The water footprint of dryland pasture based dairy enterprise located in the "Golden Mile"- A future scenarios application

By: Paige Jenje (Talbot & Talbot (Pty) Ltd) & Professor Gavin Fraser

Abstract

Climate change and its water related climatic impacts pose serious threat to South Africa in terms of water scarcity, severe droughts and flooding, and prolonged wet and dry seasons within different regions of the country. National interest has sparked over the development of market based water resource allocation strategies, with business and industry concerned about the future availability and cost of water, as well as the future impacts of water governance and penalties on business. This paper performs an economic analysis of the water footprint of a dryland dairy farm in the "Golden Mile" of the Eastern Cape, utilising the water footprint assessment (WFA) methodology. The future economic value and viability of dairy farming is directly affected by the fluctuation in market price, market demand, and the availability of adequate rainfall. These factors influence farm management strategies through capital and operational cost requirements. This study extends the economic application of the water footprint assessment to future scenario analysis, predicting the business as usual water footprint and its related economic value for a dryland dairy farm using market and climate related assumptions. Future climatic predictions indicate that the "Golden Mile" is likely to experience a significant increase in annual rainfall, whilst the rest of the country is likely to experience drought and water shortages. Through scenario forecasting the farm will be able to better manage its present day operations, and implement mitigating measures against negative externalities from nationwide water scarcity and increasing costs within the vulnerable and competitive dairy market.

Introduction

South Africa is a water stressed country predicted to experience severe water scarcity within the next 50 years (Otieno & Ochieng, 2004; Walter et al., 2011; Jarmain et al., 2014). Water scarcity due to increasing water demand for national freshwater resources from industry, agriculture, population growth and economic development is exacerbated by South Africa's inadequate freshwater infrastructure and the effects of climate change (Perret, 2002; Mukheibir, 2008; Blignaut & van Heerden, 2009; Gbetibouo & Ringler, 2009; CSIR, 2010; Walter et al., 2011; DWAF, 2013; Meissner et al., 2013; Jarmain et al., 2014; WWF-SA, 2017). Over the years, national interest has sparked over the development of market based water allocation strategies (Walter et al., 2011). Regulators have been urged, as a consequence of mounting water scarcity, to find solutions which may alleviate the pressures placed on South Africa's freshwater resources in addition to ensuring compliance with the National Water Act (Jarmain et al., 2014). Numerous tools have been developed to serve as a platform to address water scarcity issues, such as the water footprint assessment (WFA) method. The WFA has become a popular tool to address the distribution of freshwater consumption whilst accounting for environmental, social and economic sustainability considerations (Reddy et al., 2014).

Agriculture is the largest water consuming economic sector in South Africa, requiring 92% of South Africa's freshwater resources for agricultural product production (Munro et al., 2016). As of 2015, preliminary results indicated that 897 000 skilled and unskilled workers were employed in agriculture, hunting, forestry and fishing, with these sectors contributing to 2.3% of South Africa's gross domestic product (GDP) (DAFF, 2016).

The South African dairy industry is the fifth largest agricultural industry in the country, contributing 6% of the agriculture industry's gross product, producing milk every day, and providing 60 000 direct and 40 000 indirect jobs for skilled and unskilled workers (Milk SA, 2013; DAFF, 2014; Coetzee, 2015; Esterhuizen et al., 2015). Of the 2.3% contributed by agriculture to South Africa's GDP, fresh milk production contributed approximately R15 billion towards the gross value of agriculture in 2015 (DAFF, 2016). As of 2014, average milk production per cow in South Africa was 20.2 litres per day, and a total of 95% of milk produced was sold on the formal market (Coetzee, 2015).

South Africa's dairy industry faces many challenges such as trade liberalization externalities, uncertain product prices, unpredictable interest rates, governmental regulation, disease outbreaks, susceptibility to climate change and the pressures of labour costs through the minimum wage and the constraining effect of labour unions (Meissner et al., 2013; Milk SA, 2013; DAFF, 2014). Such challenges make it important for the industry to maintain competitiveness, implement mitigating measures against climate change, and develop the skills of workers in order to maintain labour market competitiveness, as well as implement good food management practices (Meissner et al., 2013; FAO, 2016).

Freshwater shortages and pollution pose major risks to business, specifically through company operations and supply chains (WWF-SA, 2017). The world economic forum has listed water scarcity as one of the three largest systemic risks of the highest concern. Fresh water scarcity is manifested through the decline in ground water tables and reduced river flow, and the increase in the pollution of surface and ground water resources (Hoekstra, 2014). As a result, business faces risk of increased regulation implemented through higher water prices, reduced water rations, stricter emissions permits and the obligatory use of water saving technology (Hoekstra, 2014). Other risks include reputational risks towards the business brand (Hoekstra, 2014), as well as the risk and accountability towards investors (Hoekstra et al., 2012). Through the economic value of water, it is possible to make informed choices regarding water development, conservation, allocation and use in the face of growing water demand and scarcity (Ward & Michelsen, 2002).

In order for a farmer to assess his/her freshwater consumption in economic terms, he/she requires information on crop water use, yield, and field scale at farm level. With these variables the farmer can determine their water use, reduce their water wastage and optimise fertilizer use and crop production across farm management areas and processes (Jarmain et al., 2014).

Few studies have been performed on the water footprint of dairy production, globally and in South Africa (Drastig et al., 2010; Mekonnen & Hoekstra, 2010; Hoekstra, 2012; Zonderland-Thomassen & Ledgard, 2012; De Boer et al., 2013; Huang et al., 2014; Bosire et al., 2015; Palhares & Pezzopane, 2015; Scheepers, 2015), with all of these studies using historic data. This paper builds on the foundations of the Water Footprint Assessment (WFA) by developing the economic application of the water footprint through future economic and climate change forecasting in a business as usual case.

Literature review

The water footprint assessment is a consumption based volumetric water footprint (WF) methodology (Hoekstra et al., 2015). This water footprinting method is used to measure, describe, and formulate water management policies regarding the direct and indirect freshwater consumption of producers and consumers (Hoekstra et al., 2011; Jefferies et al., 2012; Boulay et al., 2013). The WFA does this by quantifying water consumption into blue, green and grey water categories, which address extracted freshwater, rainfall and water pollution respectively (Hoekstra et al., 2011).

Almost a third of agricultural production is dominated by the production of animal products (Hoekstra, 2012; Mekonnen & Hoekstra, 2012; Gerbens-Leenes et al., 2013). The production and consumption of these products along with socio-economic development is likely to increase the already existing pressures on global freshwater resources (Mekonnen & Hoekstra, 2010). This shift is particularly noticeable among developing countries which are experiencing significant economic growth, rising incomes per capita, and improved purchasing power (Gerbens-Leenes et al., 2013). The increased demand for animal products has driven the demand for the intensification of production systems, and has influenced animal feed composition (Mekonnen & Hoekstra, 2010). One of the largest environmental issues concerning dairy production is the large water footprint incurred by the industry particularly for fodder crop production and its contribution to water scarcity (Levin et al., 2012).

Few studies on the water footprint assessment of dairy production have been undertaken. Dratig et al. (2010) undertook a WFA of milk production by assessing the water footprint of feed, milk processing and servicing water. Drastig et al. (2010) found that the average blue water footprint per kilogram of milk was 3.94 ± 0.29L, drinking water accounted for 82% of the blue water footprint, milk processing accounted for 11%, and service water accounted for 7% of the overall water footprint. Scheepers (2015) performed a case study on the value chain of Lucerne fed dairy in South Africa. The study found that feed production contributed most significantly to the WF of milk, and results found that the total WF composition for milk was 84% green water, 10% blue water and 6% grey water (Scheepers, 2015). Palhares & Pezzopane (2015) conducted a study which compared conventional milk and organic milk production through the water footprint. The study found that in both production systems green water was the most significant contributor to the WF of milk, and irrigation accounted for the most significant portion of the blue water footprint of conventional and organic milk (95% and 96% respectively). Bosire et al. (2015) assessed the water footprint and land footprint of cattle, sheep and goats (shoats), and camels in Kenya for meat and milk production to investigate the spatial and temporal changes of freshwater and land resources. The study found that within arid and semi-arid systems, milk production consumed 2 000m^3 of water per tonne of milk, with green water contributing most to the WF of milk production (Bosire et al., 2015). Zonderland-Thomassen & Ledgard (2012) compared the water footprint values for irrigated and non-irrigated dairy farms in New Zealand using the WFA approach and the stress-weighted life cycle assessment (LCA). The study found that non-irrigated pasture based dairy enterprises had a higher green water footprint, and irrigated pastures had a higher blue and grey water footprint. The paper found that the variables required for the WF calculations were the same, but that the treatment of the variables differed between methods and thus resulted in differing final water footprint values (Zonderland-Thomassen & Ledgard, 2012).

Goals & Scope

This study performed calculated the water footprint of dryland dairy production in the “Golden Mile” using the water footprint assessment (WFA) and future forecasting. The WFA enables the farmer to assess his/her freshwater consumption by evaluating sustainability indicators such as economic water productivity, the opportunity costs of water consumption, and water scarcity (Hoekstra et al., 2011). Through the use of the WFA, this study determines the economic risks associated with blue and green water use within dryland dairy production systems from crop-to-farm gate in the “Golden Mile. The study did this by addressing both the monthly trending and average blue and green water footprints of a case study farm over a historic five year period, and utilised this data to determine a baseline future forecast for five years. Farm volumetric water footprints were determined through water footprint calculations for pasture production, drinking water, virtual water content of bought in feed and concentrates, and servicing water.

Study Area

The “Golden Mile” is situated within the Mzimvubu-Tsitsikamma Water Management Area (WMA) in the Eastern Cape. The WMA consists of three major drainage basins and smaller rivers. Major drainage basins includethe Great Fish, Sundays, and the Groot/Gamtoos. The WMA recieves an avareage of between 150mm and 1100mm of rainfall per annum, with higher rainfall occuring along the coastline. Ignoring the water requirements for ecological reserves, the WMA requires approximately 1 158 million m^3/annum of water, with main water uses belonging within the agricultural sector (911 million m^3/annum) (DWAF, 2004).

The case study dairy farm is a dryland farm situated in the Algoa Basin Sub-province (see figure 1), within quaternary catchment P20A. The quaternary catchment covers an area of 422km^2, is part of the Albany coast ISP area, and is under the jurisdiction of the Ndlambe Municipality. This catchment is characterised by high rainfall along with favourable groundwater recharge characterised by the high ground water potential from both the fractured Witteberg Aquifers' and the primary Algoa Aquifer' along the coastal belt (DWAF, 2002, 2005).

The total farm area covers 270ha of which 210ha are used for the growing of kikuyu dryland pasture. As the farm is a dryland farm, its predominant water source is rain water. The farm is supplemented by four boreholes which supply ground water for drinking and servicing water activities on farm. The farm consists of both Jersey and Friesland cows and utilises a 60 point rotary milking parlour system, which is able to milk over 600 dairy cows an hour. In addition, the farm employs 13 full time and 2 seasonal workers annually, and provides indirect jobs through the use of contactors for certain pasture management practices. The farm's heard management revolves around two calving seasons, where a third of the herd calves down in March/April and the other two thirds calve down in July through to September. This allows for cows to reach their peak stage of lactation during the peak pasture growth periods (April to September).

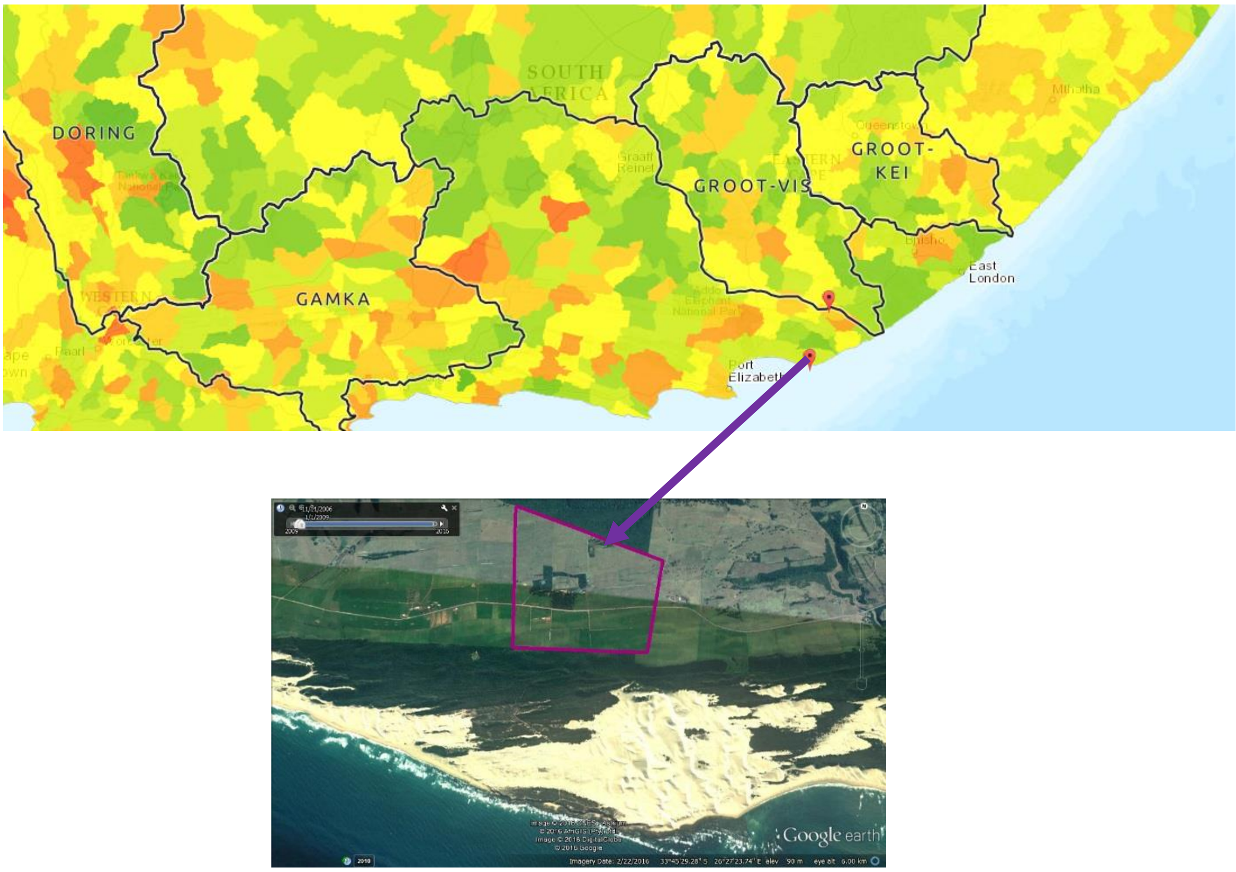

Figure 1: The case study area

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

Water Footprint accounting

On-farm milk production requires various applications of freshwater use and consumption within the water categories established by the water footprint. These water-consuming processes include the direct and indirect water footprint components of feed, drinking water and servicing water (Mekonnen & Hoekstra, 2010). The green water footprint of dairy production equates to the summation of green water consuming processes form crop-to- farm gate. These include bought in concentrates, feed and pasture production (where pasture production's green water footprint equates to effective rainfall). Blue water is incorporated throughout on-farm milk production processes such as cleaning, drinking water and the embedded water footprint content of bought in feed and concentrates (Mekonnen & Hoekstra, 2010; Levin et al., 2012; De Boer et al., 2013).

This study calculated the water footprint of the dryland dairy enterprise in equation 1, where the water footprint (WF) of dryland dairy farming is the summation of the process step water footprints for pasture growth ($WF_{pasture}$), the sum of the drinking water footprints (WF_{drink}) for cow type(s) a, servicing water (WF_{serv}) and the water footprint of bought in feed and concentrates ($WF_{bought\ in}$).

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

…………..[1]

Each process step's volumetric water footprint was calculated through the summation of their blue and green water footprints:

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

…………..[2]

Green Water Footprint

Feed production plays a significant role in the overall water footprint of raw milk products (Hoekstra, 2012; De Boer et al., 2013; Scheepers, 2015). The green water footprint is a theoretical calculation taken as the minimum of effective rainfall and evapotranspiration (Mekonnen & Hoekstra, 2010). This study assumes the green water footprint of pasture equates to effective rainfall, as actual evapotranspiration values were not measured. Dryland pasture production simply utilises green water as no irrigation is applied to pasture. The green water footprint of crop production is the effective rainfall (m^3) over total farm area (210 ha). Effective rainfall figures (for 2011-2015) were calculated using the SAPWAT 3 programme and weather data (maximum temperature, minimum temperature, wind speed, radiation and rainfall for the years 2011-2015) supplied by the ARC-ISCW and data collected on farm. The green water footprint values forecasted from 2016-2020 were calculated from climatic predictions, historic trends and correlations between data points.

South Africa's freshwater resources are dispersed throughout the country, as are its climatic zones. These climatic zones are steppe (arid), desert, sub-tropical wet and sub-tropical winter rain zones (Gbetibouo & Ringler, 2009). The eastern half of South Africa receives the majority of the nation's annual rainfall of up to 1500mm, and the western half experiences the least, as low as 100mm annually (CSIR, 2010; DWAF, 2013). Future climate projections predict that the coastal areas of the Eastern Cape are likely to experience increased rainfall, whilst the rest of South Africa will tend towards increased dry spells (DEDEA, 2011). Effective rainfall projections were calculated using the mean climate predictions presented by the Climate Information Platform (CIP) from various forecast models and datasets (GHCNv2, HadAM3, HadAM3P, HadCRUT3) which predict weather patterns for the major metropolitan areas in South Africa (CIP, 2017). The proportional changes in rainfall patterns for Port Elizabeth (the nearest metropolitan to the "Golden Mile") were used to calculate the projected effective rainfall for the case study farm in table 5. Based on this proportional change and the actual historic data provided by the farm, effective rainfall was likely to increase significantly in 2018. Projections highlight 2016 as being significantly drier than 2015, with expected improvements on 2016 figures from 2017-2020.

The case study farm buys in approximately 200 tonnes of Lucerne feed per annum in order to supplement the dry matter consumed by the dairy cows per year. Water footprint values determined by Scheepers & Jordaan (2016), illustrated in table 1 were used to calculate the bought in feed water footprint.

Table 1: The water footprint of Lucerne (m^3/tonne)

Blue WF (m^3/tonne)	Green WF (m^3/tonne)	Total WF (m^3/tonne)
171.28	206.9	378.18

Source: Scheepers & Jordaan (2016)

Using the WF values established in Scheepers & Jordaan (2016), the WF of bought in feed was calculated by multiplying the total amount of bought in Lucerne (200 tonnes) by the blue and green water footprints of Lucerne per tonne. The future green water figures for feed were assumed to be the same year on year as no detailed breakdown of feed volumes (tonnes) per annum were provided in the farm's historical data.

Concentrates are made up of high protein and energy content sources such as those from grains, oil cake meals, minerals, fishmeal and vitamins. These can be mixed on farm or bought ready mixed (Erasmus, 2009; Milk SA, 2013). According to the dairy farm, 2 150 tonnes of concentrate were bought in 2015. There were no figures available for the years 2011 through to 2014. Using this value, and the estimated kilograms of concentrates per cow (7.5kg, 6.8kg, 2.5kg for lactating Friesland, Jersey and dry cows respectively) provided by the farm, the amount of concentrate per cow type was calculated according to the weighted ratio of cow numbers to concentrate estimates for the year 2015. Using these values, the concentrate estimates for the remaining years (2011-2014) were calculated as illustrated in table 2.

Table 2: Estimated total concentrates (tonnes per year) per cow type

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

Source: Own extrapolation

The WF figures for bought in high protein concentrates were calculated using values determined by Owusu-Sekyere et al. (2016) of 50.57 m^3/tonne (blue) and 1702.42 m^3/tonne (green).

Total concentrate volumes per annum are dependent on the number of cows on farm. The predicted cow densities for 2016-2020 were calculated on a rolling 5 year average (see tables 3 and 4). Using the predicted cow populations, the value of concentrates were calculated along with their respective blue and green water footprints.

The total green water footprint of dryland pasture based dairy production for 2011-2020 is illustrated in table 5 and figure 2. Green water footprint results indicate that effective rainfall contributed most significantly to the overall green water footprint, and bought in feed contributed least.

Table 3: Friesland cow population numbers

		Lactating	Calve	Heifer	Dry	Bull
Historic Data	*2011*	514	92	313	99	10
	2012	523	166	313	89	9
	2013	452	124	298	77	9
	2014	420	80	281	72	9
	2015	412	175	227	62	8
Predicted Data	*2016*	464	127	286	80	9
	2017	454	134	281	76	9
	2018	440	128	275	73	9
	2019	438	129	270	73	9
	2020	442	139	268	73	9

Table 4: Jersey cow population numbers

		Lactating	Calve	Heifer	Dry	Bull
Historic Data	*2011*	343	62	208	66	6
	2012	379	120	227	65	7
	2013	355	97	235	61	7
	2014	358	68	239	61	7
	2015	412	175	227	61	8
Predicted Data	*2016*	369	104	227	63	7
	2017	375	113	231	62	7
	2018	374	111	232	62	7
	2019	378	114	231	62	7
	2020	381	124	230	62	7

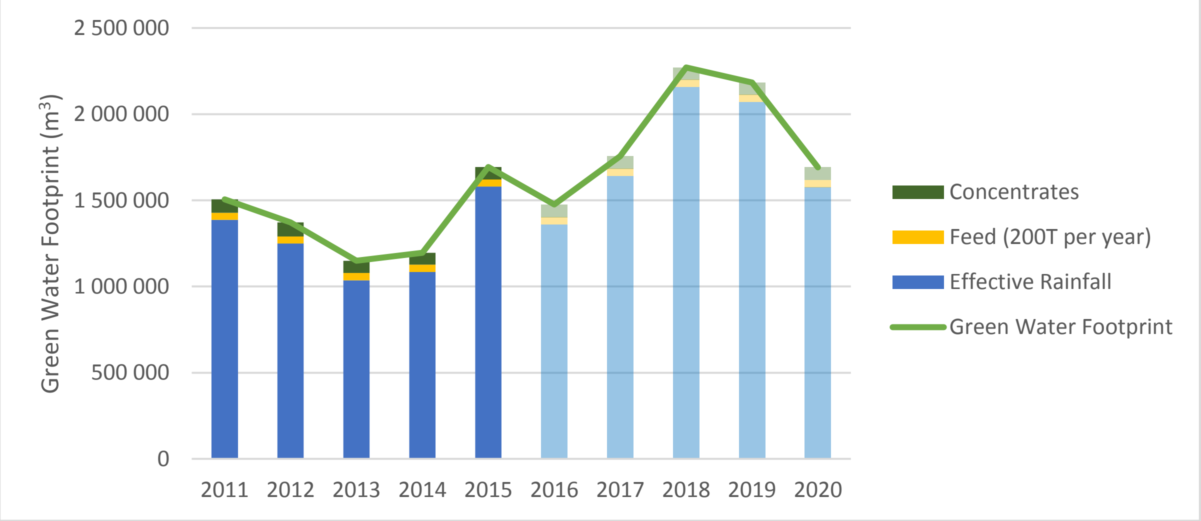

Figure 2: Green water footprint m^3 (2011-2020)

Table 5: Green water footprint (m^3) from crop-to-farm gate (2011-2020)

	Year	Effective Rainfall (m^3)	Feed (m^3)	Concentrates (m^3)	Total Green WF (m^3)
Historic Data	**2011**	1 387 050	41 380	77 057	1 505 487
	2012	1 249 500	41 380	80 382	1 371 262
	2013	1 036 350	41 380	71 792	1 149 522
	2014	1 084 650	41 380	69 082	1 195 112
	2015	1 579 200	41 380	72 377	1 692 957
Predicted Data	**2016**	1 359 855	41 380	74 138	1 475 373
	2017	1 640 864	41 380	73 554	1 755 799
	2018	2 157 313	41 380	72 189	2 270 882
	2019	2 070 148	41 380	72 268	2 183 796
	2020	1 576 915	41 380	72 905	1 691 200

Blue Water Footprint

The blue water footprint for the dryland enterprise was calculated as the sum of drinking water, blue water incorporated in bought in feed and concentrates, and cleaning water. The blue water footprint of concentrates and bought in feed was calculated as for the green water footprint. The calculations for drinking and servicing water are described below.

The water footprint of drinking water is dependent on total drinking water per cow (Mekonnen & Hoekstra, 2010) i.e. free water intake (FWI) per cow. The FWI of dairy cows is affected by daily factors such as dry matter intake, daily milk production, dry matter content of diet, the temperature of environmental factors, and sodium intake (Subcommittee on Dairy Cattle Nutrition et al., 2001). Historic drinking water figures were calculated for lactating and non-lactating dairy cows according to the methods and figures detailed by Little & Shaw (1978), Gordon & Robert (2007) and Scheepers (2015).

A variety of papers offer different calculations for the FWI of lactating cows (Subcommittee on Dairy Cattle Nutrition et al., 2001; Looper & Waldner, 2002; Meyer et al., 2004; Gordon & Robert, 2007; Cardot et al., 2008). For the purposes of this paper, this study used the drinking water calculation as determined by Little & Shaw (1978) for the calculation of lactating cow FWI.

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

………..[3]

Where free water intake (FWI) is determined by dry matter intake (DMI) and milk yield. Dry matter intake per cow type was assumed to be 20kg per cow per day for lactating Friesland cows, and 16kg per cow per day for lactating Jersey cows (these assumptions were provided by the case study farm).

Gordon & Robert (2007) suggest various prescribed free water intake (FWI) values for Jersey and Friesland cows in a technical report for reasonable stock water requirements. The literature estimates found by Gordon & Robert (2007) were averaged according to cow type and lifecycle stage, providing the mean FWI values for non-lactating cows in table 6. The drinking water footprint for bulls was assumed to equate the value provided by Scheepers (2015).

Table 6: The mean values of free water intake requirements (FWI) for non-lactating dairy cows

	Friesland FWI (Litres per cow per day)	**Jersey FWI** (Litres per cow per day)
Calves*	18.72	16.75
Heifers (<2 years old)*	29.22	23.90
Dry cows*	42.10	36.10
Bulls**	50.00	50.00

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

Forecasted drinking water values were calculated according to the assumed cow population sizes for Jersey and Friesland cows calculated in table 3 and table 4.

The WF of servicing water was calculated using the estimated water use (litres) for cleaning the farm's dairy parlour and milk tanks. Cleaning water processes were assumed to consume the same quantities of water per annum both historically and in the future.

Table 7: The water footprint of servicing water

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

Of the blue water consuming processes, cleaning water contributed the least, and blue water incorporated in high protein concentrates contributed most significantly.

Table 8: Blue water footprint (m^3) from crop-to-farm gate (2011-2020)

	Year	**Drinking Water (m^3)**	**Feed (m^3)**	**Concentrates (m^3)**	**Cleaning (m^3)**	**Total Blue WF (m^3)**
Historic Data	**2011**	27 146	34 256	115 758	3 212	180 372
	2012	30 394	34 256	120 753	3 212	188 615
	2013	27 402	34 256	107 849	3 212	172 719
	2014	26 236	34 256	103 778	3 212	167 483
	2015	27 674	34 256	108 728	3 212	173 870
Predicted Data	**2016**	27 770	34 256	111 373	3 212	176 612
	2017	27 895	34 256	110 496	3 212	175 860
	2018	27 396	34 256	108 445	3 212	173 309
	2019	27 394	34 256	108 564	3 212	173 426
	2020	27 626	34 256	109 521	3 212	174 615

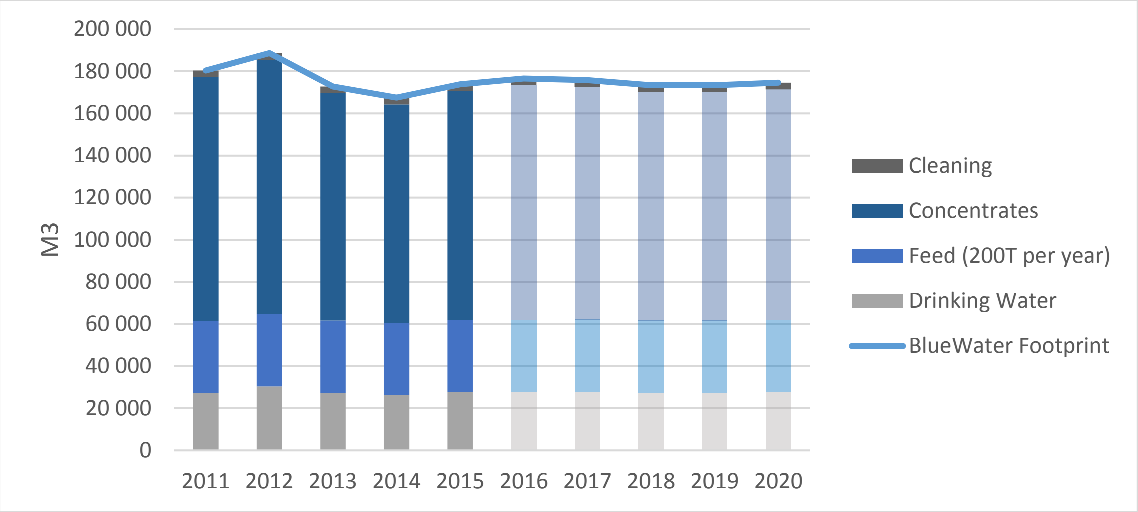

Figure 3: Blue Water footprint (m^3) (2011-2020)

Total Water Footprint

The purpose of water footprint accounting was to calculate the blue and green water footprint values for pasture based dairy enterprise. Through analysis of the overall water footprint accounting results, one observes that the green water footprint makes up the majority of the overall water footprint for dryland dairy pastures of 90%. Of the total water footprint, pasture production processes contribute most significantly at 84%. Of total blue water per annum, servicing water contributes the least (2%) and bought in concentrates contribute most significantly (63%).

Sustainability Assessment

Water should be allocated in a way that is economically efficient, with fresh water consumption benefits outweighing the costs associated with the water footprint. These costs include opportunity costs, externalities and scarcity rent. High water users such as agriculture need to enquire into more sustainable practices. From investigations, these industries can gain benefits of both monetary and physical value (Schyns & Hoekstra, 2014; Munro et al., 2016). This can be achieved through choice of cultivars and water management systems (Pahlow et al., 2015).

Historic milk production figures were collected for 2011-2015. These figures highlighted a 76% correlation (table 9) between milk produced per cow (kg) and effective rainfall (m^3). This relationship, along with the assumed cow population based on a five year rolling average, was used to predict milk production for the years 2016-2020.

Table 9: Milk production and effective rainfall correlation table

	Total Milk produced (Kg)
Total Milk produced (Kg)	1
Effective rainfall (m^3)	0.758071

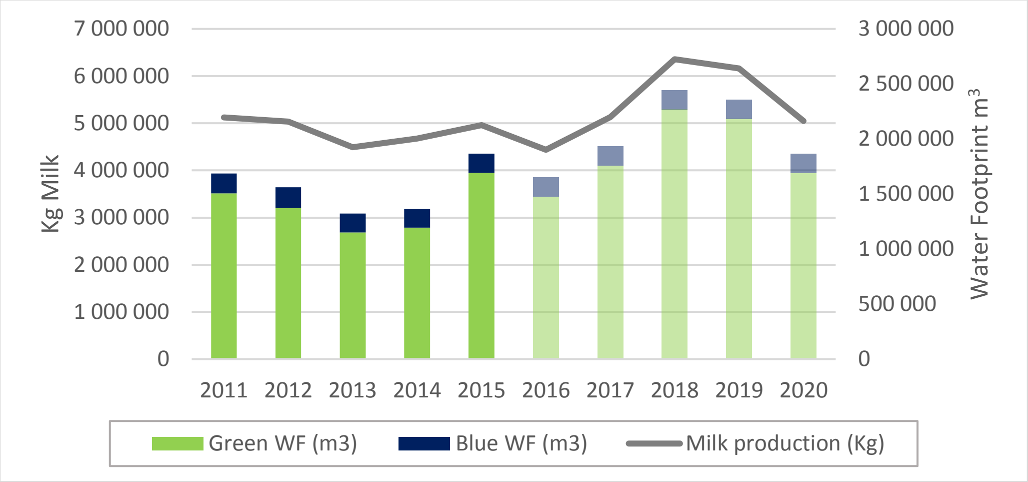

Figure 4: Milk production (kg) versus the total water footprint (m^3) (2011-2020)

Figure 4 illustrates the historic and predicted water footprints and milk production figures for the dryland dairy farm. Predictions suggest that 2016 to 2018 will see substantial milk production growth, thereafter milk production decreases due to the reduction in effective rainfall. In years where there is low rainfall, annual milk production decreases due to the resultant decrease in pasture quality. Greater water availability allows for a better quality grass, which allows for higher milk production yields per cow (Ball et al., 2001).

The costs of production for 2011-2015 were gathered from the farm. The historic costs (ZAR base 2010) for municipal electricity supply (Eskom), fertilizer, contractors, feed and concentrates were correlated against effective rainfall (m^3) in table 10 to predict the farm's future costs illustrated in figure 5.

Table 10: Cost variable correlation with effective rainfall

	Effective Rainfall
Effective Rainfall	1
Eskom	0.427829118
Fertilizer	0.918511484
Contractors	-0.431845108
Feed & concentrates	-0.289079545

The historic and projected cost figures for the farm suggest that during years with higher effective rainfall, fertilizer costs are higher and feed and concentrate costs are lower. This relationship is expected, as better rainfall conditions reduces bought in feed and concentrate requirements. Higher rainfall increases the farm's need to fertilize, as is evident in 2013 which bought in the least fertilizer and was the farms driest year according to historic data. This indicates cost minimising behaviour of dryland dairy farming.

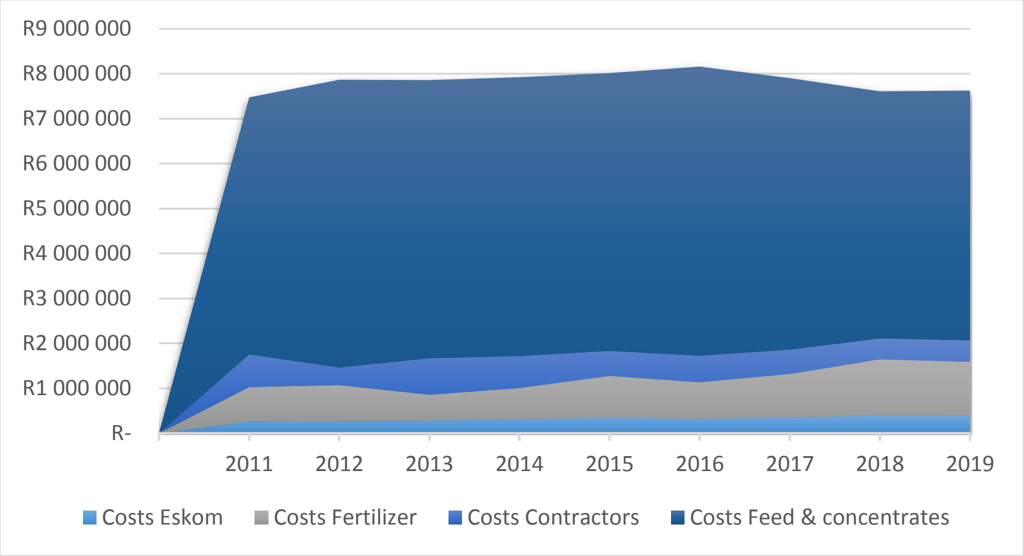

Figure 5: Historic and projected costs (ZAR) (2011-2020)

Economic Productivity

Water scarcity effects water productivity. It is for this reason that there is a need to optimise human water use in agricultural activities (Chouchane et al., 2015). In simplified terms, this is the ratio of agricultural output to water consumed, i.e. crop per drop in terms of blue and green water withdrawals (Rodrigues & Pereira, 2009; Chouchane et al., 2015). Through the use of the water productivity indicator, three possibilities for water use efficiency can be addressed. These include reducing the water footprint per unit of production at the user level, economically efficient allocation of water at the catchment level, or smart virtual water trade on an international level (Mekonnen & Hoekstra, 2014). For a farmer, blue and green water economic water productivities (EWP) are relevant in determining production decisions and assessing the economic sustainability of production (Chouchane et al., 2015; Pahlow et al., 2015). The EWP (ZAR/m^3) indicator does this by comparing direct blue or green water costs of production, to the availability of blue and green water for production in terms of current market prices (Schyns & Hoekstra, 2014; Chouchane et al., 2015; Munro et al., 2016) by dividing the average market value for a product (ZAR/litre milk) by the water footprint of that product (m^3/litre milk).

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

………..[4]

Economic water productivity (EWP) is equal to revenue at base year 2010 ($Y*P_{base}$) over the total water footprint.

In a similar vein, land productivity is considered an indicator of economic sustainability. This was calculated by multiplying the base producer price for milk (P_{base}) per water footprint cubic meter, by annual milk production (Y) (litres/ha), in order to provide a land value per hectare (ZAR/ha). This calculation is illustrated in equation 5.

$$ELP = Y * P_{base}$$

………..[5]

EWP and ELP were calculated (figures 6 and 7) utilising the farms cost schedule for electricity utilities, contractors and bought in feed and concentrate costs, and predicted milk producer price (2011-2020) (figure 5). Milk producer prices were calculated on a five year rolling average.

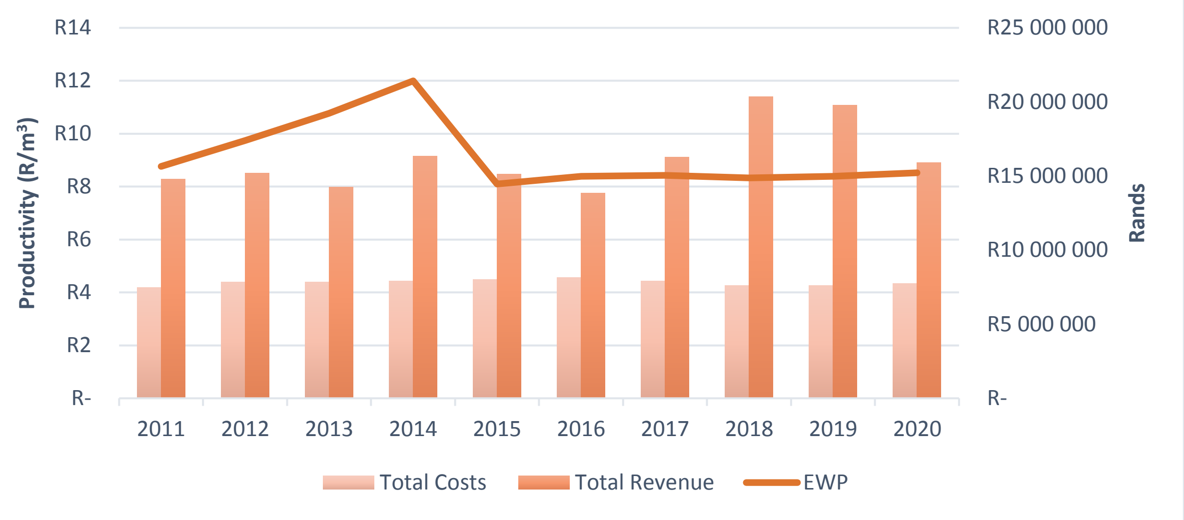

Figure 6: Economic water productivity (EWP) indicators

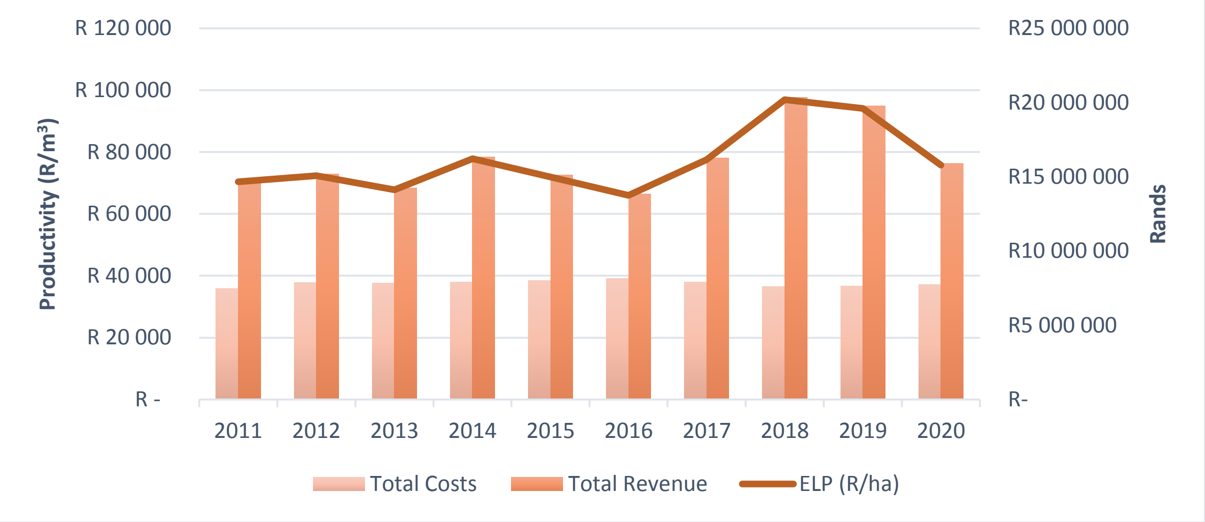

Figure 7: Economic later productivity (ELP) indicators

Of the two productivity indicators, ELP is best for describing the relationship between effective rainfall and the value of dryland dairy farming due to the nature of the various dryland water sources. Figure 7 highlights the economic implications, through the ELP indicator, of future forecasted rainfall events which can assist the farmer to forecast and mitigate productivity losses due to weather variability.

Response formulation

Water is a scarce good because it carries opportunity costs, where the benefits have been forgone towards alternative uses. This scarcity highlights the importance of addressing the imbalances between the supply and demand for freshwater resources under prevailing institutional arrangements and infrastructural conditions (Hoekstra et al., 2012; Schyns et al., 2015). Certain socio-economic questions need to be addressed when formulating a response to the values calculated in the WFA. Poor animal management along with cropping practices play a significant role in the depletion and pollution of water sources (Peden et al., 2009). Research studies on the water footprint of dairy have suggested various responses to water footprint study outcomes. The majority of these responses fall under farm management techniques, and the address of water productivity values (Meissner et al., 2013). These responses address various aspects of animal production including feed sourcing, animal productivity, drinking water provisions and water conservation techniques (Peden et al., 2009).

Years which experienced more rainfall tended to enjoy higher economic productivity. Dairy producers are price takers, which makes them susceptible to temperamental market risks. Dryland farms are at particular risk as there are no irrigation systems in place should the area experience a dry season. In response, the dryland farm behaves as a cost minimiser, where contractor and fertilizer costs were minimised during dry years. Through interactions between the farmer and the model, the producer price variables can be adjusted to reflect actual price figures, and adjust forecasted economic productivities respectively. This allows the farmer to develop scenarios and strategies around price fluctuations and climate change, and in return be able to develop adaptive capacity against negative externalities.

Conclusion

Few studies have been undertaken to assess the water footprint of dairy production, and no water footprint assessment studies have addressed future scenario modelling of the water footprint and its economic implications. This study aimed to build on the economic application of the water footprint assessment framework through future scenario analysis using a dryland dairy farm in the “Golden Mile” as a case study. To do this the study addressed the key water using areas within the dairy production process from crop-to-farm gate. Historic data highlighted the relationship between the green water footprint and dryland dairy production, as well as milk production and cost correlations with effective rainfall. Through historic trend analysis the study was able to develop a base line future scenario forecast for the dryland farm, taking into account effective rainfall, cow population sizes, producer prices and farm management costs. This information was collated into a dynamic model which can be manipulated as and when farm management decisions are made or climatic events occur in order to reflect accurate economic forecasts.

References

BALL, D.M., COLLINS, M., LACEFIELD, G.D., MARTIN, N.P., MERTENS, D.A., OLSON, K.E., PUTNAM, D.H., UNDERSANDER, D.J., WOLF, M.W. (2001). Understanding forage quality. American Farm Bureau Federation Publication.

BLIGNAUT, J. & VAN HEERDEN, J. (2009). The impact of water scarcity on economic development initiatives. Water SA, 35(4): 415–420.

BOSIRE, C.K., OGUTU, J.O., SAID, M.Y., KROL, M.S., LEEUW, J. DE, HOEKSTRA, A.Y. (2015). Trends and spatial variation in water and land footprints of meat and milk production systems in Kenya. Agriculture, Ecosystems and Environment, 205: 36–47.

BOULAY, A.M., HOEKSTRA, A.Y., VIONNET, S. (2013). Complementarities of water-focused Life Cycle Assessment and Water Footprint Assessment. Environmental Science & Technology, 47(21): 11926–11927.

CARDOT, V., LE ROUX, Y., JURJANZ, S. (2008). Drinking behaviour of lactating dairy cows and prediction of their water intake. Journal of Dairy Science 91: 2257–2264

CIP (2017). Datasets. [online]. Available at: http://cip.csag.uct.ac.za/webclient2/app/ [Accessed 1 July 2017].

CHOUCHANE, H., HOEKSTRA, A.Y., KROL, M.S., MEKONNEN, M.M. (2015). The water footprint of Tunisia from an economic perspective. Ecological Indicators, 52: 311–319.

COETZEE, K. (2015). Lacto Data, Prepared by Dr Koos Coetzee on behalf of Milk SA. Milk SA Report volume 8, Pretoria.

CSIR (2010). A CSIR perspective on water in South Africa S. Oelofse, W. Strydom, & CSIR Natural Resources and Environment, eds., CSIR. Available at: http://www.csir.co.za/nre/docs/CSIR Perspective on Water_2010.PDF.

DAFF (2014). A profile of the South African dairy market value chain, Compiled by the Department of Agriculture, Forestry and Fisheries. Arcadia, South Africa

DAFF (2016). Abstract of Agricultural Statistics, Compiled by the Directorate of Economics and Statistics on behalf of the Department of Agriculture, Forestry and Fisheries. Pretoria, South Africa.

DE BOER, I.J.M., HOVING, I.E., VELLINGA, T. V., VAN DE VEN, G.W.J., LEFFELAAR, P.A., GERBER, P.J. (2013). Assessing environmental impacts associated with freshwater consumption along the life cycle of animal products: The case of Dutch milk production in Noord-Brabant. International Journal of Life Cycle Assessment, 18(1): 193–203.

DEDEA (2011). Eastern Cape Climate Change Response Strategy. Prepared by the Eastern Cape DEDEA in association with Coastal & Environmental Services, South Africa.

DRASTIG, K., PROCHNOW, A., KRAATZ, S., KLAUSS, H., PLÖCHL, M. (2010). Water footprint analysis for the assessment of milk production in Brandenburg (Germany). Advances in Geosciences, 27: 65–70.

DWAF (2002). Fish to Tstitsikamma water management area. Prepared by Ninham Shand, on behalf of the Directorate National Water Resource Planning. DWAF Report No: P15000/00/0101, South Africa.

DWAF (2004). Albany Coast situation, Prepared by K. Sami in association with WSM Leshika (Pty) Ltd, on behalf of the Directorate National Water Resources Planning. DWAF Report No: PWMA 15/000/00/0410, South Africa.

DWAF (2005). Fish to Tsitsikamma Water Management Area: Fish to Sundays Internal Strategic Perspective. Prepared by Ninham Shand in association with Umvoto Africa, on behalf of the Directorate National Water Resource Planning. DWAF Report no. P WMA 15/000/00/0405.

DWAF (2013). Strategic overview of the water sector in South Africa, Department of Water Affairs and Forestry. Available at: http://nepadwatercoe.org/wp-content/uploads/Strategic-Overview-of-the-Water-Sector-in-South-Africa-2013.pdf.

ERASMUS, L. (2009). Milk production from cows grazing kikuyu-ryegrass pasture systems. Masters thesis. Pretoria: Department of Animal and Wildlife Sciences, University of Pretoria.

ESTERHUIZEN, L., FOSSEY, A., & POTGIETER, E. (2015). Groundwater quality on dairy farms in central South Africa. Water SA, 41(2), 194–198. https://doi.org/10.4314/wsa.v41i2.04

FAO (2016). Dairy Development. [online] Dairy production and products. Available at: http://www.fao.org/agriculture/dairy?gateway/the?dairy?chain/dairy?development/en/#.Vx4cZfl97Dc [Accessed 25 April 2016].

GBETIBOUO, G.A. & RINGLER, C. (2009). Mapping South African farming sector vulnerability to climate change and variability : A subnational assessment. In: Amsterdam conference on the human dimensions of global environmental change “Earth System Governance: People, Places and the Planet”: 1–27.

GERBENS-LEENES, P.W., MEKONNEN, M.M., HOEKSTRA, A.Y. (2013). The water footprint of poultry, pork and beef: A comparative study in different countries and production systems. Water Resources and Industry, 1-2: 25–36.

GOOGLE EARTH (2016). “Glen dye farm” 33^045’29.28S and 26^027’23.74E. February 22, 2016. [Accessed 18 September 2016.

GORDON, S. & ROBERT, R. (2007). Reasonable stock water Requirements: Guidelines for resource consent applications. Technical report prepared for Horizons Regional Council by AQUAS Consultants Ltd and Aqualinc Research Ltd. Enderley Hamilton.

HOEKSTRA, A.Y., CHAPAGAIN, A.K., ALDAYA, M.M. and MEKONNEN, M.M. (2011). The Water Footprint Assessment Manual, London: Earthscan. Available at: http://www.waterfootprint.org/?page=files/WaterFootprintAssessmentManual.

HOEKSTRA, A. Y. (2012). The hidden water resource use behind meat and dairy. Animal Frontiers, 2(2), 3–8.

HOEKSTRA, A. Y., BOOIJ, M. J., HUNINK, J. C., & MEIJER, K. S. (2012). Blue water footprint of agriculture, industry, households and water management in the Netherlands. Value of Water Research Report Series No. 58.

HOEKSTRA, A.Y. (2014). Water scarcity challenges to business. Nature Climate Change, 4(5): 318–320.

HOEKSTRA, A., CHAPAGAIN, A., & ZHANG, G. (2015). Water Footprints and Sustainable Water Allocation. Sustainability, 8(1), 20.

HUANG, J., XU, C.C., RIDOUTT, B.G., LIU, J.J., ZHANG, H.L., CHEN, F., LI, Y. (2014). Water availability footprint of milk and milk products from large-scale dairy production systems in Northeast China. Journal of Cleaner Production, 79: 1–7.

JARMAIN, C., SINGELS, A., BASTIDAS-OBANDO, E., PARASKEVOPOULOS, A., OLIVIER, F., LAAN, M. VAN DER, TAVERNA-TURISAN, D., DLAMINI, M., MUNCH, Z., BASTIAANSSEN, W., ANNANDALE, J., EVERSON, C., SAVAGE, M. and WALKER, S. (2014). Water use efficiency of selected irrigated crops determined with satellite imagery, Gezina.

JEFFERIES, D., MUÑOZ, I., HODGES, J., KING, V.J., ALDAYA, M., ERCIN, A.E., MILÀ I CANALS, L. and HOEKSTRA, A.Y. (2012). Water footprint and life cycle assessment as approaches to assess potential impacts of products on water consumption. Key learning points from pilot studies on tea and margarine. Journal of Cleaner Production, 33: 155–166.

LEVIN, J., STEVENSON, M., ANDERSON, K., ARBUTHNOT, M., AULISI, A., BJORK, A., BOSTICK, K., BRIAN, S., CESAREO, K., CLAY, J., DAVIES, R., DAVIS, K., DHAR, M., DIAMANTI, C., DOYLE, K., ECKSTEIN, M., DROS, J.M., FOX, B., GERLING, T., HARRISON, A., HOLLEY, F., LAWSON-LARTEGO, L., LINDHE, A., MACLEOD, M., MALCOLM, J., NEYROUMANDE, E., OGORZALEK, K., PERKINS, R., RENSTROM, M., SCHORR, D., SCHUMM, A., SILVA, L.N., STAGGS, A., STAMPE, J., SUDDABY, D., TANNER, N., TAYLOR, R., TROTT, P., VILLALON, J., WAGNER, W., WEBBER, D., WEECH, B., WHITE, G. (2012). Guide to Responsible Investment The 2050 Criteria, Prepared on behalf of the WWF. Washington.

LITTLE W., SHAW S.R. (1978). A note on the individuality of the intake of drinking water by dairy cows. Animal Science 26(2): 225–227.

LOOPER, M.L. & WALDNER, D.N. (2002). Water for Dairy Cattle. New Mexico State University, Cooperative Extension Service.

MEISSNER, H.H., SCHOLTZ, M.M., ENGELBRECHT, F.A. (2013). Sustainability of the South African livestock sector towards 2050 part 2: Challenges, changes and required implementations. South African Journal of Animal Sciences, 43(3): 298–319.

MEKONNEN, M.M. & HOEKSTRA, A.Y. (2010). The green, blue and grey water footprint of farm animals and animal products, Volume 1: main report. Delft.

MEKONNEN, M.M. & HOEKSTRA, A.Y. (2012). A Global Assessment of the Water Footprint of Farm Animal Products. Ecosystems 15(3), 401–415.

MEKONNEN, M.M. & HOEKSTRA, A.Y. (2014). Water conservation through trade: the case of Kenya. Water International, 39(4): 451–468.

MEYER U., EVERINGHOFF M., GÄDEKEN D., FLACHOWSKY G. (2004). Investigations on the water intake of lactating dairy cows. Livestock Production Science 90(2-3): 117–121.

MILK SA (2013). Milk SA guide to dairy farming in South Africa (second edition) H. Pheiffer, ed., Pretoria: Leza Putter.

MUKHEIBIR, P. (2008). Water resources management strategies for adaptation to climate-induced impacts in South Africa. Water Resources Management, 22(9): 1259–1276.

MUNRO, S.A., FRASER, G.C.G., SNOWBALL, J.D., PAHLOW, M. (2016). Water footprint assessment of citrus production in South Africa: a case study of the Lower Sundays River Valley. Journal of Cleaner Production 135: 668 - 678.

OTIENO, F.A.O. & OCHIENG, G.M.M. (2004). Water management tools as a means of averting a possible water scarcity in South Africa by the year 2025. Water SA, 30(5), 668–672.

OWUSU-SEKYERE, E., SCHEEPERS, M. & JORDAAN, H. (2016). Water Footprint of Milk Produced and Processed in South Africa: Implications for Policy-Makers and Stakeholders along the Dairy Value Chain. Water 8(8): 322–334.

PAHLOW, M., SNOWBALL, J., FRASER, G. (2015). Water footprint assessment to inform water management and policy making in South Africa. Water SA, 41 (3): 300–313.

PALHARES, J.C.P., PEZZOPANE, J.R.M. (2015). Water footprint accounting and scarcity indicators of conventional and organic dairy production systems. Journal of Cleaner Production, 93: 299–307.

PEDEN, D., TADDESSE, G., HAILESLASSIE A. (2009). Livestock water productivity: Implications for sub-Saharan Africa. Rangeland Journal 31(2): 187–193.

PERRET, S.R. (2002). Water policies and smallholding irrigation schemes in South Africa: A history and new institutional challenges. Water Policy, 4(3): 283–300.

REDDY, T., AMIS, M., BALETA, H. PEGRAM, G. (2014). Water Footprints for industry in South Africa: Policy and regulations report No. TT617/14, Gezina.

RODRIGUES, G.C., PEREIRA, L.S. (2009). Assessing economic impacts of deficit irrigation as related to water productivity and water costs. Biosystems Engineering, 103(4): 536–551. doi:10.1016/j.biosystemseng.2009.05.002

SCHEEPERS, M. & JORDAAN, H. (2016). Assessing the Blue and Green Water Footprint of Lucerne for Milk Production in South Africa. Sustainability, 8(1): 49–58.

SCHEEPERS, M.E. (2015). The water footprint and the value of water used in the lucerne-dairy value chain. Unpublished Masters thesis. Bloemfontein: Department of Agricultural Economics, University of the Free State.

SCHYNS, J.F. & HOEKSTRA, A.Y. (2014). The added value of Water Footprint Assessment for national water policy: A case study for Morocco. PLoS One, 9(6): 1–14.

SUBCOMMITTEE ON DAIRY CATTLE NUTRITION, COMMITTEE ON ANIMAL NUTRITION & NATIONAL RESEARCH COUNCIL (2001). Water. In Nutrient Requirements of Dairy Cattle. Washington D.C.: National Academy Press, 178–183.

WALTER, T., KLOOS, J., TSEGAI, D. (2011). Options for improving water use efficiency under worsening scarcity: Evidence from the middle olifants sub-basin in South Africa. Water SA, 37(3): 357–369Ward, F.A. & Michelsen, A., 2002. The economic value of water in agriculture: Concepts and policy applications. Water Policy, 4(5), pp.423–446.

WARD, F.A., MICHELSEN, A. (2002). The economic value of water in agriculture: Concepts and policy applications. Water Policy 4(5): 423–446.

WWF (2016). The Water Risk Filter. [online]. Available at: www.waterriskfilter.co.za [Accessed 12 October 2016].

WWF-SA (2017). Scenarios for the Future of Water in South Africa. Cape Town, South Africa.

ZONDERLAND-THOMASSEN, M.A. & LEDGARD, S.F. (2012). Water footprinting: A comparison of methods using New Zealand dairy farming as a case study. Agricultural Systems, 110: 30–40.