afrikaner should only be fed for a maximum period of 15 weeks (given the prices in the model), while the Simmentaler takes 27 weeks to reach its PMFP. In terms of the PMFP of the different breeds, it can be seen that the Afrikaner, Brahman, and Bonsmara required more or less the same feeding time, while the Simbra and Angus can be grouped together, and the Simmentaler and Limousin can be placed in a third grouping.

Table 4.1: Feedlot growth and feed intake of the different breeds

	Afrikaner	Brahman	Angus	Bonsmara	Simbra	Simmentaler	Limousin
No. of calves bought	**35**	**35**	**35**	**35**	**35**	**35**	**35**
Average weaning weight (kg)	210	232	227	250	231	222	243
Total weaning weight (kg)	**7350**	**8120**	**7945**	**8750**	**8085**	**7770**	**8505**
PMFP (weeks)	**15**	**16**	**22**	**16**	**21**	**27**	**26**
Starter intake (kg)	5057	4998	4991	5660	4623	5358	5343
Grower (kg)	16719	19492	37007	24762	34334	54341	48319
Finisher (kg)	9114	8222	12328	11633	11182	12230	10310
Total feed intake (kg)	**30890**	**32712**	**54326**	**42054**	**50139**	**71930**	**63972**
Average daily feed intake (kg)	**8.4**	**8.3**	**10.1**	**10.7**	**9.7**	**10.9**	**10.0**
Average live end weight (kg)	376	409	506	472	493	594	575
Total live end weight (kg)	**13157**	**14314**	**17720**	**16512**	**17243**	**20802**	**20127**
ADG (kg)	**1.58**	**1.58**	**1.81**	**1.98**	**1.78**	**1.97**	**1.82**
FCR (kg)	**5.32**	**5.28**	**5.56**	**5.42**	**5.47**	**5.52**	**5.50**

Source: Compiled from Oosthuizen (2016) and own data collection

The total amount of feed consumed by each breed differs greatly between the breeds and it should therefore be considered, while taking the PMFP into account. The Simmentaler, for example, consumed more than double the amount of feed that the Afrikaner did, but at the same time the feeding duration was also almost double that of the Afrikaner. The amount of LW gained by the Simmentaler was also more than double that of the Afrikaner. The high feed consumption figures of the Simmentaler are thus justified by the high output in terms of growth. The daily drinking and service water usage of the feedlot was measured at an average of 42 litres per animal per day, of which the service water was equal to two litres per animal per day.

4.2.2 Procedure to determine the water footprint of feedlot-finished calves

The WF of feedlot-finished calves is based on three main components of water use, namely the drinking water of the animal, the water embedded in the feed that the animal consumes, and the water used for cleaning (service water) (Chapagain & Hoekstra, 2003). Mekonnen and Hoekstra's (2010a) and Mekonnen and Hoekstra's (2012) calculation frameworks were followed to determine the total WF of feedlot-finished calves, and a distinction is made between the blue WF (consumption of water from surface and groundwater), green WF (evapotranspiration [ET] of rainwater), and the grey WF (the volume of freshwater to assimilate the pollution load).

According to Mekonnen and Hoekstra (2012), the WF of an animal, in terms of a year (m^3/y/animal) or over the lifetime of the animal (m^3/animal), is expressed as:

$$WF_{Animal} = WF_{feed} + WF_{drink} + WF_{service} \tag{4.1}$$

Where WF_{feed}, WF_{drink}, and $WF_{service}$ represent the total WF related to feed, drinking water, and service water respectively.

The same calculation framework was used in this study, but some differences must be taken into account. The first difference is that the WF in this study was not calculated per animal over the course of its lifetime, or per animal per year, but rather per kilogram of LW added over the time period that the animal was fed. The WF per kilogram LW of the feedlot-finished calves can then be expressed as:

$$WF_{kg\ FFCalf} = \frac{(WF_{feed}+WF_{drink}+WF_{service})}{(W_{WCalves}-W_{FFCalves})} \tag{4.2}$$

Where WF_{feed}, WF_{drink}, and $WF_{service}$ represent the WF of the entire feeding group of a specific breed over the feeding period, while $W_{WCalves}$ and $W_{FFCalves}$ comprise the total LW of the purchased weaned calves and sold feedlot-finished calves respectively.

The second difference in the case of this research is that no water was used in the mixing of the feed and therefore the WF_{feed} will differ slightly from that of Mekonnen and Hoekstra (2012) and is expressed as:

$$WF_{feed} = \sum_{p=1}^{n}\left(Feed[p]\times WF_{prod}[p]\right) \tag{4.3}$$

Where $Feed[p]$ represents the total amount of feed ingredient p consumed by the feeding group of a specific breed over the course of the feeding period, and $WF_{prod}[p]$ represents the WF of feed ingredient p.

Mekonnen and Hoekstra's (2010b) WF data for South Africa were used for all the different feed ingredients in the feed rations, except for the grass. The grass used in the feeding rations is cut and baled on rain-fed grasslands and the WF was estimated using ET data from earth observation / satellite imagery.[2] The estimated WF for natural grazing of Chapter 3 was used for the WF of the grass included in the feed rations. The ET, according to the satellite imagery data, was 703.87 mm/annum, which calculates to 1.92 mm/day, while the water use efficiency (WUE) of the grazing with a total dry matter (DM) production of 3.5 tonnes/ha/year was 4.97 kg/ha/mm.

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[2] ET data were made available from the "Wide-scale Modelling of Water and Water Availability with Earth Observation/Satellite Imagery" project co-funded by the Water Research Commission (WRC) (Project no. K5/2401//4) and the DAFF. The project is being carried out by Stellenbosch University, in partnership with eLEAF ®, Agricultural Research Council (ARC), GeoTerra Image ®, and independent consultants.

4.2.3 Procedures to determine the economic water consumption

The feedlot adds value in the value chain of beef production by increasing the weight of a weaned calf until it is ready to slaughter. The VA by the feedlot is equal to the price at which the feedlot sells the feedlot-finished calves minus the price at which the weaned calves were purchased, with no other deductions being made and the equation based on the assumption that the total revenue of the enterprise exceeds the total costs. The VA by the feedlot is thus equal to the difference between the $V_{FFCalves}$ and $V_{WCalves}$ with the economic water consumption (EWC) (WF_{VA}) for a breed then calculated by dividing the WF of breed (WF_{Breed}) by the total VA (VA_{Breed}):

$$WF_{VA} = \frac{WF_{Breed}}{VA_{Breed}} \qquad [4.4]$$

4.3 RESULTS

4.3.1 The water footprint of feedlot-finished calves for the different cattle breeds

The total WF of the different breeds and the WF per kilogram of weight gain in the feedlot are presented in Table 4.2. There were large variances in the total WF for each breed, with the Simmentaler, as the breed with the highest total WF, having a total WF of 84 460 m^3/herd, which was 133% more than that of the Afrikaner, as the breed with lowest total WF, at 36 250 m^3/herd. It must, however, be kept in mind that the feeding periods of the breeds differed as each breed was fed until it reached the PMFP. The Simmentaler's PMFP of 27 weeks in relation to the Afrikaner's of 15 weeks is the reason for the large difference in the total WF between the breeds.

The effect of the different PMFPs of the different breeds can also be seen on the drinking and servicing WFs. On average, the total drinking and servicing WFs were only 0.35% and 0.02% of the total WF of the different breeds respectively, while the rest of the total WF was contributed by the feed. Due to this small contribution to the total WF, the weekly consumption of drinking and service water of the feedlot was evenly distributed among the number of animals in the feedlot. Although each animal, according to the assumption, thus had the same weekly drinking and servicing WFs, the total drinking and servicing WFs varied between the breeds as the PMFPs of the breeds varied.

A comparison of the different breeds according to the WF per kilogram of weight gained in the feedlot showed a different ranking of the breeds according to each WF. Here the Brahman was the breed with the lowest WF/kg gain at 6 201 litres, while the Angus was the breed with highest WF/kg gain at 6 524 litres. It is interesting to note that the difference in the WF/kg gained between the most and least WF-efficient breed was only 5%, as opposed to the 133% when the total WF was compared.

Table 4.2: Water footprint of feedlot-finished calves for the different breeds

	Afrikaner	Brahman	Angus	Bonsmara	Simbra	Simmentaler	Limousin
WF OF FEED							
Green WF (m^3/herd)	33 151	35 124	58 325	45 134	53 833	77 273	68 736
Blue WF (m^3/herd)	791	837	1 382	1 074	1 276	1 826	1 625
Grey WF (m^3/herd)	2 153	2 282	3 832	2 947	3 536	5 083	4 511
WF OF DRINKING WATER							
Blue WF (m^3/herd)	147	157	216	157	206	265	255
WF OF SERVICE WATER							
Blue WF (m^3/herd)	7	8	11	8	10	13	13
TOTAL WF OF BREED (m^3/herd)	**36 250**	**38 408**	**63 767**	**49 320**	**58 861**	**84 460**	**75 141**
Green WF (m^3/herd)	33 151	35 124	58 325	45 134	53 833	77 273	68 736
Blue WF (m^3/herd)	946	1 001	1 609	1 239	1 492	2 104	1 893
Grey WF (m^3/herd)	2 153	2 282	3 832	2 947	3 536	5 083	4 511
WEIGHT GAINED IN FEEDLOT (KG)	**5 807**	**6 194**	**9 775**	**7 762**	**9 158**	**13 032**	**11 622**
Calves bought (kg)	(7 350)	(8 120)	(7 945)	(8 750)	(8 085)	(7 770)	(8 505)
Calves sold (kg)	13 157	14 314	17 720	16 512	17 243	20 802	20 127
WF OF WEIGHT GAIN (Litre/kg)	**6 243**	**6 201**	**6 524**	**6 354**	**6 427**	**6 481**	**6 465**
Green WF (litre/kg)	**5 709**	**5 671**	**5 967**	**5 815**	**5 878**	**5 930**	**5 914**
Blue WF (litre/kg)	**163**	**162**	**165**	**160**	**163**	**161**	**163**
Grey WF (litre/kg)	**371**	**368**	**392**	**380**	**386**	**390**	**388**

Source: Own calculations

The Simmentaler's WF/kg gain was also 5% more than that of the Brahman, while both the Simbra's and Limousin's was 4% more. The Bonsmara and Afrikaner exhibited the least variation from the Brahman, with their respective WFs per kilogram gain being 2% and 1% more than that of the Brahman. The percentage differences in the WF per kilogram of weight gain compared very well with differences in the FCR between the different breeds (see Table 4.1). In terms of FCR, the Brahman required the least feed to gain a kilogram of LW at 5.28 kg feed/kg LW. The FCR of the Afrikaner and Bonsmara was 1% and 3% higher respectively, while both the Simbra's and Limousin's FCR was 4% more than that of the Brahman. The Simmentaler and Angus both required 5% more feed than the Brahman to gain an additional kilogram of LW.

Although the WF per kilogram of weight gain that ranged between 6 201 and 6 524 litres for the various breeds may seem quite high, the WF should be considered in terms of the three components of the footprint being green, blue, and grey water. The average share of the green, blue, and grey WF per kilogram of weight gain was 91.5%, 2.5%, and 6% respectively. The share of especially blue water was thus very small in relation to the total WF per kilogram of weight gain and for all the breeds was on average only 162 litre/kg gain.

The results of the WF of the different breeds in the feedlot showed that the variation between the breeds was relative small, with only a 5% difference between the breed with lowest and highest WF per kilogram of weight gain. The reason for this small difference can be ascribed to the fact that all the breeds were fed according to their optimum growth cycle in the PMFP model. Since the net weight gain of the breeds varied greatly, the VA per breed also varied and therefore the difference in the economic VA must also be estimated.

4.3.2 The economic value added by feedlot-finished calves

The economic VA in the case of a feedlot is equal to the difference between the income received from the abattoir for the feedlot-finished calves and the price that the feedlot paid for the weaned calves. Since the data for this chapter were generated from an actual feedlot experiment, the actual values that were paid for the weaned calves and received for the feedlot-finished calves were used. The weaned calves were bought at R19.50/kg LW, while the feedlot-finished calves were sold at R35/kg CW. The VA by the different breeds is presented in Table 4.3.

A comparison of the VA/cycle of the different breeds exhibited large variation where the Afrikaner adds only R119 147 and the Simmentaler R299 879, a difference of R180 731. Since the PMFP of the breeds varied, the VA/cycle of the breeds cannot really be compared as the Simmentalers were fed for 17 weeks more than the Afrikaners. In order to do a fair comparison of the VA by the different breeds, the feeding cycles per year for each breed, calculated by the PMFP, should be taken into account.

Table 4.3: Value added by feedlot-finished calves for the different breeds

	Afrikaner	Brahman	Angus	Bonsmara	Simbra	Simmentaler	Limousin
Weaned calves bought (kg)	7 350	8 120	7 945	8 750	8 085	7 770	8 505
Weaned calves purchase price	**R143 325**	**R158 340**	**R154 928**	**R170 625**	**R157 658**	**R151 515**	**R165 848**
Finished calves sold (live kg)	13 157	14 314	17 720	16 512	17 243	20 802	20 127
Dressing percentage	57%	59%	58%	58%	60.5%	62%	63%
Finished calves carcasses (kg)	7 499	8 445	10 277	9 577	10 432	12 897	12 680
Finished calves selling price	**R262 472**	**R295 576**	**R359 712**	**R335 185**	**R365 123**	**R451 394**	**R443 803**
VA/cycle	**R119 147**	**R137 236**	**R204 784**	**R164 560**	**R207 465**	**R299 879**	**R277 955**
PMFP	15	16	22	16	21	27	26
Cycles / Year	3.5	3.3	2.4	3.3	2.5	1.9	2.0
VA/year	**R413 044**	**R446 016**	**R484 036**	**R534 822**	**R513 723**	**R577 544**	**R555 910**

Source: Own calculations

The difference in the VA/year between the Afrikaner and Simmentaler is still large at R164 500, but the VA of the Afrikaner is now only 28% less than that of the Simmentaler. A comparison of the other breeds with the Simmentaler, as the breed that realises the most VA/year, showed that the Brahman realised 23% less VA, while the Angus and Simbra realised 16% and 11% less respectively. The Bonsmara and Limousin had VA/year values of 7% and 4% less respectively than the Simmentaler.

The results indicate that, even in the event where the VA/year of the different breeds are compared, there are differences between the various breeds. It must, however, be kept in mind that the VA does not take into account the resources that were used to create the VA. In order to compare the WUE to create a unit of VA, the EWC (WF_{VA}) of the different breeds must be estimated and compared.

4.3.3 The economic water consumption of feedlot-finished calves

The EWC (WF_{VA}) of the different breeds is presented in Table 4.4 and indicates how large the WF (litre) of R1 VA is. A comparison of the different breeds indicates that the Angus had the highest WF_{VA} at 311 litres/R, while the Limousin had the lowest at 270 litres/R. The WF_{VA} of the Limousin, Brahman, Simmentaler, Simbra, Bonsmara, and Afrikaner was respectively 13%, 10%, 10%, 9%, 4%, and 2% lower than that of the Angus.

Table 4.4: The water footprint of the value added of feedlot-finished calves for the different breeds

	Afrikaner	Brahman	Angus	Bonsmara	Simbra	Simmentaler	Limousin
WF_{VA} (litre/R)	304	280	311	300	284	282	270
Green WF_{VA} (litre/R)	278.23	255.94	284.81	274.27	259.48	257.68	247.29
Blue WF_{VA} (litre/R)	7.94	7.30	7.86	7.53	7.19	7.02	6.81
Grey WF_{VA} (litre/R)	18.07	16.63	18.71	17.91	17.05	16.95	16.23

Source: Own calculations

The WF_{VA} in terms of the different WFs showed that the average green, blue, and grey WFs across the breeds account for 91.5%, 2.5%, and 6.0% respectively, and the bulk of the WF_{VA} is thus made up from green water. Although the total WF to create R1 worth of VA may seem high, the share of the blue and grey WFs is very low and does not raise concerns.

4.4 DISCUSSION

The objective of this chapter was to determine the WF per kilogram weight gain of feedlot-finished calves from different cattle breeds and the economic VA by each breed. In order to reach the objective, 35 weaned calves of seven different breeds (245 calves in total) were fed in a feedlot until each breed reached its PMFP. The generated growth, feed intake, and slaughter data (dressing percentage) were used to estimate the WF/kg weight gain, the yearly VA, and the WF_{VA} of each breed. The combined results of the study are summarised in Table 4.5, where the WF/kg weight gain, the total yearly VA, and the WF_{VA} of the different breeds are ranked.

Table 4.5: Breed ranking of the water footprint per kilogram, value added per year, and water footprint of the value added of feedlot-finished calves

Ranking	WF/kg gain (litre/kg)		VA/year (R'000)		WF_{VA} (litre/R)	
Best	**Brahman**	6 201	**Simmentaler**	578	**Limousin**	270
	Afrikaner	6 243	**Limousin**	556	**Brahman**	280
	Bonsmara	6 354	**Bonsmara**	535	**Simmentaler**	282
	Simbra	6 427	**Simbra**	514	**Simbra**	284
	Limousin	6 465	**Angus**	484	**Bonsmara**	300
	Simmentaler	6 481	**Brahman**	446	**Afrikaner**	304
Worst	**Angus**	6 524	**Afrikaner**	413	**Angus**	311

Source: Own calculations

Although all the breeds can be ranked according to each factor in Table 4.5, it is very interesting to note that the ranking order differed in each case. The Brahman, for example, had the best (lowest) WF/kg weight gain, the second worst (lowest) VA/year, and the second best (lowest) WF_{VA}. One would think that the WF_{VA} ranking would either follow the same trend of the WF/kg gain or of the VA/year, as it is basically a combination of these two factors, but at the end it did not. The reason for the differences in the ranking order of the three factors can largely be ascribed to the dressing percentage of each breed. The price that the feedlot receives from the abattoir for a finished calf is based on the dressing percentage of the carcass. The feedlot only gets paid for the weight of a cold carcass and the higher the weight of this carcass is in relation to the weight of the delivered calf, the higher the VA by the feedlot. When the received price for the finished calf is divided by the weight gain, the VA per kilogram of weight added differs between the breeds.

The variation in the ranking order of the factors makes it very difficult to choose the overall best breed for the feedlot. When WUE in terms of the WF/kg weight gain is chosen as the selection criterion, the Brahman is the best choice. On the other hand, if the goal is to maximise economic VA, the Simmentaler will be the breed of choice. In terms of the water-economy nexus, the feedlot will maximise the WUE in terms of creating value when the Limousin is the breed of choice. The differences in terms of all three the factors between the breeds are, however, relatively small and it will be difficult to convince a feedlot to consider one breed above another based on the results. The reason for the relatively small differences between the breeds can be ascribed to the fact that all the breeds were fed according to each breed's PMFP, which optimised the growth, feed intake, and VA of each breed. In the event where all the breeds were fed for a predetermined feeding period of approximately 19 weeks, as is done by most feedlots in South Africa, the differences between the breeds might have been larger.

The WF/kg of weight gain for the different breeds may seem high as it ranged between 6 201 and 6 524 litres/kg. Although it is very difficult to compare these results to the results of other studies, as very little research exists on the WF of beef feedlots, and the scope and goal of the studies that exist differ, some comparisons can be made. Two previous studies that specifically estimated the WF of feedlot-finished cattle are by Pearce (2016) and Palhares *et al.* (2017).

Pearce (2016) estimated the blue, green, and grey WFs of beef produced from a South African feedlot with a bottom-up approach, where the total standing numbers of the feedlot were used and assumptions were made regarding feed, growth, and slaughter statistics. Palhares *et al.* (2017) estimated the green and blue WFs of 17 different feedlots in Brazil with a bottom-up approach using the feed, growth, and slaughter data of each feedlot. Both of these mentioned studies, however, expressed the WF in terms of a kilogram of beef, where Pearce (2016) estimated it according to CW and Palhares *et al.* (2017) according to boneless beef. The studies did not, however, consider by-products and the associated VFs and allocated the total WF only to the amount of beef.

Pearce (2016) found the WF to be almost 18 million litres/kg carcass, while Palhares *et al.* (2017) found the blue and green WFs of a kilogram of boneless beef to range between 1 934 litres/kg and 9 672 litres/kg. The WF results of this study, even though calculated according to kilogram LW gain, compare very well to Palhares *et al.*'s (2017) results, while it is only a fraction of the results reported by Pearce (2016). However, when one considers the WF of a kilogram of beef produced in South Africa of other studies (where the whole value chain was considered), such as Mekonnen and Hoekstra (2010c) at 17 387 litres/kg (green, blue, and grey WFs) and Harding *et al.* (2017) at 437 litres/kg CW (blue WF only), the results of this study also show the potential to compare well in the whole value chain analysis (VCA). This study is therefore of the opinion that there might be some calculation errors in the WF estimated by Pearce (2016).

This chapter provides valuable new knowledge as, according to the knowledge of the author, it is not only the only existing study to apply a bottom-up approach to estimate and compare the WF of different cattle breeds finished in a feedlot, but it also considers the VA and thus the WUE of each breed to create value. Although the differences in the WF and VA between the breeds in the feedlot fed according to each breed's PMFP were relative small, it showed that differences exist between breeds. It is recommended that the results of this study are compared with a water footprint assessment (WFA) of a feedlot that uses the conventional, predetermined feeding period to determine whether the PMFP followed in this study improves the WF and VA of the feedlot and whether there are larger differences among breeds when a predetermined feeding period is used.

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CHAPTER 5

THE WATER-ECONOMY NEXUS OF PROCESSING BEEF

"Water is the driving force of all nature."

- Leonardo da Vinci (1452 – 1519) -

5.1 BACKGROUND AND INTRODUCTION

Direct water use and wastewater discharge have always been the measure of total abattoir water consumption. Hoekstra's (2003) water footprint (WF) approach, which developed into the water footprint assessment (WFA) concept (Hoekstra *et al*., 2011), however, also incorporates the indirect water use of a product, process, or business, and therefore reports the total water use in terms of blue, green, and grey WFs. Since the introduction of the WFA, much research has been conducted on the livestock sector to estimate the total WF of farm animal products. The research showed that the production of meat has one of the highest WFs and consumers have been urged to consume less red meat (Mekonnen & Hoekstra, 2012) or to maintain the same consumption patterns but to select products with a lower WF from other regions or production systems (Hoekstra, 2010). However, the WF information of different products, or the same type of product from different origins, does not exist in many instances (Hoekstra, 2010).

The information that exists on beef is mostly estimated from country-level data based on beef in general, or on beef from different production systems (grazing, mixed, or industrial) (Chapagain & Hoekstra, 2003; Mekonnen & Hoekstra, 2010a; Ercin *et al*., 2012; Hoekstra, 2012; Mekonnen & Hoekstra, 2012; Ridoutt *et al*., 2012; Gerbens-Leenes *et al*., 2013; Bosire *et al*., 2015). The existing published WFs were also largely based on the feed, drinking, and service WFs of beef production, with little attention paid to the processing WF of beef. This means that very little information exists on the contribution of the various links in the value chain to the WF of beef. Another factor that must be kept in mind is the allocation of the WF to the different products and by-products of beef production. Although Chapagain and Hoekstra (2003) allocated the WF of a beef carcass to the different products according to the value factor (VF) of each, they used a VF of 1 for all. In practice, different cuts of beef are sold at different prices, while the relative size (weight) of each cut also varies. In order to estimate the WF of beef, the various links of the value chain, of which processing (slaughtering and deboning) is one, should be accounted for, while the WF of beef should be allocated to the VF of the various cuts.

The objective of this chapter is to estimate the water-economy nexus of different cattle breeds at the abattoir and deboning plant by estimating the processing WF, value added (VA), and economic water consumption (EWC) of each breed in terms of various cuts and by-products of beef. The WF and VA of the abattoir and processing plant vary between the breeds, as the carcass weight (CW), bone-meat ratios, and value of the by-products differ between the breeds. In order to achieve the objective, the WF per unit of VA (WF_{VA}), as the water use efficiency (WUE) indicator in terms of economic contribution, was estimated to determine whether it differs between cattle breeds. The WF for various cuts of beef and the by-products from the different breeds, as well as the total VA by each breed type, must thus be calculated.

5.1.1 Direct water use in abattoirs

The water intake and wastewater discharge of abattoirs have been a concern for many years. The Water Research Commission (WRC) of South Africa hosted a project during 1989 to determine the water and wastewater management in the red meat industry and found that the abattoir sector consumed approximately 5.8 million m^3 water per year (Steffen, Robertson and Kirsten Inc., 1989). Steffen, Robertson and Kirsten Inc. (1989) found that abattoirs utilised between 1.36 m^3 and 2.04 m^3 freshwater per water-related cattle unit (wrcu). The wastewater from the abattoirs was found to be 80-85% of the water intake, with pollutant concentration levels for chemical oxygen demand (COD) of between 5.2 and 8.5 kg COD/wrcu and for suspended solids (SS) of between 1.4 and 1.6 kg SS/wrcu. The recommendations of the study were for abattoirs to reduce their water intake to 1.1 m^3/wrcu and their pollutant concentrations to 5 kg COD/wrcu and 1 kg SS/wrcu.

The target water intake of 1.1 m^3/wrcu as set by Steffen, Robertson and Kirsten Inc. in 1989 may sound like a vast amount, but when one takes the total working flow of an abattoir, as set out in Figure 5.1, into consideration, it becomes clear how many different areas there are that need water and which must be cleaned on a regular basis.

Abattoirs require good-quality water due to the processing of material destined for human consumption, while the effluent from these facilities significantly contributes to the organic load of raw sewage treated at sewage treatment plants.

Red meat abattoirs' water intake is regulated by the Water Act (No. 54 of 1956), as amended by the Water Amendment Act (No. 96 of 1984) and by-laws issued by local authorities. According to the legal aspects, a water supply of at least 900 litres per slaughter unit must be available under pressure and protected against contamination. The water must be clean, potable, and free of suspended material and substances that could pose a health risk. The water must also be subjected to flocculation, filtration, chlorination, or other treatments to ensure that no coliform organisms are present.

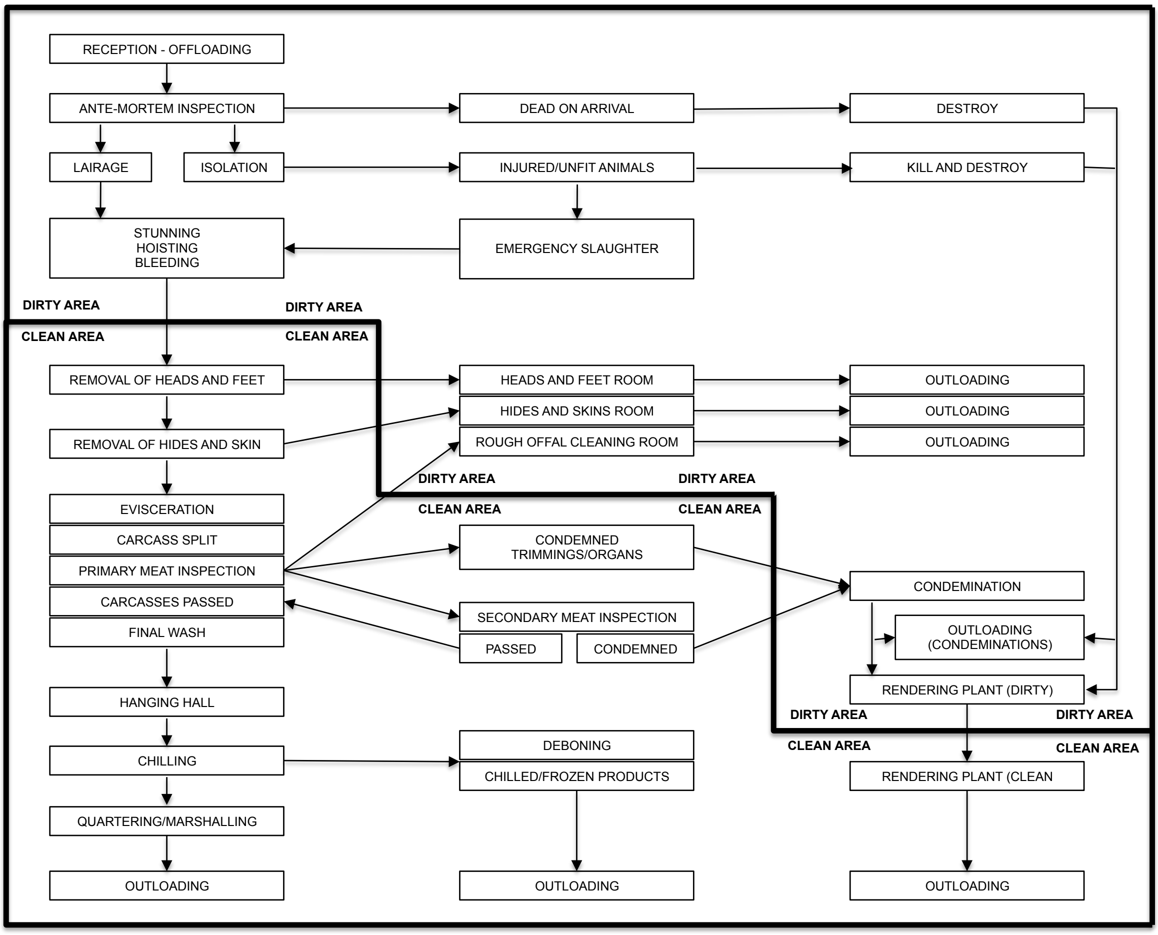

Figure 5.1: General flow diagram of high-throughput red meat abattoir operations
Source: Adopted from the Department of Agriculture and Rural Development (DARD, 2009)

An adequate supply of hot water at 60 °C and of cold water under pressure must be available during working hours in convenient places. The Director: Veterinary Services may also lay down standards and conditions from time to time that the intake water must meet (DARD, 2009). The average water consumption at red meat abattoirs can be divided into the following (DARD, 2009):

• Lairage	10%
• Slaughter and dress	20%
• Offal processing	25%
• Warm water	25%
• Steam	5%
• Chilling	8%
• Ablution and laundry	7%

The volume of effluent is approximately 82% of the total water intake and typically contains blood, pieces of meat, fat and gut, constant urine, and manure in suspension (Steffen, Robertson and Kirsten Inc., 1989). These waste materials contribute to the very high organic load of the effluent, and the wastewater quality from red meat abattoirs could be summarised as: COD 2 380 to

8 942 mg/l; total suspended solids (TSS) 189 to 3 330 mg/l; and pH 5.7 to 8.4 (Department of Water Affairs and Forestry [DWAF], 2001). These effluents, after some pre-treatment and before being discharged to the municipal sewer, must comply with municipal by-laws, which could be described as: COD ≤ 3 000 to 5 000 mg/l; TSS ≤ 500 mg/l and pH 6 to 10 (DWAF, 2001).

5.2 PROCEDURES AND DATA

5.2.1 Procedure to determine the processing water footprint of beef

In order to estimate the WF for an abattoir and deboning plant, Hoekstra *et al.*'s (2011) calculation framework was followed. The distinction between the blue WF (consumption of water from surface and groundwater), green WF (evapotranspiration [ET] of rainwater), and the grey WF (the volume of freshwater required to assimilate the pollution load to ambient water quality) is useful for this research as abattoirs only have blue and grey WFs.

Water in abattoirs is almost exclusively used for cleaning and no water is incorporated into the product. Approximately 82% of the total water intake in abattoirs is discharged through the municipal sewer system, while the rest (18%) is lost due to evaporation (Steffen, Robertson and Kirsten Inc., 1989). The blue WF, as defined by Hoekstra *et al.* (2011), in the case of abattoirs, comprises 18% evaporation. The grey WF, as defined by Franke *et al.* (2013), is calculated as:

$$GWF = \frac{L}{L_{crit}} \times R \qquad [5.1]$$

Where GWF is the grey WF in volume/time, L is the pollutant load entering a water body in mass/time, L_{crit} is the critical pollutant load in mass/time, and R is the runoff of the water body in volume/time.

The critical pollutant load (L_{crit}), as the load of pollutants that will fully consume the assimilation capacity of the receiving water body, can be calculated as (Franke *et al.*, 2013):

$$L_{crit} = R \times (C_{max} - C_{nat}) \qquad [5.2]$$

Where, C_{max} is the maximum acceptable concentration of the pollutant in mass/volume, and C_{nat} is the natural background concentration of the pollutant in mass/volume.

The pollutant load that enters a water body (L) is calculated in different ways depending on whether it stems from point or different sources of water pollution. In the case of an abattoir, it is point source pollution and is therefore calculated as (Franke *et al.*, 2013):

$$L = Effl \times C_{effl} - Abstr \times C_{act} \tag{5.3}$$

> Where $Effl$ is the effluent volume in volume/time, C_{effl} is the concentration of the pollutant in the effluent in mass/volume, $Abstr$ is the water volume of the abstraction in volume/time, and C_{act} is the concentration of the pollutant in the intake water in mass/volume.

By inserting equations [5.2] and [5.3] into equation [5.1], the grey WF (GWF) of an abattoir is calculated as:

$$GWF = \frac{Effl \times C_{effl} - Abstr \times C_{act}}{C_{max} - C_{nat}} \tag{5.4}$$

The grey WF for each contaminant of concern must be calculated separately, after which the largest grey WF of the separate grey WFs will be taken as the overall grey WF (Franke *et al.*, 2013).

Although the procedure to calculate the WF, as explained above, can be used as it is for an abattoir (as a business) or per cattle unit (CU) slaughtered (as a product), it is more difficult to calculate the WF of individual cuts or parts of the carcass. As the price (R/kg) of the different cuts and parts differs, while the relative weight of each cut or part also differs between animals, the WF of an individual cut or part of the carcass should be calculated according to its weight or economic value. Chapagain and Hoekstra (2003) used product fractions (factor of the weight of a part derived from the weight of a live animal) and VF (factor of the value of a part derived from the value of a live animal) to allocate the WF to the so-called primary bovine products, i.e. the carcass, offal, semen, and skin. The carcass, for example, was then further broken down to so-called secondary products such as carcass frozen, bovine cuts (bone in), and meat cured. The VF allocated to each of these secondary products was taken as “1”, as, according to Chapagain and Hoekstra (2003), these products are mutually exclusive and there is thus only one product at a time. This is, however, not true in the industry, as most of the carcasses that undergo processing end up in various cuts with different weights and prices. The VF of each of these cuts will thus vary according to the relative size and build of the animal the carcass stems from.

In order to calculate the WF of a kilogram of boneless beef from a respective cut according to its VF, the VF of the cut must first be determined. The slaughter process starts with an animal of a certain live weight (LW), which is then divided into the CW, by-products weight (BPW) (head, skin, and offal), as well as the lost weight of body fluids (BFW), which is the weight of the blood, urine, stomach contents, and other fluids.

$$LW = CW + BPW + BFW \qquad [5.5]$$

The CW and BPW are then multiplied by their respective prices (P) in order to determine the value (V) of the carcass and by-products.

$$V_{C\ or\ BP} = W_{C\ or\ BP} \times P_{C\ or\ BP} \qquad [5.6]$$

After adding the value of the carcass and by-products to determine the total value (TV) of the carcass, the TV can be used to calculate the VF of the carcass and by-products respectively by expressing the value of the carcass or by-products as a factor of the TV.

$$VF_{C\ or\ BP} = \frac{V_{C\ or\ BP}}{TV} \qquad [5.7]$$

The WF for the carcass and by-products can now be allocated according to the VF of each. However, since the carcass consists of different cuts, each with its own price, the VF of the different cuts in accordance with the value of the carcass should be calculated:

$$VF_{Cut1} = \frac{V_{Cut1}}{V_c} \qquad [5.8]$$

Where the V for the specific cut (cut1 or cut2) is calculated as:

$$V_{Cut1} = W_{Cut1} \times P_{Cut1} \qquad [5.9]$$

The WF per kilogram of the individual cut can then be allocated according to the VF of the cut:

$$WF_{Cut1} = \frac{WF_{Carcass} \times VF_{Cut1}}{Weight_{Cut1}} \qquad [5.10]$$

Where the processing WF of the carcass is derived from the processing WF ($WF_{Processing}$) per animal slaughtered:

$$WF_C = WF_{Processing} \times VF_C \qquad [5.11]$$

5.2.2 Procedure to determine the economic water consumption of processing beef

An abattoir and deboning plant, in general, does not realise any profits on the carcass and deboned cuts as it sells the cuts for more or less the same price as the carcass was bought for. The gross margin, as the difference between the buying and selling price of a carcass, in Table 5.1 indicates that approximately half of the carcasses are sold at a small positive margin, while the other half is sold at a small negative margin.

Table 5.1: Gross margin of the deboned carcasses for the different breeds

Breed	Carcass weight (kg/carcass)	Carcass buying Price (R/carcass)	Deboned carcass selling Price (R/carcass)	Gross margin (R/carcass)
Afrikaner	232.8	R9 213.75	R8 464.09	-R749.66
Brahman	244.5	R8 153.95	R8 154.73	R0.78
Angus	279.6	R10 270.75	R10 282.68	R11.93
Simbra	288.3	R11 076.10	R9 975.59	-R1 100.51
Bonsmara	314.6	R9 762.55	R10 954.04	R1 191.49
Limousin	319.0	R12 246.15	R11 497.84	-R748.31
Simmentaler	347.2	R11 169.55	R11 959.29	R789.74

Source: Compiled from Serfontein (2015) and own calculations

The reason for not being able to sell the various deboned cuts for exactly the same price as what was paid for the carcass can be found in the different deboning style of animals, and depending on what the market requires.

The total gross margin realised by the abattoir and deboning plant thus basically stems solely from the by-products (head, offal, and hide) that are sold. The profit margin of the abattoir thus also depends on the value of the by-products. Higher-value by-products per animal slaughtered will thus increase profits (or decrease losses) and contribute to the economic sustainability of the enterprise. The VA per CU (VA_{CU}) by the abattoir and deboning plant to the economy is thus equal to value of the by-products (V_{BP}):

$$VA_{CU} = V_{BP} \tag{5.12}$$

The WF per unit of VA (WF_{VA}) is then calculated by dividing the WF of a CU (WF_{CU}) by the VA:

$$WF_{VA} = \frac{WF_{CU}}{VA_{CU}} \tag{5.13}$$

5.2.3 Data

The data for the study were obtained from the Sernick abattoir situated in Kroonstad in the Free State province of South Africa. The abattoir has a slaughtering capacity of 230 head of cattle per day and also has a deboning plant. Monthly municipal water meter readings and the monthly slaughter numbers were used to determine Sernick's direct water use over the course of one year (see Figure 5.2). Sernick used 25 030 m^3 of municipal water over the course of one year (1 July

2015 – 30 June 2016) in order to slaughter and process 51 703 CUs. The average direct water use per unit of cattle thus amounted to 484 litres.

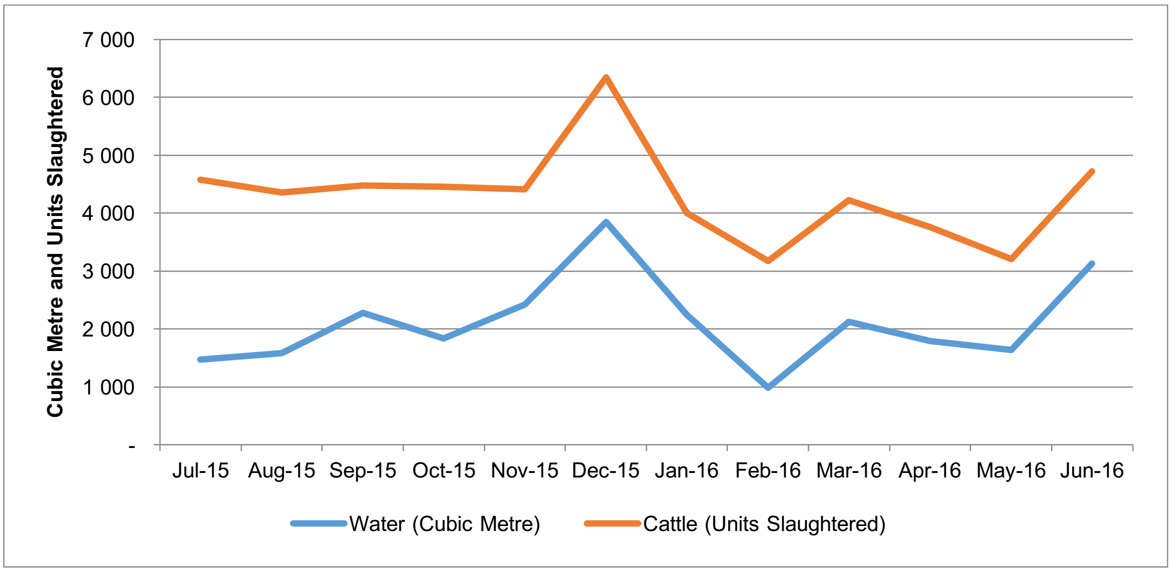

Figure 5.2: Direct water intake and cattle units slaughtered at Sernick
Source: Sernick (2016)

Water samples of the effluent discharged into the municipal sewer and water from the municipality were tested for quality purposes. The test results are presented in Tables 5.2 and 5.3. The test report for the effluent in Table 5.2 contains all the test results of the analysis that the municipality requires from abattoirs. The most important test here is for COD, as the result is directly used to determine the discharge tariff for effluent through the municipal sewer system, and it is also the pollutant with the highest concentration and which results in the highest grey WF. From Table 5.3 it is evident that the water received from the municipality is of good quality as it complies with all the specifications, except for turbidity. According to the test reports (see Tables 5.2 and 5.3), the concentration of COD in the effluent (C_{effl}) is 924 mg/litre, while the concentration of pollutants in the municipal intake water (C_{act}) is equal to zero.

Table 5.2: Test report of effluent water sample

Analysis	Unit	Result
Faecal coliforms	*Cfu*/100ml	55
BOD as total O_2	mg/l	132
COD as total O_2	mg/l	924

Source: MLS Laboratory Services (2016)

Kroonstad is situated in the Rhenoster/Vals region of the Middle Vaal Water Management Area that forms part of the greater Vaal River Catchment, which is in turn part of the greater Orange River Catchment (DWAF, 2003). The Vaal River water quality indicators and availability of water were thus used for the purposes of this study. According to Rand Water (2016), the maximum acceptable concentration (C_{max}) of COD for the Vaal River Catchment is 20 mg/litre, while the natural background concentration (C_{nat}) of the catchment was 15 mg/litre for the period 1 July 2015 to 30 June 2016.

Table 5.3: Test report of municipal water sample

Test type	Reporting units	Results	Specification – maximum limit	Uncertainty of measurement %	Complies to specification
pH	pH	8.44	5 – 9.5	4.3	Yes
Electrical conductivity	mS/m	15.4	<170	9.55	Yes
Total dissolved solids	mg/l	122	<1200	9.42	Yes
Chlorine (Cl)	mg/l	3.35	<300	9.89	Yes
Sulphate (SO_4)	mg/l	5.99	<500	9.41	Yes
Nitrate (NO_3) as N	mg/l	0.388	<11	10.25	Yes
Nitrite (NO_2) as N	mg/l	0.021	<0.9	7.06	Yes
Ammonium (NH_4) as N	mg/l	0.556	<1.5	8.43	Yes
Fluoride (F)	mg/l	<0.213	<1.5	9.86	Yes
Sodium (Na)	mg/l	4.49	<200	12.03	Yes
Aluminium (Al)	mg/l	<0.002	<0.3	6.14	Yes
Iron (Fe)	mg/l	<0.004	<0.3	5.83	Yes
Manganese (Mn)	mg/l	<0.002	<0.1	5.79	Yes
Total chromium (Cr)	mg/l	<0.003	<0.05	5.67	Yes
Copper (Cu)	mg/l	<0.002	<2	2.99	Yes
Nickel (Ni)	mg/l	<0.002	<0.07	5.35	Yes
Zinc (Zn)	mg/l	<0.002	<5	7.48	Yes
Cobalt (Co)	mg/l	<0.002	<0.5	7.9	Yes
Cadmium (Cd)	mg/l	<0.002	<0.003	6.24	Yes
Lead (Pb)	mg/l	<0.003	<0.01	6.74	Yes
Turbidity	NTU	6.39	<1	7.63	No
Free chlorine (Cl_2)	mg/l	0.2	<5	-	Yes
Colour	Hazen	<5	<15	-	Yes
Free cyanide (CN)	mg/l	<0.01	-	-	-
Phenol	mg/l	0.022	<0.01	-	Yes
Total organic carbon	mg/l	2.21	<10	-	Yes
Taste	FTN	<5	<5	-	Yes
Odour	TON	<5	<5	-	Yes
Arsenic (As)	mg/l	<0.001	<0.01	10.93	Yes
Selenium (Se)	mg/l	<0.005	<0.01	11.42	Yes
Mercury (Hg)	mg/l	<0.007	0.006	-	Yes
Dissolved Uranium (U)	mg/l	<0.001	<0.015	10.98	Yes
Vanadium (V)	mg/l	<0.001	<0.2	-	Yes
Antimony (Sb)	mg/l	<0.001	0.02	-	Yes
Trihalomethane (THM)	µg/l	13	-	-	-
Dibromochloromethane	µg/l	<2	<100	-	Yes
Bromodichloromenthane	µg/l	<2	<60	-	Yes
Monochloramine	mg/l	<0.1	-	-	-
Chloroform	µg/l	12	<300	-	Yes
Bromoform	µg/l	<2	<100	-	Yes

Source: MLS Laboratory Services (2016)

5.3 RESULTS

5.3.1 The processing water footprint of different cattle breeds

The average direct water intake per CU slaughtered at Sernick amounted to 484 litres for the year 2015/2016. According to Steffen, Robertson and Kirsten Inc. (1989), 18% of the direct water evaporates, while the remaining 82% ends up as effluent in the sewer system. The direct water use for processing was thus divided into a blue WF of 87.12 litres/CU slaughtered, while a grey WF was estimated for the remainder of the 396.88 litres. The COD concentration for a grey WF should be calculated according to the COD concentration. The grey WF is calculated by applying equation [5.4] and inserting the indicators as obtained from the data. The COD concentrations resulted in the highest processing grey WF and was equal to 73 343 litres/CU slaughtered.

The total processing WF per slaughtered cattle unit (SCU) is thus equal to 73 430 litres. Since the profit-maximising feeding periods (PMFPs) differ between breeds and result in different dressing percentages, CW, and muscle-to-bone ratios, it is necessary to allocate the processing WF per CU according to the VF of the by-products, carcasses, and cuts of the different breeds to determine whether some breeds utilise less processing water per kilogram of boneless beef than others.

The processing WFs of the seven different cattle breeds are presented in Table 5.4, with the relationship between their respective processing WFs and their CW presented in Figure 5.3.

The processing WF per CU (WF/CU) is the same for all the breeds. Although the R/kg price of the different breeds' carcasses and by-products is the same, the different relationships between the weight of the carcass (W_c) and by-products' weight (dressing percentage) caused the carcass VF (VF_c) and by-products VF (VF_{BP}) to differ slightly and thus also the processing WF per carcass (WF/carcass). The processing WF/kg of the carcass, however, differed greatly between the different breeds and ranged from 280.50 litres/kg (for the Afrikaner with a CW of 232.97 kg) to 187.45 litres/kg (for the Simmentaler with a CW of 349.89). It is also evident from Figure 5.3, which shows the relationship between the CW and processing WF per kilogram of a carcass, that there is a strong negative relationship between the CW and TWF per kilogram of carcass. Lighter carcasses thus have a higher processing WF than heavier carcasses.

It is clear from Table 5.4 that the processing WF per kilogram of boneless beef from individual cuts did not only vary between the different breeds, as was the case of the carcasses, but also between cuts due to their different VFs. The three cuts that were used in the analysis can be classified as a high-value cut (rib eye @ R113.64/kg), medium-value cut (topside @ R45.09/kg), and a low-value cut (flank @ R34.05/kg) in relation to the carcass price of R35.00/kg.

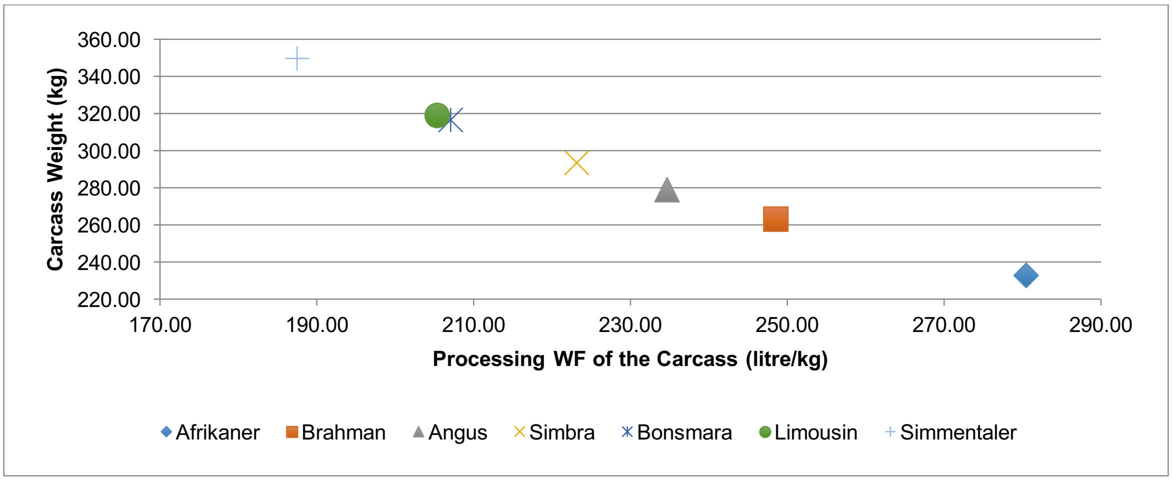

Figure 5.3: Relationship between the carcass weight and processing water footprint of the different breeds
Source: Serfontein (2015) and own calculations

Table 5.4: Processing water footprints of different cattle breeds

		Brahman	Afrikaner	Simbra	Bons-mara	Angus	Simmen-taler	Limousin
Processing WF/CU								
BWF	Litre/CU	87.12	87.12	87.12	87.12	87.12	87.12	87.12
GWF	Litre/CU	73 343	73 343	73 343	73 343	73 343	73 343	73 343
TWF	Litre/CU	**73 430**	**73 430**	**73 430**	**73 430**	**73 430**	**73 430**	**73 430**
Processing WF/by-products								
W_{BP}	kg	**97.93**	**86.66**	**109.16**	**117.72**	**103.76**	**130.16**	**118.72**
VF_{BP}		0.109	0.110	0.108	0.108	0.108	0.107	0.107
BWF_{BP}	Litre/BP	9.4	9.5	9.4	9.4	9.5	9.3	9.4
GWF_{BP}	Litre/BP	7 990	8 072	7 925	7 884	7 955	7 834	7 880
TWF_{BP}	Litre/BP	**8 000**	**8 083**	**7 935**	**7 894**	**7 965**	**7 843**	**7 889**
TWF/KG_{BP}	Litre/kg	**81.7**	**93.3**	**72.7**	**67.1**	**76.8**	**60.3**	**66.5**
Processing WF/carcass								
W_c	kg	263.25	232.97	293.45	316.46	278.93	349.89	319.13
VF_c		0.891	0.890	0.892	0.892	0.892	0.893	0.893
BWF_c	Litre/carcass	77.6	77.6	77.7	77.8	77.7	77.8	77.8
GWF_c	Litre/carcass	65 352	65 270	65 417	65 459	65 388	65 509	65 463
TWF_c	Litre/carcass	**65 430**	**65 348**	**65 495**	**65 536**	**65 465**	**65 587**	**65 541**
TWF/KG_c	Litre/kg	**248.6**	**280.5**	**223.2**	**207.1**	**234.7**	**187.5**	**205.4**
Processing WF/kg rib eye								
$W_{\text{Rib eye}}$	kg	2.90	3.03	3.52	4.11	3.91	3.85	4.47
$VF_{\text{Rib eye}}$		0.036	0.042	0.039	0.042	0.045	0.036	0.045
$BWF_{\text{Rib eye}}$	Litre/kg	0.957	1.080	0.860	0.798	0.904	0.722	0.791
$GWF_{\text{Rib eye}}$	Litre/kg	806.01	909.63	723.78	671.58	761.11	607.88	666.00
$TWF_{\text{Rib eye}}$	Litre/kg	**806.97**	**910.71**	**724.64**	**672.38**	**762.02**	**608.60**	**666.80**
Processing WF/kg topside								
W_{Topside}	kg	15.01	12.58	15.55	16.14	14.23	17.49	18.83
VF_{Topside}		0.073	0.070	0.068	0.066	0.066	0.064	0.076
BWF_{Topside}	Litre/kg	0.380	0.429	0.341	0.317	0.359	0.287	0.314
GWF_{Topside}	Litre/kg	319.82	360.94	287.20	266.48	302.01	241.21	264.27
TWF_{Topside}	Litre/kg	**320.20**	**361.37**	**287.54**	**266.80**	**302.37**	**241.49**	**264.58**
Processing WF/kg flank								
W_{Flank}	kg	12.11	10.25	11.15	12.97	12.55	12.25	11.81
VF_{Flank}		0.045	0.043	0.037	0.040	0.044	0.034	0.036
BWF_{Flank}	Litre/kg	0.287	0.324	0.258	0.239	0.271	0.216	0.237
GWF_{Flank}	Litre/kg	241.48	272.52	216.84	201.20	228.03	182.12	199.53
TWF_{Flank}	Litre/kg	**241.77**	**272.85**	**217.10**	**201.44**	**228.30**	**182.34**	**199.77**

Source: Serfontein (2015) and own calculations

The relationship between the CW and the processing WF per kilogram of rib eye is presented in Figure 5.4. The relationship in the case of the WF of rib eye is also negative, as it is in the case of the WF for the carcass.

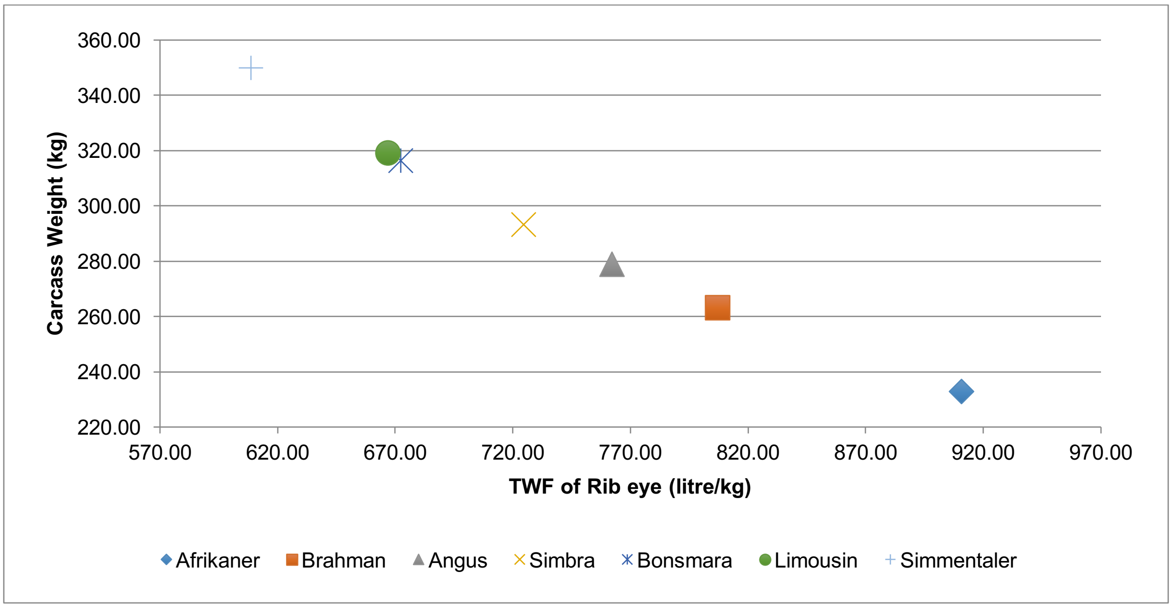

Figure 5.4: Relationship between the carcass weight and processing water footprint of rib eye for the different breeds
Source: Serfontein (2015) and own calculations

Although the processing WF of a kilogram of rib eye is much higher than that of a kilogram of carcass for all the breeds, as the price and VF make it a high-value cut, it is interesting to see that the relationship follows the exact same slope. The reason for this is due to the fact that the R/kg price of the different cuts and carcasses for all the breeds is the same. The percentage difference in the processing WF of a kilogram of carcass or an individual cut between two breeds will thus remain the same.

Table 5.5 provides the percentage difference between the processing WF of the Afrikaner, as the breed with the highest processing WF, and the other breeds. As explained above, these percentages are the same for the differences in the WF per kilogram of the carcasses, as well as for the WF per kilogram of the individual cuts. According to Table 5.5, the Brahman's WF is 11% lower than that of the Afrikaner, while the WF of the Simmentaler is 33% lower than that of the Afrikaner. The correlation between the CW and the WF of the different breeds is -0.9916 and indicates a strong negative relationship between the two factors.

Table 5.5: Differences in the processing water footprints of the breeds in relation to the Afrikaner

Breed	CW (kg)	Differences in the processing WF in relation to the Afrikaner
Afrikaner	232.97	-
Brahman	263.25	-11%
Angus	278.93	-16%
Simbra	293.45	-20%
Bonsmara	316.46	-26%
Limousin	319.13	-27%
Simmentaler	349.89	-33%

Source: Serfontein (2015) and own calculations

The results show that the relative size of an animal at slaughter point has a large effect on the processing WF of the slaughtered animal because the processing WF decreases as the CW of the animal increases. In terms of environmental stewardship, it will be better if an abattoir slaughters larger animals, with a lower processing WF, than smaller animals. The fact of the matter is that the future of the abattoir also relies on its economic sustainability and the influence of the slaughter of larger animals on the margin of and VA by the abattoir should also be addressed.

5.3.2 The economic value added by processing the different cattle breeds

The different cattle breeds, slaughtered at the PMFP for each breed, do not only realise different CWs but also different weights for the by-products. The weight of the by-products, their associated prices, as well as their respective values, are presented in Table 5.6.

Table 5.6: By-products' weights and values for the different breeds

	Brahman	Afrikaner	Simbra	Bons-mara	Angus	Simmen-taler	Limousin
By-products weight							
Head (kg)	12.37	10.95	13.79	14.87	13.11	16.44	15.00
Offal (kg)	48.70	43.10	54.29	58.55	51.60	64.73	59.04
Hide (kg)	36.86	32.62	41.08	44.30	39.05	48.98	44.68
Total weight (kg)	**97.93**	**86.66**	**109.16**	**117.72**	**103.76**	**130.16**	**118.72**
By-products value							
Head @ R100/head	R100.00	R100.00	R100.00	R100.00	R100.00	R100.00	R100.00
Offal @ R9.35/kg	R455.36	R402.98	R507.60	R547.40	R482.48	R605.22	R552.02
Hide @ R15.50/kg	R571.25	R505.54	R636.79	R686.72	R605.28	R759.26	R692.51
Total value	**R1 126.61**	**R1 008.52**	**R1 244.38**	**R1 334.11**	**R1 187.76**	**R1 464.48**	**R1 344.53**

Source: Serfontein (2015) and own calculations

It is evident from Table 5.6 that the Simmentaler, as the breed that realised the heaviest carcass, also realised the heaviest and most valuable range of by-products, while the Afrikaner, on the other hand, realised the lightest and least valuable range of by-products.

When comparing the by-product values of the different breeds (see Table 5.7), it is clear that the Simmentaler provides the abattoir with 45% more income for its by-products than the Afrikaner.

Table 5.7: Differences in the value of the by-products in relation to the Afrikaner

	By-products weight (kg)	By-products value	Differences in value in relation to the Afrikaner
Afrikaner	86.66	R1 008.52	-
Brahman	97.93	R1 126.61	12%
Angus	103.76	R1 187.76	18%
Simbra	109.16	R1 244.38	23%
Bonsmara	117.72	R1 334.11	32%
Limousin	118.72	R1 344.53	33%
Simmentaler	130.16	R1 464.48	45%

Source: Serfontein (2015) and own calculations

Since the slaughtering cost per CU is the same, the 45% higher income from the by-products of the Simmentaler will result in a higher gross margin for the abattoir than in the event where a lighter animal is slaughtered. Since the value of the by-products (V_{BP}) is equal to the economic VA by the abattoir, the VA of the Simmentaler will also be 45% more than that of the Afrikaner. The slaughtering of heavier animals, of the same carcass grade, will thus contribute to the economic prosperity of an abattoir and deboning plant.

5.3.3 The economic water consumption of processing beef

The EWC (WF_{VA}) for processing the seven different cattle breeds is presented in Figure 5.5, together with the CW of each breed.

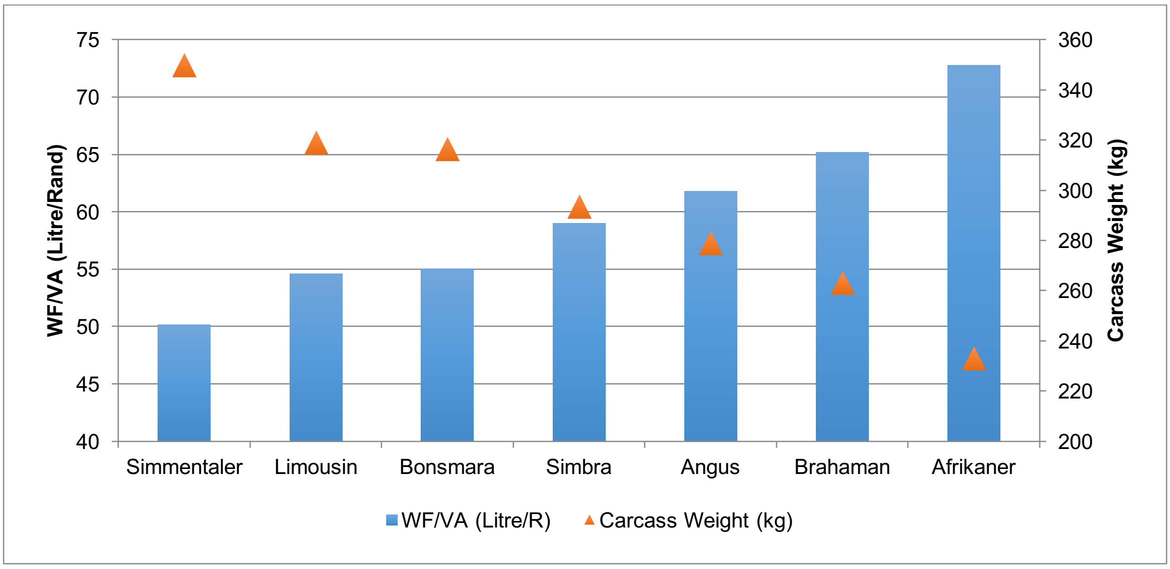

Figure 5.5: Economic water consumption and carcass weights for the different breeds
Source: Serfontein (2015) and own calculations

Figure 5.5 proves that, as in the case of the processing WF per carcass, by-products, and a kilogram of beef, there is a negative relationship between the CWs and the processing WF_{VA}.

The slaughtering of heavier carcasses will result in a lower processing WF for each unit of VA to the economy. The slaughtering of a Simmentaler, with a CW of almost 350 kg, had a total consumptive processing WF of 50 litres/R of VA, while the Afrikaner's consumptive processing WF was almost 73 litres/R for a carcass of 233 kg. The lightest breed thus consumed almost one and a half times more water to add R1 of value than the heaviest breed.

5.3.4 Implications of slaughtering heavier breeds for the abattoir

In order to test the outcomes of the research in practice, a simulation was done with three scenarios; the first scenario (No. 1) was based on the assumption that the Sernick abattoir slaughters the same number of animals as in the data and that the number of CUs from each breed is equal. The second scenario (No. 2) was based on the assumption that only Simmentalers with heavier carcasses are slaughtered but the total amount of meat produced (total CW [TCW]) remains the same as in the first scenario, so less animals are slaughtered in this case. The third scenario (No. 3) was based on the assumption that the abattoir slaughters only Simmentalers but with the same number of CUs than in the past. The outcomes of the three scenarios are presented in Table 5.8.

Table 5.8: Results of the simulation of the three slaughter scenarios

No.	Description	CUs slaughtered	CW (kg)	Total CW (tonne)	By-products income (R/CU)	Total VA (R'000)	TWF ('000 m^3)	WF$_{VA}$ (Litre/R)
1	**Different breeds**	51 703	293.40	15 170	R1 244.34	R64 336	3 797	59.01
2	**Simmentaler (same TCW)**	43 354	349.90	15 170	R1 464.48	R63 492	3 184	50.14
3	**Simmentaler (same CUs)**	51 703	349.90	18 091	R1 464.48	R75 718	3 797	50.14
(2-1)	**Difference**	**-16.15%**	**19.26%**	**0.00%**	**17.69%**	**-1.31%**	**-16.15%**	**-15.03%**
(3-1)	**Difference**	**0.00%**	**19.26%**	**19.26%**	**17.69%**	**17.69%**	**0.00%**	**-15.03%**

Source: Serfontein (2015) and own calculations

The results from the simulation indicate that when the second scenario is used, the number of animals slaughtered will decrease with 16.15%, while the same output in total CW will be realised. The important aspect is that the processing WF of the abattoir will decrease with 16.15% as well, while the WF$_{VA}$ will reduce with 15.03%. The total VA that is generated, however, also decreases but with much less than the other indicators, and the 1.31% decrease in VA will be compensated for by the lower economic cost (labour, capital, and natural resources) of slaughtering 16.15% less or 8 349 animals fewer than in the past.

When one compares the third scenario with the first, the number of CUs that are slaughtered remains the same but the total CW produced increases with 19.26%. Although the processing WFs for the two scenarios are the same, the total VA increases with 17.69%, while the WF$_{VA}$ also decreases with 15.03%, as in the case with the second scenario. The abattoir will, in this case, not reduce its processing WF, as it will remain the same, but it will improve its economic prosperity while at the same time decreasing the WF/CU slaughtered, as well as the WF_{VA}, which indicates that its EWC is improved.

5.4 DISCUSSION

The objective of this chapter was to estimate the water-economy nexus of different cattle breeds at the abattoir and deboning plant by estimating the processing WF, VA, and EWC of each breed in terms of various cuts of beef and by-products.

The results indicated that there is a negative relationship between CW and the processing WF when the different breeds were compared. In terms of the whole carcass, the processing WF/kg of the Simmentaler, as the heaviest breed, was 33% lower than that of the Afrikaner, the lightest breed. In terms of a specific cut of beef, it was found that a kilogram of rib eye from the Simmentaler had a processing WF of 614.57 litres/kg, compared to the 919.91 litres/kg for the rib eye of the Afrikaner.

Heavier animals do not only have lower processing WFs, but in terms of the economic VA of the different breeds it was found that the heaviest animals also realised the most valuable range of by-products and thus added the most value. The abattoir would realise 45% more VA by slaughtering Simmentalers rather than Afrikaners and in the process increase the economic prosperity of the business.

The WF_{VA} showed that due to the lower WF and higher VA of heavier animals, the processing of the Simmentaler had a WF of 50 litres/R of VA, while the Afrikaner's was equal to 73 litres/R. The results of the WF_{VA} show that in the case of an abattoir and deboning plant, both the environmental stewardship and economic prosperity of the business can be improved through the slaughtering of heavier animals.

The analysis of what the implications of slaughtering heavier animals for the abattoir are shows that it may not only reduce the processing WF of the abattoir per CU, but will also improve the economic prosperity of the business. The EWC also improves, as the WF_{VA} decreased with 15.03% and less water is thus required to achieve the same level of economic VA.

Even though this chapter only estimated the processing WF of beef, it contributes to knowledge as it provided a framework for the allocation of the total WF of beef, including primary production and feedlot finishing, according to the VFs of the different cuts of beef. This calculation framework is of the utmost importance to the bottom-up approach to estimate the WF of beef as it provides the necessary detailed data on which to form policy recommendations.

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CHAPTER 6

THE WATER-ECONOMY NEXUS OF BEEF PRODUCED FROM DIFFERENT CATTLE BREEDS

“Water is the key to dealing with the twin challenges of poverty and growth.”

- Sunita Narain (1961 – present) -

6.1 BACKGROUND AND INTRODUCTION

Chapters 3 to 5 estimated the process water footprint (WF), economic value added (VA), and the economic water consumption (EWC) for seven different cattle breeds in terms of a cow-calf production system, feedlot, and abattoir respectively according to a detailed bottom-up analysis. The results of the previous chapters provided valuable new knowledge on the water-economy nexus for the different production and processing stages of different cattle breeds and can be used by producers and processors in their quest to improve the EWC of their enterprises. The ultimate goal of WF research is to inform consumers regarding wise water use. The WF should thus be calculated for the product, produced through the most likely value chain, in the form it is purchased by the end consumer. As such, it is necessary to address the outcomes of these chapters together in order to draw conclusions on the water-economy nexus of different cuts of beef produced from different cattle breeds from a cow-calf production system and finished in a feedlot before being processed.

The objective of this chapter is to analyse different breeds of beef cattle, following the same production method, in terms of their WF and economic VA for different links in the value chain through a bottom-up approach to identify the breed with the best EWC figures in terms of beef production. The results of this chapter do not only provide valuable new knowledge on the WF of beef from different breeds, but also on the EWC of the different cattle breeds. The estimation of the WF for different cuts of beef further provide valuable new knowledge that can assist consumers who want to reduce their overall WF to make more informed decisions on the specific cut of beef that they want to purchase.

6.2 PROCEDURES AND DATA

The total WF of an slaughtered cattle unit (SCU) ($WF_{B\,SCU}$) for a certain breed (B) consists of the sum of the WFs of the weaned calf from the cow-calf production system ($WF_{B\,WCalf}$), the feedlot-finished calf from the feedlot ($WF_{B\,FFCalf}$), and the processing at the abattoir ($WF_{B\,Processing}$), and can be expressed as:

$$WF_{B\,SCU} = WF_{B\,WCalf} + WF_{B\,FFCalf} + WF_{B\,Processing} \qquad [6.1]$$

The $WF_{B\,WCalf}$, $WF_{B\,FFCalf}$, and $WF_{B\,Processing}$ were estimated in Chapters 3 to 5. In order to estimate the WF of beef, the $WF_{B\,SCU}$ should first be allocated according to the value factors (VFs) of the by-products and carcass, before the WF of the carcass is allocated to different cuts of beef according to the VF of each cut. The $WF_{B\,SCU}$ was thus allocated according to equations [5.6] to [5.11] in Chapter 5, with the only difference being that $WF_{Processing}$ is replaced with $WF_{B\,SCU}$ in equation [5.11] and the total WF of the carcass ($WF_{B\,C}$) is now estimated as:

$$WF_{B\,C} = WF_{B\,SCU} \times VF_{B\,C} \qquad [6.2]$$

In order to estimate the EWC for beef (WF_{VA}), the total WF (TWF_B) of all the production steps is divided by the total VA (TVA_B) from all the production steps for each breed (B):

$$WF_{VA\,(B)} = \frac{TWF_B}{TVA_B} \qquad [6.3]$$

Since the VA by each link in the value chain was expressed differently, according to a live weaned calf, a feedlot-finished calf, or slaughter unit, the easiest way to calculate the VA of the different breeds is to multiply the VA of each link in the value chain with the total number of calves weaned from the cow-calf production system:

$$TVA_B = N_{B\,Calves\,or\,CU}(VA_{B\,WCalf} + VA_{B\,FFCalf} + VA_{B\,Processing}) \qquad [6.4]$$

Where TVA_B is the total VA by breed, $N_{B\,Calves\,or\,CU}$ denotes the number of calves or CUs (depending on the value chain link) for the breed, and $VA_{B\,WCalf,FFCalf\,or\,Processing}$ is the VA per unit of the breed for every link in the value chain.

The total WF of the breed (TWF_B) was calculated by multiplying the WF of a cattle unit (CU) at slaughter ($WF_{B\,SCU}$) for each of the breeds with the number of calves or CUs for that breed:

$$TWF_B = WF_{B\,SCU} \times N_{B\,Calves\,or\,CU} \qquad [6.5]$$

6.3 RESULTS

6.3.1 The total water footprint of beef produced from different cattle breeds

The WFs of beef produced from different cattle breeds are presented in Table 6.1. The first section of Table 6.1 provides the WFs of an SCU of each of the seven breeds. Although it is clear that the total WF/SCU differs drastically between the breeds, there is no use comparing these figures as the relative weight of the products (carcass and by-products) derived from a CU of each breed differs. The total WF/SCU is thus only estimated and included in the table to base the rest of the product WFs on.

The second part of Table 6.1 provides the WFs of the by-products and carcasses of the different breeds. In terms of the by-products, the Bonsmara had the smallest WF/kg by-products at 13 539 litres/kg, while the Limousin exhibited the largest WF/kg by-products at 18 756 litres/kg. The differences in the WF/kg by-products for the different breeds were notably large, with the WF of the Angus, Simbra, and Simmentaler being respectively 16%, 18%, and 20% larger than that of the Bonsmara, while the Brahman and Afrikaner revealed differences of 29% and 30% to the Bonsmara. The Limousin's WF/kg by-products is 39% higher than that of the Bonsmara.

The total WF/kg carcass also revealed large differences between the various breeds. The Bonsmara, as in the case with the by-products, had the smallest WF/kg carcass at 41 814 litres/kg, while the Limousin had the largest at 57 962 litres/kg. Although the order of the breeds remains relatively the same as with the by-products, it is interesting to note that the WF/kg carcass of the Afrikaner was a bit lower than the Brahman's, while it was the other way around in the case of the by-products. The percentage difference in WF/kg carcass between the breeds also varied slightly from the differences between the breeds in terms of the by-products. The WF/kg carcass of the Limousin was 39% higher than that of the Bonsmara, while the Brahman, Afrikaner, Simmentaler, Simbra, and Angus had WFs/kg carcass of respectively 27%, 27%, 20%, 18%, and 15% more than the Bonsmara.

The fact that the ranking order and size of the difference in the various breeds' WFs of the by-products and carcasses differed in relation to the Bonsmara is quite interesting. The by-products and carcass WFs were allocated according to the VF of the carcass and by-products, with the product price (R/kg) that was used for all the breeds being the same. The reason for different rankings when the WFs of the by-products and the carcasses are compared stems from the differences in the dressing percentage (weight of the carcass expressed as a percentage of the live animal weight) between the breeds. Using the Afrikaner and Brahman as example, since they switched positions on the ranking, the influence of the dressing percentage is clear. In the case of the by-products, the Afrikaner had a larger WF/kg than the Brahman, while it was the other way around in terms of the WF/kg carcass. The dressing percentage of the Afrikaner was 57.61%, while that of the Brahman was 61.36%. This results in the Afrikaner's VF of the by-products being higher than that of the Brahman and a larger share of the WF is thus allocated to the by-products of the Afrikaner than in the case of the Brahman. It works the other way around in terms of the WF/kg carcass, and a smaller part of the Afrikaner's total WF is thus allocated to the carcass than in the case of the Brahman.

Table 6.1: The water footprint of beef produced from different cattle breeds

	Afrikaner	Brahman	Angus	Bonsmara	Simbra	Simmen-taler	Limou-sin
Total WF/CU (m^3)	**13 906**	**15 714**	**15 029**	**14 826**	**16 199**	**19 716**	**20 724**
Green WF/CU (m^3)	13 693	15 489	14 745	14 577	15 923	19 368	20 394
Blue WF/CU(m^3)	63	70	84	74	84	109	107
Grey WF/CU (m^3)	150	156	200	175	192	239	224
WF/kg by-products (BP)							
W_{BP} (kg)	**86.66**	**97.93**	**103.76**	**117.72**	**109.16**	**130.16**	**118.72**
VF_{BP}	**0.110**	**0.109**	**0.108**	**0.108**	**0.108**	**0.107**	**0.107**
Total WF/kg BP (litre)	**17 662**	**17 483**	**15 710**	**13 539**	**16 036**	**16 180**	**18 756**
Green WF/kg BP (litre)	17 391	17 232	15 413	13 311	15 763	15 894	18 457
Blue WF/kg BP (litre)	81	78	88	68	83	90	96
Grey WF/kg BP (litre)	190	173	209	160	190	196	202
WF/kg carcass (C)							
W_C (kg)	**232.97**	**263.25**	**278.93**	**316.46**	**293.45**	**349.89**	**319.13**
VF_C	**0.890**	**0.891**	**0.892**	**0.892**	**0.892**	**0.893**	**0.893**
Total WF/kg C (litre)	**53 122**	**53 189**	**48 035**	**41 814**	**49 236**	**50 330**	**57 962**
Green WF/kg C (litre)	52 307	52 426	47 128	41 111	48 398	49 441	57 039
Blue WF/kg C (litre)	242	237	269	210	255	279	298
Grey WF/kg C (litre)	572	526	638	493	582	610	625
WF/kg rib eye (RE)							
$W_{Rib\ eye}$ (kg)	**3.03**	**2.90**	**3.91**	**4.11**	**3.52**	**3.85**	**4.47**
$VF_{Rib\ eye}$	**0.042**	**0.036**	**0.045**	**0.042**	**0.039**	**0.036**	**0.045**
Total WF/kg RE (litre)	**172 473**	**172 691**	**155 958**	**135 760**	**159 857**	**163 409**	**188 188**
Green WF/kg RE (litre)	169 828	170 213	153 012	133 477	157 137	160 523	185 190
Blue WF/kg RE (litre)	787	769	875	682	829	906	968
Grey WF/kg RE (litre)	1 858	1 709	2 072	1 601	1 891	1 980	2 030
WF/kg topside (TS)							
$W_{Topside}$ (kg)	**12.58**	**15.01**	**14.23**	**16.14**	**15.55**	**17.49**	**18.83**
$VF_{Topside}$	**0.070**	**0.073**	**0.066**	**0.066**	**0.068**	**0.064**	**0.076**
Total WF/kg TS (litre)	**68 437**	**68 524**	**61 884**	**53 870**	**63 431**	**64 841**	**74 673**
Green WF/kg TS (litre)	67 388	67 540	60 715	52 964	62 352	63 696	73 483
Blue WF/kg TS (litre)	312	305	347	271	329	359	384
Grey WF/kg TS (litre)	737	678	822	635	750	786	806
WF/kg flank (F)							
W_{Flank} (kg)	**10.25**	**12.11**	**12.55**	**12.97**	**11.15**	**12.25**	**11.81**
VF_{Flank}	**0.043**	**0.045**	**0.044**	**0.040**	**0.037**	**0.034**	**0.036**
Total WF/kg F (litre)	**51 673**	**51 738**	**46 725**	**40 674**	**47 893**	**48 957**	**56 381**
Green WF/kg F (litre)	50 881	50 996	45 842	39 990	47 078	48 093	55 483
Blue WF/kg F (litre)	236	231	262	204	248	271	290
Grey WF/kg F (litre)	557	512	621	480	567	593	608

Source: Own calculations

The third section of Table 6.1 provides the total WF/kg beef according to three different cuts of beef (rib eye, topside, and flank). In terms of the WF of beef, there are not only large variations between the breeds, but also between the different cuts of beef from the same breed. Comparing the WFs of the different beef cuts among the breeds, the Bonsmara revealed the smallest WF/kg for al the cuts, while the Limousin had the largest WF/kg for all the cuts. The total beef cut WFs of the Bonsmara for rib eye, topside, and flank were 135 760 litres/kg, 53 870 litres/kg, and 40 674 litres/kg respectively. The beef cut WFs of the Limousin were on average 39% larger at 188 188 litres/kg rib eye, 74 673 litres/kg topside, and 56 381 litres/kg flank.

The rest of the breeds had the same ranking in terms of their beef WFs for each respective cut and although the percentage difference of each breed in relation to the Bonsmara differed slightly for various cuts, the differences were negligibly small. The average percentage differences in the WFs/kg beef of all three cuts for the various breeds in relation to the Bonsmara were 15%, 18%, 20%, 27%, 27%, and 39% respectively for the Angus, Simbra, Simmentaler, Afrikaner, Brahman, and Limousin.

Although these very large variations between the breeds definitely point out the importance of breed selection when one wants to reduce the WF of beef consumption, the variation between the WFs of different beef cuts for the same breed is even larger. Since the WF of each beef cut is calculated according to the VF of the specific cut, in relation to the total value (TV) of the carcass, rib eye, which is considered a high-value cut, is allocated a larger share of the WF than topside (medium-value cut) and flank (low-value cut). In terms of all the breeds, the WF/kg topside is equal to only 40% of the rib eye's WF/kg, while flank's WF/kg only comprises 30% of the WF/kg rib eye. The WF of topside in the case of Bonsmara beef is 81 890 litres/kg smaller than that of rib eye, while the WF of flank is 95 086 litres/kg less than that of rib eye. In the case of the breeds with higher overall beef WFs/kg, the differences are even larger; with a kilogram of Limousin rib eye having 113 515 litres/kg and 131 807 litres/kg larger WFs than topside and flank respectively.

6.3.2 The water-economy nexus of beef produced from different cattle breeds

The EWC of beef for the various breeds is presented in Table 6.2. The EWC was estimated based on the assumption that all the weaned calves moved through the entire value chain.

When the various breeds in Table 6.2 are compared on the total WF/herd over the whole value chain, it is interesting to see that the difference between the breed with the lowest total WF (Limousin) and the breed with the highest total WF (Angus) is only 10%. It thus may seem that the choice of breed only has a marginal impact on the WF of beef production. The WF/herd of the various breeds over the entire value chain is, however, only a total consumptive indicator and is not linked to the production statistics of the breeds. In order to compare the breeds with one another, a WF efficiency indicator should be used, such as the WF_{VA} (EWC), where the WF is expressed per unit of economic VA.

A comparison of the breeds in terms of total VA revealed that the Brahman adds the least value at R6.59 million, while the Angus adds the most at R8.93 million (36% more than the Brahman). The Afrikaner, Limousin, Simmentaler, Simbra, and Bonsmara add respectively 10%, 22%, 22%, and 30% more value throughout the value chain than the Brahman. However, it must be kept in mind that the total amount of product (beef) produced and the amount of production input used to produce this product also vary between the breeds. Since we are interested in the productivity with which water is used, the VA by each breed should thus be expressed in terms of the water needed if one wants to compare the breeds.

Table 6.2: The economic water consumption of beef produced from different cattle breeds

	Afrikaner	**Brahman**	**Angus**	**Bonsmara**	**Simbra**	**Simmen-taler**	**Limousin**
No. of calves	**790**	**688**	**779**	**783**	**688**	**558**	**516**
Total WF (m^3/herd)	**109 88 486**	**10 814 879**	**11 705 332**	**11 608 492**	**11 149 646**	**109 96 831**	**10 689 574**
Green WF (m^3/herd)	10 819 971	10 659 667	11 484 186	11 413 302	10 959 957	10 802 639	10 519 279
Blue WF (m^3/herd)	50 140	48 184	65 659	58 325	57 806	60 966	54 984
Grey WF (m^3/herd)	118 375	107 028	155 486	136 866	131 883	133 227	115 312
Total VA (R/herd)	**R6 722 560**	**R6 587 476**	**R8 929 961**	**R8 542 810**	**R8 036 915**	**R8 010 324**	**R7 223 922**
Cow-calf (R/herd)	R3 235 749	R3 113 548	R3 447 679	R3 816 955	R3 100 451	R2 414 569	R2 434 091
Feedlot (R/herd)	R2 689 903	R2 698 563	R4 557 170	R3 681 289	R4 079 955	R4 778 917	R4 096 315
Abattoir (R/herd)	R796 907	R775 365	R925 111	R1 044 565	R856 509	R816 839	R693 516
Total WF_{VA} (litres/R)	**1 634.57**	**1 641.73**	**1 310.79**	**1 358.86**	**1 387.30**	**1 372.83**	**1 479.75**
Green WF_{VA} (litres/R)	1 609.50	1 618.17	1 286.03	1 336.01	1 363.70	1 348.59	1 456.17
Blue WF_{VA} (litres/R)	7.46	7.31	7.35	6.83	7.19	7.61	7.61
Grey WF_{VA} (litres/R)	17.61	16.25	17.41	16.02	16.41	16.63	15.96

Source: Own calculations

It is interesting to see that the ranking order of the EWC (WF_{VA}) of the different breeds differs from both the ranking order of the total WF of the herds and the ranking of the total VA of the herds. In terms of the WF_{VA}, the Angus had the lowest EWC at 1 311 litres/R, while the Brahman had the highest consumption at 1 642 litres/R. The Angus consumed 4%, 5%, and 6% less water per rand of economic VA than the Bonsmara, Simmentaler, and Simbra respectively. The Limousine consumed 13% more water per rand of economic VA than the Angus, while both the Afrikaner and Brahman consumed 25% more.

6.4 DISCUSSION

The objective of this chapter was to analyse different breeds of beef cattle, following the same production method, regarding their WF and economic VA for different links in the value chain through a bottom-up approach to identify the breed with the best EWC figures in terms of beef production. The results indicated that there were notable differences between the WF of different breeds of cattle, and the total WF/kg carcass ranged between 41 814 litres and 57 962 litres.

Three different cuts of beef were used to estimate the WF/kg of each cut and the WF was allocated according to the VF of each cut. The cut of beef with the smallest WF was found to be Bonsmara flank, with a total WF of 40 674 litres/kg, while the cut of beef with the largest WF was Limousin rib eye at 188 188 litres/kg. The estimated beef WFs of this study are very large, even if the cut and breed with the lowest WF are compared with other studies. Since previous research did not distinguish between different breeds or cuts of beef, for comparison purposes the average WFs of all three cuts over all the breeds were used as the beef WF/kg for this study.

Table 6.3 provides a comparison between the results of this study and the results of previous studies that estimated the WF/kg of beef. It is clear from Table 6.3 that the total WF of beef from this study is much larger than the results of Mekonnen and Hoekstra (2010c) for both South Africa and the rest of the world.

Table 6.3: Comparison of results with other literature

	This study	**Mekonnen and Hoekstra (2010c)**	**Mekonnen and Hoekstra (2010c)**	**Palhares *et al.* (2017)**	**Harding *et al.* (2017)**
Location	Free State, SA	South Africa	Global	Brazil	South Africa
Production system	Mixed	Weighted average	Weighted Average	Industrial	Mixed
Value chain links	Production to processing	Production	Production	Feedlot only	Production to processing
Approach	Bottom-up	Top-down	Top-down	Bottom-up	Top-down
Product	Boneless beef	Boneless beef	Boneless beef	Boneless beef	Carcass
Total WF (l/kg)	**92 764**	**17 387**	**15 415**		
Green WF (l/kg)	91 232	17 050	14 414	5 039	-
Blue WF (l/kg)	470	226	550	769	437
Grey WF (l/kg)	1061	111	451	-	-

When one compares the estimated blue WF of the different studies, the results from this study are much in line with the results of others. While the blue WF of 470 litres/kg of boneless beef in this study is larger than the weighted average for South Africa by Mekonnen and Hoekstra (2010c), it is smaller than the global weighted average by the same authors. The blue WF of this study is also smaller than the blue WF average of beef produced in Brazilian feedlots (Palhares *et al.,* 2017), while it is only 33 litres/kg larger than the blue WF that Harding *et al.* (2017) estimated for beef produced in South Africa.

The grey WF of a kilogram of boneless beef in this study is considerably higher than that of Mekonnen and Hoekstra (2010c) for both South Africa and the rest of the world. The other two studies did not estimate the grey WF. The large difference in the grey WF between this study and the study conducted by Mekonnen and Hoekstra (2010c) can be ascribed to the fact that they used a top-down approach to estimate the WF and basically worked only with production data (meat production and feed consumption). In this study, a bottom-up approach was used and the processing of the beef (slaughter and deboning) was included, and it contributed the largest part of the estimated grey WF footprint.

Since the blue WF of this study relates well to the results from other studies, and even though the grey WF is more than double that of studies by Mekonnen and Hoekstra (2010c), the difference in the total WF is still very large compared to previous research and therefore closer attention should be paid to the green WF. The green WF of this study is basically five times larger than the estimated South African WF calculated by Mekonnen and Hoekstra (2010c). The reason for the large differences may be ascribed to the fact that Mekonnen and Hoekstra (2010c) estimated the consumption of natural grazing from the amount of beef produced by applying estimated feed conversion ratios (FCRs) in a top-down approach. In the case of this research, a more exact analysis was conducted through a bottom-up approach, where the evapotranspiration (ET) of the required natural grazing was estimated with satellite imagery. The green WF from the natural grazing in this study may also be larger due to the fact that the total feed requirement of the herd was used to express the WF of the offtake (weaned calves and culled cows) according to the VF of each, instead of using the feed requirements for the animals that were slaughtered only.

The inclusion of the green WF of natural grazing in the total WF of an animal product remains open for debate. Although it is agreed in this study that it should be included in order to provide a complete view on the WF of beef, it must, on the other hand, be kept in mind that even in the case where no farm animals grazed on the available natural grazing, the green WF of this grazing would have remained the same. If the green WF of the natural grazing is subtracted from the WF calculations, the average total WF of all the breeds and cuts reduces from 92 764 litres/kg to 9 892 litres/kg, while the green WF decreases from 91 232 litres/kg to 8 361 litres/kg.

Even though the green WF of beef in this study increases the total WF of beef to levels much higher than were found in other previous studies, the blue and grey WFs relate well with previous studies when the differences in the calculation frameworks are taken into account. The estimated WF results of this study can thus be used as the WF of beef produced from a cow-calf production system and finished in a feedlot according to the optimal growth curve of each breed before being processed.

6.5 REFERENCES

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CHAPTER 7
SUMMARY, CONCLUSION, AND RECOMMENDATIONS

"Saving our planet, lifting people out of poverty, advancing economic growth… these are one and the same fight. We must connect the dots between climate change, water scarcity, energy shortages, global health, food security and women's empowerment. Solutions to one problem must be solutions for all."

- Ban Ki-moon (1944 – present) -

7.1 INTRODUCTION

This chapter provides a summary of the study in terms of the problem statement, objectives, reviewed literature, and the results from the different chapters. The conclusion is then drawn based on the findings of the study and its contribution to knowledge in the fields of water footprint (WF) research and agricultural economics. The final section is devoted to providing recommendations to industry (producers and processors), consumers, future research, as well as policymakers.

7.2 SUMMARY OF THE STUDY

Based on the large WF of beef, previous researchers had suggested that consumers should consume less beef, or beef with a lower WF from other regions or production systems. The beef industry is very important in terms of the South African economy as large parts of agricultural land are only suitable for extensive cow-calf beef production. Consumers should thus be encouraged rather than discouraged to consume beef, but the environmental stewardship and economic prosperity of the industry should also be ensured and therefore solutions should be offered on how to reduce the WF of beef while maintaining the sector's economic viability. Owing to this problem, the primary objective of this study was to analyse different breeds of beef cattle, following the same production method, in terms of their WF and economic value added (VA) for different links in the value chain through a bottom-up approach to identify the breed with the best economic water consumption (EWC) figures in terms of beef production.

According to the reviewed literature, South Africa can definitely be considered a water-stressed country as the demand for freshwater often exceeds the supply. The high withdrawal-to-availability ratio of freshwater in South Africa highlights the need for the investigation of freshwater use in the country, and one way to do so is through WF research.

The literature revealed many approaches to conduct a water footprint analysis, with the two most popular options being the water footprint assessment (WFA) and the life-cycle assessment (LCA). Although both assessments have their respective advantages and disadvantages, the WFA was selected for this study as it provides a more comprehensive WF of products from the same area. The LCA is recommended to be used when products from different areas, with different water stress levels, are compared.

According to available literature, various authors have estimated the WF of beef in the past. Although these estimated WFs were for different countries and production systems, most of them were calculated through a top-down analysis and very little attention was paid to detailed value chain analyses through a bottom-up approach. The literature proved that the value chain of beef is very complex and that the WF and VA of beef can easily be over- or underestimated when assumptions regarding the value chain are made.

In the past, researchers considered environmental (water) and economic impacts in conjunction, but from the reviewed literature it was found that they reported the outcomes in different ways. While some reported the economic water productivity (EWP) (monetary value / water quantity), others reported the EWC (water quantity / monetary value). Since the WF of products is reported as a consumptive figure, the EWC was selected as the reporting method for the water-economy nexus.

Another problem with researching the WF and economic implications in conjunction was the different ways in which past research estimated the economic implications. In order to find a uniform estimation for the economic implications, the economic VA was used in this study. It can be defined as the total revenue from the produced products minus the cost of the intermediate production inputs, of which WF is not included in the WF of the specific production stage or product, while the definition is based on the assumption that the revenue is more than the cost of the intermediate production inputs.

In order to justify the analyses of different cattle breeds, literature was reviewed on the differences between breeds. The literature indicated that the input requirements (feed), production (growth), and reproduction figures of the various breed types and breeds varied and therefore the WF and VA of the different breeds should vary as well. Seven breeds were chosen for the purpose of this study, namely the Afrikaner, Brahman, Angus, Bonsmara, Simbra, Simmentaler, and Limousin.

Based on the identified gaps in the knowledge from the available literature, three secondary objectives were formulated. The results of these sub-objectives, one for each link in the beef value chain, were then used to achieve the primary objective of the study.

The first secondary objective was to estimate the water-economy nexus of the different cattle breeds on the same extensive farming conditions for a cow-calf enterprise. A simulation model was used to estimate the grazing and supplementary feed requirements of the different breeds and to estimate the production and reproduction data. The estimated WF for the entire herd over the course of one year was allocated to weaned calves and culled cows based on the value factor (VF) of each. The results indicated that the WF per kilogram of weaned calf ranged between 53 375 litres/kg (Bonsmara) and 77 609 litres/kg (Simmentaler), depending on the breed. The VA for the cow-calf production system also differed between the breeds, with the Bonsmara adding the most value at R4.89 million/year and the Simmentaler the least at R3.36 million/year. In terms of the EWC of the different breeds, the Bonsmara required the least water (2 737 litres) to add R1 of value, while the Simmentaler required the most (3 980 litres).

The second secondary objective was to estimate the water-economy nexus of the different cattle breeds in an intensive feedlot at the profit-maximising feeding period (PMFP). Thirty-five weaned calves from each of the seven cattle breeds were fed in a commercial feedlot according to the PMFP (the point where the value of the marginal product [VMP] was equal to the marginal factor cost [MFC]) of each breed before the feedlot-finished calves were slaughtered. The results showed that even though each breed was fed according to its optimal growth curve, there were still substantial differences between the breeds. The Brahman had the smallest WF per kilogram of live weight (LW) added at 6 201 litres/kg, while the Simmentaler had the largest at 6 481 litres/kg LW added. In terms of economic VA, it was necessary to calculate the VA for each breed for a year as the different feeding periods of breeds allowed for a different number of feeding cycles, with 35 animals per cycle, over the course of a year. The Simmentaler added the most value per year (R577 544), while the Afrikaner added the least value (R413 044). The estimation of the EWC of the feedlot-finished calves for the different breeds revealed that the Afrikaner had the highest EWC at 304 litres/R, while the Limousin had the lowest at 270 litres/R.

The third, and last, secondary objective was to estimate the water-economy nexus of the different cattle breeds at the abattoir and deboning plant. The feedlot-finished calves were slaughtered and deboned and the processing WF, VA, and EWC were estimated for the various breeds. The estimated processing WF for each breed was allocated to the by-products and carcass according to the VF of each, before the carcass' processing WF was allocated to three different cuts of beef according to the VF of each in relation to the whole carcass. The results showed that the processing WF varied greatly between different breeds and was negatively correlated with the size (weight) of each breed. The processing WF per kilogram of carcass was the smallest for the Limousin (187.5 litres/kg) and the largest for the Afrikaner (248.6 litres/kg). The differences in the market prices of the different cuts led to large variations in the processing WFs of the different cuts. The processing WF of the beef cuts for the Bonsmara, for example, ranged from 672.38 litres/kg rib eye (high-value cut) to 266.80 litres/kg topside (medium-value cut) and 201.44 litres/kg flank (low-value cut). The VA by processing the different breeds stems solely from the by-products, as the carcass is sold for basically the same price as it was bought for. The Afrikaner added the least value through processing at R1 009/SCU (slaughtered cattle unit), while the Simmentaler added the most value at R1 464/SCU. In terms of the EWC, remarkable differences were also found among the breeds, with the WF_{VA} ranging from 50 litres/R (Simmentaler) to 73 litres/R (Afrikaner).

The results from the three achieved secondary objectives were then used to achieve the primary objective and estimate the WF, VA, and EWC of beef produced from different cattle breeds, following the same production method, for different links in the value chain, through a bottom-up approach in order to identify the breed with the best EWC figures in terms of beef production. According to the results, the Angus had the lowest EWC at 1 311 litres/R, while the Brahman had the highest consumption at 1 642 litres/R. The Angus consumed 4%, 5%, and 6% less water per rand of economic VA than the Bonsmara, Simmentaler, and Simbra respectively. The Limousine consumed 13% more water per rand of economic VA than the Angus, while both the Afrikaner and Brahman consumed 25% more. In terms of the WF of beef produced from the different breeds, taking topside as the example cut, the Bonsmara had the smallest WF (53 870 litres/kg topside) and the Limousin the largest (74 673 litres/kg topside). The Angus was the breed that added the most value throughout the value chain (R8.93 million/year), while the Brahman added the least value (R6.59 million/year).

7.3 CONCLUSION

Considering the primary objective of this research, and taking the results into account, it can be concluded that the primary objective was reached as the EWC of beef produced from different breeds was estimated. The study also contributed to existing knowledge as follows:

- The WF of beef produced from a specific region through the widest utilised production system in South Africa was estimated through a bottom-up approach. Since this information was not available before, it can now be used as a new benchmark for future studies on the WF of beef or as a starting point to conduct a water sustainability analysis.
- The WFs of different cattle breeds following the same production system were estimated for every link of the value chain. Differences between cattle breeds have been neglected in the past and this new information does not only reveal the differences between breeds in terms of the WF, but since it was estimated for the individual value chain links, it provides the needed information that will allow a role player in the value chain to improve the WF of the specific value chain link.
- The economic contribution of the various breeds in terms of VA was estimated for every link of the value chain. Economic prosperity is as important for an agricultural producer as environmental stewardship as the business cannot survive in the long term if either factor is neglected. The estimated economic contribution of the different breeds now provides agricultural producers the opportunity to compare the breeds with one another and to use

the data as a benchmark to determine whether the breed he/she is currently farming with delivers the needed returns.

- The water-economy nexus for beef production was addressed as the quantity of water to produce a unit of VA (EWC) was estimated for each cattle breed. The EWC of the different breeds enables role players in the beef value chain to compare different breeds in terms of their productivity to generate economic value from the amount of freshwater used.
- A calculation framework was supplied to estimate the WF of individual cuts of beef according to the VF of each. The estimated WFs of the different beef cuts, according to the VF of each, provide the necessary information for a consumer to make an informed decision about the WF of the product that is to be purchased.

According to the results, it can be concluded that the Angus should be the breed of choice when the water-economy nexus of beef production is considered and the aim is to optimise the EWC of beef production. However, in the case where the aim is to decrease the WF of beef production, without taking economic implications into consideration, the Bonsmara should be the breed of choice. In a scenario where there is no water stress and the aim is to optimise the economic VA by beef production, the Angus should again be the breed of choice. The results also showed that the WF of different cuts of beef varied and that the low-value cuts had a smaller WF than the high-value cuts.

When one considers the results of the study, it may thus be concluded and recommended that all the cattle in the Edenville region of the Free State province in South Africa should be replaced with Angus cattle, as their EWC is the lowest and the economic VA from the consumed water will be maximised. It may further be recommended to consumers that they should only consume low-value beef cuts in order to decrease their personal WFs. The question, however, is if these conclusions and recommendations are really as simple as that.

The Angus may be the breed of choice in terms of EWC for beef production over the whole value chain, but when the individual links of the value chain are considered, the picture changes. In terms of primary cow-calf production, the EWC of the Bonsmara was the smallest, while the Limousin was the breed of choice for the feedlot. The Simmentaler, on the other hand, had the lowest EWC in terms of processing.

The results from the various value chain links and the results from the total value chain for beef seem to contradict one another, because in terms of EWC, the Angus was not the breed of choice for any one of the individual links but it is for the entire value chain. The reason for this may be in the different approaches to estimate the best breed in terms of each value chain link and in terms of the whole value chain. In terms of the various value chain links, each link was analysed separately and the breed that optimises the EWC in terms of a year's operations was identified.

In terms of the whole value chain, the original number of weaned calves, from the cow-calf enterprise, was taken through the value chain in order to compare the breeds.

The contradiction between the results of the various value chain links and the value chain as a whole, however, also proves that the reporting of WF, VA, and EWC results is not as simple as a weighted total average for country, region, or production system level. For example, when one compares the WF of different products, or the same product from different production systems, calculated with a top-down approach, it is easy to become a victim of the *fallacy of division*. This fallacy asserts that what is true for the whole must be true for any pieces of the whole as well (Kirby & Goodpaster, 2011). In the event where the EWC of the same breeds, for the same region and production system, was estimated through a top-down approach, the conclusion that the Angus should be the breed of choice would have been accepted and the assumption would have been that the Angus would be the best breed for all the links in the value chain. However, the results of the different value chain links showed than one would have been guilty of the fallacy of division by making such an assumption. The principle may also be true for previously published WF results for different products and production systems on country level. One may believe, for example, that since the WF of lamb is lower than the WF of beef for a certain country and production system, the production and consumption of lamb rather than beef in the particular country will reduce the overall WF of the country. However, this may not be true if different regions, their type and availability of natural grazing, and their water stress levels are taken into account.

It can thus be concluded that the WF of any product should rather be assessed in terms of its respective value chain links in order to avoid recommendations from results that were based on assumptions and that may cause one to become a victim of the fallacy of division. The problem with this conclusion is that it defies the primary objective of this study, which was to identify the breed with the best EWC figures in terms of beef production. Although the best breed in terms of beef production, as well as the best breed for each of the value chain links, was identified, the variation in best breeds for the different value chain links and the abovementioned conclusion force the researcher to rather draw conclusions in terms of the various value chain links.

7.3.1 Conclusions on the individual value chain links

The first link in the value chain was the primary cow-calf production system, with large variations (up to 45% difference) found between the breeds. The results indicated that the Bonsmara was the best breed in terms of EWC and the Simmentaler the worst. However, when one considers the results in conjunction with the data that were used to perform the analyses, it can be seen that there was a high negative correlation between the EWC and the weaning percentage of the various breeds. The Bonsmara, with the lowest EWC, had the highest weaning percentage. In terms of primary cow-calf production, it can thus be concluded that although there were notable differences between the breeds in terms of their EWC, these differences were largely based on the differences in the reproduction performance of the breeds. Although it is a known fact that some breeds have better average reproduction figures than others, some producers of the breed with the lowest average reproduction achieve figures comparable to the breed with the best average reproduction figures. In terms of the WF, VA, and EWC for primary cow-calf production, it can be concluded that although there were differences between the various breeds, a cow-calf producer can achieve the same results as the best breed by improving the reproduction figures of his/her breed of choice.

The second analysed value chain link was the feedlot, where the different breeds were fed according to the growth curve of each breed until the PMFP was reached. Although differences in the EWC of the different breeds were identified, the variation between the breeds was relative small (up to a 13% difference). The relatively small variation in the EWC of the different breeds can be ascribed to the fact that each breed was treated (fed) according to its growth curve. If the different breeds were all treated the same and fed for the same duration, the variation between breeds would probably have been larger as some breeds would have been fed for a longer duration than their PMFP and others for a shorter duration. The differences in terms of feedlot performance for different breeds are a known fact, and in terms of the EWC of feedlot cattle, it can be concluded that although there are differences between the breeds, these differences can be reduced by treating each breed according to its growth potential in terms of its feeding period.

The results from the analyses of the last value chain link, the abattoir and deboning plant, showed that there were also notable differences (up to 31% difference) between the various breeds. Since the direct water use for processing a cattle unit (CU) does not depend on the weight of the carcass, there was a negative correlation between the carcass size and the processing WF/kg carcass, while a positive correlation existed between carcass weight (CW) and VA. It was thus found that it is more beneficial in ecological and economical terms to process breeds with larger carcasses than breeds with smaller carcasses. However, in practice it is not always possible as the abattoir must process all the different types of animals that the market supplies. Since the processing grey WF comprises 99.88% of the total processing WF for cattle, it can be concluded that since abattoirs have very little control over the type of animal that the market supplies them with, they should rather focus on the pre-treatment of wastewater before it becomes effluent in order to decrease the WF and EWC of processing beef.

7.3.2 Conclusions on the estimated beef water footprint

Based on the conclusion that was made earlier, which stated that the WF of any product should rather be assessed in terms of its respective value chain links, it will not be wise to compare the total WFs of beef produced from different breeds with one another. This does not mean that some other important conclusions cannot be drawn from the WF of beef estimated in this study.

The estimated average blue WF of beef for this study, across all the breeds and cuts, compared very well with previously published estimated blue WFs for beef, while the average grey WF of this study was slightly higher than that of previous studies, and the estimated green WF of this study was considerably higher than that of previous studies. Based on the good comparison of the blue WF, it can be concluded that the estimated total WF of this study can be used as the WF for beef produced in the Edenville region of the Free State province. The differences in the grey and green WFs in comparison with previous studies are ascribed to the fact that the green WF of the natural grazing for the cow-calf production system was more accurately estimated and more attention was also paid to the grey WF of processing beef. The average total WF of 92 764 litres/kg beef may raise concerns, but if the green WF of the natural grazing was subtracted, the total WF reduced to only 9 892 litres/kg (of which 8 361 litres/kg was the remaining green WF of the other value chain links). Even though the importance of the green WF in a comprehensive WF analysis is agreed upon, the rain that falls on natural pasture will result in evapotranspiration (ET) (green WF), whether it is utilised for grazing or not. It can thus be concluded that the WF of beef produced in the Edenville region of the Free State province is not excessive, even though the total WF may seem high.

The total WF/kg beef for the different cuts of beef provides valuable new knowledge that can be applied to inform consumers regarding the WF of their diets. Although there is truth in the conclusion that a consumer can decrease his/her WF by consuming less valuable cuts of beef, this action should be considered in the larger picture. If consumers take this conclusion to heart, the demand for low-value cuts will increase and the demand for high-value cuts will decrease. The prices for the different cuts will then move closer together and the WF of the previously low-value cuts will increase and the WF for the previously high-value cuts will decrease. The overall WF to produce a CU for slaughter will, however, remain the same, regardless of the WF per kilogram of the individual cut. The same principle can also be applied to the WF differences between a product and its associated by-products that were estimated on the VF of each. Regardless of the VF of the product and its associated by-products, the overall WF to produce the product and by-products will remain the same. It can thus be concluded that although it does make sense in theory to allocate a WF to primary, secondary, and by-products based on the VF of each, the utilisation of the products and by-products, based on their associated VF-determined WF, will not decrease the overall WF of the production process.

7.3.3 Conclusions on the approach followed in this study

The WF approach had previously been applied in numerous studies to estimate the green, blue, and grey WFs of products, processes, businesses, and countries, to name a few. In some previous studies there were also attempts to combine the WF with an economic indicator to provide a more comprehensive picture of both the ecological and economic scenarios in question. Even though all the previous studies that were conducted on these aspects certainly deserve their place in research, there were certain gaps in the knowledge. For example, in the past, very little attention was paid to value chain analysis (VCA) through a bottom-up approach in combination with WF to provide a WF for each link in the value chain. There was also no consensus on which economic indicator to use in conjunction with WF research, which factors should be included in this economic indicator, and if it should be used to estimate EWC or EWP. Another gap in current knowledge is that the consumer cannot make informed decisions regarding WFs when purchasing products as information on the WF of the specific product under consideration often does not exist.

Based on the results of this study, it can be concluded that the approach that was followed assisted in addressing many of the current gaps in the knowledge and can be applied to other regions, products, or production systems. The applied bottom-up approach for the calculation of the WF and economic VA enables one to address each of the value chain links on their own. This is a very important aspect as the various value chain links are not always situated in the same region and the WF results can then be paired with the water availability of the specific region to conduct a sustainability analysis. The separate results further enable one to identify the specific link with problems if it is found that the total WF is too large.

The estimated EWC brings the aspects of ecological stewardship and economic prosperity together. Although this indicator does not necessarily indicate the sustainability of the production process, it does show whether the consumed freshwater contributes to the economy and with how much.

The calculation framework to determine the WF of various cuts of beef according to the VF of each supply type provides much-needed information that can be applied to inform the consumer about the WF of his/her food choices. Even though the purchasing of cuts with a lower WF will not assist in reducing the WF of beef, since the WF of the carcass remains the same, it can be used as a way to make consumers more aware of their personal WFs. This may lead to a scenario where consumers insist on knowing the WF of the products they consume, which may help to keep products of which the water use is not sustainable off the shelves.

7.4 RECOMMENDATIONS

Based on the results and conclusions of this study, recommendations can be made to industry regarding the environmental stewardship and economic prosperity of beef production. The outcomes of the study can also be applied to policy recommendations. In terms of future research, recommendations can be made regarding proposed procedures to analyse the water-economy nexus of products, while recommendations regarding gaps and problems concerning the current research can also be made.

In order to improve the EWC of beef production, it is recommended that primary cow-calf producers evaluate the reproduction performance of the breed that they are farming with. If the reproduction performance, and thus the associated EWC, is not on par with the results of this study, they should either improve the reproduction performance through management and selection practices, or they should switch to a breed with better overall production statistics. It is further recommended that feedlot owners should consider precision feeding practices to address the variability in terms of the growth curve of different breeds by introducing different feeding periods and possibly different feed rations to optimise the feedlot growth performance of each breed and thereby improve the EWC of the feedlot. Although it was proven that it is ecologically and economically more beneficial for the abattoir and deboning plant to process CUs from larger breeds, it is practically not possible. In order to improve the EWC of processing beef, it is recommended that the abattoir should reduce its grey WF through the pre-treatment of wastewater, which will improve the quality of the effluent.

Water remains a scare resource that should be protected and managed by government policies. The problem with current water management in South Africa is the fact that there is basically no, or very little, control over the use of groundwater (from boreholes) in agriculture. Since this water use is not regulated through pricing or other policies, the owners of the land can use as much groundwater as they like for agricultural production purposes. Since the WF includes groundwater in the blue WF, limitations on the WF of a certain product through policy formulation can assist. The formulation of any policy should, however, be based on solid research that supports the policy. Although all WF research may certainly contribute to future policy formulation, it is recommended that no policy regarding the WF of products should be formulated unless detailed information regarding the WFs of the different value chain links is available. It is recommended that the results of this study be applied by policymakers to start developing WF benchmarks for the different value chain links in the beef production value chain. The WF benchmark ranges can then be used to formulate tax incentives for farmers, feedlots, and processors whose WFs are within the ranges, or tax burdens for those whose WF is higher than the set ranges.

In terms of future research, it is recommended that the WF, VA, and EWC of any product be estimated separately for each link in the value chain through a bottom-up approach. The detailed information from the different value chain links will firstly ensure that the fallacy of division does not occur, and, secondly, that possible problem areas in the value chain will be identified and be addressed separately. It is also recommended that when the water-economy nexus of products or processes is analysed in WF research, the EWC should be used rather than the EWP. Moreover, it is recommended that the economic indicator for EWC should be the economic VA, which is equal to the total revenue of a certain value chain link minus the cost of the production factors, of which the WF is not estimated and thus does not form part of the total WF. The WFs of primary, secondary, and by-products that are allocated to the VF of each do help to break down the total WF according to different product types, but the consumption of the lower-value products with smaller WFs, instead of the high-value products with larger WFs, does not improve the total overall WF. Based on this fact, it is proposed that future research considers other approaches to divide the WF among primary, secondary, and by-products, or that the same WF is used for all product variations. In terms of future research, it is lastly recommended that more attention should be paid to methods that will reduce the WF of a certain product. The results of this study lay a good foundation for the EWC of beef produced in the Edenville district of the Free State province, but future research is needed to actively search for ways that will assist in the reduction of the EWC.

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