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The Water Footprint of Primary Cow–Calf Production: A Revised Bottom-Up Approach Applied on Different Breeds of Beef Cattle

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Abstract: Beef has been identified as the farm animal product with the largest total water footprint in previous research, although various concerns have been raised regarding the top-down analyses approach followed in these studies. The objective of this study was to estimate the water footprint of weaned calves and culled cows from seven different beef breeds by applying a revised water footprint analyses approach. A bottom-up approach was followed to provide a true representation of the production system, and the water footprint of the production system, with the estimated water footprint for the system being allocated to weaned calves and culled cows according to the value factor of each. The results show that there are prominent differences between the seven breeds in terms of their respective water footprints per kilogram weaned calf, even though the total water footprint per herd for each breed revealed little variation between the breeds. There is a 45% difference between the breed with the lowest and the breed with the highest water footprint per kg calf. This knowledge can be applied by both water users (primary producers) and policy formulators to assist in the optimal use of fresh water for beef production.

Keywords: water footprint; cow–calf production; cattle breed; bottom-up approach; weaned calves

1. Introduction

In terms of freshwater use, various authors identified beef as the farm animal product with the largest total Water Footprint (WF) [1–3]. Mekonnen and Hoekstra [1], Gerbens-Leenes et al. [2], Bosire et al. [4], and Harding et al. [5], among others, estimated the WF of beef following a top-down approach with country-level data to estimate the WF for different production systems. A top-down approach is a typical input–output approach that is often done at country level, while a bottom-up approach refers to a process analysis that includes more detail of individual production processes [6]. Although a top-down approach is certainly the route to follow to estimate the WF of beef at country level, it cannot be used to make any recommendations within the value chain of beef to improve the WF of the product. When a bottom-up approach is used, each value chain link is investigated individually and accurate estimations can be done on the WF of each link, which can then be used in recommendations.

In addition to the limitation when following a top-down approach, some of the previous studies that estimated the WF of beef also raised other concerns. Mekonnen and Hoekstra [1] and Gerbens-Leenes et al. [2] admitted that there are concerns regarding the assumptions that were made in the country-specific top-down approach as not all the required data were available. Concerns were also raised about the assumptions about animal numbers, the feed intake of the animals, and the composition of the feed. The concerns were further specifically about the distribution of the assumed data across production systems, especially in the case of the Organization for Economic Co-operation and Development (OECD) and developing countries.

Although not mentioned by authors such as Mekonnen and Hoekstra [1], a second concern, especially in developing countries, is the cattle of communal and smallholder farmers. These animals are often not included in the formal animal number statistics of a country, while some of the offtake (carcasses) do enter the formal market. Using these statistics may cause the offtake rate in relation to the livestock numbers to be higher than what it actually was. This would result in a lower estimated WF than what it actually should have been.

The third concern is the calculation framework for the WF of beef. According to Mekonnen and Hoekstra [1,7], the WF of beef, over the lifetime of the animal (m^3/animal), is expressed as:

$$WF_{Animal} = WF_{feed} + WF_{drink} + WF_{service} \tag{1}$$

where, WF_{feed}, WF_{drink}, and $WF_{service}$ represent the total WF related to feed, drinking water, and service water, respectively, for the specific animal. Although this is certainly the route to follow when one wants to calculate the WF of a single animal over its lifetime, the same calculation framework cannot be used to calculate the WF of beef. When one considers the beef value chain, the first link in the value chain is the cow–calf producer that produces weaned calves. The problem with the WF over the lifetime of the animal calculation framework occurs especially at this first link in the value chain. The producer has to keep an entire herd of cattle consisting of cows, young heifers, two-year-old heifers, and bulls, which all require feed, drinking water, and service water, in order to wean a certain number of calves and slaughter a certain number of culled cows. The total yearly WF of the herd should thus be divided by the offtake of the herd, in terms of weaned calves and culled cows, as the first step in the WF calculation for beef.

According to Menendez et al. [8], the problem with the current assessment methods of water use is the fact that they are static and make the meaningful assessment of livestock water use difficult as they are poorly adaptable to understand future scenarios of water use and requirements. It is proposed that a dynamic model should rather be used that can incorporate future changes in production.

In addition to the above-mentioned concerns, an interesting observation made from previous studies on the WF of beef can be made. Even though Mekonnen and Hoekstra [1,7], Hoekstra [9], Ridoutt et al. [10], Gerbens-Leenes et al. [2], and Bosire et al. [4] all stated the feed that the cattle (animals) consume contributes the largest share of the WF of beef (meat), and that the feed conversion ratio (FCR) or feed efficiency (kilogram feed required per kilogram live weight gained) is an important factor to consider in the total WF of beef, none of them recommended an investigation into the WF of different breeds of beef cattle. The fact that the FCR of beef cattle differs between breeds, as well as within a particular 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 raise or when the selection criteria for the breed are determined [11–15]. Except for the difference in the FCR between cattle breeds, other biological traits, e.g., cow productivity, also differ between breeds and will ultimately affect the breed's freshwater consumption and must therefore be investigated.

The concerns related to the approach that was followed, the calculation framework that was employed, and also the assumptions that may have led to underestimating the water footprint of beef raises questions about the accuracy of some of the previous reported water footprints. Previous research that made use of country level data in a top-down analysis were also not able to report on or make recommendations about different value chain links as the analyses were done for the value chain as a whole without considering the different links. These aforementioned reported WF estimates can thus not be used for informing policy makers and water users towards the sustainable use of water in the value chain of beef production. It implies that the current estimation procedures for the WF of beef should be revised to address the mentioned concerns and propose a procedure which would result in more accurate estimations to be used in production and policy decisions.

Two previous studies which applied bottom-up up approaches to estimate the WF for specific beef value chain links were presented by Palhares et al. [16] and Maré et al. [17]. Both studies however focused on beef feedlots and not cow–calf production. Spore et al. [18] made use of data from different reports to estimate the WF of beef cattle production in Nebraska. Although their approach cannot really be considered as bottom-up, they did improve on previous studies by not only incorporating both the WF of a cow over a year and the WF for growing and finishing the calf in the total WF of produced beef. They however made no mention of the water used by the rest of the herd, such as bulls, heifers, and cows that did not calf.

In this study, the WF estimation procedure was revised for primary beef cow–calf production systems. A bottom-up approach was followed to provide a true representation of the production system, and thus the WF of the production system, with the estimated WF for the system being allocated to both weaned calves (primary product) and culled cows (secondary product) according to the value fraction (VF) of each. The usefulness of the revised procedure for water users (primary producers) was tested by estimating the WF for different cattle breeds on the same extensive farming conditions. To treat all the cattle breeds the same, it was necessary to make use of a farm simulation model where it is assumed that all breeds are raised on the same farm. Sufficient information, in terms of the genetic and production potential for each breed, was available to make accurate assumptions for the simulation model. It was expected that the WF/kg weaned calf of the breeds should differ as the grazing capacity, need for supplement feed, inter-calving period, and weaning weights differ.

2. Procedures and Data

The procedures and data used in the study can be divided into two main sections: the revised procedure to determine the WF of cow–calf production and the simulated farming system used. In terms of the farming system, there are two aspects to account for: the cow–calf herd data and the feed requirements of the different breeds.

2.1. Revised Procedure to Determine the WF of Cow–Calf Production

According to Chapagain and Hoekstra [19], the WF beef is basically based on three main components of water use: the drinking water of the animal, the water embedded in the feed that the animal consumes, and the water used for cleaning (service water). Mekonnen and Hoekstra's [1] calculation framework made a 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 to assimilate the pollution load). Although the same basic calculation framework was used for the purpose of this research, there are some fundamental differences.

In this study, the WF of weaned calves as primary products and culled cows as by-products was calculated through a bottom-up approach based on a farm perspective. A weaned calf is the final product of the cow–calf producer, but, when one considers 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 but the WF required to raise a calf to the age of weaning (approximately seven months). To calculate the WF in a bottom-up approach, the WF of the entire breeding herd must be divided by the products and by-products produced by the herd. Since there are many factors that influence the production and reproduction of cattle, the most acceptable way to calculate the WF per kilogram of live weaned calf is to do the calculation over a fixed term of one year. 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 fraction (VF) for each. The WF per kilogram live weight of the weaned calves can then be expressed as:

$$WF_{kg\ Calf} = \frac{(WF_{feed} + WF_{drink} + WF_{service}) \times VF_{Calves}}{W_{Calves}} \tag{2}$$

where WF_{feed}, WF_{drink}, and $WF_{service}$ represent the WF of the entire herd, VF_{Calves} is the value fraction of the calves, and W_{Calves} is the total live weight of the calves.

The VF_{Calves} is calculated as:

$$VF_{Calves} = \frac{V_{Calves}}{V_{Calves} + V_{Culled\ cows}} \tag{3}$$

where V_{Calves} and $V_{Culled\ cows}$ represent the total value of the weaned calves and culled cows, respectively.

The second difference in the calculation framework was that no water was used in the mixing of supplementary feed and therefore the $WF_{SupFeed}$ differed slightly from that of Mekonnen and Hoekstra [1] and was expressed as:

$$WF_{SupFeed} = \sum_{p=1}^{n} \big(SupFeed(p) \times WF_{prod}(p)\big) \tag{4}$$

where $SupFeed(p)$ represents the total amount of feed ingredient p consumed by the herd and $WF_{prod}(p)$ is the WF of producing feed ingredient p.

2.2. Description of the Farming System

This study was conducted through a simulation model based on the production data of the farmland owned by the Sernick group, which is situated near the town of Edenville in the Free State province of South Africa. The farm consists of 5013 hectares (ha) grazing, divided into 220 camps with an average size of 23 ha. 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, including drinking water for the cow–calf production system and service water, is supplied from underground water sourced from 38 boreholes that are scattered across the property [20].

Seven beef breed types were selected for the study. The selected breed types were then used to identify specific breeds, one breed from each breed type. The seven chosen breeds represented the most preferred breed in each breed type for cattle producers in the Edenville region. The final selection in terms of breed types, as well as breeds, is presented in Table 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. These differences resulted in the maturity and other biological factors to differ between the breeds and these influence reproduction and production efficiency. It will have an impact on the calving percentage, calf weight, and cow weight of each breed or type and will thus influence the WF of each since the supplementary feed consumption and the VF weaned calves and culled cows will differ between the breeds.

Table 1. Selected breed types and breeds.

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 and Maré [21].

Sernick currently farms with Bonsmara cattle on the property, and for the sake of the analysis, 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 in turn used to simulate the data for the other breeds. The cow weights, inter-calving periods, and weaned calf weights were determined by using average data from seven different breeders in a radius of 150 km around Sernick for each of the seven cattle breeds.

2.2.1. 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 available grazing. Although there is a large variety of grass species on the farm the grazing is dominated by three species of grass, of which the composition is described in Table 2.

Table 2. Natural grazing composition at Sernick.

Species of Grass	Quantity (ha)	Carrying Capacity (ha/LSU)	Stocking Rate (Number of LSUs)
Digitaria eriantha	1300	1.5	867
Themeda triandra	3383	5	677
Eragrostis curvula	330	1.5	220
Total/(Average)	5013	(2.8)	1790

Source: Serfontein [22].

According to the grazing composition, the farm has an average weighted carrying capacity of 2.8 ha/LSU and can accommodate 1763 LSUs. An LSU has, however, a very specific description and is defined as "the equivalent of an ox with a live weight 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" [23]. To determine how lactating cows of the different breeds compare to a LSU, the frame size regression equations that were developed by Mokolobate [24] were used:

$$\text{Small frame}: \ Y = 0.2871428571 + 0.0025542857x - 0.0000005714x^2 \tag{5}$$

$$\text{Medium frame}: \ Y = 0.220714286 + 0.0030978571x - 0.0000010714x^2 \tag{6}$$

$$\text{Large frame}: \ Y = 0.3239285714 + 0.0036535717x - 0.0000015x^2 \tag{7}$$

where Y represents LSU and x is the cow weight.

By substituting the average cow weights of the different breeds into the abovementioned equations, making assumptions about the replacement rate of cows (15%), number of bulls (3%), mortality rates of cows and calves (1% and 2%, respectively), and calculating the annual calving percentage from the inter-calf period as done by Scholtz [25] of each respective breed, the herd compositions of the various breeds that can be kept on the farm could be simulated. The simulated herd composition for the different breeds is presented in Table 3.

Table 3 shows 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 1285 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 considered.

Since the LSUs of some 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 show that the total mass (kilogram) of calves sold differ significantly between the breeds, with the Bonsmara producing 162,197 kg of sellable calves, while the Limousin produces only 96,931 kg.

Table 3. Simulated herd composition of the different cattle breeds.

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							
Calving %	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 with data from various breeders and own calculations.

The simulated herd composition of the various breeds was then used to calculate the required amount of supplementary feed for each breed that was used in combination with the utilized amount of natural grazing in order to calculate the WF per kilogram of weaned calf sold from each breed.

2.2.2. 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. [23], a LSU (as defined in Section 2.2.1) will consume approximately 10 kg of dry matter (DM) per day. Since the farm can accommodate 1790 LSUs and the total LSUs of each of the different breeds also calculates to 1790 LSUs, it means that each breed will consume approximately 6533 tonnes of DM per year or 1.3 tonnes/ha/year. The utilization factor of natural grazing ranges between 0.2 and 0.5, and, for good-quality natural grazing, which are based on the combination of plant types (pioneer, sub-climax, and climax plants) and palatability of each, a utilization factor of 0.4 can be used [26]. The total annual natural grazing DM production at Sernick is given as 3.5 tonnes/ha [22], meaning that the actual utilization factor at a utilization rate of 1.3 tonnes/ha is 0.37 and lower than the benchmark of 0.4.

The WF for the natural grazing at Sernick was not available and was therefore estimated using evapotranspiration (ET) data from earth observation/satellite imagery. (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 (Stellenbosch, South Africa), in partnership with eLEAF® (Wageningen, Netherlands), Agricultural Research Council (ARC) (Stellenbosch, South Africa), GeoTerra Image® (Pretoria, South Africa), and independent consultants). Since the natural grazing is only rain fed and not fertilized, 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, was 703.87 mm in total for the year 2014/2015, which equals 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, 2012 L of green water are used to produce one kilogram of DM, while Kannan et al. [27] found that native grasses (natural grazing) in the United States of America (USA) consumes on average between 431 and 705 L of green water to produce a kilogram of DM. The Sernick data, however, compare very well to work done by Snyman [28] 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 vegetation in the work done by Snyman [28] ranged between 1664 and 2119 L of green water per kilogram of DM.

The supplementary feed requirements of the different breeds were estimated based on the amount of lick that Sernick supplies to its current Bonsmara herd. Table 4 provides the three types of lick that female Bonsmara cattle require at 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.

Figure 1 summarizes the annual supplementary feed requirements of the different breeds in terms of production lick, summer lick, and winter lick. It is interesting to note that the total lick requirements of the breeds differ, as one would expect all the herds to utilize the same amount of lick since it was calculated according to the LSU of each breed. The difference in lick utilization is, however, caused by the differences in the inter-calving 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. Mekonnen and Hoekstra's [29] WF data for South Africa were used for the different feed ingredients in the supplementary feed (the different supplementary feed ingredients used in the analysis, as well as the WF data, are available from the author on request). The WF of supplementary feed ingredients other than whole grain (such as hominy chop or bran) was estimated according to the value fraction approach where the WF of the grain (maize) was allocated according to the value proportions the co-products (maize meal and hominy chop) contribute to the total value.

Table 4. Supplementary feed requirements of the Bonsmara and a LSU (kg/day).

Bonsmara kg/Day (LSU = 1.6)												
	January	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
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)												
	January	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
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 [22] and own calculations.

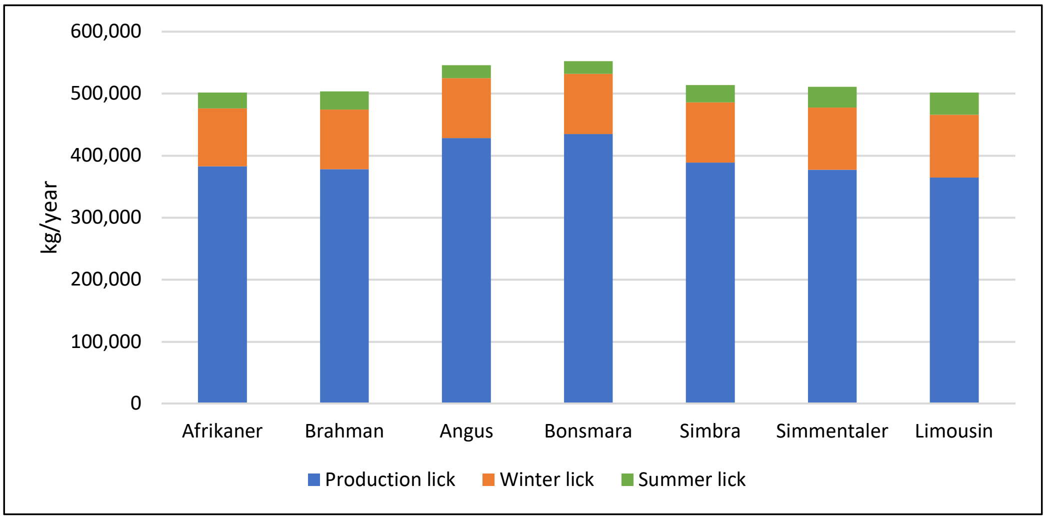

Figure 1. Annual lick requirements of the different breeds. Source: Own calculations.

3. Results

The WF of the different cattle breeds is presented in Table 5. The WFs of the feed, drinking, and service water are presented in cubic meter (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.

The specific quantities of especially drinking and service water may differ between the breeds in a real-life scenario, but, as the average drinking and service water requirements in Table 5 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 allocated according to the LSU values, the differences in the reproductive data of the breeds (see Table 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, was 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 total WF, is only 0.22% less than that of the Bonsmara herd, as the herd with the highest total 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 was 99.59% of the average total WF, while the blue and grey WFs were equal to only 0.29% and 0.12%, respectively, of the total. The grey WF only include the grey WFs of the different supplementary feed sources.

The second part of Table 5 divides the total WF of each herd between the culled cows, as the secondary 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). The allocated WF of the weaned calves is divided by the total live weight of the calves to calculate the WF per kilogram of live calf sold.

Table 5 clearly shows 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 grey 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.

Table 5. The WF of weaned calves and culled cows for the different breeds.

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)	1287	1287	1287	1287	1287	1287	1287
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 (L)	60,940	62,687	57,856	53,375	62,526	77,609	76,462
Green WF (L/kg)	60,695.45	62,435.32	57,613.18	53,149.91	62,273.26	77,296.86	76,156.81
Blue WF (L/kg)	172.40	177.35	167.80	155.35	177.94	220.25	215.77
Grey WF (L/kg)	0.20	0.21	0.21	0.20	0.21	0.26	0.25

Source: Own calculations.

4. Discussion

The results of the study clearly show that there are prominent differences between the seven breeds in terms of their respective WFs per kilogram weaned calf, even though the total WF per herd for each breed revealed little variation between the breeds. The Bonsmara herd, as the herd with lowest WF/kg calf, has a 45% lower WF/kg calf than the Simmentaler, as the herd with the highest WF/kg calf. Farming with Bonsmara rather than Simmentaler in this specific study would thus provide the producer the opportunity to lower the WF of the operation by 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 and 77,609 L/kg weaned calf—are compared with the results of other beef WF studies, such as the work done by Mekonnen and Hoekstra [1], who found the global WF of a kilogram boneless beef to be 15,415 L/kg and that of South Africa to be 17,387 L/kg [30]. While it is recognized that the water footprint of a kilogram of live weaned calf and a kilogram of boneless beef is not directly comparable, the difference in the WF of the two studies is still too large for comfort as one would expect the WF of the weaned calf to become even larger as it continues through the feedlot and abattoir.

Some factors should however 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 [1].

The second factor is that country-perspective studies, e.g., those by Mekonnen and Hoekstra [1] and Gerbens-Leenes et al. [2], 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 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 is that previous authors used the WF of an animal over its lifetime to estimate the WF of beef. In this study, the total WF of the herd was allocated to the offtake over the course of one year. It is basically impossible to do accurate estimations on the WF of beef estimated from the WF over the lifetime of the animal. If this want to be achieved then the age, as well as feed consumption history, of every animal must be known when that animal reaches the point of slaughter. The beef from a ten-year-old cow which was used for reproduction her entire life will basically have a ten times higher WF than the beef from a one-year-old fattened calf.

The fourth 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, in turn, will reduce the WF/kg boneless beef.

The results from this study provided valuable new knowledge on the differences between different cattle breeds in terms of their WF. This information and the calculation framework can be used by beef producers to determine which breed of beef cattle will improve their environmental stewardship through comparing the WF of different cattle breeds. It is recommended that future research should focus on estimating the WF for beef in the other value chain links (feedlot, abattoir, etc.) through a bottom-up approach as well. The differences between cattle breeds should also be part of future research attempts as the FCR of different breeds may influence the WF especially in terms of feedlot performance, while the carcass size of the different breeds may be an important factor in terms of the WF of abattoir processing.

5. Conclusions

The results of this study prove that the revised WF estimation procedure for primary cow–calve producers is accurate enough to distinguish between different breeds. This provides valuable new knowledge as it is the first time that accurate WF information for primary beef cattle producers is revealed. This new knowledge can be applied by both water users (primary producers) and policy formulators to assist in the optimal use of fresh water for beef production and in reporting the environmental stewardship of beef production.

Although the results show that the total WF of cow–calf production is very high, 99.59% of the total WF is green water. Since the cow–calf production of the given study occurs on natural, rain fed rangeland the only blue water incorporated is the drinking and servicing water of the animals and the irrigation water used for the production of some of the feedstuffs in the supplementary feeding. The fresh (blue) water subtracted for cow–calf production on natural grazing only comprises 0.29% of the total WF. The reporting of the WF for cattle production should thus be done with care and rather be reported in terms of the different water footprints than as a total. The green WF of natural rangeland will remain the same, with or without animals grazing the given land, and therefore should not be used as a component to base an argument of the large total WF of beef production. Yes, in areas with high rainfall, the green water may be applied more efficiently for crop production, but in marginal areas the rainfall is too low to support crop production and the natural rangeland can only be utilized by livestock and wildlife enterprises.

Nevertheless, livestock producers usually strives to be more productive. An increase in productivity means that the proportional increase in output is higher than the proportional increase in production inputs. Increased productivity thus leads to lower input use per unit of output and higher financial margins. One way to improve the productivity of cow–calf production is to increase the weaning percentage of cattle. The weaning percentage of the different breeds is closely correlated with the WF/kg weaned calve ($r = -0.916$) and is the factor that influence the WF/kg weaned calve the most. In the event where the weaning percentage of all the breeds are set equal to that of the Bonsmara (89%) in the simulation, the difference in the WF/kg weaned calve is much smaller between the breeds and the WFs of the Brahman, Afrikaner, Simbra, Angus, Limousin, and Simmentaler are then, respectively, only 4%, 5%, 6%, 7%, 18%, and 24% higher than that of the Bonsmara. The fact that the Bonsmara remains the breed with the lowest WF, even though the calving percentage of all the breeds was the same in this case, proves that other production factors also influence the WF. The improvement of only the reproduction rate (calving percentage) can assist a Simmentaler producer, as example, to reduce the WF/kg weaned calf by as much as 11.3 m^3/kg. This increase in productivity should also improve the financial position of the enterprise, as, in the case of study, more calves can be weaned and sold from the same number of calves and the same size farm than in the past.

Even though many researchers proposed how the WF concept can be used in policy formulation, the current use of WF information to base policy formulation on is very limited. This might be due to fact that WF research is still a relatively young and currently fast evolving research field. The differences in the outcomes of research on the same aspect, but in different countries or areas or for different production methods, and the fact that most previous studies made use of very wide datasets, make it even harder for policy makers to set certain benchmarks on which policies can be based. The outcomes of this study are however area specific and very accurate due to the bottom up approach and might be used in a first step to set a benchmark for the WF of cow–calf production in South Africa. More studies, following the same calculation framework, can be done on other production areas in South Africa in order to determine how the WF of cow–cattle production differs between production areas. Once this information is available, informed decisions can be made on the need and implementation on WF based policies for cow–calf production.

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