APPLYING WATER FOOTPRINT ASSESSMENT WITH THE AIM OF ACHIEVING SUSTAINABLE WATER RESOURCE MANAGEMENT AT A LARGE COMMERCIAL BEEF CATTLE FEEDLOT IN GAUTENG PROVINCE

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DECLARATION

To Whom It May Concern:

I, Lisa Pearce, ID number 7902060011087, Student Number PRCLIS003; hereby declare that the work has not been previously submitted in whole, or in part, for the award of any degree. All content in this dissertation is my own work. Each significant contribution to, and quotation in, this dissertation from the work, or works, of other people has been attributed, and has been cited and referenced.

Signed:______Signed______________________ Date: ___15__/_02__/_2006______

DEDICATION

I dedicate this work to my husband, Anthony Pearce.

ACKNOWLEDGEMENTS

"…you'll do best by filling your minds and meditating on things true, noble, reputable, authentic, compelling, gracious – the best, not the worst; the beautiful, not the ugly; things to praise, not things to curse…. Do that, and God, who makes everything work together, will work you into his most excellent harmonies" - Phil4:8-9

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To my husband – Anthony, your perseverance, good humour, patience and undeniable strength in a time of great personal trial has been my inspiration. “You raise me up to more than I can be.”

And to the Lord, Who never tires and never gives up, be all the Glory.

ABSTRACT

The commercial production of beef meat is associated with a wide array of environmental impacts, and is itself very sensitive to environmental conditions. Water in particular is a critical environmental resource and the commercial success of an agri-business is closely tied to reliance on fresh water resources. In an economic sector that is increasingly faced with competition for resources as well as negative public opinion about environmental impacts, the management of water-related risks and impacts is essential to ensure business resilience and sustainability.

Global trends in animal production are causing the environmental problems to become more harmful, and intensive animal production is being separated from traditional crop farming systems where manure could be used as a fertilizer to replenish soil nutrients. There is a spatial disconnect in the production value chain brought about by commercial trends.

An on-site water efficiency approach to water resources management of an agri-business does not enable it to evaluate value chain water-related risks, or its' own contribution to sustainable water use in the catchments where raw materials are produced and production wastes are distributed.

The question of sustainable water use within the production value chain of beef meat is not solved with an on-site efficiency approach to water resources management because the approach is inadequate in evaluating the freshwater environmental impact, or in managing water-related business risks of the whole beef production value chain. It is argued that a systems approach is more credible because it allows a beef cattle feedlot enterprise to evaluate freshwater impacts across the production value chain and will enable a feedlot to transition towards a sustainable value chain water resources management model

The Water Footprint of food, goods and services is a volumetric expression of the water that is consumed during the production process. Unlike water use, the water footprint refers to water that is imbedded into a product (also referred to as virtual water) or otherwise made unavailable for further use within a catchment, province or country through pollution dilution.

The Water Footprint Network developed the Water Footprint Assessment and describes three types of WF: the green water footprint refers to evaporated water, typically in the form of rainwater. The blue water footprint refers to water that is abstracted from a resource and delivered to the point of use, for example in the case of irrigation from a river, borehole or dam.

The grey water footprint is a volumetric expression of the amount of fresh water required to dilute chemical substances to a safe or acceptable concentration in the natural environment.

A Water Footprint Assessment (WFA) was undertaken at a beef cattle feedlot in Gauteng, South Africa. The WFA focused on the Bovine WF of the 4-month winter- and summer finishing periods that cattle spend at the feedlot. The second focus was on the monthly grey WF of waste management activities at the feedlot. The purpose of the study was to determine how the application of a WFA would enable an agri-business to transition from an on-site approach to water resources management, to a value-chain systems approach to sustainable water resource management.

The WFA enables a beef cattle feedlot to view water-related risk from a WF-component perspective and customize response strategies to align with areas of greatest perceived risk. WFA is very data demanding, yet is not well suited to reflect the granularity of variables present at the local level of a single water user. WFA of a single water user in a catchment will benefit from more publicly available data on the total WF of production in a catchment, as well as more frequently updated data at the quaternary catchment level.

This study estimates the WF of beef meat produced during the 4-month summer- and winter finishing cycles at the feedlot, at 17,962,061.77L/kg hot carcass and 17,962,042.41L/kg hot carcass respectively. The difference is attributed to seasonal changes in drinking water requirements. In contrast, Mekonnen & Hoekstra (2010) estimated the global average lifetime WF for industrial production systems at 10,244L/kg hot carcass, and the Australian average at 5,130L/kg. Capper (2012) estimated the lifetime WF at 32,864L/kg hot carcass (excludes the green WF of crop production), and Riddout *et al* (2011) estimated the water footprint of different beef production systems in Australia between 3,3 and 221L H_2Oe per kg live weight. The considerable difference between results from different studies suggests that methodological differences in WFA, as well as production value chain differences, may have a significant influence on the outcome of a WFA. Animal slaughter weight in this study was only 250kg, compared to the average slaughter weight of 569kg reported by Capper (2012), while slaughter age in this study is only 10 months, compared to between 12 and 36 months in other studies (Riddout *et al,* 2011). In this study there is an acknowledged and significant error in the published feed WF data which was quoted from Mekonnen & Hoekstra (2010) and used in the water footprint accounting. Assumptions were made about feed mix ratios, as well as for certain aspects of the WFA methodology where the granularity was inappropriate, and where local data was unavailable.

The Tier 1 Supporting Guidelines for Grey Water Footprint uses qualitative descriptions of factors that influence the grey WF, and will benefit from well-defined quantitative indicators for the range in which influencing factors may exist. Also, the Guidelines specific to N and P require more detailed description to be relevant for a dynamic agricultural application.

Further methodological development to address the shortcomings of both the WFA and the Tier 1 Grey Water Footprint Guidelines will greatly benefit a commercial agri-business in managing water-related risk, improve business resilience and strengthen sustainability.

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ACRONYMS

LCA – life cycle assessment
LW – live weight
MAP – mean annual precipitation
MAR – mean annual rainfall
WF – water footprint
WFA – water footprint assessment
WFN – water footprint network
WMA – water management area
WRM – water resource management
SWRM – sustainable water resource management

1. INTRODUCTION

The commercial production of beef meat in South Africa drives demand for weaner (weaned calves) production for the feedlot industry. As much as 75% of the beef cattle weaners grown in South Africa are destined for Concentrated Animal Feeding Operations (CAFOs) (DAFF, 2014). Approximately 80% of the total number of cattle in South Africa are beef cattle, whereas the remaining 20% are dairy cattle (ibid.). Beef cattle feedlots require sufficient volumes of clean and cool freshwater for cattle to drink (Gadberry, 2015; Parish and Rhinehart, 2008). Drinking water is “a critical nutrient for all classes of drinking water” (Parish and Rhinehart, 2008, p1). It is therefore reasonable for beef cattle feedlots to emphasize on-site water resource management and place great value on feedlot design and operational management for on-site water-efficiency. This thesis is an investigation into the water management of a large feedlot in South Africa.

An agri-business, which includes beef cattle feedlot enterprises, can experience water stress at operational sites because of a host of factors including inadequate water supply, competition for water, water quality and social demands for water (Schornagel *et al*, 2012). There is increasing awareness of the impact of an enterprise’s production activities on the sustainability of water resources, and of material business risks associated with this impact on water resources (Morrison *et al,* 2009; Larson *et al*, 2010). Awareness inevitably increases:

i) in regions that are subjected to water scarcity at certain times of the year (Larson *et al*, 2010);
ii) in cases where an enterprise’s water use causes conflict with other users; where biodiversity is degraded or depleted (Mekonnen and Hoekstra, 2010a);
iii) where the water use may affect its’ license to operate (Morrison and Gleick, 2004); where water shortages limit economic growth due to unsustainable use (TATA, 2013);
iv) where climate change and changing precipitation patterns impact on water security (Morrison *et al*, 2009);
v) where there is an absence of public policy engagements between corporates and governments around shared water risk in a catchment (Pegram *et al*, 2009);
vi) and where pollution arising from operations impacts other water users in the river basin (Mekonnen & Hoekstra, 2012).

Given these conditions at play, it is essential that agri-business enterprises use effective management tools to analyse the water-related risk and develop strategies for sustainable water resource management (SWRM).

Röckstrom *et al* (2009) argue that there are environmental preconditions for social and economic development, and that water-related tipping points exist on a planetary level that, when triggered, may result in "potentially disastrous and long-term implications for human civilization" (Röckstrom *et al*, 2014, p1250). The Humane Society of the United States argues that global trends in animal production are causing the environmental problems to become more harmful, and that intensive animal production is being separated from traditional crop farming systems where manure could be used as a fertilizer to replenish soil nutrients (HSI, 2016). Thus there is a spatial disconnect in the production value chain brought about by commercial trends. Moreover, the problem is not solved with an on-site efficiency approach to water resources management because the approach is inadequate in evaluating the freshwater environmental impact, or in managing water-related business risks of the whole beef production value chain. The Humane Society opposes feedlot production of beef meat. Its' views are therefore biased, but remain relevant as a respected institution that shapes public opinion. Fiksel supports the Human Society's observations, who argues that a systems approach is more credible because it allows a beef cattle feedlot enterprise to evaluate freshwater impacts across the production value chain and will enable a feedlot to transition towards a sustainable value chain water resources management model (Fiksel, 2006).

The Water Footprint Assessment (WFA) is part of a suite of 'footprint' tools used to measure the impact of human activities on the environment (Hastings & Pegram, 2011). The WFA is a framework of analysis that is capable of examining the link between product consumption and use of global water resources. Hoekstra and Chapagain (2007) describe the WF as the volume of freshwater used to produce the goods and services consumed by people. The WF recognises that there is a spatial disconnect between the place where consumption of everyday goods and services take place, and the place where the water use and freshwater impacts occur (Fulton *et al,* 2014). In essence, the water footprint of a product is the aggregate of consumptive water uses, both direct and indirect, throughout the entire production chain (Hoekstra *et al,* 2009). WF considers consumption (not withdrawals per se) of blue, green and grey water, which is in contrast to conventional water resource management that is limited primarily to direct water withdrawals for agricultural, industrial and domestic use (Hastings & Pegram, 2011).

2. RESEARCH QUESTION

This research aims to address the question: "Can the application of a Water Footprint Assessment (WFA) enable a beef cattle feedlot to transition from an on-site water-efficiency management approach to a value-chain based sustainable water resources management approach?”

Emphasis is placed on how the application of the WFA process contributes to greater understanding of water-related risks within the Feedlot’s beef production value chain. The scholarly undertaking of this thesis is to contribute further to knowledge and understanding of the application of the WFA at a feedlot enterprise scale. To date, most applications of WFA are at a national, regional or catchment scale.

3. RESEARCH AIM AND OBJECTIVES

The first aim is to apply the WFA to a beef cattle feedlot to determine if the methodology is suitable for examining the freshwater impacts and water-related risks of the production value chain of a beef meat producer.

The second aim is to examine the potential of WFA to enable a beef cattle feedlot to transition from an on-site efficiency approach to a sustainable value chain approach.

These aims will be undertaken by using three objectives:

i) To calculate the Bovine Water Footprint (L/kg carcass produced) for the 4-month winter- and summer production cycles undertaken by the Feedlot,

ii) To calculate the monthly Grey Water Footprint of waste management activities, and

iii) To use the outcome of the WFA to investigate how current water resource management practices are informed by the process.

4. STUDY SITE

The research study site is a large commercial beef cattle feedlot in Gauteng province. The selection of study site was based on factors that make it ideally suited for the application of a WFA. The site is located in the Vaal River Basin and in Gauteng province, which is the most industrialized, economically active and populous province in South Africa (Figure 1 and 2). The site is located in the Upper Vaal Water Management Area (WMA) where water resources are heavily abstracted and polluted by industrial, agricultural and domestic water use (Figure 3).

The Vaal River Basin (Figure 1) hosts three of the nine WMA’s in South Africa (DWAF, 2013): Upper Vaal, Middle Vaal and Lower Vaal WMAs. There is diversity in the “hydro-meteorological characteristics as well as nature and level of development in these WMAs”

(DWAF, 2002, p.VI). The Vaal River is the most regulated and developed river in southern Africa. Inter-basin and inter-catchment transfers play an important role in water provisioning in the region. “Although linked together by the natural watercourses, a particular characteristic of the [Orange]/Vaal WMAs is the extensive inter-catchment transfer of water within WMAs as well as inter-basin transfers between these and other adjoining WMAs” (Ibid, p.VI). Flow volume, flow regime and water quality are the foremost interdependencies within the [Orange]/Vaal (and other interlinked) WMAs (Ibid).

An increase in water demand from expanding urban areas in the province, together with increasing agricultural development (irrigation), pressure on water quality from industrial and mining pollution puts surface water resources under stress. Further growth in water demand is expected in this area due to ongoing economic growth and continued urbanisation. Water allocation decisions and water licensing must recognise the implications of the marginal potential for further water resource development. More than 80% of South Africa’s electricity requirements and around 50% of its GDP is produced in the Upper Vaal WMA. According to the Department of Water and Sanitation (DWS), the entire Vaal River System is at maximum capacity (DWS, 2015). Water resources are a potential constraint to economic development and a possible source of conflict within this urban-industrial landscape.

Secondly, the Feedlot is an industrial agri-business which relies on fresh water availability of acceptable quality year round. Water is abstracted directly from the Blesbokspruit River nearby.

The third factor is the availability of relevant data. The company keeps detailed records of water quality at the site and surrounding sites. Records of abstraction and effluent lagoon volumes are available and date back several years.

Figure 1: Water Management Area boundaries for South Africa (DWAF, 2013).

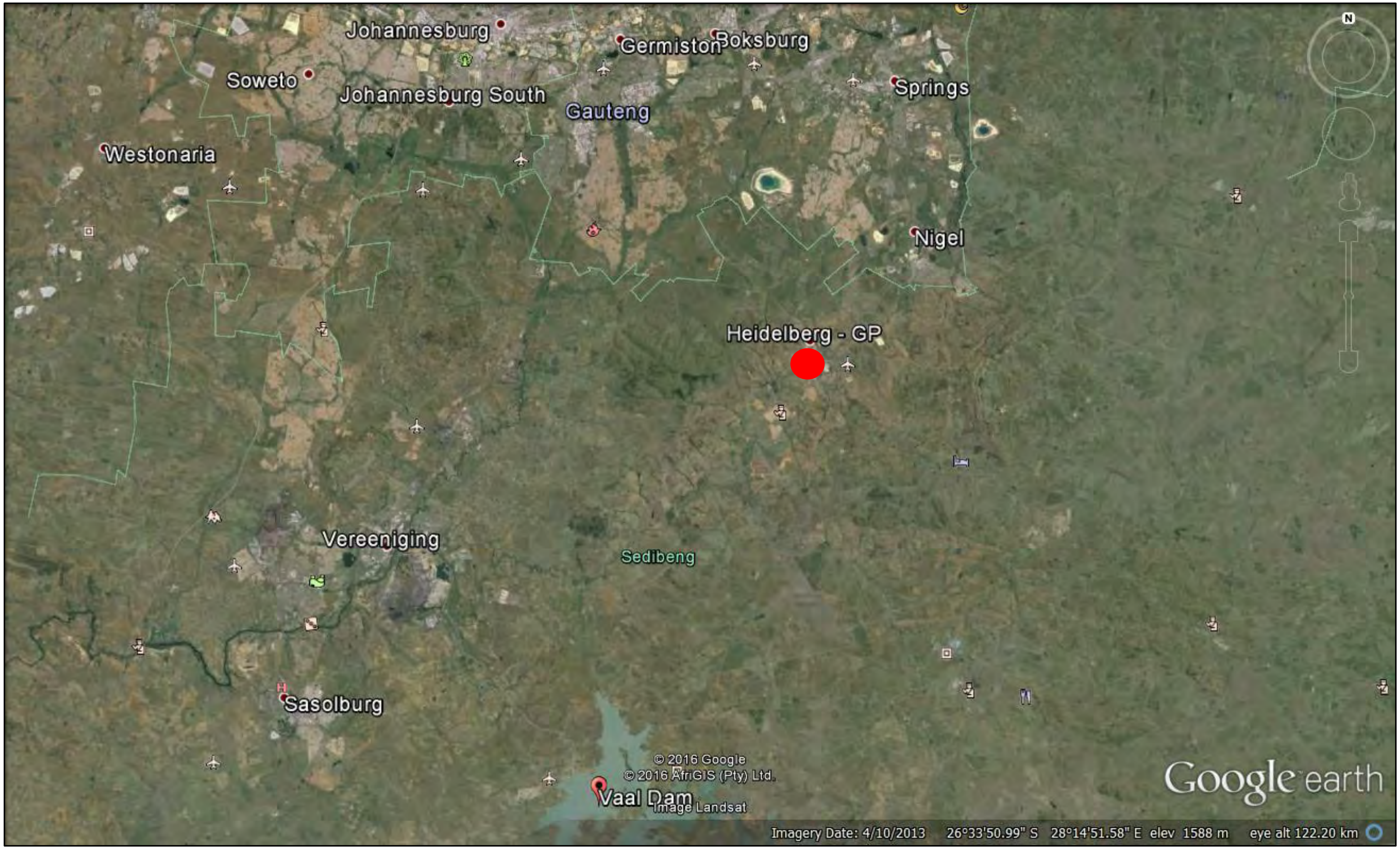


Figure 2: Study site location in Gauteng Province.

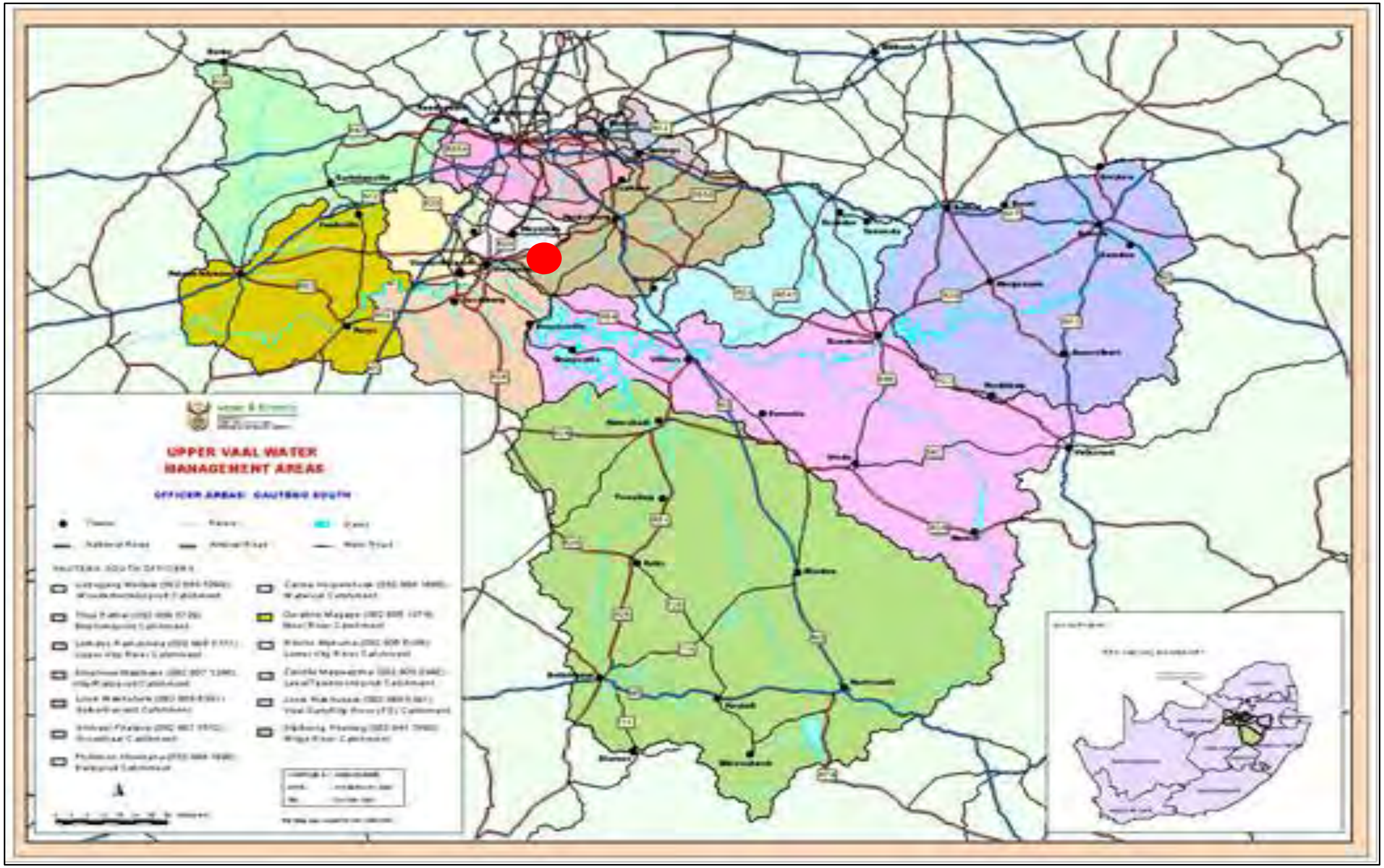


Figure 3: The study site relative to the Upper Vaal Water Management Area (DWAF 2002).

4.1. Study Site Location

4.1.1. Suikerbosrand Tertiary Catchment

The study site is the last downstream commercial water user within the Suikerbosrand tertiary catchment in the Upper Vaal Water Management Area (WMA) (Figure 3). The Upper Vaal WMA is the "most developed, industrialised and populous of the Orange/Vaal WMAs. *From a water resource management perspective it is a pivotal WMA in the country* (emphasis added)" (DWAF, 2002, p.VII). Significant volumes of water are transferred into the Upper Vaal WMA from the Thukela and the Usutu to Mhlatuze WMAs as well as from the Senqu (Orange) River in Lesotho. Large quantities of water are released along the Vaal River to the Middle Vaal and Lower Vaal WMAs and are artificially transferred to the Crocodile West and Marico, and the Olifants WMAs (Ibid).

The Suikerbosrand catchment is a tertiary catchment Number C21 located in the Suikerbosrand/Klip/Mooi secondary catchment (C2) within the Upper Vaal Water Management Area (WMA) (DWAF, 2002). (Figure 4). The Upper Vaal WMA was previously known as WMA8 in the 2004 National Water Resources Strategy classification, and included tertiary drainage regions C11 to C13, C21 to C23 and C81 to C83. In 2012 the Upper, Middle and Lower Vaal WMA's were combined into a single WMA, the Vaal WMA or WMA5 (DWAF, 2013) (Figure 1).

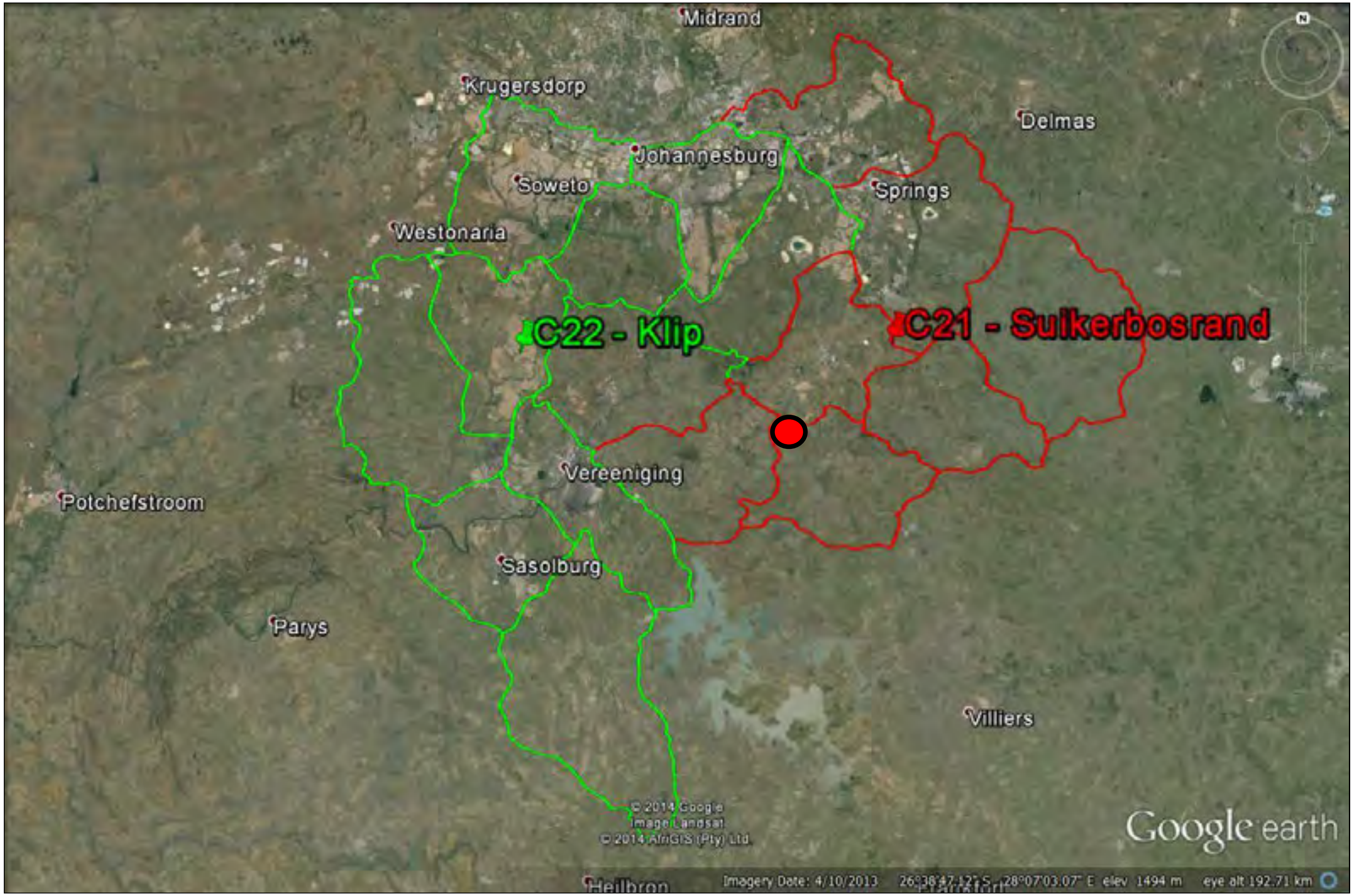


Figure 4: The study site relative to the Vaal Barrage Quaternary catchment boundaries - Suikerbosrand quaternary catchment boundaries in red. (personal communication from Blesbokspruit Forum, Marc de Fontaine, July 2014).

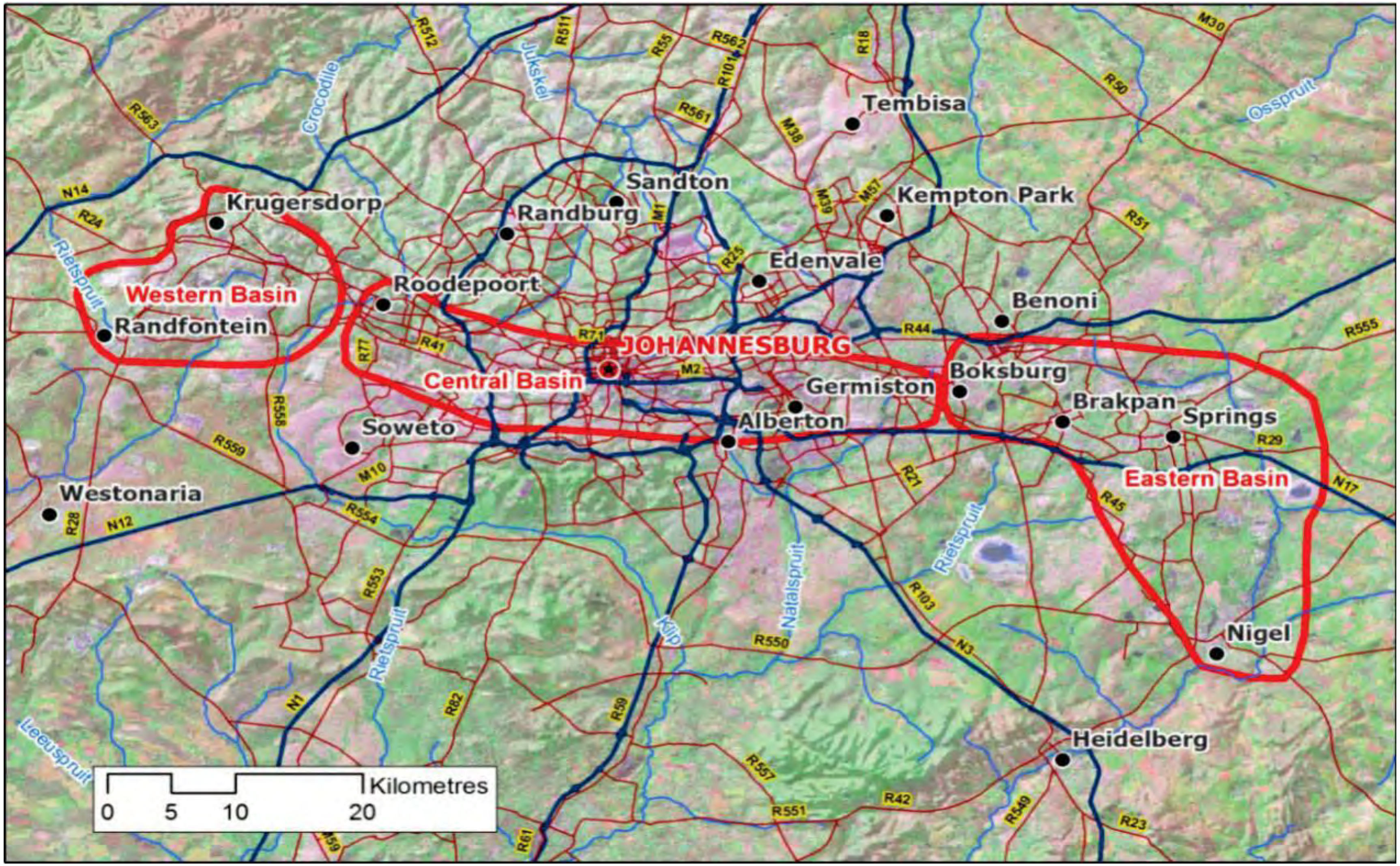


Figure 5: Locations of the Western, Eastern and Central basins in the Witwatersrand (Digby Wells, 2014)

Tertiary catchments C21 and C22 form the Vaal Barrage (Figure 4). The Suikerbosrand tertiary catchment (C21) is the focus of study. The catchment also falls within the Eastern Basin – an area defined by gold mining activities and groundwater drainage from depleted gold mines. The Eastern Basin covers the East Rand area and includes the towns of Boksburg, Brakpan, Springs and Nigel which fall under the jurisdiction of the Ekurhuleni Metropolitan Municipality in the Gauteng Province (Digby Wells, 2014) (Figure 5). Acid mine drainage (AMD) is an environmental legacy from more than a century of gold mining in the Eastern Basin. Attempts are currently being made to address the pollution impact from AMD, for instance through the partial treatment of AMD in the Blesbokspruit catchment which is the focus of an environmental impact assessment (Digby Wells, 2014).

The Upper Vaal WMA spans a catchment area of 55 565 km^2, and includes the very economically and socially important dams Vaal Dam, Grootdraai Dam and Sterkfontein Dam. Parts of Gauteng province, Mpumalanga province, Free State province and North-West province are included in the Upper Vaal WMA (DWAF, 2002). The Upper Vaal WMA forms a physical, economic and social link between South African and neighbouring countries Lesotho, Botswana, Namibia, Mozambique, Zimbabwe and Swaziland (DWS, 2015).

There is considerable variation in the climatic conditions from west to east across the Upper Vaal WMA. Mean annual temperature ranges vary between 16 °C in the west to 12 °C in the east, with an average of about 15 °C for the catchment as a whole. January is the hottest month, while minimum temperatures occur mainly in July. Rainfall occurs mostly in the summer period (October – April, with the peak rainfall occurring in December and January. Thunderstorms, sometimes accompanied by hail, characterises the rainfall of this region (DWAF, 2002). Mean annual rainfall over the Upper Vaal WMA decreases rather uniformly westwards across the central plateau area. Mean Annual Precipitation (MAP) for the watershed ranges 1000 mm in the east to 500 mm in the west; while the average MAP is around 700 mm. The relative humidity corresponds with this trend and is higher in summer than in winter. Humidity is mostly highest in February (the daily mean ranges from 65 % in the west to 70 % in the east) and lowest in August (the daily mean ranges from 62 % in the east to 55 % in the west). Average potential gross mean annual evaporation ranges from 1600mm in the east to a high of 2200 mm in the dry western areas (Ibid).

The Upper Vaal's total urban and rural population exceeds 5,6 million (1996 RSA Census) with the urban population being just over 5 million (Ibid). Urbanisation covers 1700 km^2 and accounts for about 60% of the total land use. Irrigation land use accounts for about 17% and alien vegetation covers about 20% or the land area. About 1 % of the land area is afforested (Ibid).

Table 1 shows the land use and population per tertiary catchment in the Upper Vaal WMA. Land use in the Suikerbosrand tertiary catchment is dominated by dryland crops, nature reserves and rural settlements. The urban population in the tertiary catchment covers only 0.45% of the land use. Available water resources from surface and groundwater sources per key area are shown in Table 2, while Table 3 indicates the water requirements per water use sector in each key area.

Table 1: Land use and population per key area in the Upper Vaal WMA (adapted from Table 3.5.1.1 in DWAF, 2002)

CATCHMENT				**Irrigation**		**Afforestation**		**Alien vegetation**		**Urban**		**Other ***		**Total (km^2)**	**Population**
SECONDARY		**TERTIARY**		**km^2**	**%**	**km^2**	**%**	**km^2**	**%**	**km^2**	**%**	**km^2**	**%**		
No	**Description**	**No**	**Key Area Description**												
C8	Wilge	C81 C82 C83	Wilge (C81A-M; C82A-H;C83A-M)	46.00	0.25	14.60	0.08	137.40	0.76	171.00	0.94	17 801.0	97.97	18170.00	523879
C1	Klip – C13	C13	Klip (C13A-H)	0.00	0.00	0.00	0.00	17.90	0.35	0.00	0.00	5164.10	99.65	5182.00	35295
	Grootdraai	C11	Grootdraai (C11A-L)	0.00	0.00	0.00	0.00	17.90	0.35	0.00	0.00	5164.10	99.65	5182.00	35295
	Grootdraai	C11 C12	Grootdraai to Vaaldam (C11M; C12A-L)	40.70	0.51	2.10	0.03	47.30	0.59	28.00	0.35	7876.90	98.52	7995.00	156254
C2	**Suikerbosrand**	**C21**	**Suikerbosrand (C21A-G)**	**26.60**	**0.36**	**0.00**	**0.00**	**15.60**	**0.21**	**33.00**	**0.45**	**7218.80**	**98.97**	**7294.00**	**259784**
	Klip	C22	Klip (C22A-E)	25.40	0.08	0.00	0.00	10.30	0.03	132.40	0.42	3372.90	10.69	31541.00	885576
	Mooi	C23	Mooi (C23D-K)	21.30	0.93	0.00	0.00	26.60	1.17	395.90	17.35	1838.20	80.55	2282.00	2 375 989
	Vaal Dam to Vaal Barrage	C22	Vaal Dam to Vaal Barrage (C22F-K)	45.10	0.90	0.00	0.00	15.80	0.31	155.00	3.08	4818.10	95.71	5034.00	532131
	Barrage to Mooi	C23	Barrage to Mooi (C23A-C; C23L)	29.20	1.03	0.00	0.00	72.40	2.56	119.90	4.24	2606.50	92.17	2828.00	797152
Total in Gauteng				63.8	0.78	0	25.10	0.77	0.00	0.00	6.00	0.19	0.00	0.00	3207.90
Total in Free State				77.3	0.29	14.6	63.80	0.78	0.00	0.00	74.70	0.91	731.20	8.91	7332.30
Total in Mpumalanga				62.7	0.40	2.1	77.30	0.29	14.60	0.05	191.60	0.71	210.10	0.78	26354.40
Total in North West				55.6	1.12	0	62.70	0.40	2.10	0.01	63.10	0.41	69.30	0.45	15370.80
TOTAL IN WMA				**259.4**	**0.47**	**16.7**	**55.60**	**1.12**	**0.00**	**0.00**	**19.90**	**0.40**	**24.60**	**0.50**	**4846.90**

* Other land use includes dryland crops, nature reserves and rural settlements for which information was not readily available.

Table 2: Water resources per key area in the Upper Vaal WMA (adapted from Table 6.1.1 in DWAF, 2002)

CATCHMENT				**Surface water resources ($10^6 m^3/a$)**			**Groundwater exploitation potential ($10^6 m^3/a$)**		**Total water resource ($10^6 m^3/a$)**	
SECONDARY		**TERTIARY**								
No	**Description**	**No**	**Key Area Description**	**Natural MAR**	**1:50 year developed yield in 1995(2)**	**1:50 year total potential yield**	**Developed in 1995**	**Total Potential**	**1:50 year developed in 1995**	**1:50 year total potential**
C8	Wilge	C81; C82; C83	Wilge (C81A-M; C82A-H;C83A-M)	868.3	64.1	64.1	4	84.6	68.1	148.70
C1	Klip – C13	C13	Klip (C13A-H)	291.1	7.6	7.6	0.7	22.1	8.3	29.70
	Grootdraai	C11	Grootdraai (C11A-L)	457.7	288.6	288.6	5	70.6	293.6	359.20
	Grootdraai	C11; C12	Grootdraai to Vaaldam (C11M; C12A-L)	360	109	109	2.2	50.1	111.2	159.10
C2	**Suikerbosrand**	**C21**	**Suikerbosrand (C21A-G)**	**92.4**	**99.8**	**99.8**	**1.3**	**42.7**	**101.1**	**142.50**
	Klip	C22	Klip (C22A-E)	96.2	293.2	293.2	3.7(1)	13.1	296.9	306.30
	Mooi	C23	Mooi (C23D-K)	113	16.3	16.3	9	25.1	25.3	41.40
	Vaal Dam to Vaal Barrage	C22	Vaal Dam to Vaal Barrage (C22F-K)	68.5	1691.7	1691.7	3.4	44.8	1695.1	1736.50
	Barrage to Mooi	C23	Barrage to Mooi (C23A-C; C23L)	75.6	-8	-8	4.5	32.4	-3.5	24.30
Total in Gauteng				855.6	NRA	NRA	7.4	120.6	NRA	NRA
Total in Free State				240.1	NRA	NRA	7.1	236.7	NRA	NRA
Total in Mpumalanga				1208.6	NRA	NRA	8.6	111.6	NRA	NRA
Total in North West				118.5	NRA	NRA	10.7	16.5	NRA	NRA
TOTAL IN WMA				**2422.8**	**2562.3**	**2562.3**	**33.8**	**385.4**	**2596.1**	**2947.7 [Ss(L1][Ss(L2]**

Notes : (1) Figure adjusted by WRSA consultant from 1,7 to 3,7 because Zuurbekom abstractions are 10 Mℓ per day (3,7 x $10^6 m^3/a$).

(2) Yield determined by the DWAF and includes impact of dam evaporation losses.

(NRA) Provincial split not readily available.

Table 3: Water requirements per key area at 1:50 year assurance (adapted from Table 7.2.2 in DWAF, 2002)

CATCHMENT				**Streamflow reduction activities**		**Water use**		**Water requirement**						**Ecological reserve**	**Total**
SECONDARY		**TERTIARY**		**Afforestation**	**Dryland Suger cane**	**Alien Vegetation**	**River losses(4)**	**Bulk**	**Irrigation**	**Rural**	**Urban**	**Water transfers out(1)**	**Neighbouring states**		
No	**Description**	**No**	**Key Area Description**												
C8	Wilge	C81; C82; C83	Wilge (C81A-M; C82A-H;C83A-M)	0.2	0.0	7.2	0.0	0.0	17.8	22.5	18.7	0.0	0.0	15.5	1089.0
C1	Klip	C13	Klip (C13A-H)	0.0	0.0	0.9	0.0	2.4	0.0	3.2	1.2	0.3	0.0	2.1	10.1
	Groot-draai	C11	Grootdraai (C11A-L)	0.0	0.0	2.3	0.0	39.1	21.7	11.1	7.3	125.9	0.0	13.5	247.0
	Groot-draai	C11; C12	Grootdraai to Vaaldam (C11M; C12A-L)	0.0	0.0	0.7	0.0	97.4	6.9	6.6	19.2	0.0	0.0	0*	1568.0
C2	**Suikerbosrand**	**C21**	**Suikerbosrand (C21A-G)**	**0.0**	**0.0**	**0.3**	**9.8**	**3.7**	**7.2**	**2.3**	**96.5**	**0.0**	**0.0**	**1.2**	**148.0**
	Klip	C22	Klip (C22A-E)	0.0	0.0	1.1	0.0	1.0	10.3	0.6	306.4	3.7	0.0	3.3	348.0
	Mooi	C23	Mooi (C23D-K)	0.0	0.0	0.5	11.9	3.9	40.3	3.4	25.3	0.0	0.0	11.4	130.0
	Vaal Dam to Vaal Barrage	C22	Vaal Dam to Vaal Barrage (C22F-K)	0.0	0.0	2.3	0.0	94.6	1.5	2.6	61.0	906.8	0.0	1.2	10970.0
	Barrage to Mooi	C23	Barrage to Mooi (C23A-C; C23L)	0.0	0.0	0.2	15.3	0.0	1.0	2.8	4.1	0.0	0.0	0.0*	456.0
Total in Gauteng				0.0	0.0	2.8	9.9	38.4	28.3	6.7	457.8	457.1	0.0	8.5	1009.5
Total in Free State				0.2	0.0	9.2	7.7	69.2	29.7	28.4	45.8	453.4	0.0	17.0	660.6
Total in Mpumalanga				0.0	0.0	3.1	0.0	133.6	28.4	17.8	26.8	126.2	0.0	14.1	350.0
Total in North West				0.0	0.0	0.4	19.6	0.9	27.3	2.2	9.3	0.0	0.0	8.6	68.3
TOTAL IN WMA				**0.2**	**0.0**	**15.5**	**37.2**	**242.3**	**113.7**	**66.1**	**539.7**	**1036.7(2)**	**0.0**	**48.2**	**2088.4(3)**

Notes: * Negative values for ecological reserve taken as zero (original author).

(1) Only potable water transfers considered.

(2) Total transfers (including those between key areas) = 1 036,7 x 10^6 m^3/a, transfers out of WMA are: 472 x 10^6 m^3/a to Crocodile West and Marico WMA (by Rand Water), 35,4 x 10^6 m^3 to Eskom in Olifants WMA and 0,3 x 10^6 m^3/a to Volksrust in the Thukela WMA (total of 507,7 x 10^6 m^3/a). The remainder are transfers within the WMA between key areas = 529 x 10^6 m^3/a.

(3) Total requirement in 1995 at 1:50 assurance: 2 088,4 x 10^6 m^3/a – 529 x 10^6 m3/a = 1 559,4 x 10^6 m^3/a because the internal transfers are accounted for in the water requirements of key areas.

(4) Evaporation losses from dams and wetlands not included. These losses including Wilge River losses are included in the yield determinations

Mean Annual Runoff (MAR) is 92.4 x10^6 m^3/a in the Suikerbosrand tertiary catchment the. The total potential 1:50 year yield from surface water resources is 99.8X10^6 m^3/a, indicating that water resources in the catchment is augmented by additional supply over and above the MAR. The surface water yield was already fully exploited in 1995. Groundwater resources present an opportunity for further development. DWAF estimated that the potential yield from groundwater resources is 42.7 x10^6 m^3/a. Only 1.3 x10^6 m^3/a has been developed from groundwater sources (Table 2).

The main water requirements in the Suikerbosrand tertiary catchment are urban supply, bulk supply, irrigation, rural supply, water transfers out of the catchment and water transfers to neighbouring water management areas (WMAs). Urban water requirements are by far the greatest demand at 96.5 x10^6 m^3/a, followed by irrigation (7.2 x10^6 m^3/a), bulk supply (3.7 x10^6 m^3/a) and rural supply (2.3 x10^6 m^3/a). River losses account for a further 9.8 x10^6 m^3/a in water used (Table 3).

The Suikerbosrand tertiary catchment's Present Ecological Status Class (PESC) is classified as category D (where PESC category A indicates a near natural landscape; B a largely natural landscape; C a moderately modified landscape; D a largely modified landscape; E a seriously modified landscape and F a critically modified landscape (DWAF, 2002). The ecological reserve (riverine ecological water requirement) for the Suikerbosrand quaternary catchment demands 9.4% of the virgin MAR, which accounts for 8.7 x 10^6 m^3/annum (Table 4).

Table 4: Water requirement for ecological component of the reserve (from Table 5.2.4.1 in DWAF, 2002)

Key Point	**Present ecological status class (PESC)**	**Riverine ecological water requirements for PESC**		
		% Virgin MAR	**Volume (10^6 m^3/a)**	**Impact on existing yield as 1:50 year yield * (10^6 m^3/a)**
Wilge (C83M)	C	13.4	116.4	15.5
Klip River (C13H)	C	13.4	39	2.1
Grootdraai (C11L)	E-F (use default D)	8.9	40.7	13.5
Grootdraai to Vaal Dam (C12L)	C	12.8	46.1	0 (-12.3)
Suikerbosrand (C21G)	**D**	**9.4**	**8.7**	**1.2**
Klipspruit (C22E)	E-F (use default D)	9.7	9.3	3.3
Mooi (C23K)	D	22.6	25.5	11.4
Vaal Dam to Vaal Barrage (C22K)	D	9.4	6.4	1.2
Barrage to Mooi (C23L)	D	9.7	7.3	0 (-2.2)

Note: * negative values are given as zero.

4.1.2. Study Site: A Large Commercial Beef Cattle Feedlot in Gauteng Province

The Feedlot is located near Heidelberg in the southern Gauteng Province, South Africa. This is the largest feedlot in Africa and houses approximately 130 000 heads of cattle at any one time of the year. The enterprise aspires to position its business for sustainable growth, and desires to maintain their leadership in setting the benchmark for quality South African beef. Feeds (mainly grains and fodder) are sourced through trade from within an approximately 200km radius around the feedlot. This area extends beyond the Suikerbosrand catchment and includes Swaziland, other SADC countries and various provinces in South Africa. A small amount of fodder is produced at the feedlot farm.

According to the management of the feedlot, a production cycle cohort of 130,000 cattle is finished every four months. Cattle enter the feedlot at 6 months of age and an approximate weight of 150kg. Cattle are slaughtered at approximately 10 months of age in this production system, at a minimum finished live weight of 250kg. Average hot carcass weight is 240kg. According to the operators, this feedlot supplies the country with 25% of its beef. The feedlot uses Brahman breed cattle (*Bos indicus*) for their hardiness and heat tolerance.

5. RESEARCH METHOD

As an overview, this study applies the WFA process in a local context to evaluate its contribution to SWRM and to understanding water-related risk dynamics within a catchment. Only existing available data is used and existing literature is used to augment data where gaps exist. The research process is summarised into two distinct phases:

Phase 1: data collection and calculation of the Feedlot's Bovine Water Footprint for average winter- and summer production cycles.

Phase 2: interaction with the facility's operational water management team to analyse the findings. The Feedlot's reliance on blue and green water is considered from a blue water scarcity (BWS) perspective. Conclusions are drawn regarding the facility's sensitivity to changes in the availability and quality of blue and green water in the product supply chain. The Feedlot's contribution to the nitrogen (N) and phosphorous (P) grey water footprint burden from animal wastes is calculated and discussed.

5.1. Scope and Limitations

The scale of the WFA is a commercial beef cattle feedlot in Gauteng province. The WFA is applied to the winter- and summer production cycles over a two-year period from January 2012 – April 2015.

The WFA is limited to available abstraction and water quality data from the study site's records and publicly available data concerning the Blesbokspruit/Suikerbosrand tertiary catchment from the Department of Water Affairs. Since the purpose of this dissertation is to test the application of the WFA process no new data will be generated using laboratory analyses or any other method.

5.2. Dissertation Structure

The introduction chapter discusses water-related supply chain risks and argues that the conventional process efficiency approach to water management provides limited insight into these risks to allow optimal sustainable water resource management strategies to be developed. The chapter introduces the concepts of Virtual Water and the Water Footprint of goods and services. It describes the purpose of- and approach to Water Footprint Assessment. The study site is introduced and the water resources in the catchment are briefly described.

Chapter 2 contains a detailed Literature Review. It discusses the current body literature on sustainability of an agri-business from a water resources perspective; the impact of beef cattle production on water resources; the water-related vulnerabilities of beef cattle feedlots that affect enterprise resilience; the body of Water Footprint literature and the trends in Water Footprint Assessment methodology.

Chapter 3 gives an in-depth description of the research methodology. The methodology for the four phases of a Level C WFA is described. The grey water footprint methodology has been developed in greater detail and the chapter describes how the study site's grey water footprint is calculated as well as the assumptions that are made regarding effluent runoff factors. The sources of data are identified.

Chapter 4 describes the study site. Water management practices on the site and within the catchment are discussed. Future changes in the catchment that may impact on water-related risks for the Feedlot are discussed.

The fifth chapter covers the data and the calculations for the WFA. The Bovine Water Footprint for winter- and summer production cycles are determined; as well as the monthly Grey Water Footprint of waste management activities.

The findings from the previous chapter are discussed in Chapter 6. Emphasis is placed on methodological challenges encountered with the Bovine Water Footprint and the Grey Water Footprint of waste management activities. Water Footprint components are discussed in terms of their risk to business resilience, and various options to improve the Water Footprint of each component are discussed.

The dissertation concludes in Chapter 7 with a discussion on the contribution made to water resources- and water-risk management through the application of the WFA at the Feedlot. Shortcomings of the use of the WFA at the local level are discussed. The chapter ends with recommendations for further research.

6. LITERATURE REVIEW

Primary agricultural production depends on both green (evapotranspiration) and blue (surface and ground) water. Although many other factors such as food distribution, agricultural subsidies and policy impediments collectively determine national and global food security, the production of food is directly dependent on both water and land (Molden *et al,* 2002).

One cubic meter (m^3) of crop evapotranspiration is required to produce approximately one kilogram of grain. In contrast, the production of one kilogram of beef requires around $13.5m^3$ of water, depending on whether animals mostly rely on grazing or on concentrated feed (Molden *et al,* 2002). Beckett and Oltjen (2011) estimate the water requirement of 1kg boneless beef at 3,682L/kg. Up to 40% of global grain production is used for animal feed (Röckstrom *et al,* 2014*).* Many cattle feeds are derived from grain by-products, such as maize chop, brewery by-products and by-products from the bio-energy industry, and forage or pasture which does not compete directly with human food production (Mekonnen and Hoekstra, 2010; Capper, 2012; Wilkinsin, 2011). Since the world's population is expected to increase by an additional 2 billion people by 2050 it is expected that consumption patterns will shift to a higher protein diet. Since land and global water resources are effectively limited, food production may need to increase by between 50-70% to meet this demand by obtaining more nutritional value per drop of water consumed in agriculture (Röckstrom, *et al,* 2014).

The production of meat products contributes 29% of the total agricultural water footprint for the world (Mekonnen and Hoekstra, 2010). Water is considered the "single largest nutritional component in the diet… in most intensive animal enterprises" (Pluske and Schlink, 2007, p.1). This is true for the feed and grazing required to rear beef cattle, as well as the actual drinking requirements for beef cattle. Consumption patterns are expected to change because of a growing middle-income population in South Africa (Schreiner, 2011) and follow the global trend to become more meat intensive. Increased beef consumption will place a greater burden on water resources at the local production scale. Concurrent pressures may expose a commercial beef cattle feedlot to increased water-related risk if fresh water consumption along the product value chain is unsustainable within its geographical location/s. Sustainable enterprises require resilience at many levels (Fiksel, 2006). Resilience of a commercial beef cattle feedlot depends on an "ability to integrate" three resilience capabilities - buffer capability, adaptive capability and transformative capability - to "address sudden shocks, unpredictable 'surprises' as well as slow-onset changes (Darnhofer, 2014, p.9). This prompts the need for further research on sustainable water resource management (SWRM) at a feedlot scale as well as an improved understanding of the production value chain that is required to increase enterprise resilience. Water Footprint Assessment may be a novel approach for a commercial beef cattle feedlot to gain a deeper understanding of the role of water in improving resilience and integrating SWRM into operational decision-making and management practice.

6.1. Sustainable Water Resource Management in a Beef Cattle Feedlot

6.1.1. SWRM at the Operational Scale of a Commercial Beef Cattle Feedlot

Water is considered to be an essential and critical nutrient for all breeds of beef cattle (Parish and Rhinehart, 2008). Water is absolutely necessary for the operation and growth of a commercial beef cattle feedlot and the welfare of animals (NSW, 2014). Beef cattle require water as a nutrient and for body temperature regulation through evaporation from the lungs and skin (Ibid). The most important aspects of water for beef cattle are sufficient quantities of fresh, cool drinking water (the volume required increases with increased ambient temperature, bovine body weight and life stage) and water quality that is acceptable and healthy for beef cattle (Ibid). The suitability of water for beef cattle is affected by salinity, pH, toxicity and algae (NSW, 2014). Chemical substances of particular concern to beef cattle are sulfates and phosphates from agricultural residues and acid mine drainage (AMD) due to the stimulation of algal blooms in standing fresh water (Dissertation Workshop Minutes, 2016. Appendix A). It is therefore reasonable for on-site water management and security of supply to be important components of SWRM for a beef cattle feedlot.

SWRM for a beef cattle feedlot must also consider environmental externalities such as diffuse water pollution impacts from effluent and manure. Effluent from feedlot pads and manure contain animal wastes such as urine and manure residues which may contain agricultural macronutrients such a nitrogen (N) and phosphorous (P), and micronutrients such as heavy metals which were added to feeds (Burkholder *et al*, 2007).

Röckstrom *et al* (2014) proposed a planetary freshwater boundary defined as the maximum consumptive blue water use, or “safe operating space”, in which the risk of abrupt and large-scale changes to the Earth System is unlikely. The global freshwater boundary is based on the role of water in “providing resilience through wetness of landscapes, providing water for ecological functions and services, and preventing water scarcity (Ibid, p. 1251). The planetary water boundary is the maximum average withdrawal estimated to be 2800km^3 year^{-1}. At a local level, the water boundary refers to the volume of freshwater requires by rivers to provide important ecological functions and maintain stability (Ibid). When water withdrawals from a river intrude on ecological needs it exceeds the blue water tipping point and a river is considered to be closed to further withdrawals (Ibid). The Orange River basin in South Africa, which includes the Vaal River basin, is among the list of global closed river basins. River basin closure signifies that the limit to traditional water development is fast approaching (Ibid).

A freshwater boundary at catchment level is the balance of available water resources in the catchment (surface and groundwater), minus the environmental flow requirement. Catchment-level ecological tipping points may exist and will be exceeded if unrestrained human demand for blue water leads to local water scarcity (increasing number of people rely on a unit of water) and local water stress (increased cost of access to- and mobilization of water resources) (Falkenmark, 2013; Röckstrom *et al*, 2014).

SWRM must enable a beef cattle feedlot to identify freshwater tipping-points in its operational catchment (where the feedlot is located), as well as freshwater tipping points in the catchments where animal feed is produced and where animal wastes as disposed. A beef cattle feedlot must be able to examine its contribution to human exploitation of blue water approaching the freshwater tipping points in those catchments where it operates, sources raw materials (feeds) from, and disposes of animals wastes, and determine SWRM goals that will contribute to sustainability and enterprise resilience. Röckstrom *et al* (2014) argues that resilience-based approaches to SWRM are needed to achieve water stewardship that ultimately supports the pursuit of human prosperity within “the safe operating space of a stable planet” (p.1257).

CAFOs, like all agricultural enterprises, exist within coupled social-ecological and agri-ecological systems with feedback loops between and among the domains (Vidal *et al,* 2009). Resilience of a system is widely quoted as “the capacity of a system to absorb disturbance and reorganise while undergoing change so as to still remain essentially the same function, structure, identity, and feedbacks” (Walker and Meyers, 2004; quoted in Vidal *et al,* 2009, p. 67). Cumming *et al* provides an alternative and useful definition to social-ecological resilience: “the ability of the system to maintain its identity in the face of internal change and external shocks and disturbances” (Cumming *et al,* 2005, quoted in Vidal *et al,* 2009, p.67). Resilience in agri-ecosystems then “has to do with limits, or thresholds, to change” (Vidal *et al,* 2009 p.67).

Agricultural enterprises function in agri-ecological systems that are not predictable and controllable and do not follow linear trajectories. In theory, water productivity of agricultural systems increase continuously along the transition trajectory from relying exclusively on green water (dry-land, rainfed crop production) to relying on blue water-dominated irrigated systems (Vidal *et al,* 2009). In fact, Vidal *et al* (2009) demonstrates that the continuum between blue-and-green water use in such systems often experience disruptive changes (ibid.) and are therefore vulnerable to unpredictable and complex shocks and changes. Beef cattle feedlots are exposed to the vulnerabilities of the green-to-blue continuum in agricultural production of feeds (cereals, concentrated bovine feeds, crop roughages and residues). Sudden shocks like drought may expose weaknesses in a blue water-dominated agricultural system and increase the cost and availability of feed, or may change the nutritional value of feeds. In order for a beef cattle feedlot to continue feeding grains and feed concentrates, the price of beef meat must remain high relative to the grain price (Steinfeld *et al,* 2006). SWRM for a beef cattle feedlot must take the vulnerabilities in the green-to-blue continuum into account when sourcing feeds and planning feed mixes.

6.1.2. Environmental Impacts on Freshwater Resources of Beef Meat Production in Industrial Systems

Traditionally beef cattle were reared on grazing systems at low density on large portions of land. As the demand for meat products increase due to human population growth and increased prosperity, meat production transitions from grazing, to mixed-industrial and to high-density industrial production systems, also called feedlots or Concentrated Animal Feeding Operations (CAFO). The type of feed used to produce beef meat transitions from low body-weight gain yielding silage and fodder to high body-weight gain grains and concentrated crop derivatives (Steinfeld *et al,* 2006).

Approximately 75% of all beef meat produced in South Africa are produced in feedlots (DAFF, 2014). Environmental impacts on freshwater resources of beef meat production in industrial systems “can be generated by both freshwater consumptive and freshwater degradative use” (Zonderland-Thomassen *et al*, 2014 p.253) and occur in three main components of the production supply chain: feed production, feedlot operations and waste management.

Feed Production

Meat production from cattle requires particularly large amounts of feed per unit of meat product (Mekonnen and Hoekstra, 2010). Wilkinsin differentiates between human edible and human inedible crops. Accordingly, it is estimated that 5,9kg fresh concentrate feeds are required to produce 1kg beef meat, of which 2,9kg is human-edible concentrate feeds (Wilkinsin 2011). Globally beef cattle consume approximately 110-million ton/yr cereals, 15-million ton/yr root crops, 15-million ton/yr brans and 15-million ton/yr oil meals (derived from cotton, soya, wheat etc) (Ibid). The feed mix used in this dissertation is largely dominated by maize and maize-derived products. According to the Department of Agriculture, Forestry and Fisheries (DAFF, 2014) “maize is the most important grain crop in SA, being both the major feed grain and the staple food of the majority of the South African population" (Ibid p.9). The majority of the maize crop (52%) is yellow maize, which is used for animal feed (Ibid). In 2013 the estimated land area under commercial maize cultivation was 2,781 million ha – 3,0% more than the previous season and 6,6% more than the five-year average planted up to 2011/12 (Ibid). 41% of the maize production occurs in the Free State, followed by Mpumalanga (26%) and North West (14%). 13,8% of the area planted under yellow maize is under irrigation and the remaining 86,2% is dryland (Ibid). The average water footprint of maize production per province in South Africa is 1661m^3/ton green water, 34 m^3/ton blue water and 131 m^3/ton grey water (Mekonnen and Hoekstra, 2010a).

Diffuse pollution from agricultural pollutants nitrogen (N) and phosphorous (P) can cause and increase in salinity of water and soil, and lead to algal blooms (Parish and Rhinehart, 2008; Zonderland-Thomassen *et al,* 2014)

Feedlot Operations

Consumptive use of blue water leads to environmental impacts associated with feedlot operations. Blue water is consumed by beef cattle and used for dust control; for bovine temperature control; and for services such a washing vehicles, washing watering troughs and washing cattle (washing of animals is a common practice in the US due to extreme cold and wet winter conditions causing animals' hides to be covered in mud, but is not practiced in South Africa) (Mekonnen & Hoekstra, 2010)

Waste management

Degraded water use (grey water footprint) refers to the management and disposal or dispersion of feedlot pad effluent and dry manure, and often collects in effluent lagoons. Dry manure is a sought-after organic fertiliser due to its ability to improve soil properties and soil replenish nutrients (Van Averbeke and Yoganathan, 1997). Over-application of beef cattle manure, as well as inappropriate application during rainfall events, can lead to elevated levels of N and P in soil. Excess N and P can enter freshwater bodies through leaching and runoff where it may lead to over-stimulation of aquatic systems and eventually cause eutrophication, water odour and taste that is unsuitable for livestock, and excessive bacteria load (Mekonnen & Hoekstra, 2010; Steinfeld *et al*, 2006; Parish and Rhinehart, 2008; NSW, 2014). "The two most commonly recognised symptoms of eutrophication are harmful algal blooms and hypoxia. Due to human activities, bioavailable N as nearly doubled and bioavailable P tripled in the environment. Agriculture, sewage, urban runoff, industrial wastewater and fossil fuel combustion are the most common anthropogenic sources of nutrients delivered to freshwater systems… In South America, Asia and Africa, animal manure and sewage are often an important anthropogenic cause of eutrophication.” (Liu *et al,* 2012 p.42).

Nutrient intake by livestock is very high. For example, dairy cows consume 163,7kg/yr N, but retain only 34,1kg/yr and excrete 129,6kg/yr (69%). The same dairy cow will consume 22,6kg/yr P and excrete 73% (16,7kg/yr). Beef cattle manure typically contains 32,5% N and 6,7% P (Steinfeld *et al*, 2006).

6.2. Water-related Vulnerabilities of Beef Cattle Feedlots Relevant for Resilience

Beef cattle breeds like *Bos indicus* and *Bos indicus*-infused breeds (Brahman breed cattle) which are commonly used in South African conditions are adaptable to hot, dry conditions and can survive periods of short-term water deprivation (Parish and Rhinehart, 2008). ~~However, cattle are vulnerable to long periods of water restriction which will lead to thirst, animal dehydration, production losses and stress (ibid.).~~

Dust is a health issue for beef cattle feedlot, as it exacerbates respiratory diseases (Dissertation Workshop Minutes, 2016. Appendix A). Spraying water on feedlot pads and road surfaces is a common dust-control mitigation strategy. During drought periods when water use must be optimized, feedlot cattle may suffer more from respiratory diseases (Dissertation Workshop Minutes, 2016. Appendix A). Water pH affects the palatability and a pH lower than 5,5 can lead to reduced feed intake and acidosis in beef cattle (Parish and Rhinehart, 2008). Salinity is a critical indicator of the suitability of water for beef cattle, and high levels of total dissolved solids (TDS) in water will reduce feed intake and daily body weight gains (NSW, 2014; Parish and Rhinehart, 2008).

Water containing Acid Mine Drainage (AMD) may contain high levels of sulfates (Dissertation Workshop Minutes, 2016. Appendix A) and other toxic chemicals like cadmium, mercury, arsenic, chloride iron, chromium, vanadium, molybdenum and lead (Ibid). Organic effluent containing high phosphate levels (such as Waste Water Treatment Works outlets and contamination caused by animal fouling of river banks) will lead to toxic blue-green algae blooms. Blue-green algae produce nerve- and liver toxins that can lead to the death of beef cattle (Ibid). Blue-green algae can also build up easily in drinking troughs due to food and spittle falling into the water from cattle mouths. Nitrates from agricultural fertilizers or from cattle manure can cause nitrate poisoning and lead to reduced feed intake and low growth rates (Ibid).

6.3. Tools and Models for Water Resource Management for a Beef Cattle Feedlot

The agricultural sector has a long history of applying sophisticated tools and models for optimal water use, especially for rain fed and irrigated crops. The United Nations' Food and Agriculture Organisation's decision support tool such as CROPWAT8.0 for Windows (FAO, 1998) and databases like AQUASTAT (FAO, 2014) and AQUACROP 5.0 (Steduto *et al,* 2009) provide farmers with mechanisms to optimize crop yields from water application, given complex climatic, soil and water scenarios. In Australia H2OBeef is used to model the economic value of water for beef feedlots to raise the profile of water as a cost driver in these enterprises (Pluske and Schlink, 2007). The SA Feedlot Association prescribes feedlot codes related to animal treatment and environmental issues (SAFA, 2015). The reference to water management is that cattle have the right to unrestricted access to fresh feed and water at all times; water troughs should be sited in relation to feedbunkers such that the animals cannot easily foul the water with feed still in their mouths and they can be easily inspected (SAFA, 2015).

6.4. Water Footprint in Sustainable Water Resource Management for a Beef Cattle Feedlot

"One-third of the global water footprint of animal production is related to beef cattle" (Mekonnen and Hoekstra, 2012 p. 413). Beef cattle feedlots function within local, regional and sometimes global supply chains. Mekonnen and Hoekstra (2012) argue that although animal products are widely known to be water intensive, the water use impacts of the total livestock supply chain have not received much attention. Production of animal feed contributes the majority water use in the animal products supply chain. Due to global trade in feed crops and animal products, and advances in meat preservation technology that allows transport of perishable animal products over greater distances, "consumers of animal products have often become spatially disconnected from the processes necessary to produce the products" (Mekonnen and Hoekstra, 2012 p.402), and the impacts of those processes on freshwater resources (ibid.).

Animal waste disposal, specifically the distribution of cattle manure, is another spatial disconnect between the place where a product is produced, and the place where impacts on freshwater resources occur. For producers of animal products, the supply chain impacts of feed production and the 'downstream' impacts of animal waste disposal are often regarded as 'environmental externalities' (author's own observation). SWRM for a beef cattle feedlot should recognise the spatial disconnect between the impacts of production of animal feeds and the impacts of feedlot operations, and include supply chain- and animal waste disposal impacts on water resources in enterprise sustainability goals.

Water Footprint Assessment (WFA) differs from before-mentioned models and tools for water resource management, in that it links the impacts of production on freshwater resources along the supply chain to the consumption of food, goods and products. WFA can be used in SWRM to account for environmental externalities and improve enterprise resilience.

6.5. Water Footprint

6.5.1. Overview of the Water Footprint

Origin and Purpose

The Water Footprint was developed by the Water Footprint Network (Hoekstra *et al,* 2011; Launiainen *et al*, 2014). The purpose of the Water Footprint is to demonstrate that the production of goods and services have affects freshwater resources in locations that are geographically removed from the production location (ibid).

Overview of the Water Footprint Concept

The Water footprint (WF) differs from the carbon footprint (CF) in that it focuses on the quantification of water use, but does not reveal the extent of environmental or social impacts of water use. Unlike the CF, the WF developed independently from the Life Cycle Assessment (LCA) and focuses on the quantification of water use rather than aggregated index (Jeswani and Azapagic, 2011). According to Jeswani and Azapagic (Jeswani and Azapagic, 2011, p.1288) the WF “does not reflect the potential environmental (and social) impacts of water use, which are important from the LCA perspective”. The WF expresses water use on a volumetric basis, which “is useful from water-resource management perspective” (Jeswani Ibid).

Several water-accounting methodologies exist to account for water use. These have evolved from different perspectives and have different objectives. The three most relevant water accounting methodologies are WFA, LCA and the Global Water Tool (GWT). A fourth methodology was recently introduced to address the specific needs of water accounting for industrial users – the Industrial Water Accounting Methodology (Schornagel *et al,* 2012) (see Table 5).

Table 5: Overview of available water-accounting methodologies (after Schornagel *et al* 2012)

Methodology	**Perspective**	**Objective**
Life Cycle Assessment	Environmental impact assessment	Assessment of aggregated environmental impacts of products (Hoekstra *et al,* 2009; Riddout *et al,* 2011).
Water Footprint	Water resource management	About a measurement of sustainable, equitable and efficient freshwater use and allocation (Hoekstra *et al,* 2009).
Global Water Tool	Contextualisation of corporate water demands	Compilation of water-related data for assessment and communication of water-related risk.
Industrial Water Accounting	Industrial operations	Reduction of water-related risks and seizing water-related business opportunities for both industrial sites and industrial pathways.

Since the 1990's the WF concept has seen substantial development in scientific literature (Fulton *et al,* 2014). The WF compliments the virtual water concept in contributing detail on the characteristics of water consumption, such as whether surface or rainwater is consumed, the source of the water and the water use over time (Hastings & Pegram, 2012). The WF is an explicit representation of the spatial and temporal aspects of the volume of freshwater associated with the production of a good or service along the entire supply chain (Hoekstra *et al,* 2001). In order to understand water dependencies and risks, it is therefore necessary to understand the nature of water use (the WF) and the social and environmental context of the water resource in its local context (ibid.).

The WFA calculates the volume of freshwater consumed in the production of a product. Consumption occurs when water is removed from the river basin for the purpose of a production process which includes trade in the products, through evaporation or via discharge of waste water into another watershed. The WF therefore does not refer to water withdrawals, but as consumed water (Hoekstra *et al,* 2011).

The Water Footprint Manual is the standard for WFA endorsed by the Water Footprint Network (Ibid) and it makes a distinction between direct and indirect water consumption. Direct consumption is water consumed in the production process and is limited to, for instance, a single production facility. Indirect water consumption refers to the water used in the entire supply chain, such as irrigation water required for growing crops. Indirect water consumption often far exceeds direct water requirements (Hastings & Pegram, 2012).

The Water Footprint Manual divides a WF into three distinct components: the blue WF describes the volume of surface or groundwater required to produce a good or service, and links closely with the water withdrawal focus of traditional water resources management. Blue WF in industrial and agricultural settings is often associated with pumped or piped water from a dam, river, canal, reservoir or underground (Schornagel *et al* 2012). The green WF is the volume of rainwater which is temporarily stored in, or on top of, the soil, or is evaporated by crops. Green water by definition does not recharge groundwater and does not run off to surface water sources. The grey WF refers to the volume of freshwater required for the assimilation, or dilution, of a pollution load relative to existing ambient water quality standards (Hastings & Pegram, 2012). The grey WF is consequently a measure of the volumetric burden of effluent on the receiving water source, and is an indicator of effluent quality, or the volume of dilution needed to achieve acceptable concentrations and water quality.

The WF Manual makes a further distinction between consumptive and non-consumptive use. Water that is incorporated into a product, returned to a different watershed, evapo-transpirated, or returned to the original watershed at a different time, is defined as consumptive water use. Non-consumptive water use refers to water that is returned to and made available for other uses in the same watershed (Ibid) (see Figure 7).

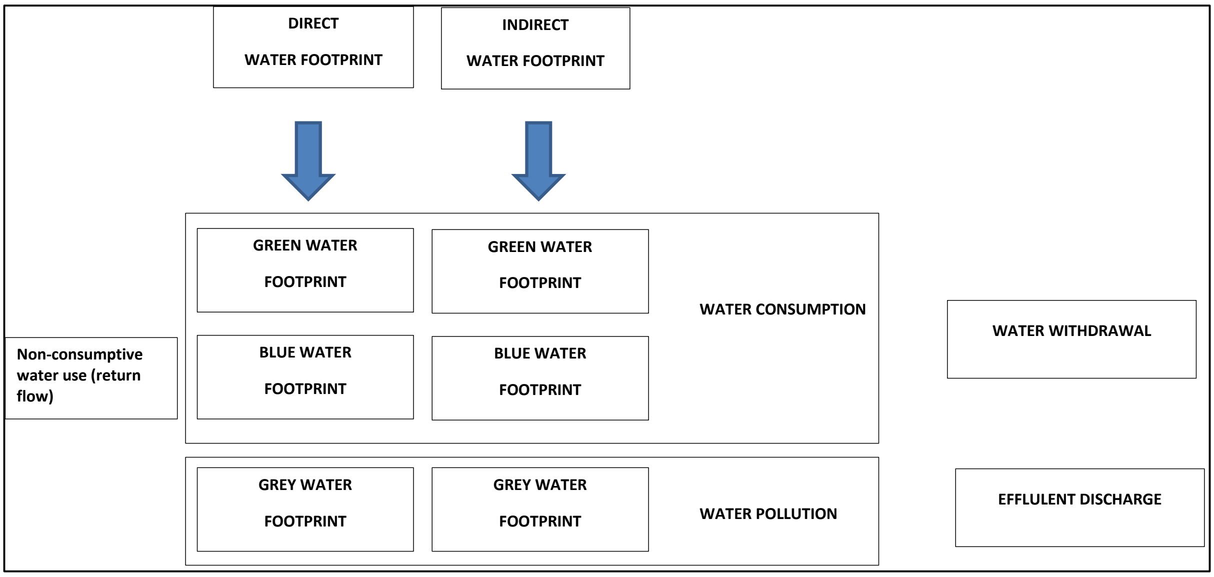


Figure 7: WF components based on the Water Footprint Assessment Manual (Hoekstra *et al,* 2011).

The *Water Footprint Manual* states that the WF is a “volumetric measure of water consumption and pollution” (Hoekstra *et al,* 2011, p.3). Volumetric measures are not intended to be a “measure of the severity of the local environmental impact of water consumption and pollution” (Hoekstra *et al,* 2011, p.3). The local characteristics of the basin where the activity takes place

- human demographics, local water demand, water scarcity, ecological and geological conditions, and water quality - provides the necessary context to determine vulnerability of the local water system (Hoekstra *et al,* 2011; Jeswani and Azapagic, 2011).

The scale of application is a key consideration in this study. WFA can be applied at various scales. A national WF uses national units of analysis which are functionally the average of potentially diverse and smaller constituents (Fulton *et al,* 2014). National WFs are useful for global and regional policy makers concerned with the impact on water resources by trade in commodities, manufacturing and production, but may have little relevance for a local basin management association concerned with local nuances of urbanisation and industrial growth. For the same reason, a national WF may not be relevant to an agri-business enterprise seeking to reduce its vulnerability to disruption (Schornagel *et al,* 2012). The WF of a smaller unit may differ materially from a larger unit, for two reasons: 1) decision-making and the capacity to enact policy may differ; and 2) the connections between global water resource concerns and consumption patterns (the so-called "phenomenon of interest") may also differ (Fulton *et al,* 2014). Fulton *et al* (2014) argues that WF is relevant for policy when "scaled to analytical units where water-related decision making occurs" (Ibid, p.1). Scaled appropriately, a local WF may suggest specific policy options and vulnerabilities that "do not emerge in national-level assessments" (Ibid, p.1) and may inform sustainable water resource management (SWRM) at the local level.

Water Footprint Assessments at Different Geographical Scales

WFA can be applied at various scales. A national WF uses national units of analysis, which are functionally the average of potentially diverse and smaller constituents (Fulton *et al,* 2014). National WFs are useful for global and regional policy makers concerned with the impact on water resources by trade in commodities, manufacturing and production, but may have little relevance for a local basin management association concerned with local nuances of urbanisation and industrial growth. For the same reason, a national WF may not be relevant to an industrial operation seeking to reduce its vulnerability to disruption (Schornagel *et al,* 2012). The WF of a smaller unit may differ materially from a larger unit, for two reasons: 1) decision-making and the capacity to enact policy may differ; and 2) the connections between global water resource concerns and consumption patterns (the so-called "phenomenon of interest"), may also differ (Fulton *et al,* 2014). Fulton *et al* argues that WF is relevant for policy when "scaled to analytical units where water-related decision making occurs" (Ibid, p.1). Scaled appropriately, a local WF may suggest specific policy options and vulnerabilities that "do not emerge in national-level assessments" (Ibid, p.1).

The WFA has been applied at a global, national, provincial, river basin, product and supply chain scale (Chapagain *et al,* 2006; Van Oel *et al*, 2009; Ridoutt *et al,* 2011; Hoekstra and Mekonnen, 2012; Zeng *et al,* 2012; Ercin *et al,* 2013; Fulton *et al,* 2014; Launiainen *et al,* 2014; Schyns and Hoekstra, 2014; Zonderland-Thomassen *et al,* 2014). It has been used as an analytical tool to quantify the virtual water burden of products and processes across temporal and geographical scales (Van Oel *et al*, 2009; Fulton *et al,* 2014). The WFA has also been used to identify dependencies on blue and green water resources in countries, provinces or states and river basins (Ercin *et al,* 2013; Fulton *et al,* 2014; Zeng *et al,* 2012).

Considerable focus has been placed on global, national and catchment-level WFAs, as well as product WF's for cotton, coffee and steel (Chapagain *et al,* 2006; Eriyagama *et al*, 2011; Unger *et al,* 2013), and international virtual water flows for trade in agricultural and industrial products (Mekonnen & Hoekstra, 2011). These investigations are mostly concerned with the interactions between national and subnational units in terms of the WF of traded products, that is, the "virtual water flows" (Fulton *et al,* 2014). More research is required to test the effectiveness and purpose of the WFA at the level of a single water user in a river basin (Ibid)

Some authors recommend the application of WFA at a scale that is relevant to individual jurisdictional units, that is at the decision-making level (Ibid). A few WFA's have been applied to the catchment or basin level (Zeng *et al,* 2012), or even to the production of a single food product within a country, such as beef cattle in New Zealand (Zonderland-Thomassen *et al,* 2013), and have been useful in informing decision making at those levels.

Grey WF Supporting Guidelines

The WFA Manual describes three tiers of increasing complexity in approaches to estimate "diffuse pollution loads entering a water body" (Franke *et al,* 2013, page 7). Tier 1 uses leaching run-off fractions derived from existing literature for specific chemical compounds; Tier 2 uses simplified and standardized models and utilizes easily obtainable data like climatic and topographic data, soil characteristics and chemical properties; and Tier 3 makes use of sophisticated modelling and intensive measurement (Franke *et al,* 2013).

Recent studies to determine grey water footprints of regions, particular products or activities focus on the pollution burden of nitrogen (Aldaya and Hoekstra, 2010; Bulsink *et al,* 2010; Dabrowski *et al,* 2009; Gerbens-Leenes *et al*, 2009; Mekonnen and Hoekstra, 2010, 2010a; Van Oel *et al,* 2009)

The complexity of water quality impacts and the “lack of guidance and reference values” (Franke *et al,* 2013, page 8) necessitated the development of Tier 1 supporting guidelines on the assessment of the grey WF component (the Grey WF Guidelines). The Grey WF Guidelines address three issues, namely “i) how to estimate the leaching run-off fractions depending on the chemical substance, environmental conditions and application practices; ii) the water quality standards to use in calculations; and iii) assumptions regarding natural background concentrations” (Franke *et al,* 2013, page 8). The Grey WF Guidelines are used in this study to examine the grey WF at a beef CAFO.

6.5.2. The Water Footprint of Beef Production

The global WF for animal production amounts to approximately 2422Gm^2 per year, of which around 807Gm^2 is attributed to beef cattle (Mekonnen and Hoekstra, 2010). Three key factors play a role in the WF of animal products, namely the animal’s feed conversion efficiency (Mekonnen and Hoekstra, 2010; Simpson, 1998); the composition and origin of the feed (Mekonnen and Hoekstra, 2010). Beef cattle have low feed conversion efficiency (FCE) and therefore beef production has a large WF compared to other animal products (beef production requires eight times and eleven times more dry matter feed per kilogram of meat respectively than meat produced from pigs and chicken) (ibid.). Wilkinson states that the feed conversion ratio (FCR) for UK beef is 5,9kg concentrate feeds to 1kg beef product, whereas the FCR for pig meat is 4,0kg concentrate feed/kg meat product and that for poultry meat and eggs are 2,3kg and 2,5kg respectively (Wilkinson, 2011). On average the WF of one live ox over its lifetime (average 3 years) is 1889m^3/animal. This is equal to 630m^3/yr/animal (ibid.).

Blue, green and grey WFs for beef cattle differ between grazing and industrial production systems. Grazing systems tend to have larger WFs overall, whereas industrial systems (like CAFO) have the smaller WF overall. The larger WF of grazing systems is attributed to the comparatively large green WF component (evaporation on grazing fields). Industrial systems have smaller green WFs, but significantly, higher blue and grey WFs attributed to concentrate feed (ibid.). From a water resources perspective industrial systems are more favourable, given that “freshwater problems generally relate to blue water scarcity and water pollution and to a lesser extent to competition over green water” (Mekonnen and Hoekstra, 2010, page 24).

Water Footprint Approaches for Beef Cattle

Two approaches to water footprint assessment dominate the science (Zonderland-Thomassen, 2014). The LCA approach to water footprinting was developed by life cycle assessment scientists (Ridoutt and Pfister, 2010), while the water footprint approach developed by the Water Footprint Network (WFN) was developed by water resource management scientists (Hoekstra et al, 2011; Zonderland-Thomassen et al, 2014).

Water footprint assessments based on the WFN method have been published for farm animals and farm animal products (Mekonnen and Hoekstra, 2010; Mekonnen and Hoekstra 2012); for production (not limited to food production) in countries (Ercin *et al,* 2013) and river basins (Zeng, *et al,* 2012). The global average WF of beef cattle is expressed in litre/kg carcass and amounts to 10,244L/kg carcass over the lifetime of a beef cow (Mekonnen and Hoekstra, 2010). The WF of beef produced in industrial systems of selected countries are as follows (ibid):

- Australia: 5,130L/kg
- Brazil: 8,812L/kg
- China: 13,089L/kg
- India: 14,749L/kg
- Netherlands: 4,508L/kg
- Russia: 25, 464L/kg
- USA: 3,856L/kg

These values do not provide an indication of the impact of water consumption by themselves. The blue water scarcity of a river catchment of country is determined by dividing the sum of the water footprints of production by the water availability in the same area. Water availability is determined by abstracting the environmental flow requirement from the total volume of available freshwater (Hoekstra, 2011).

Case studies on the water footprint of beef cattle in southern Australia and New Zealand followed the methodology consistent with Life Cycle Assessment (LCA) (Ridoutt *et al,* 2014; Zonderland-Thomassen *et al,* 2014), and use a stress-weighted water footprint as an indicator of the impact of blue water consumption (Zonderland-Thomassen *et al,* 2014). In these studies water scarcity is expressed in terms of L H_2O-eq/kg live weight (LW); and eutrophication potential is expressed in terms of phosphate equivalents (PO_4^{3-}) and chemical oxygen demand (COD).

In their 2011 study on comparing the carbon- and water footprints of six geographically distinct beef cattle production systems using the LCA method based on Riddout and Pfister (2010), Riddout *et al* (2011) estimated the WF of 1kg live weight beef ranges between 3,3 and 221 L H_2O equivalent. Capper (2012) estimated the WF of conventionally produced beef, that is, non-grass-fed beef and utilizing growth-enhancing technology, at 32,864L/kg hot carcass for beef produced in the U.S. This estimate considered animal drinking water and water used to irrigate crops, comparable to the blue water footprint in the WFA of this study. In both examples, the green WF of crop production is not considered.

While the two methods (LCA and WFA) differ significantly in approach and estimate significantly different results, both methods reach a similar conclusion that the greatest water consumption impact in the production of beef meat is associated with the water consumption of the production of feed.

6.5.3. Water Footprint Assessment in Sustainable Water Resource Management for a Beef Cattle Feedlot

Water Footprint identifies direct and indirect water footprint components of a production of a product such as beef meat within a spatial and temporal context. This allows the spatial and temporal assessment of water-related risks (for example, reliance on well-developed blue water systems or green water imports), freshwater impacts and resilience aspects of each component. For this reason, it is expected that WF can potentially enable SWRM of a beef cattle feedlot to strengthen enterprise resilience to stresses and shocks, account for environmental externalities and enable the feedlot to achieve sustainability goals along the whole meat production supply chain.

Steinfeld *et al* (2006) in *Livestock's Long Shadow* identifies nitrogen (N) and phosphorous (P) as the main pollutants associated with livestock production. Nutrient surpluses in beef cattle manure "can overwhelm the absorption capacities of local ecosystems and degrade surface and groundwater quality" (Steinfeld *et al,* 2006 page137). The grey water footprint of animal waste management can allow a beef cattle feedlot to identify environmental impacts and apply management practices that reduce environmental impacts of manure and effluent disposal.

6.6. Relevance of This Dissertation

This dissertation is positioned within the academic literature that is concerned with sustainable water resources management at a Concentrated Animal Feeding Operation and in works that seek to apply the Water Footprint Assessment tool.

7. WATER FOOTPRINT ASSESSMENT METHODOLOGY

The methodology used in this thesis is based on the definitions and methodology of the Water Footprint Manual – Setting the Global Standard (Hoekstra *et al*, 2009). This thesis distinguishes between two themes for the water footprint of the beef cattle feedlot: firstly, the water footprint of feedlot beef cattle for three annual 4-month production cycles (Bovine Water Footprint) and secondly, for the waste management activities corresponding to the same 4-month production cycles (Grey Water Footprint of Waste Management Activities).

For the water footprint of feedlot beef cattle, methodological guidance is taken from the further methodological development by Mekonnen and Hoekstra for the calculation of the green, blue and grey water footprint of crops, derived crop products; and the calculation of the green, blue and grey water footprint of farm animals and animal products (Mekonnen and Hoekstra 2010a and 2010). The determination of the grey water footprint of waste management activities for the feedlot is guided by the Grey Water Footprint Accounting Tier 1 Supporting Guidelines (Franke *et al,* 2013).

The Water Footprint Manual uses a phased approach to the water footprint calculation process (Hoekstra *et al,* 2009). The four phases were applied in the research process. Phase one deals with setting goals and scope (boundaries) for the assessment; phase two is the water footprint accounting phase; in phase three the sustainability of the Water Footprint components of feedlot beef cattle and feedlot waste management activities is considered and in phase four options and strategies to achieve the Water Footprint goals are discussed.

Finally, the usefulness of the Water Footprint method as a tool to enable the feedlot to achieve business-relevant sustainability- and water risk management goals is discussed by comparing the water footprint goals against information obtained by the Water Footprint Assessment.

7.1. PHASE ONE: Goal and Scope

Possible business-relevant sustainability and water risk management goals for a beef cattle feedlot - or Concentrated Animal Feeding Operation, CAFO - could be any one or a combination of the following:

- to reduce the cost associated with water use (pumping and storing water, treatment and discharge of effluent);
- to optimize water use efficiency in different parts of the CAFO (for instance, by identifying practices that contribute to water losses on the CAFO site);
- to reduce the impacts of pollution on the receiving environment;

- to negate negative perceptions about the impacts of beef cattle CAFO's on the surrounding environment;
- to gain competitive marketing advantage over competitors;
- to promote meat produced in CAFO production systems over meat produced in grazing systems; or
- to improve the overall sustainability of the CAFO site in terms of water use for industrial production of beef meat.

In all instances, the catchment within which the CAFO operates should serve as a reference point to measure performance against set goals.

In this dissertation the business-relevant sustainability and water risk management goals of the assessment were co-created with the Feedlot management. The goals are:

1. Reduce the cost associated with the components of the Water Footprint
2. Optimize water use efficiency in the different parts of the feedlot
3. Reduce the impacts of pollution on the receiving environment (environmental externalities)
4. Improve the feedlot's resilience against water quality risks from upstream municipal waste water discharge and mine-water discharge.

The temporal scope of the assessment is a 40-month period from January 2012 to April 2015 to allow seasonal variations to emerge. The temporal unit of measurement is a 4-month production cycle which is the finishing period for a feedlot bovine. One calendar year contains roughly one winter cycle and two summer cycles, defined by bovine disease patterns rather than by seasons. For the purpose of this assessment the winter cycle occurs from June to September. The first summer cycle runs from October to January in the following calendar year, while the second summer cycle occurs from February to May. Weaned calves enter the feedlot at approximately 6 months of age, weighing about 150kg. It is important to note that this thesis excludes the water footprint of the calves prior to entering the feedlot, as well as that of the abattoir and the distribution of meat products into the commercial market.

The water footprint components for the Feedlot are shown in Table 6 below. The physical boundary for each component is given in Table 7. The animal feed water footprint is for the most part an indirect green component of the total bovine water footprint. Drinking water and service water are direct blue water components of the total bovine water footprint. The feedlot’s waste water management account for the direct and indirect operational grey water footprint.

Table 6: Water Footprint components for the Feedlot

Feedlot Bovine	Waste Management Activity
Water Footprint of Feed (indirect green, blue and grey WF)	Effluent lagoon water irrigation (direct grey WF)
Drinking water (direct blue WF)	Manure distribution (indirect grey WF)
Service Water (direct blue WF)	

Table 7: Assessment boundaries for the WF components for the Feedlot

WF Component	Assessment Boundary
Water Footprint of Feed (indirect green, blue and grey WF)	Feed is sourced within an approximately 200km radius around the feedlot site, but the exact location of production is not known. The national WF of production of crops for South Africa and Swaziland is used to balance the variance between provincial values (Mekonnen and Hoekstra, 2010a).
Drinking water (direct blue WF)	Drinking water consumption at the feedlot
Service Water (direct blue WF)	Service water consumption at the feedlot
Effluent lagoon water irrigation (direct grey WF)	Irrigation of supernatant effluent lagoon water onto 50ha fodder crops at the feedlot
Manure distribution (indirect grey WF)	Manure is used for fertiliser within the tertiary catchment and as far afield as Malelane in Mpumalanga (approximately 410km from the feedlot). The physical boundary for this WF component is not defined.

7.2. PHASE TWO: Water Footprint Accounting

The beef cattle feedlot is viewed as a production system within a river catchment system, with water inputs from the catchment, throughputs through the property and outputs into the catchment (Figure 8). The water footprint is an expression of the volumetric consumption of water by the production system. The size of the water footprint is dependent both on actual volume removed from the catchment (consumed), and by the volume consumed by the dilution of pollutants and therefore no longer available for further use inside the catchment. This system is shown in Figure 8 below. Rainwater that falls on the property and is diverted around the feedlot surface drains away without being consumed or polluted is not considered as part of the CAFO production system as it does not satisfy the definition of the water footprint.

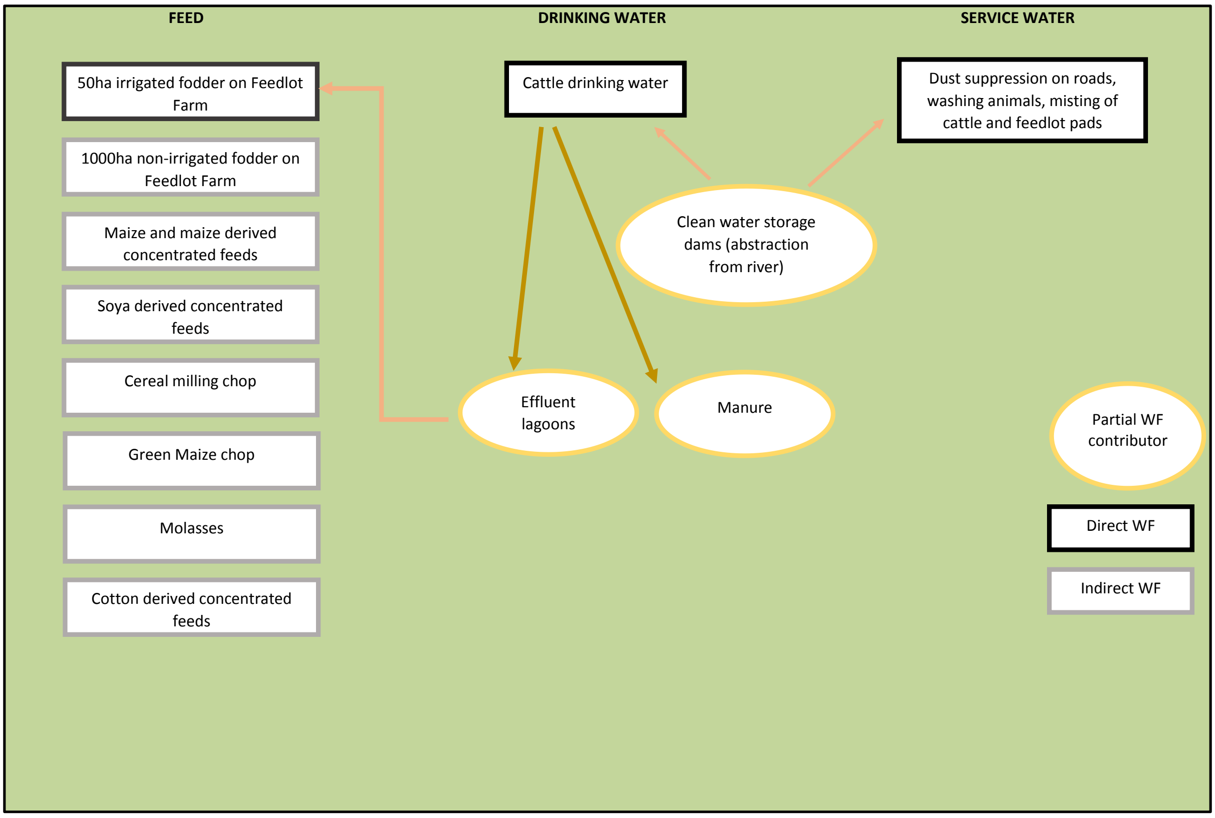


Figure 8: The beef cattle feedlot production system from a water consumption perspective.

7.2.1. Water Footprint Equations

This study utilized actual data from the feedlot where it was available, and applied assumed values as per the WFA methodology recommendations. Actual data included the number of animals per production cycle, some aspects of the feed mix (Table 8), rainfall data for Heidelberg town and atmospheric nitrogen data for the region. Assumed data was used for certain aspects of the feed mix (Table 8), aspects of the grey WF (discussion in section 7.1.2.2).

Bovine Water Footprint

The WF of the industrial farming of beef cattle in a CAFO is expressed as the water consumed for animal drinking water, the water consumed by services (washing of vehicles, dust suppression on roads and feedlot pads, and misting of cattle for temperature control during high heat periods) and the water footprint of the cattle feed. The WF of beef cattle is measured in terms of the carcass weight of one bovine over its 4-month residency at the feedlot (m^3/kg).

The WF of an animal is calculated using the following basic equation:

$$WF[a,c,s] = WF_{feed}[a,c,s] + WF_{drink}[a,c,s] + WF_{serv}[a,c,s]$$

"where $WF_{feed}[a,c,s]$, $WF_{drink}[a,c,s]$ and $WF_{serv}[a,c,s]$ represents the WF of an animal for animal category *a* in country *c* in production system *s* related to feed, drinking water and service water consumption, respectively" (Mekonnen and Hoekstra, 2010, p.9). In this thesis animal category *a* refers to beef cattle (mostly of the Brahman cattle race which is known for being hardy and requiring less drinking water than other feedlot cattle races or dairy cattle races), *c* refers to a particular catchment (Suikerbosrand tertiary catchment) and *s* represents the industrial production system known as Concentrated Animal Feeding Operation, or CAFO – in this case a beef cattle feedlot located near Heidelberg, Gauteng Province.

Meat products are produced when an animal is slaughtered, and therefore it is most useful to express the WF of beef cattle farmed for meat in terms of live weight at the end of their lifetime, or in terms of the carcass weight. In this thesis the carcass weight is used as the reference unit.

The WF of production of animal feed consumed by an animal is made up of two parts: the water used to mix the feed and the indirect WF of production of the various feed ingredients. The Water Footprint methodology for farm animals and animal-derived products (Mekonnen and Hoekstra, 2010) uses this equation to calculate the annual weighted average WF of feed consumed by a class of animals in a certain production system:

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

"Feed[*a,c,s*] refers to the annual amount of feed ingredient *p* consumed by beef cattle (*a*) in catchment (*c)* in a CAFO production system (*s)* (ton/yer), $WF^{*}_{prod}[p]$ the WF of feed ingredient *p* (m^3/ton), $WF_{mixing}[a,c,s]$ the volume of water consumed for mixing the feed of animal class (*a*) in catchment (*c)* and in an industrial production system (*s) (*m^3/yr/animal) and *Pop**[*a,c,s*] the number of slaughtered animals per year" (Mekonnen and Hoekstra, 2010, page 10). First attempts in this thesis attempted to calculate the WF of feed on a monthly basis, but were problematic in that the monthly slaughter volume is not equal to the entire standing population. Therefore, the temporal unit of measurement is adjusted to an average 4-month production cycle, instead of the annual or monthly production. This approach aligns with production cycles on the feedlot and allows the feedlot to account for the total WF of feed consumed by the entire slaughtered population from one production cycle.

Composition and Volume of Monthly Organic Feed Mix

For the composition of the feed mix, this study deviated from the Mekonnen and Hoekstra (2010) methodology, because the average monthly feed composition was largely provided by the feedlot. The feedlot provided typical daily feed volumes for certain organic and inorganic feed types. Inorganic feed types such as lime, veterinary feed conditioners and nutritional additives like urea were excluded from the thesis.

For the values not provided by the feedlot (zero values), literature was consulted to inform assumptions based on typical feedlot feed ratios. The following assumptions informed the average monthly feed mix:

1. The standing cattle population on the feedlot is taken as 130,000 heads of cattle (according to the Feedlot). Cattle of different ages and weight classes consume different volumes of feed per day. A bovine typically consumes 2.5 to 3.0% of body weight per day (Queensland Department of Agriculture and Fisheries, 2011). The feedlot indicated that the midpoint average feed consumption per bovine is 10kg feed per day, translating into an expected average daily feedlot organic feed demand of 1,300,000kg.

2. The feedlot indicated that silage (fodder) produced on the farm (silage HQ) contributes only 10% to the total silage consumed on the feedlot. Silage from other sources is estimated as ten times the volume of silage HQ.

3. Assumptions on organic feed ratios are based on Hendy et al (1995). Typical feedlot cattle diets include 25% oilmeals, 40-50% cereal milling by-products, and 20% of other ingredients like molasses and sugarbeet pulp. Therefore, the assumptions for the Feedlot are as follows: molasses and glutenfeed is 20% of the total; hominy chop and maize chop is 40% of the total and the ratio between wheat straw and wheat bran is 50:50.

The feed categories used by Hendy et al (1995) were used and adjusted where necessary to categorise the feedlot’s feed mix into four feed categories: cereals, oilmeals, other concentrates, and roughages and residues. The assumptions on feed categories and ratios for the Feedlot are shown in Table 8:

Table 8: Organic Feed Mix Assumptions for the Feedlot

Feed Category	% in Feed Mix	Feed Type Components	Assumption
Cereals	5	cotton seed; maize	adjusted from 10% given by Hendy et al (1995) to accommodate the Feedlot figure for fodder
Oilmeals	20	cotton oil cake; soya oil cake	Hendy et al (1995)
Other concentrates	20	Glutenfeed	Hendy et al (1995)
	40	green maize chop; hominy chop	Adjusted from 60% given by Hendy et al (1995) to accommodate the Feedlot figure for fodder
Roughages	15	wheatstraw, silage, wheatbran	Adjusted from the value provided in consultations with the Feedlot (10%)
Total	100		

Water Footprint of Production of Feed Ingredients

The WF of production of crops and derived crop by-products ($WF*_{prod}[p]$, in m^3/ton) consumed by the feedlot beef cattle is based on the data published by Mekonnen and Hoekstra (2010a, Volume 2) for main crops produced in South Africa (maize, wheat, cotton) and Swaziland (sugarcane). The global average water footprint of production for green maize and silage was used (Mekonnen and Hoekstra, 2010. Volume 1). Product fractions used by the Food and Agriculture Organisation and published in Chapagain and Hoekstra (2004, Volume 2) were used to assign the fraction of the WF of production to concentrated feeds, roughages and residues and cereals in the feed mix. The water footprint of production of low value crop residues (wheatstraw) is attributed to the main product and therefore assumed to be zero as recommended by Mekonnen and Hoekstra, 2010a, Volume 1. The fraction per water footprint component (green, blue and grey) is calculated.

Volume of Mixing Water

According Mekonnen and Hoekstra (2010, vol 1) the volume of mixing water is 0,5m^3/ton of concentrate feed.

Water Footprint of Volume of Feed Consumed at the Feedlot Per Month

The weighted water footprint of feed consumed per month is calculated by multiplying the volume of each feed category with its water WF fraction per WF component (green, blue and grey).

Water Footprint per Slaughtered Carcass

The average carcass weight used is 240kg (information provided by the Feedlot).

Drinking Water Requirements

Similar to feed intake, water intake depends on the bovine's body weight, climatic conditions and diet (Queensland Department of Agriculture and Fisheries, 2011). For this thesis the total bovine population (130 000 heads of cattle) in a production cycle was divided into thirds, with typical drinking water demand being 30*l*, 40*l* and 45*l* per the respective age groups (drinking water requirements provided by feedlot – see Annexure C) .

Manure contains approximately 88% urine (Queensland Department of Agriculture and Fisheries, 2011). Urine that is excreted with manure is diverted into effluent lagoons at the Feedlot. In this dissertation urine is excluded from the Bovine Water Footprint, but included in the grey water footprint of waste management to avoid double accounting.

Service Water Requirements

Service water at the Feedlot is used to wash vehicles, for misting of cattle and feedlot pads for temperature regulation during high heat periods and for dust control. Service water use is not metered. Mekonnen and Hoekstra (2010, Vol 1) suggest that service water contributes 0,8% to the total Bovine Water Footprint for feedlot cattle. In this thesis, service water is assumed to be 1% of drinking water, because service- and drinking water is taken from a single reticulation system. Water for washing vehicles is considered to be especially significant, since the large fleet of trucks is washed at the feedlot.

Misting of cattle and feedlot pads only takes place during high temperature and dry periods to assist with cattle temperature regulation and dust control. Dust control on access roads is done with specialized trucks spraying water on road surfaces. Climate conditions determine how must misting and dust control is needed, and therefore fluctuates over time. In this thesis however, service water is treated as a constant.

Grey Water Footprint for Waste Management Activities at the Feedlot

The *Water Footprint Assessment Manual* (Hoekstra *et al*, 2011) recommends a "three tier approach to estimate diffuse pollution loads which enter into a water body" in order to account for the grey water footprint of a process or product (Franke *et al,* 2013, p.7). Guidelines were developed by the UNESCO-IHE Institute for Water Education to supplement the Tier 1 grey water footprint accounting methodology contained in the *Water Footprint Assessment Manual* (Franke *et al,* 2013).

The Tier 1 Guidelines describe the best methodology to estimate leaching run-off fraction values and parameter values for the grey water footprint (Franke *et al,* 2013). Guidance is specifically given on "(i) how to estimate leaching-runoff fractions depending on chemical substance, environmental conditions and application practice; (ii) what water quality standards (maximum allowable concentrations) to use in the calculations; and (iii) what to assume regarding natural background concentrations" (Franke *et al,* 2013 p.8).

Two waste streams were considered in this thesis: effluent water and manure. The grey water footprint associated with Nitrogen and Phosphorous deposition was calculated.

The following equation is used to calculate the grey water footprint for a chemical substance:

$$GWF = \frac{L}{C_{max} - C_{nat}}$$

Where L is the load of the chemical substance entering a water body; C_{max} is the maximum allowed concentration of the substance and C_{nat} is the naturally occurring background concentration of the substance.

Volume of Supernatant Effluent Water Distributed through Irrigation

The volume of supernatant effluent irrigated onto land wasn't made available by the Feedlot, but data for the effluent lagoon volumes over time was available. A water-balance approach using the monthly effluent lagoon volume fluctuations, effluent lagoon surface area, estimated monthly evaporation and actual monthly rainfall in Heidelberg was used to estimate the volume and timing of irrigation on the Feedlot.

Volume of Dry Manure Distributed on Land

An average manure production of 3kg dry matter per bovine per day was used as the population mid-point volume (Queensland Department of Agriculture and Fisheries, 2011). Although manure production would naturally fluctuate with climatic conditions, animal age and weight and diet, this value is treated as constant over time.

N- and P- content of Supernatant Effluent and Manure

Assumptions were made about the N- and P-content of supernatant effluent and manure based on literature sources for published studies on other beef cattle feedlots (Ullman and Mukhtar, 2007). N-values for effluent lagoons in these studies included the sludge at the bottom of effluent lagoons as well as the entire water column. N-values are therefore very likely to be over-estimated.

N- leaching-runoff

The leaching-runoff of N was based on the N-application rate approach, using a rough estimate of the leaching-runoff fraction α and the estimate leaching-runoff potential. α is given a weight for each influencing factor, and an incremental score ranging between 0 and 1 for each influencing factor is assigned based on actual data. Where actual data is not available, a mid-point score of 0,5 is assigned.

N-deposition is based on the dataset for the spatial distribution of global nitrogen deposition from 1860 to 2050 (Dentener 2006) (Figure 9).

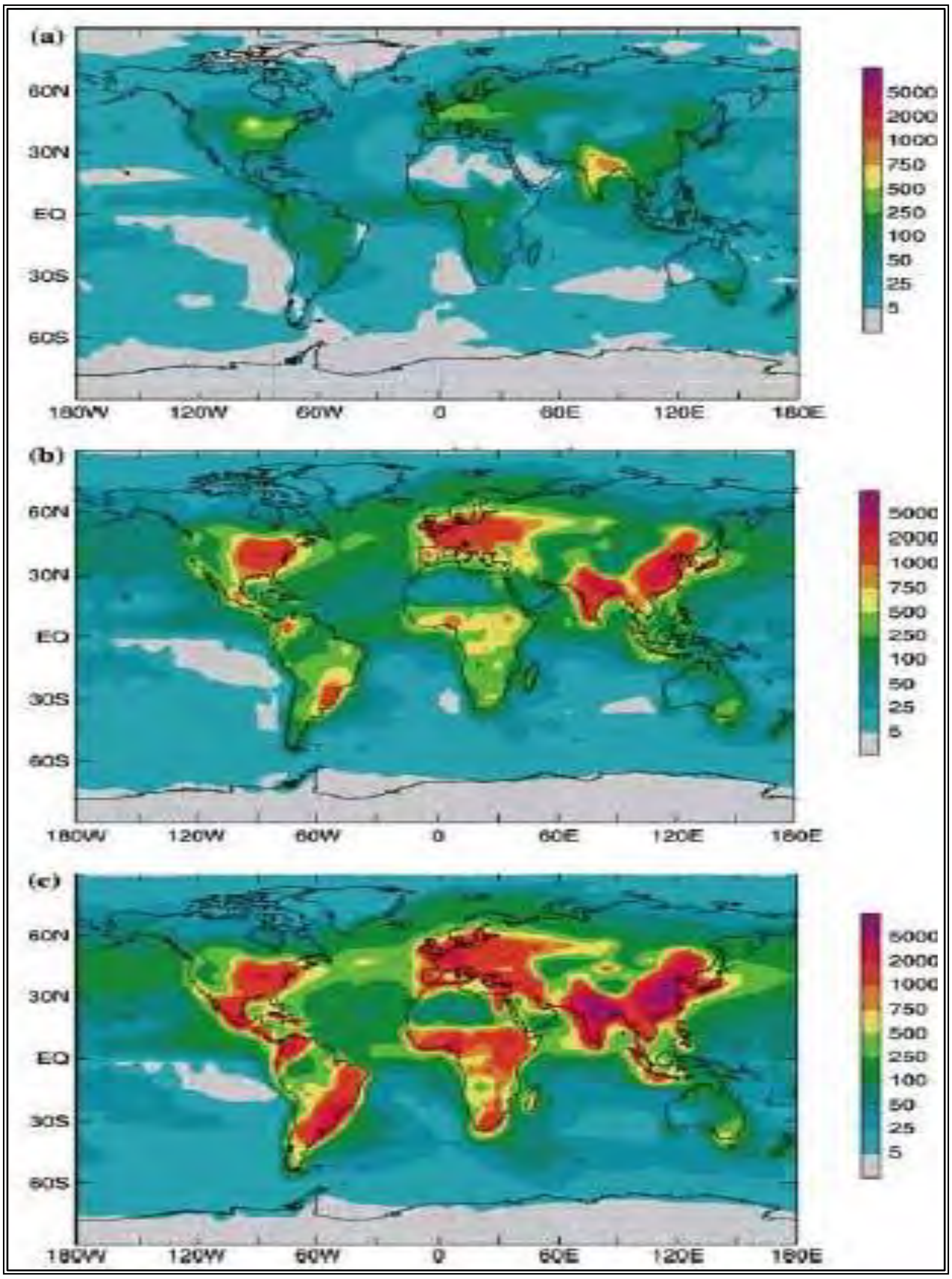


Figure 9: Spatial patterns of total inorganic nitrogen deposition in (a) 1860, (b) early 1990s, and (c) 2050, mg N/m2/y (Dentener, 2006)

P-leaching-runoff

The leaching-runoff of P was based on the N-application rate approach, using a rough estimate of the leaching-runoff fraction α and the estimate leaching-runoff potential. α is given a weight for each influencing factor, and an incremental score ranging between 0 and 1 for each influencing factor is assigned based on actual data. Where actual data is not available, a mid-point score of 0,5 is assigned.

Grey Water Footprint from Effluent and Manure Distribution

The leaching-runoff of N and P associated with irrigation of supernatant effluent water and distribution of dry manure is calculated by multiplying the leaching-runoff potential for each chemical substance with the volume of water or manure being distributed.

7.3. PHASE THREE: Sustainability Assessment

Blue water scarcity is used by the Water Footprint Manual to indicate periods and locations where water consumption is unsustainable. The following equation is used to calculate Blue Water Scarcity:

$$WS_{blue}[x,t] = \frac{\Sigma WF_{blue}[x,t]}{WA_{blue}[x,t]}$$

Where Blue Water Scarcity in catchment *x* in period *t* ($WS_{blue}[x,t]$) is equal to the sum of the blue water footprint (ΣWF_{blue}) of all production activities in catchment *x* in period *t* divided by the blue water availability in catchment *x* in period *t* (Mekonnen and Hoekstra, 2010).

Blue water availability is calculated using the following equation:

$$WA_{blue}[x,t] = R_{nat} - EFR[x,t]$$

Where the natural runoff (R_{nat}) less the environmental flow requirement in catchment *x* in period *t* equals the blue water availability in catchment *x* in period *t* (Mekonnen and Hoekstra, 2010).

A Blue Water Scarcity (BWS) value above 100 is considered unsustainable. In this dissertation the annual blue water availability is known on a tertiary catchment level, but the blue water footprint of all production activities in the catchment is not known. Likely scenarios for the BWS are considered, acknowledging that both the blue water availability on a monthly scale and the blue water footprint of production activities in the catchment are beyond the scope of this dissertation.

7.4. PHASE FOUR: Response Strategies

In this phase the potential strategies to reduce the Bovine- and Waste Management Water Footprint components were considered.

7.5. Sources of Data

The Water Footprint Assessment is demanding in terms of data and sources of data. The sources of data used in this thesis is summarized in Table 9:

Table 9: Data Sources used in this research project

Data Element	Data Source
Water footprint of production of feed crops	Mekonnen and Hoekstra, 2010a
Product fraction of crop-derived products	Mekonnen and Hoekstra, 2010a
Feed types, categories, ratios	Hendy et al, 1995
Feed volumes	Information provided by Feedlot
Production volumes; carcass weight	Information provided by Feedlot
Evaporation potential	Schulze, 1997
Effluent lagoon volumes	Information provided by Feedlot
Rainfall in Heidelberg	Historical climate records for Heidelberg, Gauteng. Climate Information platform, 2015: http://cip.csag.uct.ac.za/webclient2/datasets/south-africa-all/#nodes/observed-cmip5?folder_id=35&extent=103951
N- and P content of supernatant effluent and manure	Ullman and Mukhtar, 2007
Manure volumes	Information provided by Feedlot; Queensland Department of Agriculture and Fisheries, 2011
N-deposition	Cleveland et al, 2013 (Dentener ,2006)
Soil type	Communication from the Feedlot
N- and P- plant uptake	Roy et al, 2003
Tertiary catchment water demand, availability and environmental flow requirements	DWAF, 2002
Leaching-runoff fractions for N and P	Franke et al, 2013

7.6. Examining the Application of Water Footprint Assessment At A Local Agri-Business

Two formal interactions took place with the Feedlot during the course of the study, the first in July 2015 and the second in January 2016. At the first formal interaction, the Feedlot played a co-creation role in Phase 1 of the WFA, the development of water footprint goals. The second formal interaction was held in a workshop format where the results of the WFA were presented to the Feedlot, and the Feedlot participated in the sustainability discussions for Phase 4 of the WFA.

The proceedings of the Workshop were recorded. The results of the WF accounting were considered to firstly examine the methodology applied and discuss ways in which the methodology fails to provide adequate information for SWRM, and secondly to consider the insights provided by the WFA that enable the Feedlot to improve SWRM. The original WF goals were subsequently re-examined to determine if the way in which a WF goal is framed has an influence on how well the WFA can address the inherent question, and whether or not any of the original goals could not be achieved by applying the results of the WFA. The presentations used for both formal interactions and the Workshop Discussion presentation are attached in Appendix A. The audio recording of the Workshop is submitted separately as an audio file in Appendix B.

8. GENERAL DESCRIPTION OF THE FEEDLOT

8.1. Feedlot Design

The Feedlot houses around 130,000 head of cattle at any point in time. Beef cattle are finished over a 4-month period. Three 4-month production cycles are completed per year. Feedlot pads measure approximately 35mX70m and cattle are housed at an approximate density of 100 head of cattle per feedlot pad. Figure 10 shows the schematic layout of a feedlot pad Information provided by the Feedlot during the Study Workshop held on 20 February 2016. (Appendix 1).

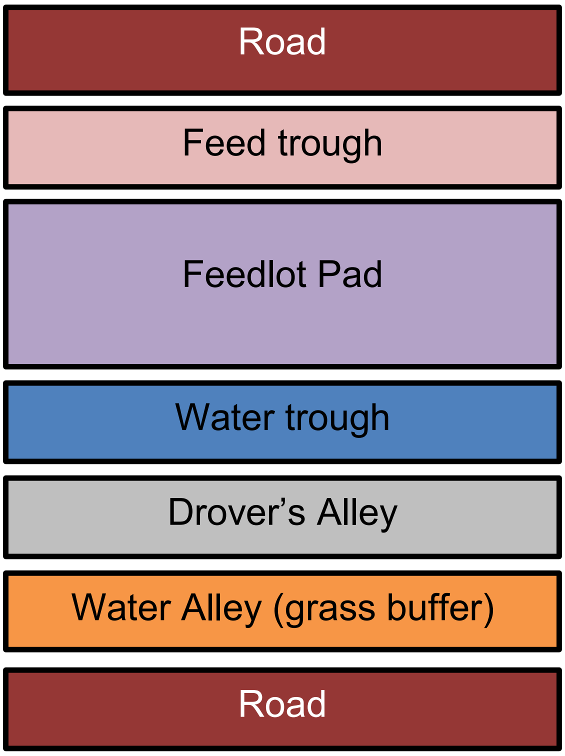


Figure 10: Schematic layout of a feedlot pad at the study site

The feedlot floor is an important design feature to prevent water pollution from impacting the environment surrounding the feedlot premises. Feedlot pads are constructed with a permanent bio-filter layer which traps substances like heavy metals, phosphates, sulfates and ammonia and prevents contaminated runoff from flowing off the feedlot pad. The mixture of manure and sand protects the bio-filter layer from damage by bovine hooves and when loose manure is collected from feedlot pads. Figure 11 shows the design of the feedlot floor (information provided by the feedlot).

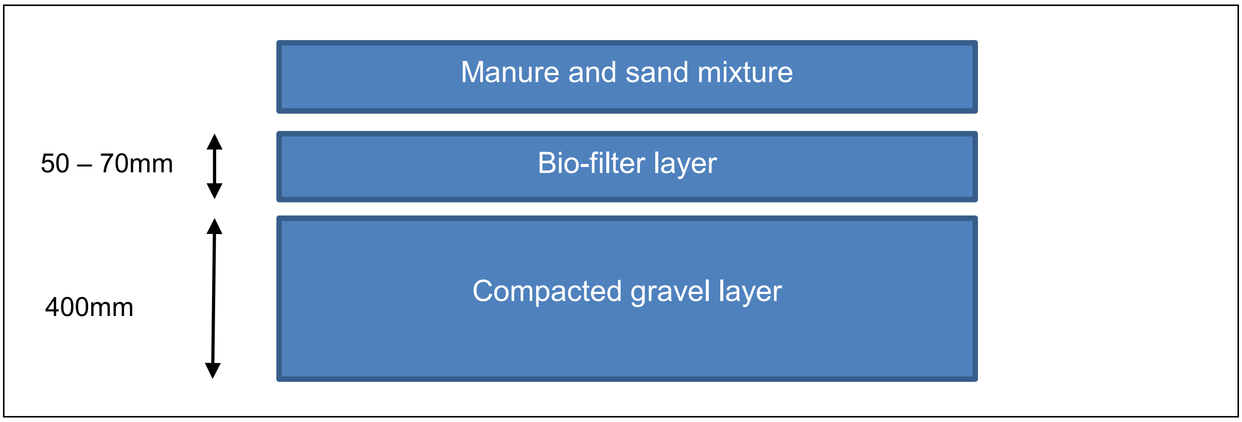


Figure 11: Schematic design of the feedlot floor.

8.2. Water Management at the Feedlot

Water is abstracted from the Suikerbosrand River (Figure 13). Clean water storage is sufficient to supply the Feedlot with cattle drinking water for 5 days. Water is reticulated throughout the feedlot operations in a continuous reticulation system to fill water troughs and supply water to overhead misters used for bovine temperature control during hot weather. Water use is not metered beyond the abstraction point.

Water troughs are emptied and cleaned on a constant daily rotational basis to prevent the build-up of algal blooms in the drinking water. Feed troughs and water troughs are deliberately placed at opposite ends of the feedlot pad to keep water as free as possible from food residues being transferred by cattle from the feed troughs (Figure 10). There are approximately 600 water troughs throughout the Feedlot.

The feedlot is constructed on a slope which aids in gravitational flow of effluent off the feedlot pads and into effluent lagoons (Figure 12). Clean storm water is directed between feedlot pads to flow through the 'water alley', or grass buffer areas between feedlot pads.

The levels of effluent lagoons are managed to prevent accidental spillages during high rainfall periods. The Lagoon levels are maintained by pumping water from one lagoon to another, and by irrigating supernatant effluent water onto a 50ha area of fodder grass.

Water quality is tested in the Blesbokspruit- and Suikerbosrand rivers adjacent to the Feedlot. Secchi scores are determined monthly and *daphnia spp.* are used as a biological indicator of water quality downstream from the Feedlot. Water quality monitoring is done in accordance with water use license requirements.

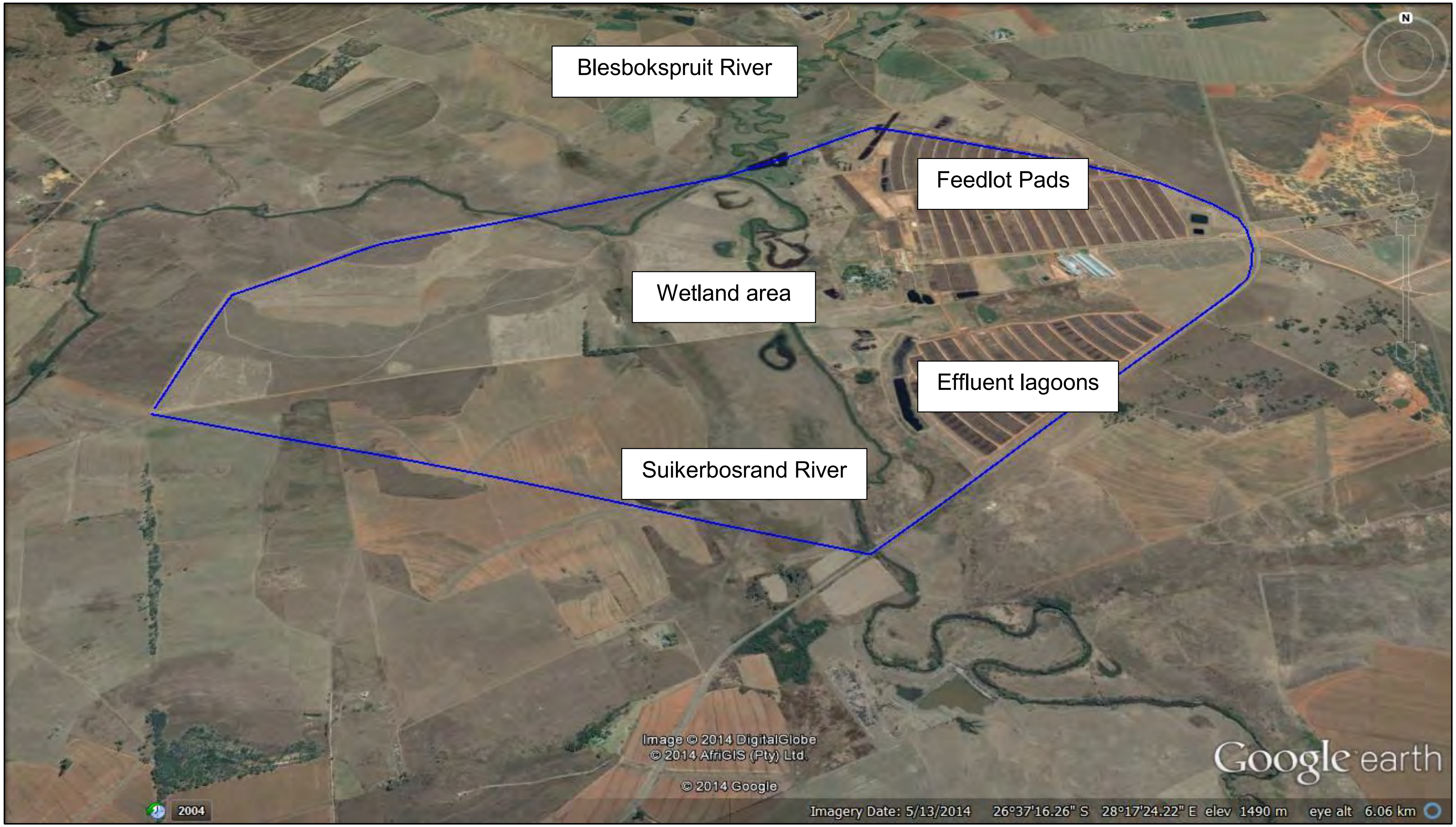


Figure 12: The Feedlot site layout.

Figure 13: Effluent lagoons on the Study Site.

9. WATER FOOTPRINT ACCOUNTING RESULTS

All spreadsheets for the calculation of the Bovine WF and grey WF are attached in Appendix C.

9.1. The Bovine Water Footprint

9.1.1. Monthly Feedlot Feed Mix

The study feedlot provided some of the values for the typical daily feed mix used at the feedlot (all non-zero values in Table 10). Limited information provided by the feedlot is due to concerns about competition and market advantage.

Table 10: Feed volumes provided by the Feedlot

Feed Type	Daily Mix (kg)
Wheatstraw	0
Silage HQ	693
Silage bought	0
Green maize chop	0
Wheatbran	0
Glutenfeed	137
Cotton oil cake	135
Hominychop	2625
Maize	1305
Soja oil cake	0
Cotton seed	0
Lime	97
TOTAL FEED	**0**

Literature was consulted to guide assumptions on typical beef cattle feedlot feed ratios. The daily and monthly feed mix (Table 11) was estimated by applying the assumptions detailed in the Methodology. Feed types were then grouped into organic feed categories (Table 12).

Table 11: The Feedlot average monthly feed mix

Feedlot Feed Mix			
Feed Type		**Daily Quantity (kg)**	**Monthly Quantity (kg)**
Roughages & Crop Residues	**Concentrate Feeds**		
Wheatstraw		92 500	2 775 000
Silage HQ		693	20 790
Silage from other sources		6 930	
	Cotton seed	64 000	1 920 000
	Wheatbran	92 500	2 775 000
Lime		97	2 910
	Maize	1 305	39 150
	Molasses	260 000	7 800 000
	Glutenfeed	137	4 110
	Cotton Oil Cake	135	4 050
	Hominy Chop (cereal milling)	2 625	78 750
	Soya Oil Cake	260 000	7 800 000
	Green Maize Chop (cereal milling)	520 000	15 600 000
Estimated Total feed consumption (kg)		**1 300 922**	**39 027 660**
Expected organic feed demand (kg)		**1 300 000**	**39 000 000**

Table 12: Typical Daily and Monthly Volumes of Organic Feeds Consumed at the Feedlot

Feed Category	**Daily Quantity (kg)**	**Required ratio (%)**	**Monthly Quantity (kg)**
Cereals	65 305	5	1959150
Oilmeals	260 135	20	7804050
Other Concentrates	782 762	60	23482860
Roughages & Residues	192 623	15	5778690
TOTAL	1 300 000	100	39 000 000

9.1.2. Water Footprint for Production of Feed

The water footprint of production of main crops is given in Table 13. These values were taken from Mekonnen and Hoekstra (2010a). For all crops except sugarcane and silage the South Africa national average was used to compensate for regional differences. The country average of Swaziland is used for sugarcane, and the global average for silage is used (Ibid).

Table 13: The water footprint of production of main crops from which the Feedlot feed mix is derived.

	Annual WF Production		
Main Crop	**$WF_{GreenProduction}$**	**$WF_{BlueProduction}$**	**$WF_{GreyProduction}$**
Cotton (SA national)	1386	3790	91
Wheat (SA national)	1040	230	98
Maize (SA national)	1661	34	131
Sugarcane (Swaziland national)	55	66	0
Green maize (SA national)	366	320	70
Soya (SA national)	2739	88	14
Silage HQ (global average)	207	27	20
Silage bought (global average)	207	27	20

The value fraction of crop derivatives published by the FAO (Ibid) is multiplied by the water footprint of the main crop to calculate the annual and monthly water footprint fraction of each feed type in m^3/ton of feed produced (Table 14).

Table 14: Water footprint fraction for each feed type

			Annual production fraction m^3/ton			**Monthly production fraction m^3/ton**		
FEED TYPE	Product Fraction	Value Fraction	WF_{green} Fraction	WF_{blue} Fraction	WF_{grey} Fraction	WF_{green} Fraction	WF_{blue} Fraction	WF_{grey} Fraction
Cotton seed	0,63	0,21	291,06	795,90	19,11	24,26	66,33	1,59
Wheatbran	1,00	1,00	1 040,00	230,00	98,00	86,67	19,17	8,17
Molasses	0,05	0,10	5,50	6,60	0,00	0,46	0,55	0,00
Glutenfeed (wheat)	0,15	0,36	374,40	82,80	35,28	31,20	6,90	2,94
Cotton Oil Cake	0,51	0,51	706,86	1 932,90	46,41	58,91	161,08	3,87
Hominy Chop (maize grouts)	0,11	0,09	149,49	3,06	11,79	12,46	0,26	0,98
Soya Oil Cake	0,79	0,66	1 807,74	58,08	9,24	150,65	4,84	0,77
Green Maize Chop	1,00	1,00	366,00	320,00	70,00	30,50	26,67	5,83
Maize	1,00	1,00	1 661,00	34,00	131,00	138,42	2,83	10,92
Wheat straw	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Silage HQ	1,00	1,00	207,00	27,00	20,00	17,25	2,25	1,67
Silage bought	1,00	1,00	207,00	27,00	20,00	17,25	2,25	1,67

By multiplying the volume of each feed type consumed per month with its corresponding water footprint fraction, the actual water footprint of the feed consumed per month is calculated in m^3/month (Table 15).

Table 15: Water footprint of feed consumed per month

WF (m^3) feed consumed per month			
FEED TYPE	WF_{green}	WF_{blue}	WF_{grey}
Cotton seed	46 569,60	127 344,00	3 057,60
Wheatbran	240 500,00	53 187,50	22 662,50
Molasses	3 575,00	4 290,00	0,00
Glutenfeed (wheat)	128,23	28,36	12,08
Cotton Oil Cake	238,57	652,35	15,66
Hominy Chop (maize grouts)	981,03	20,08	77,37
Soya Oil Cake	1 175 031,00	37 752,00	6 006,00
Green Maize Chop	475 800,00	416 000,00	91 000,00
Maize	5 419,01	110,93	427,39
Wheat straw	0,00	0,00	0,00
Silage HQ	358,63	46,78	34,65
Silage bought	3 586,28	467,78	346,50

Finally, the water footprint of feed consumed of each feed type is combined into four feed categories, namely cereal, oilmeals, other concentrates and roughages and residues (Table 16). No distinction is made between the amount of feed consumed in the winter- and summer production cycles.

Table 16: The water footprint of feed categories in m^3 per month and m^3/4-month production cycle

Feed Category	**WF of feed (m^3) consumed per month**			**4-month production cycle WF of feed (m^3) consumed per month**		
	Green	**Blue**	**Grey**	**Green**	**Blue**	**Grey**
Cereals	51 988,61	127 454,93	3 484,99	207 954,45	509 819,70	13 939,95
Oilmeals	1 175 269,57	38 404,35	6 021,66	4 701 078,26	153 617,42	24 086,65
Other Concentrates	480 484,26	420 338,44	91 089,46	1 921 937,04	1 681 353,76	364 357,82
Roughages & Residues	244 444,90	53 702,05	23 043,65	977 779,61	214 808,21	92 174,60

9.1.3. Water Footprint of Drinking Water Consumed

Feedlot beef cattle drink considerable volumes of water per day depending on climatic conditions, their diet and body weight. A large proportion of this water is voided from the bovine together with manure – 85% - 90% of manure is water (Queensland Department of Agriculture and Fisheries, 2015).

A bovine at the Feedlot consumes on average 1150L water per month. This was calculated by dividing the typical 130,000 head of cattle for one production cycle into thirds, and allocating a typical daily drinking water demand to each third (information on the volume demand was provided by the Feedlot). In this dissertation it is assumed that cattle consume double the volume of drinking water in summer than they do in winter

(Table 17 and Table 19), based on observed trends at the Feedlot and literature references (NSW, 2015 Queensland Department of Agriculture and Fisheries, 2015).

Table 17: Drinking water demand at the Feedlot – winter cycle

Drinking water demand per month (m^3) - winter cycle		**Urine (m^3)**	**Drinking water consumed (m^3)**
Nr of Animals on farm	130 000,00		
33% @ 25 - 35 L (30avg L per day)	39 000 000,00		
33% @ 40 L per day	52 000 000,00		
33% @ 45 L per day	58 500 000,00		
Total water demand per month (L)	149 500 000,00		
Total feedlot drinking water demand per month (m^3)	149 500,00		
Monthly drinking water demand per animal (m^3)	1,15		
4-month production cycle water demand per bovine (m^3)	4,6	4,048	0,552

Table 18: Drinking water demand at the Feedlot – summer cycle

Drinking water demand - summer cycle		Urine (m^3)	Drinking water consumed (m^3)
Nr of Animals on farm	130 000,00		
33% @ 25 - 35 L (30avg L per day)	78 000 000,00		
33% @ 40 L per day	104 000 000,00		
33% @ 45 L per day	117 000 000,00		
Total water demand per month (L)	299 000 000,00		
Total feedlot drinking water demand per month (m^3)	299 000,00		
Monthly drinking water demand per animal (m^3)	2,30		
4-month production cycle water demand per bovine (m^3)	9,2	8,096	1,104

It is assumed that by the end of the 4-month production cycle the entire number of cattle in each cohort (130,000 bovine) is slaughtered. An average carcass weight of 240kg is assumed. By dividing the water demand for the production cycle by the total carcass weight of the slaughtered cohort, the water footprint of drinking water per production cycle is calculated in L/kg carcass weight (Table 19).

Table 19: The WF of drinking water in winter and summer production cycles

Carcass weight slaughtered per 4-month production cycle (kg)	**winter production cycle water demand for feedlot (L)**	**summer production cycle water demand for feedlot (L)**	**WF of drinking water – winter production cycle (L/kg carcass)**	**WF of drinking water – summer cycle (L/kg carcass)**
31 200 000	598 000 000,00	1 196 000 000,00	19,16	38,33

Water excreted with manure is excluded from the Bovine Water Footprint since it is collected in effluent lagoons and forms part of the Grey Water Footprint of Waste Management Activities. The volume of urine is estimated to be 88% of drinking water demand (Queensland Department of Agriculture and Fisheries, 2015). The balance of water consumed over a typical 4-month production cycle is shown in Table 18 and Table 19 for winter and summer production cycles.

9.1.4. Service Water

Service water was estimated to be 1% of the feedlot drinking water demand (drinking water demand doubles in summer), that is 5 980m^3 for the winter production cycle and 11 960m^3 for the summer production cycle. Dividing the total carcass weight of the slaughtered cohort by the service water demand gives the WF of service water for the winter and summer production cycles (Table 20 and Table 21).

Table 20: WF of service water for the winter production cycle

Service water - winter cycle		
Carcass weight slaughtered per 4-month production cycle (kg)	**Service water over winter production cycle (L)**	**WF of service water L/kg carcass for winter production cycle**
31 200 000	5 980 000,00	0,19

Table 21: WF of service water for the summer production cycle

Service water - summer cycle		
Carcass weight slaughtered per 4-month production cycle (kg)	**Service water over summer production cycle (L)**	**Service water L/kg carcass for summer production cycle**
31 200 000	11 960 000,00	0,38

9.1.5. Bovine Water Footprint Components

The total water footprint of a 4-month winter- and summer production cycles at the Feedlot is given in Table 22 and Table 23 in L/kg slaughtered carcass. The water footprint components of a beef carcass are the WF of Feed, the WF of Drinking Water and the WF of Service Water.

Table 22: The components of the winter production cycle water footprint of beef cattle at the Feedlot

The components of the water footprint of beef cattle at the Feedlot (4 month winter production cycle)					
		Water Footprint (L/kg carcass)			
Feed Category	**Feed amount (kg feed/kg carcass)**	**Green**	**Blue**	**Grey**	**Total**
Cereals	0,25	52 232,56	128 052,98	3 501,34	183 786,88
Oilmeals	1,00	4 703 519,21	153 697,18	24 099,16	4 881 315,54
Other Concentrates	3,01	5 786 228,01	5 061 922,43	1 096 944,06	11 945 094,50
Roughages & Residues	0,74	724 395,55	159 142,31	68 288,26	951 826,12
WF related to Feed		**11 266 375,32**	**5 502 814,91**	**1 192 832,83**	**17 962 023,05**
Drinking water consumed			**19,17**		
Service water			**0,19**		
Total water footprint per 4-month winter production cycle (L/kg carcass)		**11 266 375,32**	**5 502 834,27**	**1 192 832,83**	**17 962 042,41**

Table 23: The components of the summer production cycle water footprint of beef cattle at the Feedlot

The components of the water footprint of beef cattle at the Feedlot (4 month summer production cycle)					
Feed Category	**Feed amount (kg/kg carcass)**	**Weighted average water footprint of feed (L/kg feed)**			**Water Footprint (L/kg carcass)**
		Green	**Blue**	**Grey**	**Total**
Cereals	0,25	52 232,56	128 052,98	3 501,34	183 786,88
Oilmeals	1,00	4 703 519,21	153 697,18	24 099,16	4 881 315,54
Other Concentrates	3,01	5 786 228,01	5 061 922,43	1 096 944,06	11 945 094,50
Roughages & Residues	0,74	724 395,55	159 142,31	68 288,26	951 826,12
WF related to Feed		**11 266 375,32**	**5 502 814,91**	**1 192 832,83**	**17 962 023,05**
Drinking water consumed			**38,33**		
Service water			**0,38**		
Total water footprint per 4-month summer production cycle (L/kg carcass)		**11 266 375,32**	**5 502 853,63**	**1 192 832,83**	**17 962 061,77**

9.2. The Water Footprint of Waste Management Practices

The two major waste streams considered in this dissertation are effluent from feedlot ponds and dry manure. The monthly grey water footprint for nitrogen and phosphorous associated with its disposal or management was examined for both waste streams.

The Tier 1 Guidelines calculates the Grey Water Footprint (Franke *et al,* 2013) use these equations for diffuse pollution:

GWF = $L/C_{max} – C_{min})$

And

$L = \alpha \text{ X } Appl$

Where L is the chemical load of a pollutant entering a water body, C_{max} is the maximum acceptable concentration of the pollutant and C_{min} is the natural background concentration in the receiving water body. α is the dimensionless leaching-runoff fraction whereas *Appl* is the application of pollutants into or on soil, measured in mass/time.

9.2.1. Nitrogen Leaching-Runoff Potential

The factors that determine the nitrogen leaching run-off fraction are catalogued in Table 24. For certain factors the Tier 1 Guidelines use qualitative descriptions for score levels such as ‘poorly to very poorly drained’ and ‘excessively to extremely drained’ without providing quantitative guidance on the expected ranges of these scores. Therefore an ‘unknown’ score (0,5) was assigned for both the natural drainage factors related to runoff and leaching.

The actual N-deposition value is 0,6g N/m^2/yr and the corresponding score is 0,33. This value is taken as midpoint in the N-deposition over the Gauteng region (N-deposition in the region ranges between 431,69 mg N/m^2/yr and 833,27 mg N/m^2/yr (Dentener, 2006).

The soil texture (relevant to runoff and leaching) is described as loam. Therefore the soil texture score relevant for leaching is 0,67 and relevant for runoff is 0,33.

Rainfall records for Heidelberg from 2005 – 2009 indicate that precipitation never exceeds 600mm per month, an only exceeded 600mm annual rainfall in 2005 and 2006. Average rainfall does not exceed 600mm/annum. The grey water footprint for this study is calculated on a monthly basis, therefore the score for precipitation is 0 (Figure 14). 600mm is the threshold used by Mekonnen and Hoekstra (2010) in the WFA methodology for farm animals.

N-fixation in the receiving soils is not monitored and the resulting score is 0,5 (unknown).

The estimated N-content in the irrigation water is 1.63mg/m^3. A score of 0 (very low) is given, partly because the ranges for ‘very low’, ‘low’, ‘high’ and ‘very high’ are not defined and partly because the N-content of irrigation water is expected to be overestimated in this study since it is based on data from a another study which measured the N-content of effluent lagoons which included both supernatant water and the sludge at the bottom of the lagoon. In this study only supernatant water is used for irrigation.

The score for the plant uptake of nitrogen is 0,5 (unknown). The N-content or fodder grown on the feedlot property is not measured, however a reference value nutrient uptake of 300kg N for a dry matter yield of 10tonnes/ha for temperate grassland and fodder can be used (Roy et al, 2006). The Tier 1 Guidelines do not provide quantitative ranges for scores for plant uptake of Nitrogen.

Management Practise is given a score of 0,33 (good), based on the results of the Agricultural Management Practice Questionnaire (Table 25) completed with Feedlot management. Question 7 does not apply to the study site since climatic conditions do not produce frozen ground. The answer to Question 7 was selected as ‘yes’, to avoid an unrealistic negative outcome. Scoring of the questionnaire provides “a very rough classification of the management practise” (Franke *et al*, 2013): if all the listed measures are applied, management practices is considered ‘best’; 7-8 measures classifies the management practice as ‘good’; if 5-6 measures are applied the management practice is considered ‘average’ and less than 5 applied measures classifies as ‘worst’.

Table 24: Nitrogen leaching-runoff potential factors for the Feedlot

NITROGEN LEACHING RUN-OFF POTENTIAL									
Category	**Factor**		**Leaching runoff potential**		**Score (*s*)**				
			Weight (*w*)*		**Very low**	**Low**	**No Information available**	**High**	**Very high**
			α	**β**	**0**	**0,33**	**0,5**	**0,67**	**1**
Environmental Factors	Atmospheric input	N-deposition (g N m^{-2}yr^{-1})	10	10	<0.5	**>0.5**		<1.5	>1.5
	Soil	Texture (relevant for leaching)	15	15	Clay	Silt		**Loam**	Sand
		Texture (relevant for runoff)	10	10	Sand	**Loam**		Silt	Clay
		Natural drainage (relevant for leaching)	10	15	Poorly to very poorly drained	Moderately to imperfectly drained	**unknown**	Well drained	Excessively to extremely drained
		Natural drainage (relevant for runoff)	5	10	Excessively to extremely drained	Well drained	**unknown**	Moderately to imperfectly drained	Poorly to very poorly drained
	Climate	Precipitation (mm)	15	15	**0 - 600**	600 - 1200		1200 - 1800	>1800
Agricultural practice	N-fixation (kg/ha)		10	10	0	>0	**unknown**	<60	>60
	Application rate		10	0	**Very low**	Low		High	Very high
	Plant uptake (crop yield)		5	0	Very high	High	**unknown**	Low	Very low
	Management practice		10	15	Best	**Good**		Average	Worst

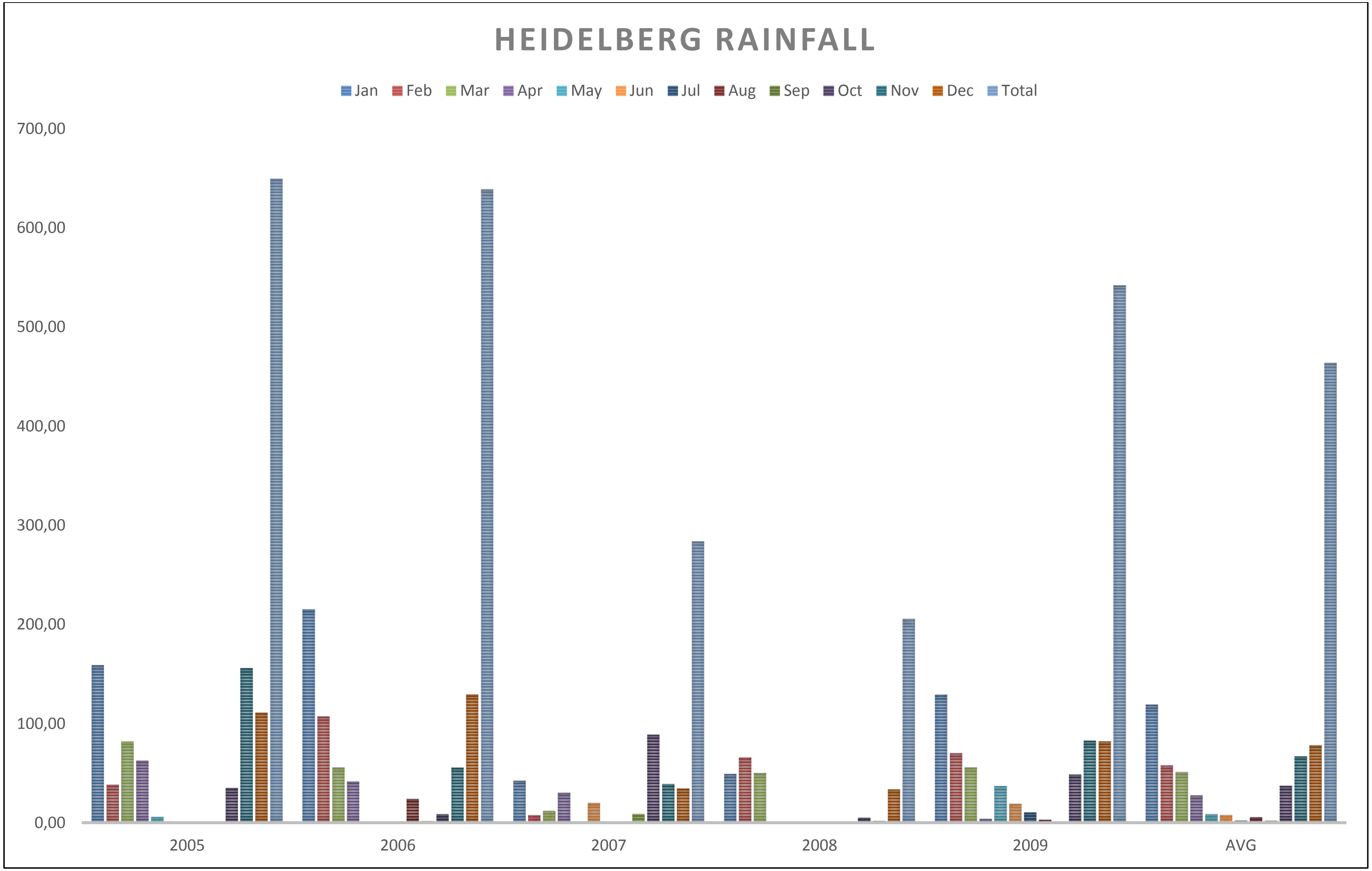


Figure 14: Rainfall data for Heidelberg Town from 2005 - 2009

Table 25: Agricultural management practice questionnaire for the Feedlot

Measure		Example	Applied?		Management Practice at Study Site
			Yes	No	
1	Controlled application of chemicals.	Through aerial application considerable losses may occur through spray drift and volatilization; with soil-incorporated application methods, losses are much lower	X		Animal veterinary chemicals are given to individual animals, not aerial spray
2	Diffuse pollution mitigation measures.	Buffer zones, stream fencing, and cattle management can reduce the fraction of the contaminant entering a water body	X		Buffer zones around feedlot pads absorb any substances that may be flushed off the pads during rainfall, and direct storm water away from feedlot pads to minimize contact with pollutants. Effluent is collected in effluent lagoons.
3	Careful handling of chemicals.	During storage, transport or disposal	X		All chemicals are controlled during storage, transport, handling and disposal
4	Application immediately before heavy rainfall or irrigation is avoided.	During heavy rainfall and in case of excessive irrigation, runoff can be very substantial	X		Cattle aren’t sprayed with chemicals immediately before a rainfall event.
5	Controlled irrigation.	Sprinkle of drip irrigation do not easily flush chemicals		X	Pivot irrigation
6	Field is only naturally drained.	Artificial drains can lead to a faster loss of the contaminant	X		Gravity is used to drain effluent into effluent lagoons, and maintain separation between storm water and effluent
7	Spreading on frozen ground or foliage is avoided.	Losses through runoff may be severe if this is not avoided	X		This is not applicable to the study site
8	Usage of winter cover crops.	This may reduce runoff		X	No cover crops are used in winter
9	Soil organic matter management.	Returning crop residues and animal wastes to soils helps to maintain soil organic matter content; practices that harvest or destroy residues tend to reduce soil organic matter, leading to greater losses from the field	X		Manure is sold to other farmers for use as fertilizer, thereby returning nutrients to soil and improving soil condition

The dimensionless factor alpha (α) represents the leaching-runoff fraction, referring to the fraction of a chemical substance that reaches a freshwater body (Franke *et al*, 2013). The Tier 1 Guidelines uses this equation to determine the leaching-runoff fraction α:

$$\alpha = \alpha_{min} + \left[\frac{\Sigma s_i \times wi}{\Sigma w_i} \right] \times (\alpha_{max} - \alpha_{min})$$

The Tier 1 Guidelines recommend using the values for α, C_{nat} and C_{max} in Table 26 for a grey water footprint calculation based on N-application rate (level 3) (Franke *et al*, 2013).

Table 26: Recommended values for α, $_{nat}$ and C_{max} for Nitrogen

Nitrogen	
α_{min}	0,01
α_{avg}	0,1
α_{max}	0,25
C_{max} (mg/l)	3
C_{nat} (mg/l)	0

The value of α for N in this study is calculated as 0,084, based on the scores described above.

9.2.2. Phosphorous Leaching-Runoff Potential

The factors that determine the phosphorous leaching run-off fraction are catalogued in Table 28. As with the leaching-runoff factors for nitrogen, a score of 0,5 is given to a factor where the actual value is unknown.

The soil texture is again identified as loam and given a score of 0,33.

The erosion factor is given a score of 0,5 (unknown). The score levels give an option between 'low', 'moderate', 'high' and 'very high'. It is not clear whether these description refer to erosion potential of the soil type, slope of the land where pollutants are released, or actual erosion present.

Since the P-content of the soil is not measured on the Feedlot property (in the case of effluent irrigation), and is unknown for the areas where manure is distributed, this factor is given a score of 0,5.

Rain intensity is given a score of 0,67 (strong). The score descriptions of 'light', 'moderate', 'strong' and 'heavy' are too qualitative to provide definite guidance, however since the Heidelberg region anecdotally often experiences thunderstorms a qualitative value of 'strong' was agreed with Feedlot management.

Application rate is calculated for this study, however a lack of definitive guidance on the boundaries of the different score categories necessitates a score of 0,5 (unknown).

The plant uptake of phosphorous is not measured at the study site, however a reference value nutrient uptake of 80kg P_2O_5 for a dry matter yield of 10tonnes/ha for temperate grassland and fodder can be used (Roy et al, 2006). The Tier 1 Guidelines do not provide quantitative ranges for scores for plant uptake of Phosphorous and a score of 0,5 is given (0,5).

Management practice is given a score of 0,33 (good) (Table 25).

The dimensionless factor alpha (α) represents the leaching-runoff fraction, referring to the fraction of a chemical substance that reaches a freshwater body (Franke *et al*, 2013). The Tier 1 Guidelines uses this equation to determine the leaching-runoff fraction α:

$$\alpha = \alpha_{min} + \left[\frac{\Sigma s_i \times wi}{\Sigma w_i} \right] \times (\alpha_{max} - \alpha_{min})$$

The Tier 1 Guidelines recommend using the values for α, C_{nat} and C_{max} in Table 27 for a grey water footprint calculation based on P-application rate (level 3) (Franke et al, 2013).

Table 27: Recommended values for α, $_{nat}$ and C_{max} for Phosphorous

Phosphorous	
α_{min}	0,0001
α_{avg}	0,03
α_{max}	0,05
C_{max} (mg/l)	10
C_{nat} (mg/l)	0

The value of α for P in this study is calculated as 0,00023 based on the scores described above.

Table 28: Phosphorous Leaching-runoff potential factors for the Feedlot

PHOSPHOROUS LEACHING RUN-OFF POTENTIAL									
Category	**Factor**		**Leaching runoff potential**		**Score (*s*)**				
			Weight (*w*)*		**Very low**	**Low**	**No information available**	**High**	**Very high**
			α	**β**	**0**	**0,33**	**0,5**	**0,67**	**1**
Environmental Factors	Soil	Texture (relevant for runoff)	15	25	Sand	**Loam**		Silt	**Clay**
		Erosion	20	25	Low	**Moderate**	**unknown**	High	Very high
		P-content (g P m^{-2})	15	20	<200	200 - 400	**unknown**	400 - 700	>700
	Climate	Rain intensity	10	15	Light	Moderate		**Strong**	Heavy
Agricultural practice	Application rate		15	0	Very low	Low	**moderate**	High	Very high
	Plant uptake (crop yield)		10	0	Very high	High	**unknown**	Low	Very low
	Management practice		15	15	Best	**Good**		Average	Worst

9.2.3. Grey Water Footprint Related to Effluent Management

Effluent Irrigation Volume and Timing

The volume and timing of irrigation over the study period was calculated using a water-balance approach comparing known effluent lagoon volumes and estimated evaporation. Evaporation was estimated using evaporation potential for the Heidelberg area and the surface area of the effluent lagoons. The location of the effluent lagoons is shown in Figure 15, and the surface area of each lagoon in Figure 6. The total surface area of the effluent lagoons is 155 988m^2.

Figure 15: Location of Effluent Lagoons at Study Site

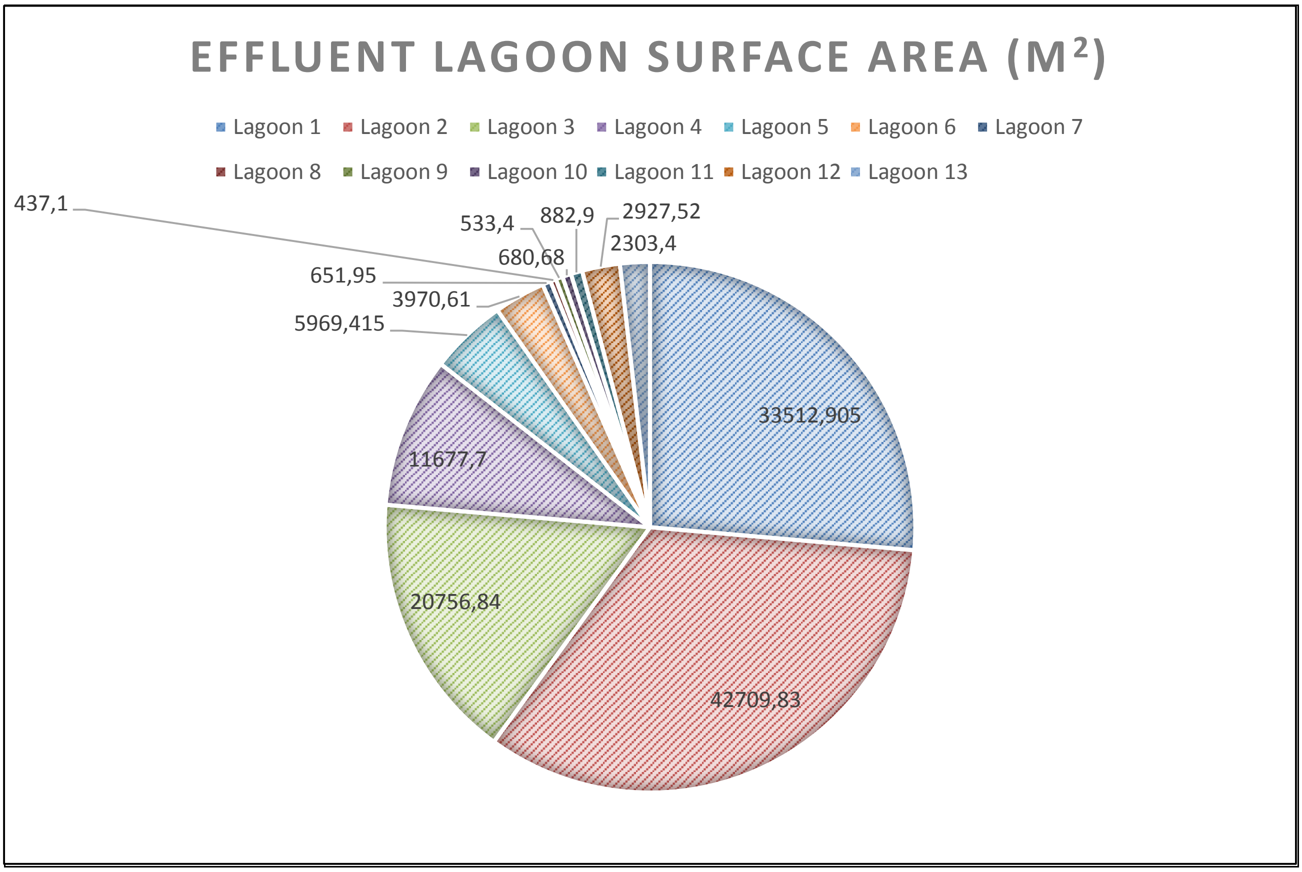


Figure 16: Effluent Lagoon surface areas

The volume of the effluent lagoons is closely monitored. Total effluent lagoon volume records for the study period provided by the Feedlot are given in Figure 17.

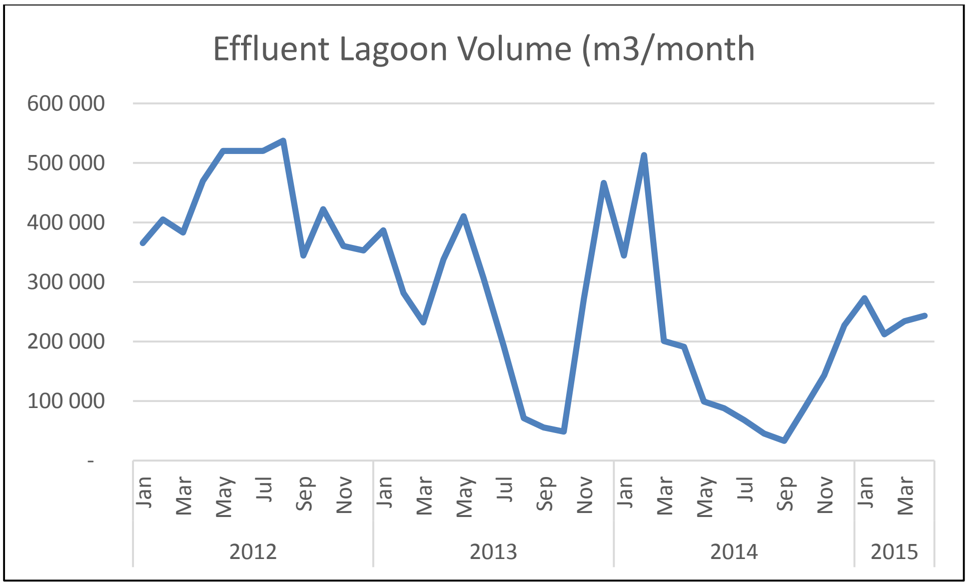


Figure17: Effluent Lagoon volume fluctuations over the study period.

Evaporation potential for the Heidelberg area was taken from Shulze, 1997 (Figure 18). Evaporation was estimated by multiplying the surface area of the effluent lagoons with the expected monthly evaporation potential (Figure 19).

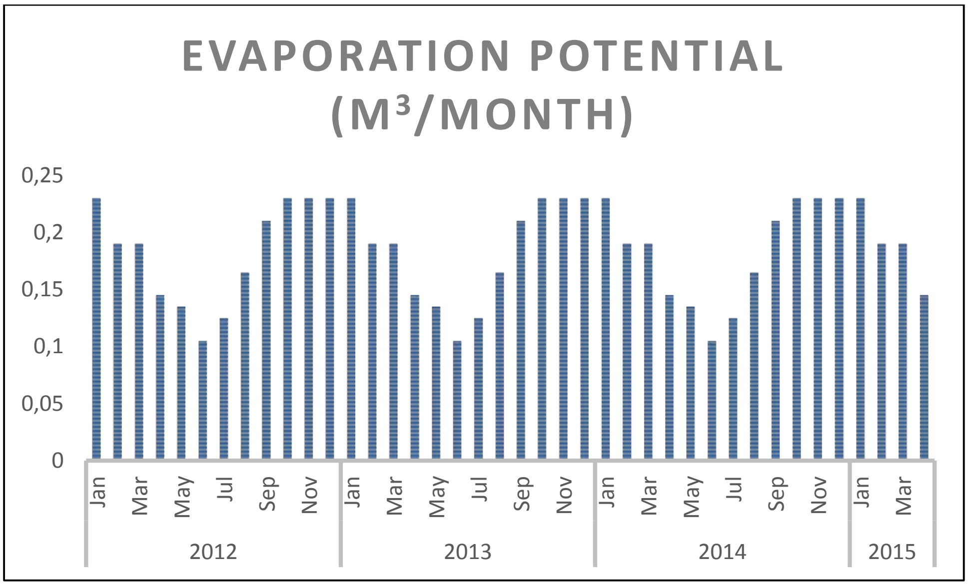


Figure 18: Evaporation potential (m³/month) for the Heidelberg area (Shulze, 1997).

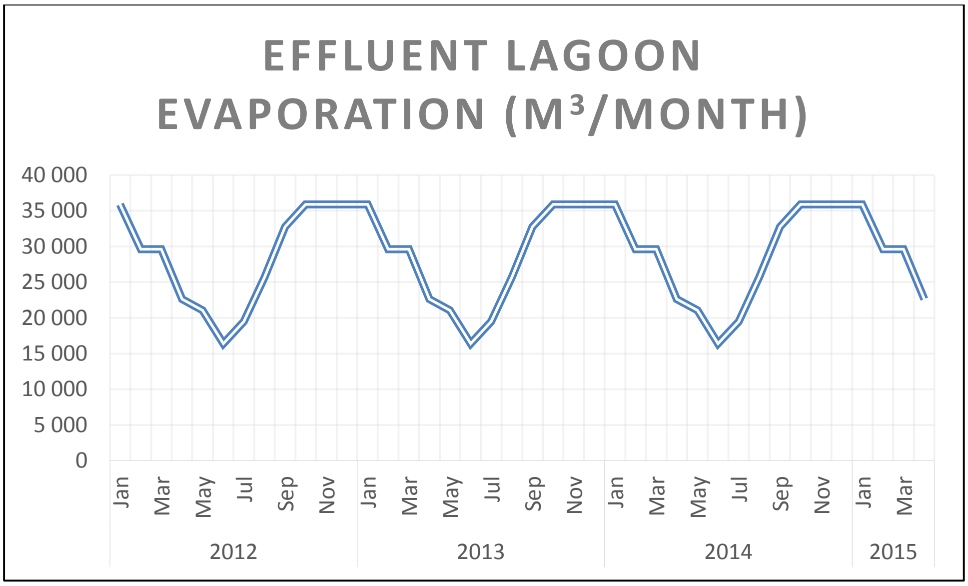


Figure 19: Estimated evaporation from the effluent lagoon surface over the study period.

Irrigation was estimated by subtracting monthly evaporation from the difference between monthly lagoon volumes. Non-zero values are reported as irrigation volume (Figure 20).

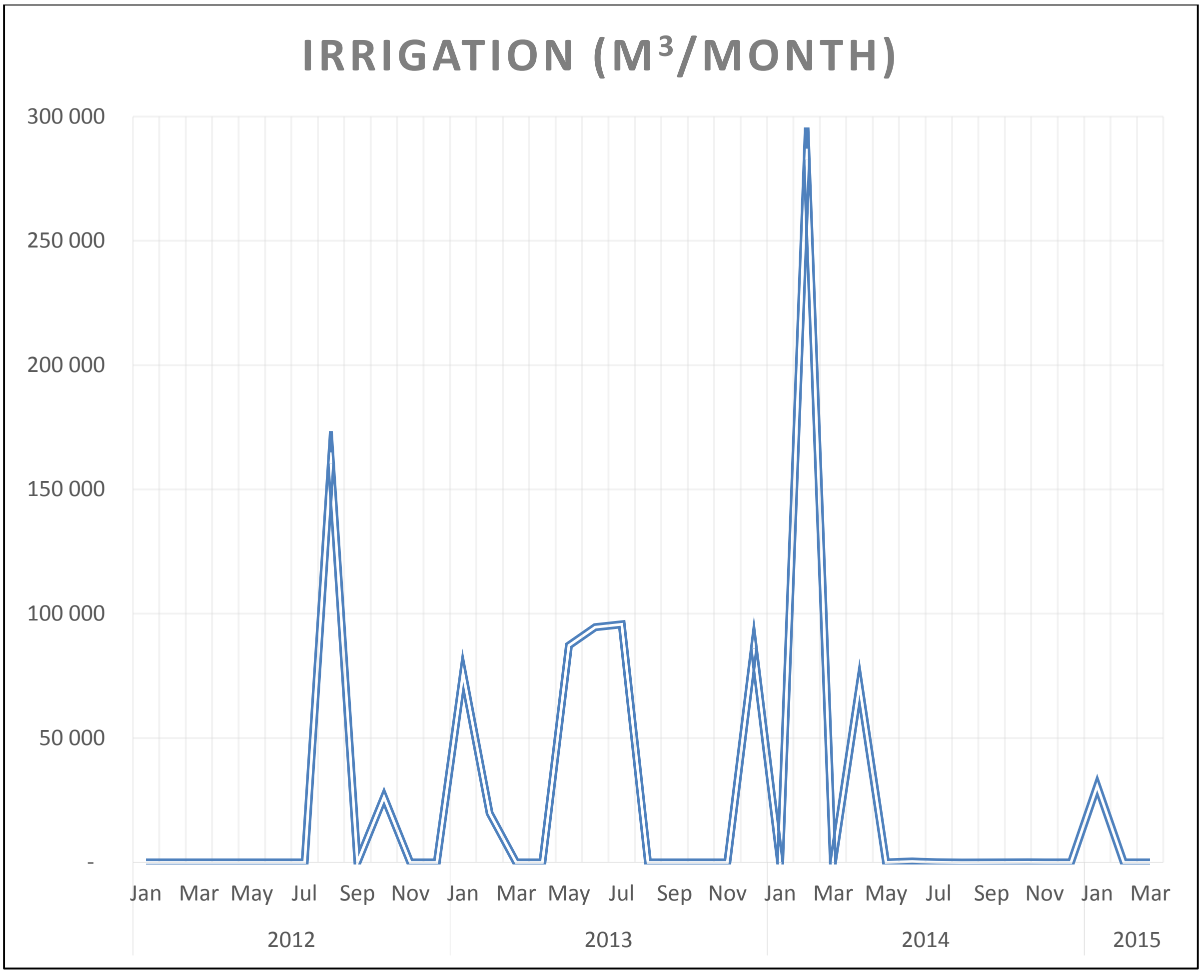


Figure 20: Estimated irrigation volumes from effluent lagoons.

N and P-content of Irrigated Effluent Water

The water quality of irrigation water is not monitored by the Feedlot. Reference values for expected N and P-content of the irrigation water were used to input into the grey water footprint equation. For this purpose a study on a dairy cattle feedlot lagoon's effluent characteristics was used as the reference values for N and P in effluent lagoon water.

Although the diets and manure production of feedlot dairy cows differs from that of feedlot beef cattle, the feedlot pads in the reference study are dry lots similar to that of the study site. In the case of the reference site, the total Kjeldahl Nitrogen (TKN) and total Phosphorous (P) values were used. The reference study analysed lagoon sludge and supernatant water as a single sample. Contaminants such as N, P, K, Ca, Mg, Na, Zn, Cu and Mn are expected to settle at the bottom of the lagoon with solid matter, and not be present in equally significant concentrations in the supernatant water. Volatilization of N from the surface of the lagoon also reduces N in the supernatant water. The Feedlot irrigates supernatant water onto 50a fodder in order to manage the levels of effluent lagoons to prevent accidental spillages during intensive rainfall periods. The reference N and P-values are therefore expected to be potentially significantly larger than the actual N and P-content of the supernatant water used for irrigation at the Feedlot study site. The reference TKN value used in this study is 1630ppm TKN. The reference P value used in this study is 376ppm P.

Effluent Management Grey Water Footprint

The feedlot irrigates supernatant effluent onto 50ha of fodder crops as a risk management practice to maintain effluent lagoon levels and avoid spillage or overflow during high rainfall periods. The grey water footprint of effluent management is determined by the volume and timing of irrigation onto land, as well as the N- and P-content of irrigation water.

The grey water footprint of effluent management is calculated as follows:

Equations to calculate the grey water footprint:

$$\mathrm{GWF} = L/(C_{max} - C_{nat})$$

$$L = \alpha \times Appl$$

$$Appl = Appl.Rate \times Area$$

$$\alpha = \alpha_{\mathrm{min}} + \frac{\Sigma s_i \times w_i}{\Sigma w_i} \times (\alpha_{max} - \alpha_{min})$$

The monthly irrigation volume is multiplied by the N or P concentration, to calculate the N and P application per month in mg. In this study, the monthly application rate multiplied by the irrigated area (50ha) equals *Appl*. *Load* (mg) is calculated by multiplying monthly *Appl* values with α. The *GWF* is then determined by dividing *Load* by the difference between the recommended C_{max} and C_{nat} values. Figure 21 illustrates the grey water footprint for effluent management associated with N and P over the study period.

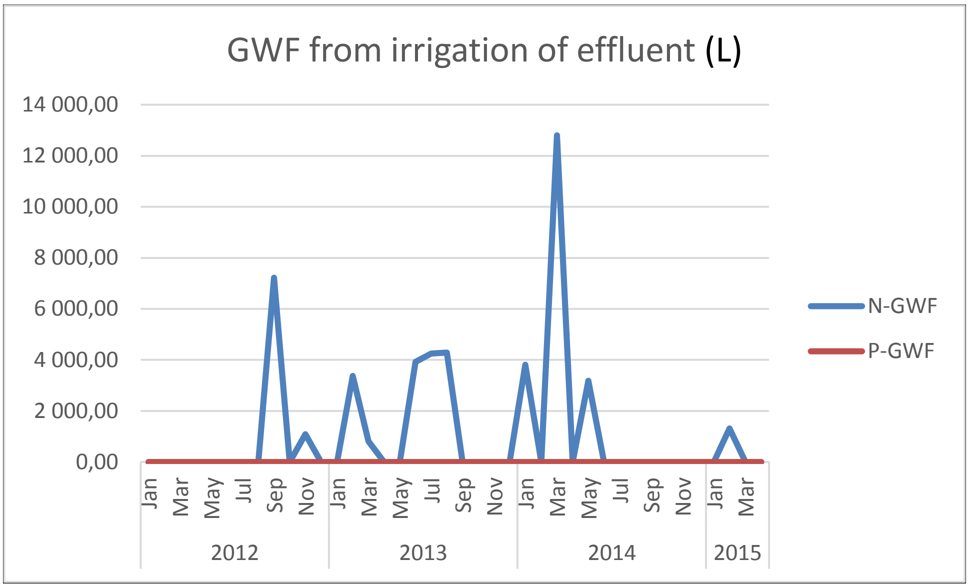


Figure 21: The grey water footprint (L) of effluent management at the study feedlot.

9.2.4. Grey Water Footprint Related to Manure Distribution

Volume of Manure Produced

Manure is a combination of dry matter and urine. A feedlot bovine produces around 5% - 6% of body weight of manure per day. A 450kg bovine would produce approximately 27kg manure, of which approximately 88% (or 24kg) is moisture and 3kg is dry matter (Queensland Department of Agriculture and Fisheries, 2011). There is a considerable size difference between calves entering the feedlot at about 150kg body weight, and finished cattle weighing approximately 250kg after four months. The mid-point body weight (200kg) is used in this study to estimate the amount of manure produced on the feedlot per month. Therefore, the daily manure production is assumed to be 6% of 200kg, which equals 12kg manure consisting of 10,56kg (88%) water and 1,44kg dry matter. The daily manure production on the feedlot is then assumed to be 187,2ton/month dry matter for the feedlot bovine population of 130,000 head of bovine.

N and P-content of Manure

The N- and P-content of manure is not analysed by the feedlot. A reference value for manure-N was adopted from a study on soil carbon and nitrogen response to annual cattle manure applications (Hao et al, 2003). The N-reference value is 15,9kg/ton dry manure.

The reference value for P-content of dry manure was estimated based on the ratio of N:P in dry manure used in a study on the effects of long-term cattle manure application in soil (Parham et al, 2002). The reported ratio is 3,3, therefore the P-content of dry manure is estimated to be 4,82kg/ton dry manure.

Manure Distribution Grey Water Footprint

The feedlot collects manure from the feedlot pads on a regular weekly basis. The compaction of manure on top of the upper bio-filter layer of the feedlot pad is an important process to protect the integrity of the feedlot pad. Loose manure is scraped from the feedlot pads without damaging the bio-filter layer and collected at a central point on the farm. Dry manure is sold to other farmers in the area, and exchanged for bagasse with farmers as far afield as Malelane and Swaziland. Manure is used as soil fertilizer (Mooleki *et al,* 2003; Van Averbeke and Yoganathan, 1997).

The grey water footprint of manure distribution is determined by the volume and timing of placement onto land, as well as the N- and P-content of dry manure.

The grey water footprint of effluent management is calculated as follows:

Equations to calculate the grey water footprint:

$$GWF = L/(C_{max} - C_{nat})$$

$$L = \alpha \text{ X } Appl$$

$$Appl = Appl.Rate \text{ X } Area$$

$$\alpha = \alpha_{min} + \frac{\Sigma s_i \text{ X } w_i}{\Sigma w_i} \text{ X } (\alpha_{max} - \alpha_{min})$$

The monthly manure production volume is multiplied by the N or P concentration, to calculate the N and P application per month in mg. In this study, extent of the distribution area is unknown. *Load* (mg) is calculated by multiplying monthly *Appl* values with α. The *GWF* is then determined by dividing *Load* by the difference between the recommended C_{max} and C_{nat} values. Figure 22 illustrates the grey water footprint for manure distribution associated with N and P over the study period.

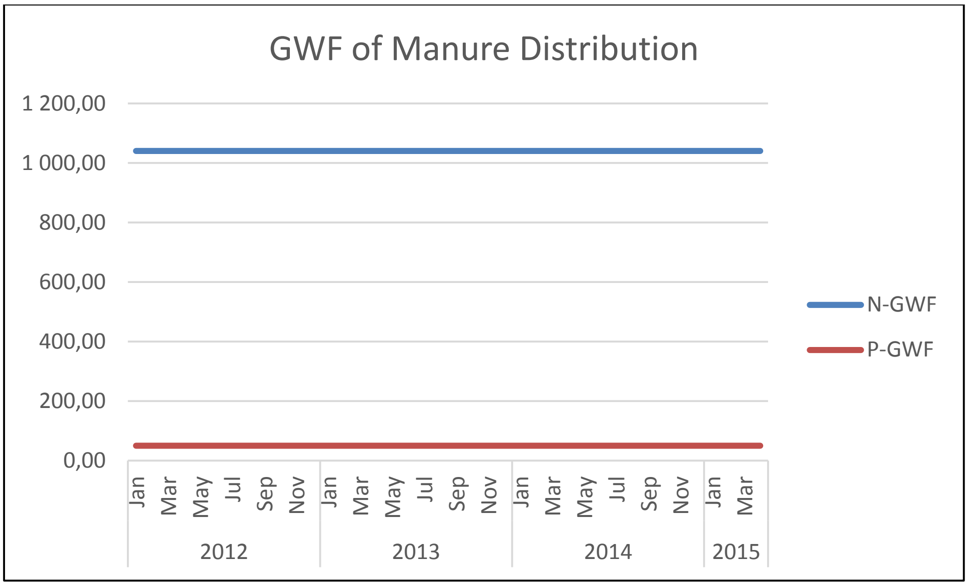


Figure 22: The grey water footprint of manure distribution from the study feedlot.

9.3. WFA Summary

The WF of 1kg beef carcass for beef meat produced at the Feedlot is 17 962 042,41L/kg for the winter production cycle, and 17 962 061,77L/kg for the summer production cycle. The bovine drinking water requirement varies for winter and summer cycles, however drinking water and service water do not have a significant effect on the overall WF. Feed production is the largest component of the Bovine WF, and different feed types each have different WF profiles, which could be used to analyse the WF of different feed supply scenarios.

Manure distribution is responsible for the majority of the grey WF. Manure distribution is an environmental externality, which the Feedlot was not able to include in its SWRM using an on-site water efficiency approach to water management.

The WFA simultaneously enables the Feedlot to consider the water-related risks in its raw material supply chain, which have bearing on enterprise resilience, and to consider the enterprises role in the sustainability of the catchments where feeds are produced and animal waste is distributed. WFA enables the Feedlot to implement a systems approach to SWRM.

10. DISCUSSION

10.1. Feed for Beef Meat Production in South Africa

Beef cattle feedlots are simultaneously agricultural, commercial and industrial enterprises. Such enterprises lend themselves to close supervision and oversight within a corporate Management structure. The success of an agri-commercial-industrial enterprise is often determined by monitoring performance against targets related to process efficiency, cost containment and profits.

Beef meat production in South Africa is mostly undertaken in feedlots (Ibid), where the bovine diet is dominated by maize and maize-derived feed products (Ibid; Study Feedlot Feed Mix). Maize is a dominant crop in the South African landscape, most of which is produced in the Free State province (Figure 24). There has been a marked decrease in maize yield in South Africa in the five years since 2008/9 (Table 29). The 2008/9 yield was 4,96t/ha, and decreased to 4,21t/ha in the 2012/13 season. There was also marked annual variation which saw yields increasing slightly in 2011/12 to 4,49t/ha from the previous year's 4,37t/ha yield. The decrease in yield is ascribed to drought conditions which affected maize yields (Ibid).

Drought conditions can be expected to impact maize crop yields in the future. A reduction in the availability of locally produced maize may compel the Feedlot to import maize from other regions. The findings of the Water Footprint Assessment (WFA) in the following sections will demonstrate the significance of the water footprint of maize production to the overall Bovine Water Footprint of beef meat produced at the Feedlot.

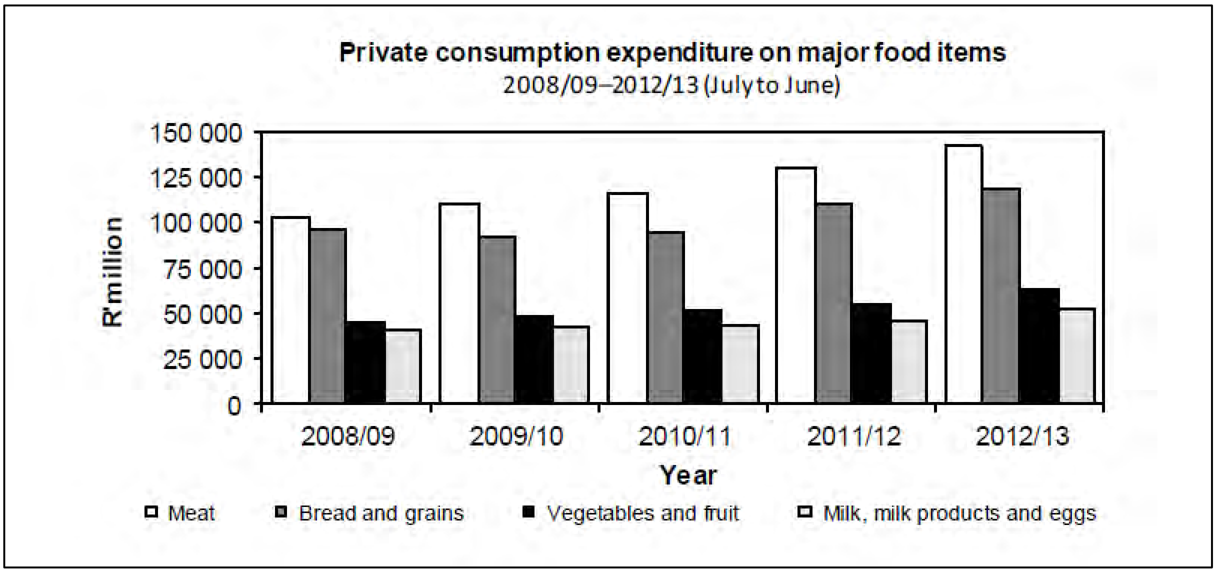


Figure 23: Private household expenditure on major food items in South Africa (DAFF, 2014)

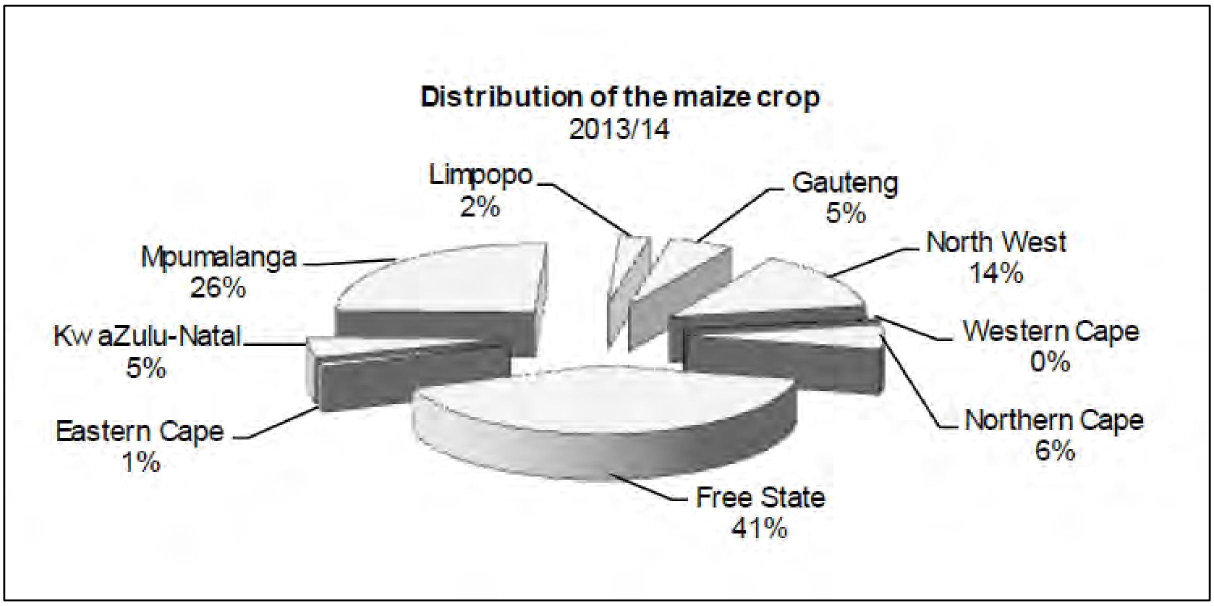


Figure 24: Distribution of the maize crop in South Africa per province (DAFF, 2014)

Table 29: Variation in crop yield in SA (DAFF, 2014)

Season	2008/09	2009/10	2010/11	2011/12	2012/13
Plantings (ha)	2 427 500	2 742 400	2 372 300	2 699 200	2 781 200
Production (t)	12 050 000	12 815 000	10 360 000	12 120 656	11 722 550
Yield (t/ha)	4,96	4,67	4,37	4,49	4,21

10.2. Freshwater Impact of a Beef Cattle Feedlot

Beef cattle feedlots produce significant amounts of pollutants in the form of excess nutrients nitrogen (N) and phosphorous (P) excreted in manure and urine (Burkholder *et al,* 2007; Dickey and Vanderholm, 1977; Ferguson *et al,* 2005; Mooleki *et al,* 2003; Simpson, 1998). Effluent, mostly consisting of urine, is collected in effluent lagoons on the feedlot premises. Manure on the other hand is useful as a soil fertiliser to increase N, P and potassium (K) in soil (Hao *et al,* 2003). High transportation costs often result in manure being applied to agricultural land in close proximity to a feedlot, so that manure is actually being disposed onto land instead of being “utilized as a valuable resource” (Hao *et al,* 2003 page 239).

Freshwater impacts can be caused by point sources of pollution from effluent lagoons that either leak or spill over, or from diffuse pollution sources from disposal of manure. Van Averbeke and Yoganathan (1997) recommend that feedlot manure be applied at a rate of 5t/ha to high-yielding maize plantings. However, Dao (1999) states that the narrow N to P ratio that exists in animal manure, may result in over-application of P to meet N demands of crops.

The results of the WFA on waste management demonstrates that manure distribution is the most significant component of the Feedlot’s grey water footprint.

10.3. Bovine Water Footprint Results

This study estimates the WF of beef meat produced during the 4-month summer- and winter finishing cycles at the feedlot, at 17,962,061.77L/kg hot carcass and 17,962,042.41L/kg hot carcass respectively (the difference is attributed to seasonal changes in drinking water requirements). In contrast, Mekonnen & Hoekstra (2010) estimated the global average lifetime WF for industrial production systems at 10,244L/kg live weight, and the Australian average at 5,130L/kg (Australia has a comparable climate to South Africa). Capper (2012) estimated the lifetime WF at 32,864L/kg live weight, considering animal drinking water and irrigated crops (blue WF) only. Animal slaughter weight in this study was only 250kg, compared to the average slaughter weight of 569kg reported by Capper (2012). The considerable difference between results from different studies suggests that methodological differences may exist. In this study there is an acknowledged and significant error in the published feed WF data which was quoted from Mekonnen & Hoekstra (2010) and used in the water footprint accounting. The error relates to incorrect representation of the number of provinces in South Africa: Mekonnen & Hoekstra (2010) incorrectly report 9 provinces, whereas South Africa only has 8 provinces. Since it was not known to what extent the error affects the national average, or where the provincial data duplication occurred, this study did not attempt to correct the data. The error was reported to the Water Footprint Network, who took note of the error but did not respond with corrected data.

Furthermore, assumptions were made about feed mix ratios, as well as for certain aspects of the WFA methodology where the national or global average was inappropriate, but where local data was unavailable. These assumptions can possibly over-or under estimate the final results.

10.3.1. WF of Feeds

The Feedlot provided only partial information on the composition of the monthly feedlot feed mix. To arrive at a feed mix that is a reasonable representation of the average reality, it was necessary to rely on reference values and typical feed ratios for feedlot beef cattle from literature. Due to the limited feed mix information provided it was necessary to treat the feed mix as a monthly constant although in reality the composition of the feed mix is regularly adjusted to respond to changes in temperature, bovine feed intake, bovine water intake and bovine feed preferences. According to the Feedlot management, cattle that enter the feedlot require a period of adjustment during which time they may eat less than normal. Periods of disease will also affect the actual feedlot feed mix and the volume of feed consumed.

Approximately 60% of the Feedlot feed mix is made up of concentrated feed products: molasses, glutenfeed, green maize chop and hominy chop. Green maize chop is the largest component of the monthly Feedlot feed mix (15 600t/month), followed by molasses (7800t/month). The glutenfeed requirement is 4t/month. Oilmeals make up 20% of the Feedlot feed mix. Oilmeals consist of soya oil cake (7 800t/month) and cotton oil cake (4t/month). The remaining 20% is made up of cereals (maize and cotton seed – 1959t/month) and roughages and residues (5779t/month). Thus it can be deducted that the Feedlot feed mix is predominantly derived from maize, soya, wheat, cotton and sugarcane crops. The largest contributor is maize.

The WFA uses allocation fractions to allocate the green, blue and grey water of the main product to its byproducts (Thaler *et al,* 2012). The value fraction of main crops (Mekonnen and Hoekstra, 2010a) was used to allocate the water footprint of production to different feed categories consumed at the Feedlot. The green WF is the largest component of the feed consumed in a 4-month production cycle (7 808 749$m^{3/}$month, or 72% of the WF of feed). The blue WF is 24% of the total and the grey WF is 4% of the total WF of feed consumed in a 4-month production cycle.

Although oilmeals only make up only 20% of the feed mix, it contributes 60% to the green WF of Feedlot feed. Concentrated feeds contribute 66% to the blue WF, owing to the fact that these feeds are highly dependent on rainfall (green WF). Concentrated feeds are often by-products of brewery processes and bio-ethanol production, both large water consumption industries. 74% of the grey WF is also associated with concentrated feeds. In conclusion, concentrated feeds and oilmeals together make the largest contribution to the WF of feeds consumed by beef cattle at the Feedlot.

Mekonnen and Hoekstra (2010) describe three main factors that contribute to most of the water footprint of beef cattle (98%). The feed conversion efficiency of beef cattle is the first factor. According to Mekonnen and Hoekstra the “relatively large water footprint of beef” is attributed to their “unfavourable feed conversion efficiency” (Mekonnen and Hoekstra, 2010. Page 5). The second key factor relates to the composition of the feed. In this the ratio of roughages to concentrates is significant, as is the ratio of crop residues like beetroot leaves and tops, bran or chaff, to valuable crop components, like wheat or sugar beet. Crop residues contribute about zero to the water footprint of feed, since the crop water footprint is attributed to the main crop. The third factor is the origin of the feed, specifically if the feed crops were irrigated or produced in dryland conditions. The remaining portion of the water footprint of beef is made up of drinking water (1,1%), feed mixing water (0,03%) and service water (0,8%).

The WFA made apparent that different feed types have unique influences on this WF-component of beef cattle. Being able to objectively demonstrate that the Feedlot's largest green WF resides in the Free State province where the majority of South Africa's maize is produced, and that concentrated feeds are very dependent on blue water (and by implication depend on the effective management of clean water reticulation), allows the Feedlot to adjust feed purchasing practices and the Feedlot feed mix when necessary to manage risk and improve resilience. For instance, the $WF_{production}$ for molasses referred to the country average for molasses produced in Swaziland. Molasses is also produced commercially in South Africa, but the $WF_{production}$ for molasses in South Africa is much larger than in Swaziland. The annual green $WF_{production}$ for sugarcane in Swaziland is 55m^3/ton, while in South Africa it is 299 m^3/ton. South Africa has a larger blue- and grey $WF_{production}$ for sugarcane than Swaziland, at 70m^3/ton and 33m^3/ton respectively compared to Swaziland's 66m^3/ton blue WF and zero grey WF (Vidal *et al,* 2010).

The dynamic in the blue-green continuum is also made apparent. If continued drought or other factors compel the Feedlot to import more expensive maize-products from irrigated regions, the blue component of the WF will increase, along with the associated dependence on well-managed water reticulation systems. This demonstrates the Feedlot's reliance not only on rainfall, but also on the lower cost of a feed WF that is largely green. In times of water stress the Feedlot may also be able to objectively balance the need for return on investment against SWRM by selecting feeds that still provide desirable weight gains in feedlot cattle, but have a lighter WF requirement. The green WF is largely attributed to rainfall and climate and is therefore beyond the control of food producers. Crops produced in high rainfall areas will have high green WFs, but this is not necessarily a cause for concern. Instead of analysis the significance of the green WF to sustainability from a quantity perspective, it ought be viewed from a risk point of view.

The WFA revealed objectively that the freshwater impact of feed for beef cattle at this feedlot is geographically separated from the actual production site of beef meat. Efforts to improve SWRM can be targeted at the specific component of the feed-WF that requires intervention, and will ensure that efforts aren't wasted on feed types that do not have a large WF. WFA also allows analysis of the blue-green continuum and it may be possible to model future scenarios to plan for water's role in enterprise resilience.

10.3.2. WF of Drinking Water and Service Water

The contribution made by drinking- and service water to the overall WF of 1kg of beef carcass is negligible. Since the Feedlot's focus for WRM is only directed at drinking- and service water, it becomes clear that the enterprise is not able to account for its' freshwater impact using current management practices.

The WFA demonstrated objectively that the water used on the Feedlot premises for cattle drinking water and for service water is insignificant in terms of the freshwater impact of beef meat production. These direct WF-components remain significant from an operational perspective for the day-to-day running of the Feedlot, but should be balanced against the impact of the Feedlot's indirect WF for SWRM.

10.4. Grey Water Footprint of Waste Management Activities

The Tier 1 Grey WF methodology (Franke *et* al, 2013) presented the greatest challenge for the WFA. An attempt was made to quantify the N and P grey WF associated with irrigation of supernatant effluent lagoon water on the premises of the Feedlot, and associated with the distribution of dry manure beyond the premises of the Feedlot. A level 3 assessment approach was applied to the N- and P- grey WF.

10.4.1. Nitrogen in the Grey Water Footprint

The WFA demonstrated that N played a greater role in the grey WF of irrigation, than of manure distribution. It further demonstrated that N is the dominant contributor to both effluent irrigation and manure distribution. These results are however based on certain assumptions on the N-content of effluent and manure that may cause the effluent N-content to be overstated. Analysis of the actual N-content of supernatant effluent water before irrigation and dry manure before it leaves the Feedlot premises will make a more representative analysis possible.

The WFA used the recommended values for α_{min} and α_{max}, and C_{nat} and C_{max} for N. Since the soil N-content is not measured on the Feedlot premises (relevant for irrigation of effluent water) or known for the land where dry manure is distributed, it was not possible to use location-specific values. The grey WF associated with irrigation of supernatant effluent water will be more site-specific for N if soil analyses on the Feedlot premises is performed once a year.

The methodology to calculate the leaching-runoff fraction for N has certain shortcomings for application at the scale of a local agri-business enterprise. The descriptions for natural drainage, N-application rate and plant N-uptake in the Tier 1 Guidelines are inadequate to make a quantitative selection of the score to be applied to each parameter. The ranges for precipitation are too wide to apply this parameter on a monthly basis in a region where annual rainfall is below 600mm/annum.

The methodology does not distinguish between the different types of N, except to state that one should use consistent forms of N in all calculations. In the case of irrigation with supernatant effluent water, the methodology doesn't account for N that is lost to the atmosphere during the activity of irrigation. The different forms of N have unique pollution characteristics. During the process of nitrification, both NO_2^- (nitrite) –ions and NO_3^- (nitrate) – ions are formed from NH_3 (ammonia) by aerobic bacteria. Nitrite-ions are toxic to animals, while nirate-ions are a plant nutrient (Miller *et al,* 1999). A volumetric assessment of the grey WF to assimilate either nitrite- or nitrate ions would need to be qualified against the polluting effect of the substance to be informative from an agricultural application perspective. Furthermore, to be able to analyse the sustainability of the grey WF of N the ongoing assessment of the C_{nat} value for N is necessary.

10.4.2. Phosphorous in the Grey Water Footprint

The WFA demonstrated that P has a lesser influence on the grey WF for both irrigation of effluent and manure distribution than N. As with N, the actual P-content of irrigated effluent water and dry manure is not measured and the reference P-content values used may not be representative of the actual P-contribution to the grey WF.

The WFA used the recommended values for α_{min} and α_{max}, and C_{min} and C_{max} for P. Since the soil P-content is not measured on the Feedlot premises (relevant for irrigation of effluent water) or known for the land where dry manure is distributed, it was not possible to use location-specific values. The grey WF associated with irrigation of supernatant effluent water will be more site-specific for P if soil analyses on the Feedlot premises is performed once a year.

The descriptions for erosion, rain intensity, P-application rate and plant P-uptake in the Tier 1 Guidelines are inadequate to make a quantitative selection of the score to be applied to each parameter.

No differentiation is made in the methodology between the different forms of P found in soil. PO_4^{3-} and HPO_4^{2-} are essential nutrients, and phosphate is a growth limiting factor in plants if insufficient amounts are present. To be able to analyse the sustainability of the grey WF of P the ongoing assessment of the C_{nat} value for P is necessary.

10.4.3. Grey WF as a Proxy for Water Quality Impact

The WFA demonstrated objectively that N is the substance of greatest concern when considering the grey WF associated with irrigation of supernatant effluent water and distribution of dry manure. Feedlot beef cattle consume a diet rich in N, and thus excrete large amounts of N as a result. Furthermore, the WFA made apparent that the freshwater impact of waste management by the Feedlot is geographically separated from the Feedlot operations. Efforts to improve SWRM of the Feedlot could consider feeding less N-rich feeds to reduce the N-content of effluent and manure. The Feedlot does not have control over the land management practices in the areas where manure is distributed, but awareness about over-application of nutrients to soil can be improved among users of the manure.

Wichelns (2015) argues that the grey WF is a theoretical proxy for the difference between ambient concentrations of a substance, and water quality standards for the substance. The grey WF assumes that dilution is the only treatment solution for pollution, and does not consider any pre-treatment which may be taking place or the natural pollution assimilation process of landscape features such as wetlands. The results from this study concur with these assumptions.

The grey WF is silent on a number of factors that are important from a water resources management point of view (Wichelns, 2015): the source of pollution; the incremental costs and opportunities to reduce pollution; impacts of pollution on people and water resources; and cumulative pollution from multiple sources. This study confirms these concerns. The grey WF should be used as an indicator of potential environmental burden, and not an indicator of actual pollution.

10.5. Blue Water Scarcity in The Suikerbosrand Tertiary Catchment

The blue water scarcity of the Suikerbosrand tertiary catchment was beyond the scope of this dissertation. However, when one considers the narrow margin between the current water demand and the still-available potential development of the resource, it appears that the catchment is approaching a state of over-allocation. The WFA made it apparent that the Feedlot should also consider the blue water scarcity in the catchments where feed crops are grown to develop SWRM strategies that align with the actual freshwater impact of beef production.

Wichelns' (2015) view on water scarcity is that scarcity is the sum of competing demands. The growth outlook of demand and supply for both climate and human ingenuity has bearing on water scarcity.

10.6. Results of Study Workshop with Feedlot Management

The results of the Water Footprint Assessment were presented to the Feedlot in a workshop format. Feedlot management were asked to reflect on three central questions: 1) Is there a business case for a CAFO like the study Feedlot to use Water Footprint Assessment to manage water-related risk?; 2) Can a Water Footprint Assessment be used to improve sustainability, reduce costs, maintain legal compliance and improve business resilience to water-related change?; and 3) Which component of the Water Footprint represents the greatest business risk? (Appendix A; Appendix B).

The discussions of the workshop framed water-related risk, enterprise resilience and sustainable WRM within the wider context of the beef meat supply chain. Of particular benefit was the WFA's ability to focus on each WF component individually, and discuss individual risks and sustainability aspects.

The freshwater impact of feed production was an important discussion topic. The Feedlot's reliance on indirect green water was highlighted as a potential risk factor worth considering, especially in light of the impact of drought on maize production in South Africa.

The grey WF highlighted the need for the Feedlot to incorporate environmental externalities into the SWRM of the enterprise. Since the grey WF clearly demonstrated that the distribution of manure has significant environmental impact potential, it enabled the Feedlot to consider strategies to reduce the off-site impact of the waste management practices. This can be achieved from a feed perspective, in considering the concentration of N in feeds, and also from an awareness perspective by engaging with farmers that use the manure as fertilizer. Manure from this Feedlot is potentially high in N, which increases the likelihood of over-application of nutrients to land if manure is consistently placed in the same areas over extended periods of time.

Another complex concept discussed was the fact the manure is not distributed back to the farms where the feed crops are grown. The manure from this Feedlot is not used to replenish soil nutrients lost in the production of feed, which increases the need for crop-growing areas to be fertilized with commercial fertilizers.

A limitation of the study that was discussed at length during the workshop was the need to assume reference values and use constant volumes of feed and drinking water in the calculations. This type of information is highly sensitive in the industry and can therefore not readily be made available without compromising the enterprise's competitive advantage in the market. However, it was agreed that the methodology and application of the WFA was clearly demonstrated.

The workshop concluded that there is a business case for a beef CAFO to use WFA for SWRM, and that WFA can be applied to reduce the value-chain costs and legal compliance water-related risks of the enterprise. The WF components that present the greatest risk to the Feedlot are the $WF_{production}$ Feeds, WF_{drink} and the grey WF of manure distribution.

11. CONCLUSION

The research question for this study was: “Can the application of a Water Footprint Assessment (WFA) enable a beef cattle feedlot to transition from an on-site water-efficiency management approach to a value-chain based sustainable water resources management approach?” The emphasis was placed on how the application of the WFA process contributes to greater understanding of water-related risks within the Feedlot’s beef production value chain.

At the commencement of this study the Feedlot applied an efficiency approach to water resource management (WRM) which focused on freshwater supply to the feedlot to meet the drinking water demand of beef cattle. This approach is aimed at a narrow view of supplying the direct freshwater needs of Feedlot cattle and complying with legal requirements which govern abstraction volumes. The Feedlot did not have a mechanism to consider the freshwater impacts of the whole beef meat value chain – incorporating the production of animal feed, on-site water consumption and the freshwater pollution burden of waste management. The conventional WRM approach did not enable the Feedlot to assess water’s broader role in the enterprise’s resilience to water-related stresses and shocks or the Feedlot’s role in achieving SWRM at the catchment level (Röckstrom, J *et al,* 2014).

The WFA for the Feedlot made it apparent that the most significant impact on freshwater resources is associated with the production of feed crops. Furthermore, it demonstrated the potential significance of the off-site pollution burden of manure disposal. However, the study demonstrated that the grey WF alone has limited relevance for sustainability assessment, and the conclusion by Thaler *et al* (2012) that goal-oriented development of the grey WF method is necessary, is therefore supported.

The benefit of the WFA is that the different WF components can be evaluated separately to improve enterprise resilience and inform sustainable WRM. The grey WF should be viewed as an indicator of potential pollution burden, and not as an indicator of actual pollution impact.

The Bovine WF of 1kg of beef carcass can be reduced by reducing the WF of crop production; by increasing the feed conversion efficiency and by using less concentrated feeds derived from irrigated crops. The temporal scale of the WFA must be aligned with production cycles to give an objective assessment of the Bovine WF at a beef cattle feedlot.

The grey WF of waste management can be reduced by matching the nutrient content of feeds closer to the animal's nutritional needs to reduce excessive excretion on N and P. The grey WF of waste management can further be reduced by analysing soil properties and manure properties prior to disposal to prevent over-application of nutrients. The ongoing monitoring C_{nat}, combined with a goal-oriented approach will improve the worth of the grey WF for sustainable WRM. The grey WF should be used as an indicator of potential environmental burden, and not an indicator of actual pollution.

The WFA enables a beef cattle feedlot to transition from on-site water efficiency approach to WRM, to a sustainable supply chain approach to WRM based on objective findings. Further refinement of the WF methodology for application by agricultural production value chains should be the topic of further research.

12. RECOMMEDATIONS FOR FURTHER RESEARCH OPPORTUNITIES

Several areas of further research would enable the wider application of WFA to food production supply chains:

a) Utilization of more by-product feeds in beef cattle diets to leverage efficiency gains.
b) The WF of concentrated feed categories, and considering alternatives to maize for concentrated feeds
c) Grey WF methodologies to reflect the actual impact of pollutants more realistically by demonstrating the source of pollutants, the fate of pollutants and cumulative impacts of pollutants
d) Models to examine alternative WF scenarios for a food production value chain to enable real-time decision-making to benefit SWRM and improve enterprise resilience.
e) Catchment-wide WFA of all production activities will contribute to SWRM at quaternary catchment level.
f) Quantitative refinement to describe the parameters that influence leaching-runoff fractions of N and P in the Tier 1 guidelines will result in greater confidence in the results of a grey WFA, and allow greater comparability between for instance manure disposal sites for consideration of sustainable waste management practice over time.

14. REFERENCES

ALDAYA, M.M., HOEKSTRA, A.Y., 2010: The Water Needed for Italians to Eat Pasta and Pizza. *Agricultural Systems Volume 103 page 351-360*.

BLESBOKSPRUIT FORUM, 2014: Personal Communication from Marc de Fontaine, July 2014 http://www.reservoir.co.za/forums/vaalbarrage/blesbok_forum/blesbok_home.htm

BULSINK, F., HOEKSTRA, A.Y., BOOIJ, M.J., 2010: The Water Footprint of Indonesian Provinces Related to the Consumption of Crop Products. *Hydrology and Earth System Sciences Volume 14 page 119 – 128.*

BURKHOLDER, J., LIBRA, B., WEYER, P., HEATHCOTE, S., KOLPIN, D., THOME, P.S. and WICHMAN, M., 2007. Impacts of waste from concentrated animal feeding operations on water quality. *Environmental health perspectives,* , pp. 308-312.

CAPPER, J.l., 2012: Is the grass always greener? Comparing the Environmental Impact of Conventional, Natural and Grass-Fed Beef Production Systems. *Animals 2012 Volume 2* page 127 - 143. www.mdpi.com/journals/animals.

CHAPAGAIN, A.K., HOEKSTRA, A.Y., 2004: Water footprint of Nations. Value of Water Research Report Series no. 16, *UNESCO IHE, Delft, The Netherlands.* *www.waterfoorprint.org/Reports/Report16Vol2.pdf*

CHAPAGAIN, A.K., HOEKSTRA, A., SAVENIJE, H. and GAUTAM, R., 2006. The water footprint of cotton consumption: An assessment of the impact of worldwide consumption of cotton products on the water resources in the cotton producing countries. *Ecological Economics,* **60**(1), pp. 186-203.

CLEVELAND, C., HOULTON, B.Z.,, SMITH, W.K., MARKLEIN, A.R., REED, S.C., PARTON, W., DEL GROSSO, S.J., RUNNING, S.W., 2013: Patterns of new versus recycled primary production in the terrestrial biosphere. www.pnas.org/cgi/doi/10.1073/pnas.1302768110CUMMING, G.S., BARNES,G., PERZ, S., SCHMINK, M., SIEVING, K.E., SOUTHWORTH, J., BINFORD, M., HOLT, R.D., STICKLER, C., VAN HOLT, T., 2015: An exploratory frameworkfor the emprirical measurement of resilience. *Ecosystems Vol 8 page 975-987.*

CLIMATE INFORMATION PLATFORM, 2015*:* Historical climate reocrds for Heidelberg, Gauteng downloaded on 20 January 2016 from *http://cip.csag.uct.ac.za/webclient2/datasets/south-africa-all/#nodes/observed-cmip5?folder_id=35&extent=103951*

DABROWSKI J.M., MURRAY, K.A., LEANER, J.J., 2009: Agricultural Impacts on Water Quality and Implications for Virtual Water Trading Decisions. *Ecological Economics Volume 68 page 1074 – 1082.*

DAO, T.H., 1999. Coamendments to modify phosphorus extractability and nitrogen/phosphorus ratio in feedlot manure and composted manure. *Journal of environmental quality,* **28**(4), pp. 1114-1121.

DARNHOFER, I., 2014. Resilience and why it matters for farm management. *European Review of Agricultural Economics,* , pp. jbu012.

DENTENER, F. J. 2006. Global Maps of Atmospheric Nitrogen Deposition, 1860, 1993, and 2050. Data set. *Available on-line http://daac.ornl.gov/ from Oak Ridge National Laboratory Distributed Active Archive Center, Oak Ridge, Tennessee, U.S.A. doi:10.3334/ORNLDAAC/830. Map downloaded on 03/02/2016 from* http://webmap.ornl.gov/wcsdown/wcsdown.jsp?dg_id=830_2

DEPARTMENT OF AGRICULTURE, FORESTRY AND FISHERIES, 2014: Trends in the Agricultural Sector. *Republic of South Africa.*

DEPARTMENT OF WATER AFFAIRS AND FORESTRY, 2002: Upper Vaal Water Management Area – Water Resources Situation Assessment. Final Report: July 2002*. Republic of South Africa*.

DEPARTMENT OF WATER AFFAIRS, 2013: National Water Resources Strategy, 2nd edition - Water for an Equitable and Sustainable Future. June 2013. *Republic of South Africa*.

DEPARTMENT OF WATER AND SANITATION, 2015: Business Case for the Establishment of the Vaal River Catchment Management Agency*. Republic of South Africa.*

DICKEY, E.C. and VANDERHOLM, D., 1977. Feedlot Runoff Holding Ponds—Nutrient Levels and Related Management Aspects. *Journal of environmental quality,* **6**(3), pp. 307-312.

DIGBY WELLS, 2014: Background information document Environmental impact assessment for the proposed sludge disposal facility and pipeline associated with the treatment of acid mine drainage in the eastern basin of the Witwatersrand goldfields, Gauteng province. *DEA Reference Number: 14/12/16/3/3/3/111*

ERCIN, A.E. and HOEKSTRA, A.Y., 2014. Water footprint scenarios for 2050: A global analysis. *Environment international,* **64**, pp. 71-82.

ERIYAGAMA, N., CHEMIN, Y., AMARASINGHE, U., ALANKARA, R. and HOANH, C.T., 2011. Estimation of consumptive water use and vulnerability mapping of coffee: a global analysis. Project report submitted to Nestle Ltd. under the project" Global Consumptive Water Use of Coffee?. .

FALKENMARK, M., 2013. Growing water scarcity in agriculture: future challenge to global water security. *Philosophical transactions.Series A, Mathematical, physical, and engineering sciences,* **371**(2002), pp. 20120410.

FAO 1998: Irrigation and Drainage Paper No. 56, 1998. Crop Evapotranspiration – guidelines for computing crop water requirements. *Food and Agriculture Organization of the Nations. 1998*.

FAO, 2014: Understanding AQUASTAT FAO'S global water information system. *Food and Agriculture Organization of the Nations. 2014* *h*ttp://www.fao.org/nr/water/aquastat/catalogues/index.stm

FERGUSON, R.B., NIENABER, J.A., EIGENBERG, R.A. and WOODBURY, B.L., 2005. Long-term effects of sustained beef feedlot manure application on soil nutrients, corn silage yield, and nutrient uptake. *Journal of environmental quality,* **34**(5), pp. 1672-1681.

FIKSEL, J., 2006: Sustainability and Resilience: toward a systems approach. *Sustainability: Science, Practice, & Policy.* http://ejournal.nbii.org

FRANKE, N., HOEKSTRA, A. and BOYACIOGLU, H., 2013. Grey water footprint accounting: Tier 1 supporting guidelines.

FULTON, J., COOLEY, H. and GLEICK, P.H., 2014. Water Footprint Outcomes and Policy Relevance Change with Scale Considered: Evidence from California. *Water Resources Management,* **28**(11), pp. 3637-3649.

GADBERRY, S., 2015: Water for Beef Cattle. *University of Arkansa Division of Agriculture.* Document downloaded on 20 January 2016 https://www.uaex.edu/farm-ranch/animals-forages/beef-cattle/nutrition-feeding.aspx

GERBENS-LEENES, W., HOEKSTRA, A.Y., VAN DER MEER, T.H., 2009: The Water Footprint of Bioenergy. *Proceedings of the National Academy of Sciences Volume 106 page 10219-10233.*

HAO, X., CHANG, C., TRAVIS, G.R. and ZHANG, F., 2003. Soil carbon and nitrogen response to 25 annual cattle manure applications. *Journal of Plant Nutrition and Soil Science,* **166**(2), pp. 239-245.

HASTINGS, E. and PEGRAM, G., 2011. *Literature review for the applicability of water footprints in South Africa.* Water Research Commission.

HENDY, C.R.C., KLEIH, U., CRASHAW, R., PHILLIPS, M., 1995: Livestock and the environment finding a balance: Interactions between livestock production systems and the environment. Impact Domain: concentrate feed demand. *Food and Agriculture Organization, Rome, Italy.*

HOEKSTRA, A.Y., CHAPAGAIN, A.K., 2007: Water footprint of Nations: water use by people as a function of their consumption pattern. *Water Resources Management Vol 21, page 35 – 48.*

HOEKSTRA, A.Y., CHAPAGAIN, A.K., ALDAYA, M.M. and MEKONNEN, M.M., 2011. Water footprint manual: Setting the Global Standard 2011. *Earthscan*.

HOEKSTRA, A.Y. and MEKONNEN, M.M., 2012. The water footprint of humanity. *Proceedings of the National Academy of Sciences of the United States of America,* **109**(9), pp. 3232-3237.

HSI REPORT, 2016: The Impact of Animal Agriculture on Global Warming and Climate Change. Document downloaded on 20 January 2016 www.humanesociety.org/.../hsus-the-impact-of-animal-agriculture-on-global- warming-and-climate-change.pdf

JESWANI, H.K. and AZAPAGIC, A., 2011. Water footprint: methodologies and a case study for assessing the impacts of water use. *Journal of Cleaner Production,* **19**(12), pp. 1288-1299.

LARSON, W., RICHTER, B., BIRNER, S. and SELVENDIRAN, P., 2010. Water footprint assessments: Dehydrated onion products and micro-irrigation systems. *Prepared in collaboration with The Nature Conservancy for Jain Irrigation Systems Ltd.and International Finance Corporation,* .

LAUNIAINEN, S., FUTTER, M.N., ELLISON, D., CLARKE, N., FINÉR, L., HÖGBOM, L., LAURÉN, A. and RING, E., 2014. Is the water footprint an appropriate tool for forestry and forest products: The Fennoscandian case. *Ambio,* **43**(2), pp. 244-256.

LIU, C., KROEZE, C., HOEKSTRA, A.Y. and GERBENS-LEENES, W., 2012. Past and future trends in grey water footprints of anthropogenic nitrogen and phosphorus inputs to major world rivers. *Ecological Indicators,* **18**, pp. 42-49.

MEKONNEN, M., HOEKSTRA, A. and BECHT, R., 2012. Mitigating the water footprint of export cut flowers from the Lake Naivasha Basin, Kenya. *Water Resources Management,* **26**(13), pp. 3725-3742.

MEKONNEN, M.M. and HOEKSTRA, A.Y., 2012. A global assessment of the water footprint of farm animal products. *Ecosystems,* **15**(3), pp. 401-415.

MEKONNEN, M.M. and HOEKSTRA, A.Y., 2010a. The green, blue and grey water footprint of crops and derived crop products. UNESCO-IHE Value of Water Research Report Series No. 47

MEKONNEN, M. and HOEKSTRA, A., 2010. The green, blue and grey water footprint of farm animals and animal products. UNESCO-IHE Value of Water Research Report Series No. 48

MILLER, G.T., 2000. Living in the Environment: Principles, connection and solutions. *Brooks/Cole Publishers.*

MOLDEN, D., AMARASINGHE, U., BHATTARAI, M., WANG, J. and MAKIN, I., 2002. Water and food security: Background paper for the world water development report. *Comprehensive Assessment Research Paper,* **2**.

MOOLEKI, S., SCHOENAU, J., CHARLES, J. and WEN, G., 2004. Effect of rate, frequency and incorporation of feedlot cattle manure on soil nitrogen availability, crop performance and nitrogen use efficiency in east-central Saskatchewan. *Canadian Journal of Soil Science,* **84**(2), pp. 199-210.

MORRISON, J.I. and GLEICK, P.H., 2004. *Freshwater resources: Managing the risks facing the private sector.* Pacific Institute for Studies in Development, Environment, and Security.

NEW SOUTH WALES GOVERNMENT, 2014: Water requirements for sheep and cattle. *Primefact 326 3rd edition. Agriculture NSW Water Unit.* http://www.dpi.nsw.gov.au/agriculture/emergency/drought/drought-publication-archive/water-requirements-sheep-cattle

PARHAM, J., DENG, S., RAUN, W. and JOHNSON, G., 2002. Long-term cattle manure application in soil. *Biology and Fertility of Soils,* **35**(5), pp. 328-337.

PARISH, J.A. and RHINEHART, J.D., 2008. Beef cattle water requirements and source management.

PEGRAM, G., ORR, S. and WILLIAMS, C., 2009. *Investigating Shared Risk in Water: Corporate Engagement with the Public Policy Process.WWF.Authored by Pegasys Consulting,* .

PLUSKE, J.M. and SCHLINK, A., 2007. Managing water as a scarce resource in beef feedlots. *Australasian Agribusiness Review,* **15**.

QUEENSLAND DEPARTMENT OF AGRICULTURE AND FISHERIRES, 2011: Manure Production Data. *Document downloaded on 20 January 2016* https://www.daf.qld.gov.au/environment/intensive-livestock/cattle-feedlots/managing-environmental-impacts/manure-production-data

RIDOUTT, B.G., PAGE, G., OPIE, K., HUANG, J. and BELLOTTI, W., 2014. Carbon, water and land use footprints of beef cattle production systems in southern Australia. *Journal of Cleaner Production,* **73**, pp. 24-30.

RIDOUTT, B.G. and PFISTER, S., 2010. A revised approach to water footprinting to make transparent the impacts of consumption and production on global freshwater scarcity. *Global Environmental Change,* **20**(1), pp. 113-120.

RIDOUTT, B.G., SANGUANSRI, P. and HARPER, G.S., 2011. Comparing carbon and water footprints for beef cattle production in southern Australia. *Sustainability,* **3**(12), pp. 2443-2455.

ROCKSTRÖM, J., FALKENMARK, M., ALLAN, T., FOLKE, C., GORDON, L., JÄGERSKOG, A., KUMMU, M., LANNERSTAD, M., MEYBECK, M. and MOLDEN, D., 2014. The unfolding water drama in the Anthropocene: towards a resilience-based perspective on water for global sustainability. *Ecohydrology,* **7**(5), pp. 1249-1261.

ROCKSTRÖM, J., FALKENMARK, M., KARLBERG, L., HOFF, H., ROST, S. and GERTEN, D., 2009. Future water availability for global food production: the potential of green water for increasing resilience to global change. *Water Resources Research,* **45**(7),.

ROY, R., FINCK, A., BLAIR, G. and TANDON, H., 2006. Plant nutrition for food security. *A guide for integrated nutrient management.FAO Fertilizer and Plant Nutrition Bulletin,* **16**.

SA FEEDLOT ASSOCIATION, 2015: Feedlot Codes downloaded from www.safeedlot.co.za on 20 October 2015.

SCHORNAGEL, J., NIELE, F., WORRELL, E. and BÖGGEMANN, M., 2012. Water accounting for (agro) industrial operations and its application to energy pathways. *Resources, Conservation and Recycling,* **61**, pp. 1-15.

SCHREINER, B., 2011. WRC 40-year Celebration Conference concluding address-the Water Research Commission 40 years on. *Water SA,* **37**(5), pp. 619-620.

SCHULZE, R.E. 1997: South African Atlas of Agrohydrology and –Climatology*. Water Research Commission, Pretoria, Report TT82/96.*

SCHYNS, J.F. and HOEKSTRA, A.Y., 2014. The added value of water footprint assessment for national water policy: a case study for Morocco. *PloS one,* **9**(6), pp. e99705.

SIMPSON, D.E., 1998: Collection and Evaluation of runoff water quality from a disused feedlot in KwaZulu-Natal. *WRC Report No 498/1/98.*

STEDUTO, P., RAES, D., HSIAO, T.C., FERERES, E., 2009: AquaCrop—The FAO Crop Model to Simulate Yield Response to Water: I. Concepts and Underlying Principles. *Agron J 2009 101: 426–437*

STEINFELD, H., GERBER, P., WASSENAAR, T., CASTEL, V. and DE HAAN, C., 2006. *Livestock's long shadow: environmental issues and options.* Food & Agriculture Org.

THALER, S., ZESSNER, M., DE LIS, F.B., KREUZINGER, N. and FEHRINGER, R., 2012. Considerations on methodological challenges for water footprint calculations. *Water Science & Technology,* **65**(7), pp. 1258-1264.

ULLMAN, J. and MUKHTAR, S., 2007. Impact of dairy housing practices on lagoon effluent characteristics: Implications for nitrogen dynamics and salt accumulation. *Bioresource technology,* **98**(4), pp. 745-752.

UNGER, K., ZHANG, G. and MATHEWS, R., 2013. Water footprint assessment results and learning: Tata Chemicals, Tata Motors, Tata Power, Tata Steel, Tata Quality Management Services. *The Water Network*.

VAN AVERBEKE, W. and YOGANATHAN, S., 1997. *Using kraal manure as a fertiliser.* National Department of Agriculture.

VAN OEL, P., MEKONNEN, M. and HOEKSTRA, A., 2009. The external water footprint of the Netherlands: Geographically-explicit quantification and impact assessment. *Ecological Economics,* **69**(1), pp. 82-92.

VIDAL, A., 2010. The Green to Blue Water Continuum: An Approach to Improve Agricultural Systems' Resilience to Water Scarcity.

WICHELNS, D., 2015. Virtual water and water footprints: Overreaching into the discourse on sustainability, efficiency, and equity. *Water Alternatives,* **8**(3),.

WILKINSON, J.M., 2011: Re-defining efficiency of feed use by livestock. *Animal 2011 Volume 5:7* page 1014 – 1022.

WWF, 2013: Water Stewardship. Perspectives on business risks and responses to water challenges. *World Wide Fund for Nature Brief, August 2013.*

ZHENG, Z., LIU, J., KOENEMAN, P., ZARATE, E. and HOEKSTRA, A., 2012. Assessing water footprint at river basin level: a case study for the Heihe River Basin in northwest China. *Hydrology and earth system sciences,* **16**(8), pp. 2771-2781.

ZONDERLAND-THOMASSEN, M., LIEFFERING, M. and LEDGARD, S., 2014. Water footprint of beef cattle and sheep produced in New Zealand: water scarcity and eutrophication impacts. *Journal of Cleaner Production,* **73**, pp. 253-262.

13. APPENDICES

13.1. Appendix A – Records of formal interaction with the Feedlot

A1. Presentations to Study Site during formal engagements in July 2015 and January 2016

A2. Background document for dissertation workshop

13.2. Appendix B – Workshop audio recording

B1. Audio recording of the Dissertation Workshop

13.3. Appendix C - WFA spreadsheets

C1. Bovine Water Footprint

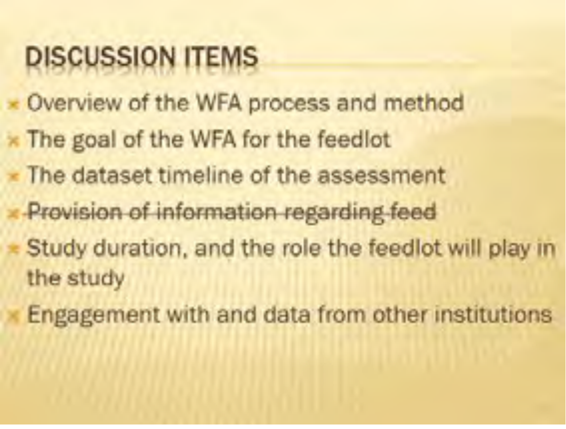
C2. Grey Water Footprint of Waste Management

Appendix A – Records of formal interaction with the Feedlot

A1. Presentations to Study Site during formal engagements in July 2015 and January 2016

15 July 2015

THE FEEDLOT
WATER FOOTPRINT ASSESSMENT STUDY

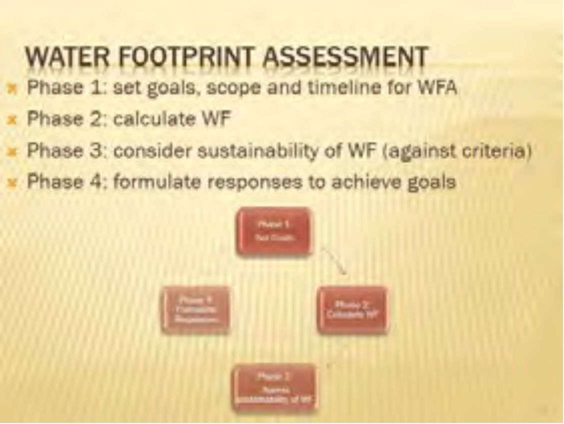


DISCUSSION ITEMS

- Overview of the WFA process and method
- The goal of the WFA for the feedlot
- The dataset timeline of the assessment
- ~~Provision of information regarding feed~~
- Study duration, and the role the feedlot will play in the study
- Engagement with and data from other institutions

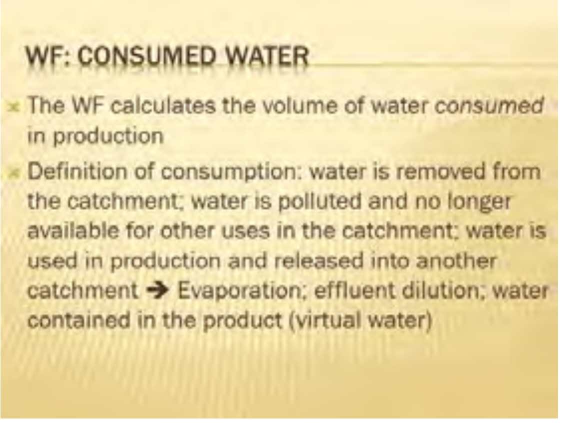
Introduction

WATER FOOTPRINT ASSESSMENT PROCESS



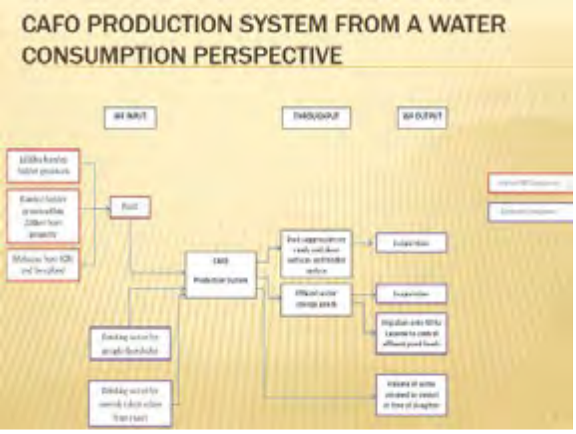
WATER FOOTPRINT ASSESSMENT

- Phase 1: set goals, scope and timeline for WFA
- Phase 2: calculate WF
- Phase 3: consider sustainability of WF (against criteria)
- Phase 4: formulate responses to achieve goals



WF: CONSUMED WATER

- The WF calculates the volume of water *consumed* in production
- Definition of consumption: water is removed from the catchment; water is polluted and no longer available for other uses in the catchment; water is used in production and released into another catchment ➔ Evaporation; effluent dilution; water contained in the product (virtual water)



CAFO PRODUCTION SYSTEM FROM A WATER CONSUMPTION PERSPECTIVE

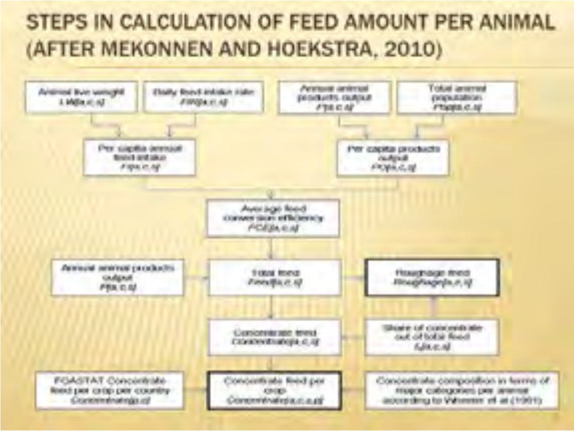
BLUE, GREEN AND GREY WATER FOR THE FEEDLOT: INDIVIDUAL FINISHED CATTLE

FEEDLOT

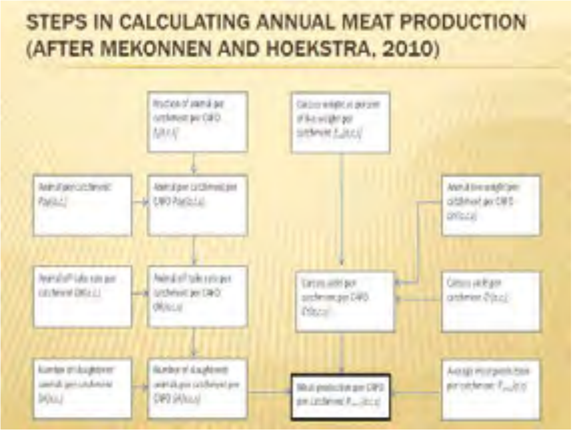
- Blue WF: water abstracted from Suikerbosrand river
- Green WF: water used to produce feed
- Grey WF: effluent water used for irrigation on own land

FINISHED CATTLE

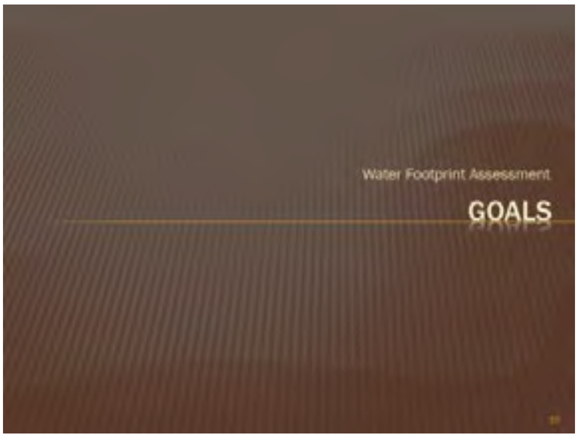
- Blue WF: drinking water
- Green WF: water used to produce feed



STEPS IN CALCULATION OF FEED AMOUNT PER ANIMAL (AFTER MEKONNEN AND HOEKSTRA, 2010)

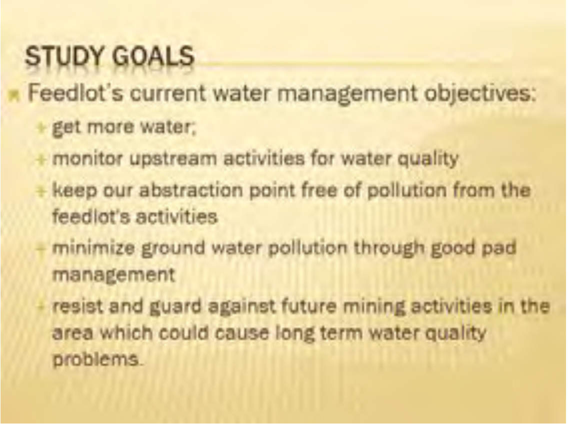


STEPS IN CALCULATING ANNUAL MEAT PRODUCTION (AFTER MEKONNEN AND HOEKSTRA, 2010)



Water Footprint Assessment

GOALS



STUDY GOALS

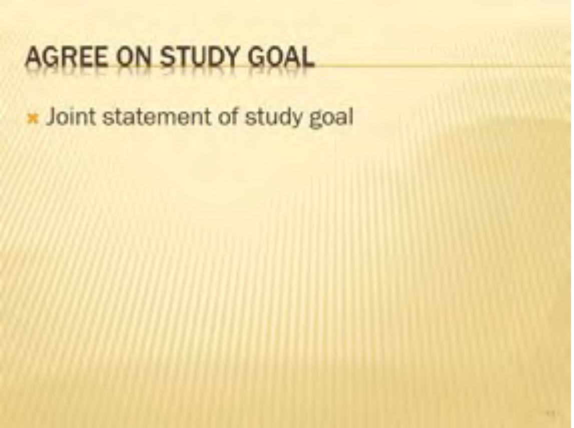
- Feedlot's current water management objectives:
  - get more water;
  - monitor upstream activities for water quality
  - keep our abstraction point free of pollution from the feedlot's activities
  - minimize ground water pollution through good pad management
  - resist and guard against future mining activities in the area which could cause long term water quality problems.

STUDY GOALS

- WF of beef production is tied to 3 main factors:
  - Feed conversion efficiency of animals (beef cattle have an unfavourable FCE)
  - Composition of feed:
    - ratio of roughages to concentrates;
    - ratio of crop residues (beetroot leaves and tops, bran or chaff) to valuable crop components, (wheat or sugar beet)
  - Origin of feed (irrigated, non-irrigated)

STUDY GOALS

- *WFA considers the value chain impact of water consumption in the production of goods and services; allows a deeper analyses of the role of water in an operation (impact of consumption, operational resilience sustainability/equity)*
- Study goals can be:
  - reduce the cost associated with water use
  - optimize water use efficiency in different parts of the CAFO
  - reduce the impacts of pollution on the receiving environment
  - **negate negative perceptions about the impacts of beef cattle CAFO's on the surrounding environment**
  - **gain competitive marketing advantage over competitors**, to promote meat produced in CAFO production systems over meat produced in grazing systems
  - improve the overall sustainability of the CAFO site in terms of water use for industrial production of beef meat
  - **Compare feedlot WF against global WF estimates for beef production**

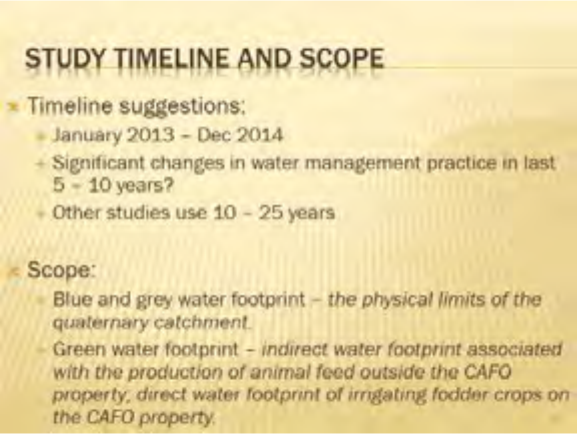


AGREE ON STUDY GOAL

- Joint statement of study goal

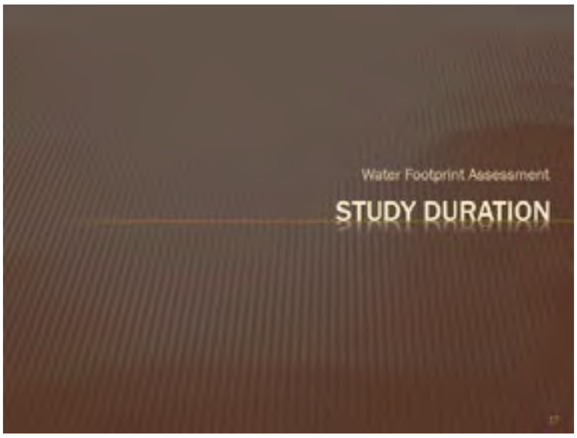
Water Footprint Assessment

DATASET TIMELINE



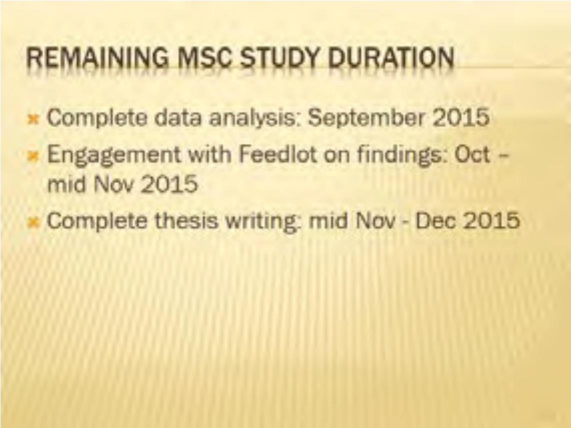
STUDY TIMELINE AND SCOPE

- Timeline suggestions:
  - January 2013 – Dec 2014
  - Significant changes in water management practice in last 5 – 10 years?
  - Other studies use 10 – 25 years
- Scope:
  - Blue and grey water footprint – *the physical limits of the quaternary catchment*
  - Green water footprint – *indirect water footprint associated with the production of animal feed outside the CAFO property, direct water footprint of irrigating fodder crops on the CAFO property*



Water Footprint Assessment

STUDY DURATION

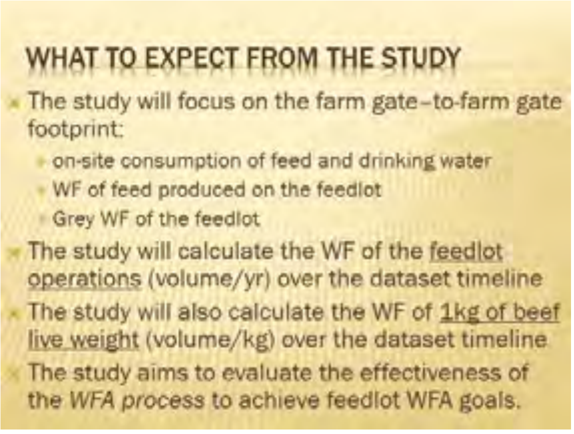


REMAINING MSC STUDY DURATION

- Complete data analysis: September 2015
- Engagement with Feedlot on findings: Oct – mid Nov 2015
- Complete thesis writing: mid Nov - Dec 2015

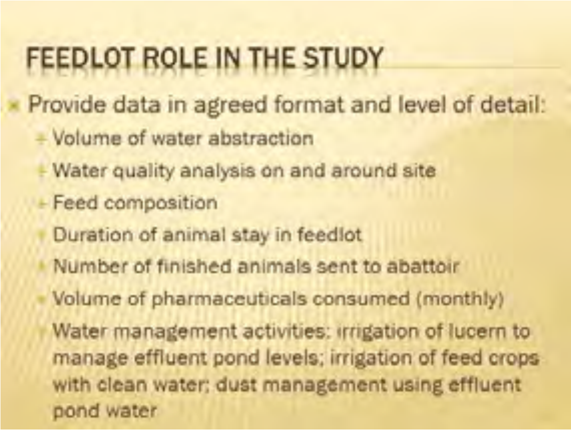
Water Footprint Assessment

ROLE OF THE FEEDLOT IN THE STUDY



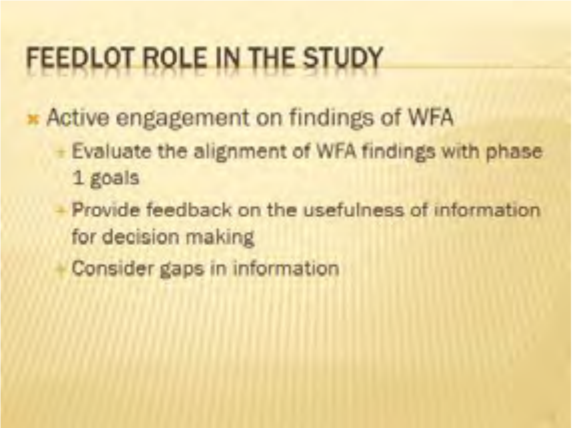
WHAT TO EXPECT FROM THE STUDY

- The study will focus on the farm gate–to-farm gate footprint:
  - on-site consumption of feed and drinking water
  - WF of feed produced on the feedlot
  - Grey WF of the feedlot
- The study will calculate the WF of the feedlot operations (volume/yr) over the dataset timeline
- The study will also calculate the WF of 1kg of beef live weight (volume/kg) over the dataset timeline
- The study aims to evaluate the effectiveness of the *WFA process* to achieve feedlot WFA goals.



FEEDLOT ROLE IN THE STUDY

- Provide data in agreed format and level of detail:
  - Volume of water abstraction
  - Water quality analysis on and around site
  - Feed composition
  - Duration of animal stay in feedlot
  - Number of finished animals sent to abattoir
  - Volume of pharmaceuticals consumed (monthly)
  - Water management activities: irrigation of lucern to manage effluent pond levels; irrigation of feed crops with clean water; dust management using effluent pond water



FEEDLOT ROLE IN THE STUDY

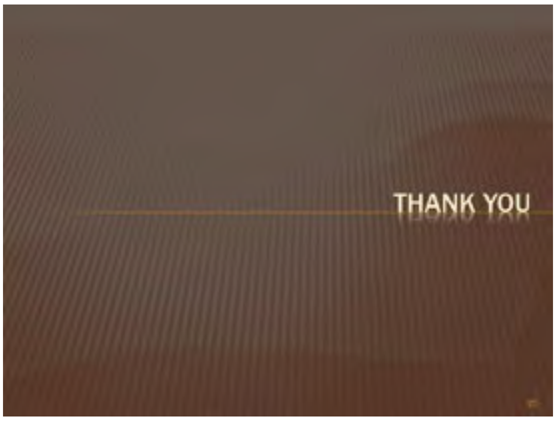
- Active engagement on findings of WFA
  - Evaluate the alignment of WFA findings with phase 1 goals
  - Provide feedback on the usefulness of information for decision making
  - Consider gaps in information

Water Footprint Assessment

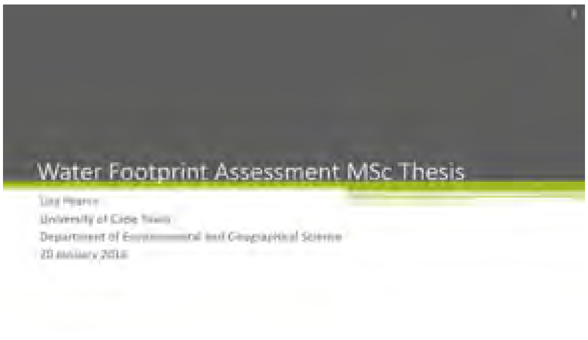
ENGAGEMENT WITH ARC, WEATHER SERVICE ETC

INFORMATION FROM OTHER SOURCES

- Feed conversion efficiency
- Rainfall and evaporation
- Land use planning
- Disposal of partially treated AMD EIA studies
- Statistics on beef production in SA

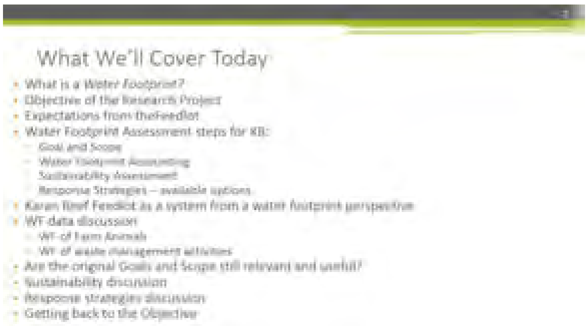


THANK YOU



Water Footprint Assessment MSc Thesis

Lisa Pearce
University of Cape Town
Department of Environmental and Geographical Science
20 January 2016

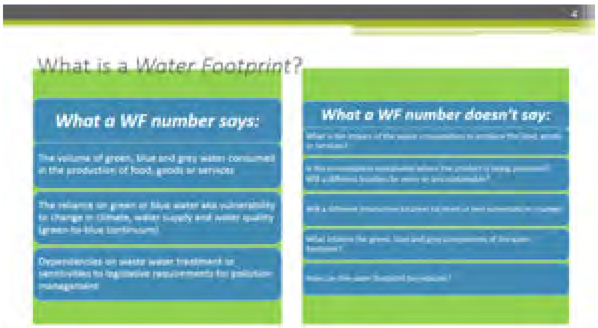


What We'll Cover Today

- What is a *Water Footprint*?
- Objective of the Research Project
- Expectations from theFeedlot
- Water Footprint Assessment steps for KB:
  - Goal and Scope
  - Water Footprint Accounting
  - Sustainability Assessment
  - Response Strategies – available options
- Karan Beef Feedlot as a system from a water footprint perspective
- WF data discussion
  - WF of Farm Animals
  - WF of waste management activities
- Are the original Goals and Scope still relevant and useful?
- Sustainability discussion
- Response strategies discussion
- Getting back to the Objective

What is a *Water Footprint*?

What makes up your water footprint?

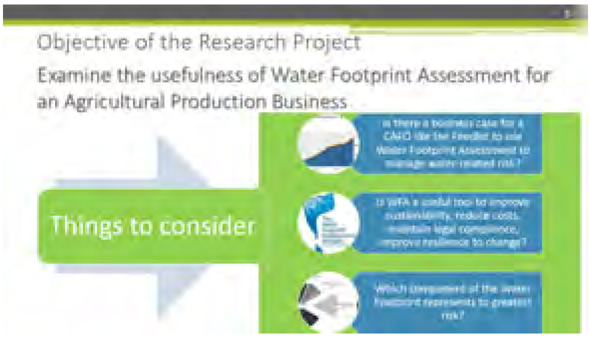


What is a *Water Footprint*?

What a WF number says:

- The volume of green, blue and grey water consumed in the production of food, goods or services
- The reliance on green or blue water aka vulnerability to change in climate, water supply and water quality (green-to-blue continuum)
- Dependencies on waste water treatment or sensitivities to legislative requirements for pollution management

What a WF number doesn't say:

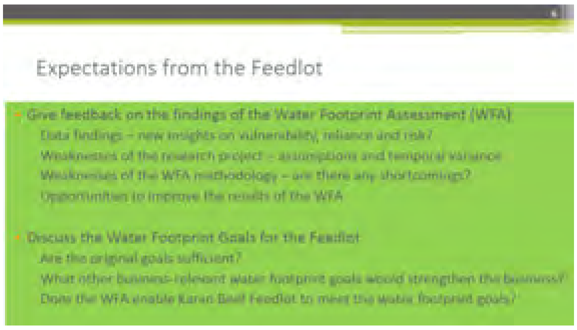


Objective of the Research Project

Examine the usefulness of Water Footprint Assessment for an Agricultural Production Business

Things to consider

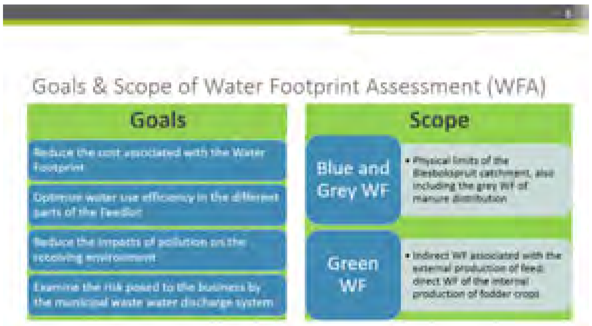
- Is there a business case for a CAFO like the Feedlot to use Water Footprint Assessment to manage water-related risk?
- Is WFA a useful tool to improve sustainability, reduce costs, maintain legal compliance, improve resilience to change?
- Which component of the Water Footprint represents to greatest risk?



Expectations from the Feedlot

- Give feedback on the findings of the Water Footprint Assessment (WFA)
  - Data findings – new insights on vulnerability, reliance and risk?
  - Weaknesses of the research project – assumptions and temporal variance
  - Weaknesses of the WFA methodology – are there any shortcomings?
  - Opportunities to improve the results of the WFA
- Discuss the Water Footprint Goals for the Feedlot
  - Are the original goals sufficient?
  - What other business-relevant water footprint goals would strengthen the business?
  - Does the WFA enable Karan Beef Feedlot to meet the water footprint goals?

Water Footprint Assessment steps for the Feedlot



Goals & Scope of Water Footprint Assessment (WFA)

Goals

- Reduce the cost associated with the Water Footprint
- Optimise water use efficiency in the different parts of the Feedlot
- Reduce the impacts of pollution on the receiving environment
- Examine the risk posed to the business by the municipal waste water discharge system

Scope

Blue and Grey WF	Physical limits of the Riebeeksprui catchment, also including the grey WF of manure distribution
Green WF	Indirect WF associated with the external production of feed; direct WF of the internal production of fodder crops

Water Footprint Accounting

- Water Footprint of Farm Animals:
  - $WF_{[slaughtered\ animal/month]} = WF_{[feed/month]} + WF_{[drink/month]} + WF_{[serv]}$

Note: traditional WFA methodology

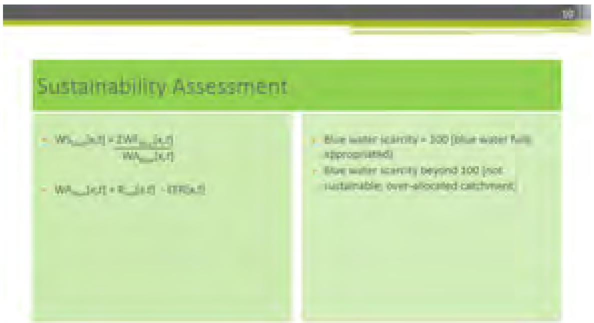
Indirect: green, blue, grey

Direct: blue

Direct: blue (grey)

- Grey Water Footprint of waste management practices:
  - $GWF = L/(C_{max} - C_{nat})$

Indirect: grey



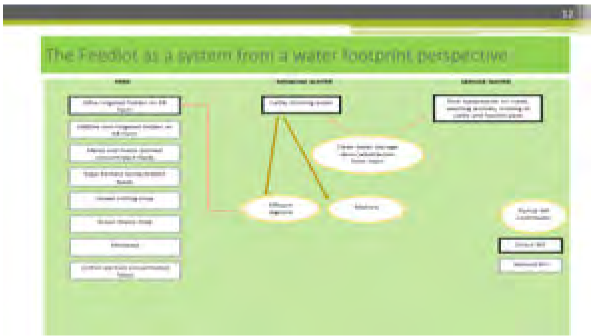
Sustainability Assessment

- $WS_{blue}[x,t] = \frac{\sum WF_{blue}[x,t]}{WA_{blue}[x,t]}$
- $WA_{blue}[x,t] = R_{nat}[x,t] - EFR[x,t]$

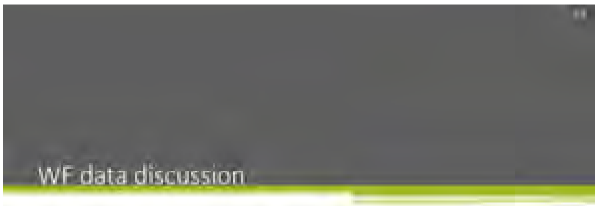
- Blue water scarcity = 100 (blue water fully appropriated)
- Blue water scarcity beyond 100 (not sustainable; over-allocated catchment)

Response Strategies

- Consider the outcome of the WFA and Sustainability Assessment and determine how to achieve the water footprint goals
  - Which component of the WF represents the greatest risk?
  - Review water footprint goals again



The Feedlot as a system from a water footprint perspective

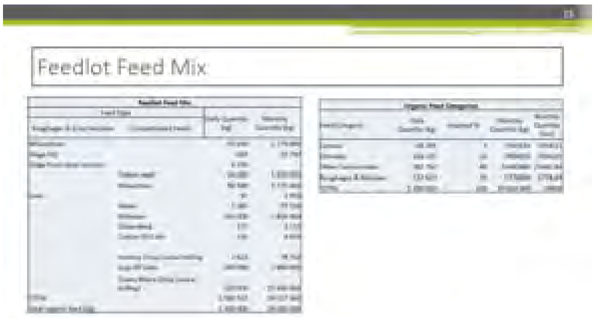


WF data discussion

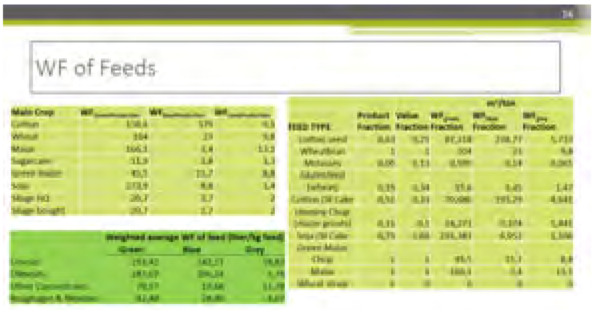
Water Footprint of Farm Animals – methodology

$$WF_{(slaughtered\ animal/month)} = WF_{(feed/month)} + WF_{(drink/month)} + WF_{(serv)}$$

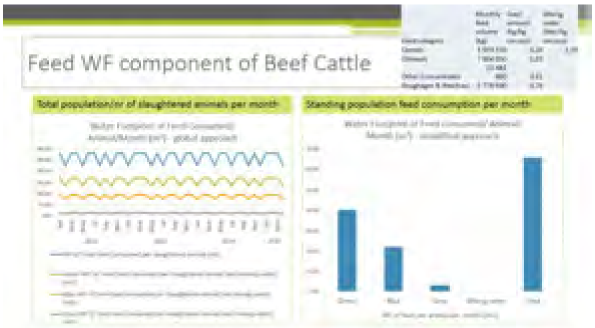
- Step 1: WF of production of feed
  - Feedlot Feed Mix
  - WF_{prod} of crops in SA
  - Product fraction
  - Weighted WF_{prod} of feed consumed on Feedlot per month (liter/kg feed per month)
- Step 2: Drinking Water
- Step 3: Service Water



Feedlot Feed Mix



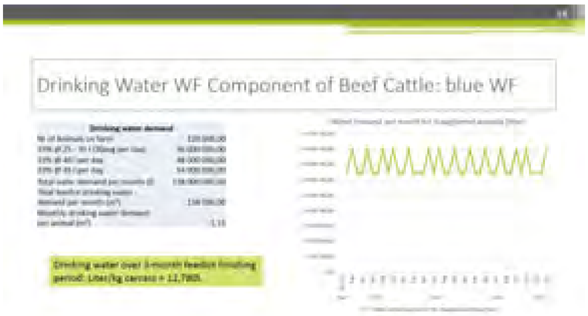
WF of Feeds



Feed WF component of Beef Cattle

Total population/nr of slaughtered animals per month

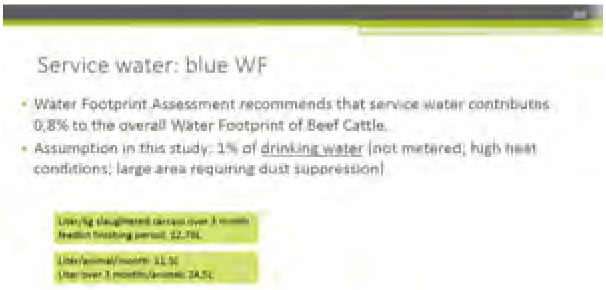
Standing population feed consumption per month



Drinking Water WF Component of Beef Cattle: blue WF

Drinking water demand

Drinking water over 3-month feedlot finishing period: Liter/kg carcass = 12,78

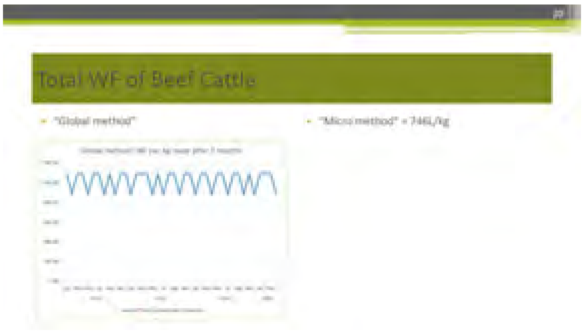


Service water: blue WF

- Water Footprint Assessment recommends that service water contributes 0,8% to the overall Water Footprint of Beef Cattle.
- Assumption in this study: 1% of drinking water (not metered; high heat conditions; large area requiring dust suppression)

Liter/kg slaughtered carcass over 3 month feedlot finishing period: 12,78L

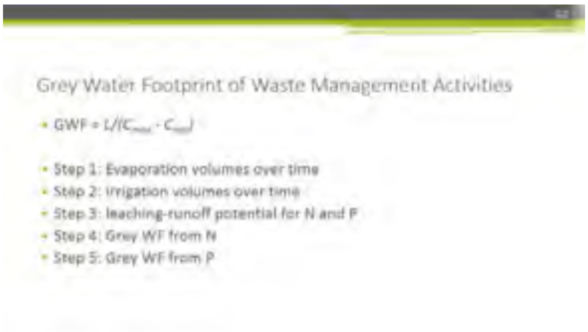
Liter/animal/month: 11,5L
Liter/over 3 months/animal: 24,5L



Total WF of Beef Cattle

- "Global method"
- "Micro method" = 746L/kg

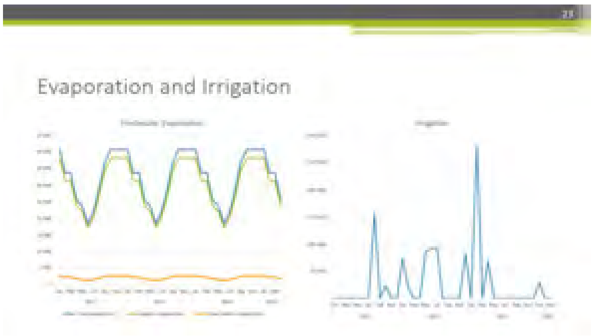
Grey Water Footprint of Waste Management Activities



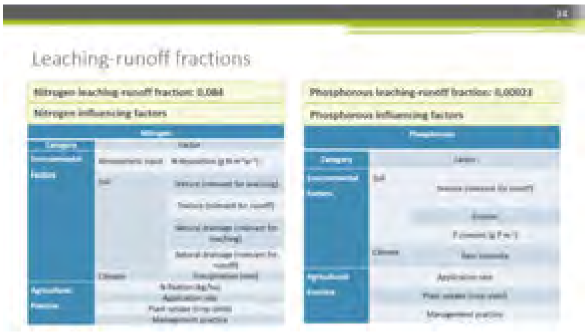
Grey Water Footprint of Waste Management Activities

- GWF = $L/(C_{max} - C_{nat})$

- Step 1: Evaporation volumes over time
- Step 2: Irrigation volumes over time
- Step 3: leaching-runoff potential for N and P
- Step 4: Grey WF from N
- Step 5: Grey WF from P



Evaporation and Irrigation



Leaching-runoff fractions

Nitrogen leaching-runoff fraction: 0,084

Nitrogen influencing factors

Phosphorous leaching-runoff fraction: 0,00003

Phosphorous influencing factors

Leaching-runoff potential - N

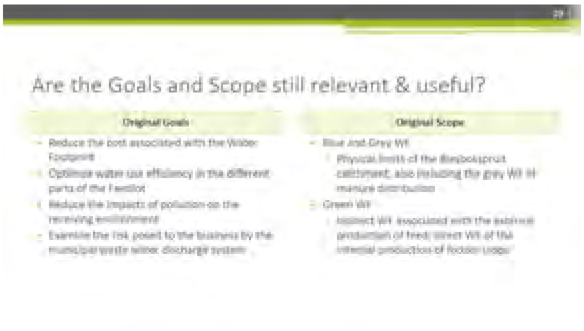
Leaching-runoff potential - P

PHOSPHOROUS LEACHING RUN-OFF POTENTIAL

Category	Factor		Leaching runoff potential Weight (w)*		Score (s)				
					Very low	Low	No information available	High	Very high
			α	β	0	0,33	0,5	0,67	1
Environmental Factors	Soil	Texture (relevant for runoff)	15	25	Sand	Loam		Silt	Clay
		Erosion	20	25	Low	Moderate	unknown	High	Very high
		P-content (g P m⁻²)	15	20	<200	200 - 400	unknown	400 - 700	>700
	Climate	Rain intensity	10	15	Light	Moderate		Strong	Heavy
Agricultural practice	Application rate		15	0	Very low	Low	moderate	High	Very high
	Plant uptake (crop yield)		10	0	Very high	High	unknown	Low	Very low
	Management practice		15	15	Best	Good		Average	Worst

Grey WF - N

Grey WF - P



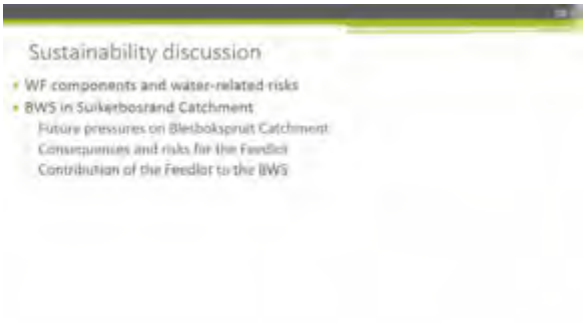
Are the Goals and Scope still relevant & useful?

Original Goals

- Reduce the cost associated with the Water Footprint
- Optimise water use efficiency in the different parts of the Feedlot
- Reduce the impacts of pollution on the receiving environment
- Examine the risk posed to the business by the municipal waste water discharge system

Original Scope

- Blue and Grey WF
  - Physical limits of the Bospoortspruit catchment, also including the grey WF in manure distribution
- Green WF
  - Indirect WF associated with the external production of feed; direct WF of the internal production of fodder crops

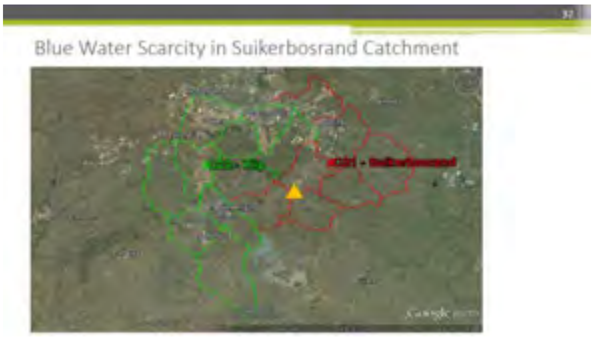


Sustainability discussion

- WF components and water-related risks
- BWS in Suikerbosrand Catchment
  - Future pressures on Blesbokspruit Catchment
  - Consequences and risks for the Feedlot
  - Contribution of the Feedlot to the BWS

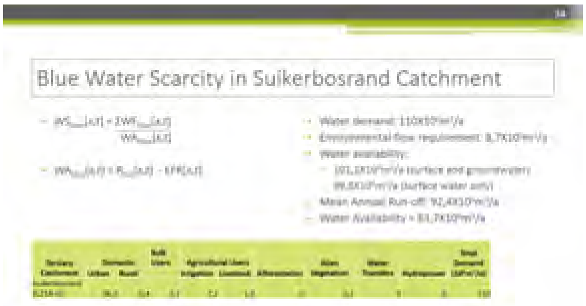
WF components and water-related risks

WF Component	Water-related Risks
WF of Feed	Reliance on rain-fed agriculture; Reliance on a certain range of crops and crop derived feed; No control over farm management practices
WF – drinking water	Reliance on river flow volume; Reliance on river water quality; Vulnerable to upstream user practices; Vulnerable to Water Use Licence changes
WF – service water	Reliance on river flow volume; Reliance on river water quality; Vulnerable to upstream user practices; Vulnerable to Water Use Licence changes; [illegible]
Grey WF – N	No control over manure distribution; Reliance on wetland to assimilate nutrients; Cycling of N back to cattle feed; Over application of N over time
Grey WF – P	No control over manure distribution; Reliance on wetland to assimilate nutrients; Cycling of N back to cattle feed; Over application of N over time



Blue Water Scarcity in Suikerbosrand Catchment

Blue Water Scarcity in Suikerbosrand Catchment



Blue Water Scarcity in Suikerbosrand Catchment

- $WS_{blue}[x,t] = \frac{\sum WF_{blue}[x,t]}{WA_{blue}[x,t]}$
- $WA_{blue}[x,t] = R_{nat}[x,t] - EFR[x,t]$

- Water demand: $110 \times 10^6 m^3/a$
- Environmental flow requirement: $8,7 \times 10^6 m^3/a$
- Water availability:
  - $101,1 \times 10^6 m^3/a$ (surface and groundwater)
  - $99,5 \times 10^6 m^3/a$ (surface water only)
- Mean Annual Run-off: $92,4 \times 10^6 m^3/a$
- Water Availability = $83,7 \times 10^6 m^3/a$

Tertiary Catchment	Domestic		Bulk Users	Agricultural Users		Afforestation	Alien Vegetation	Water Transfers	Hydropower	Total Demand ($10^6 m^3/a$)
	Urban	Rural		Irrigation	Livestock					
Suikerbosrand C21A-D	96,3	0,4	3,1	7,2	1,8	0	0,2	1	0	110

Response strategies discussion

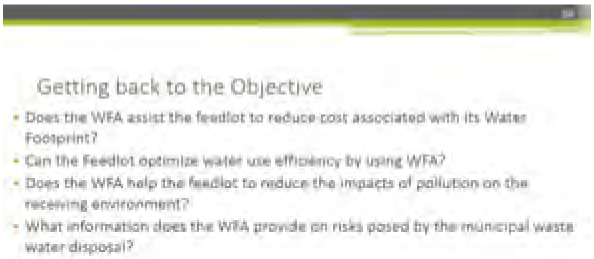
- Reduce water-related risks for WF components
  - WF-Feed
  - WF-drink
  - WF-services
  - Grey WF – N
  - Grey WF – P
- Achieve Water Footprint Goals

Reduce the cost associated with the Water Footprint

Optimize water use efficiency in the different parts of the feedlot

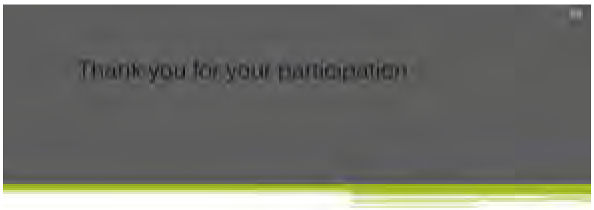
Reduce the impacts of pollution on the receiving environment

Examine the risk posed to the business by the municipal waste water discharge system



Getting back to the Objective

- Does the WFA assist the feedlot to reduce cost associated with its Water Footprint?
- Can the Feedlot optimize water use efficiency by using WFA?
- Does the WFA help the feedlot to reduce the impacts of pollution on the receiving environment?
- What information does the WFA provide on risks posed by the municipal waste water disposal?



Thank you for your participation

A2. Background document for dissertation workshop

WATER FOOTPRINT ASSESSMENT RESEARCH PROJECT
THE BEEF FEEDLOT
HEIDELBERG, GAUTENG

MSc Research Project by Lisa Pearce
University of Cape Town
Department of Environmental and Geographical Science

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Date: January 2016
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Introduction to Water Footprint and its relevance for Beef Production

A Water Footprint is a measure of the water that is consumed in the production of the world's food, goods and services. The measurement distinguishes between water consumption and water use, and makes apparent that the impact of water consumption is sometimes far removed geographically from the consumption of the food, goods or services that were produced. Consumption of water occurs when water is used and consequently is no longer available for other users within the same catchment or other geographical boundary. For instance, water contained in food products, water evaporated from a power stations' cooling towers, or water that is polluted above a certain safe threshold are included in a water footprint. Water that is used to transport materials without any contamination taking place, or water that is treated and released directly back into the same water resource, should not be included in a water footprint.

A Water Footprint has three distinct components. The green water footprint is the volume of rainwater consumed, for example, by crops to produce the valuable crop components such as edible grains from maize and edible beetroot bulbs. Blue water footprint is the water that is removed from a freshwater source such as a river, borehole or dam, and pumped to the place where it is consumed, for example in the form ofirrigation water. The grey water footprint is a theoretical indicator of the volume of water needed to dilute pollutants to a safe and/ or acceptable level. The grey water footprint can also be described as an indicator of the pollution burden placed on the available water resources by an activity or the production of food, goods and services. The water footprint is usually expressed as the water volume per unit of product, or the water volume per unit of time. A water footprint could also be expressed per number of jobs, per nutritional value or per electricity unit (Pahlow et al, 2015).

The Water Footprint concept examines the human impact in the consumption of water resources by evaluating whole production and supply chains (Pahlow et al, 2015). In South Africa the water footprint of economic production is dominated by crop production (75,7%) followed by grazing (18,5%), domestic water supply (4,7%), industrial activities (0,6%) and livestock production (drinking and service water only) (0,5%) (Pahlow et al, 2015). The production of maize consumes the largest proportion of green water (45,7%), and contributes 40,5% to the grey water footprint of crop production. Maize production contributes only 5,1% to the blue water footprint, attributed to large scale dry-land (non-irrigated) production of maize. Fodder crops are the second largest consumer of green water (22,7%), and the largest consumer of blue water (irrigation) (38,4%). Fodder crops further contribute 17,5% to the grey water footprint of crop production (Pahlow et al, 2015).

The diet of beef cattle in Concentrated Animal Feeding Operations (CAFO), or feedlots, consists mainly of maize and maize-derived products (maize, gluten feed, green maize chop), and fodder crops (silage). Other concentrated feeds and roughages like soya oil cake, molasses, cotton oil cake, chop and wheat straw complete the diet. The direct water footprint of the feedlot operations (drinking and service water, irrigation of fodder crops, and waste management practices) as well as the indirect water footprint of the production of feed consumed by the cattle is used in understanding the impact on water resources from the production of beef meat. The water footprint of the production of beef cattle can be expressed in terms of monthly consumption by the feedlot operations, or in terms of the volume of water consumed per kg of slaughtered carcass.

Purpose of the Research Project: Examine the usefulness of Water Footprint Assessment for an Agricultural Production Business

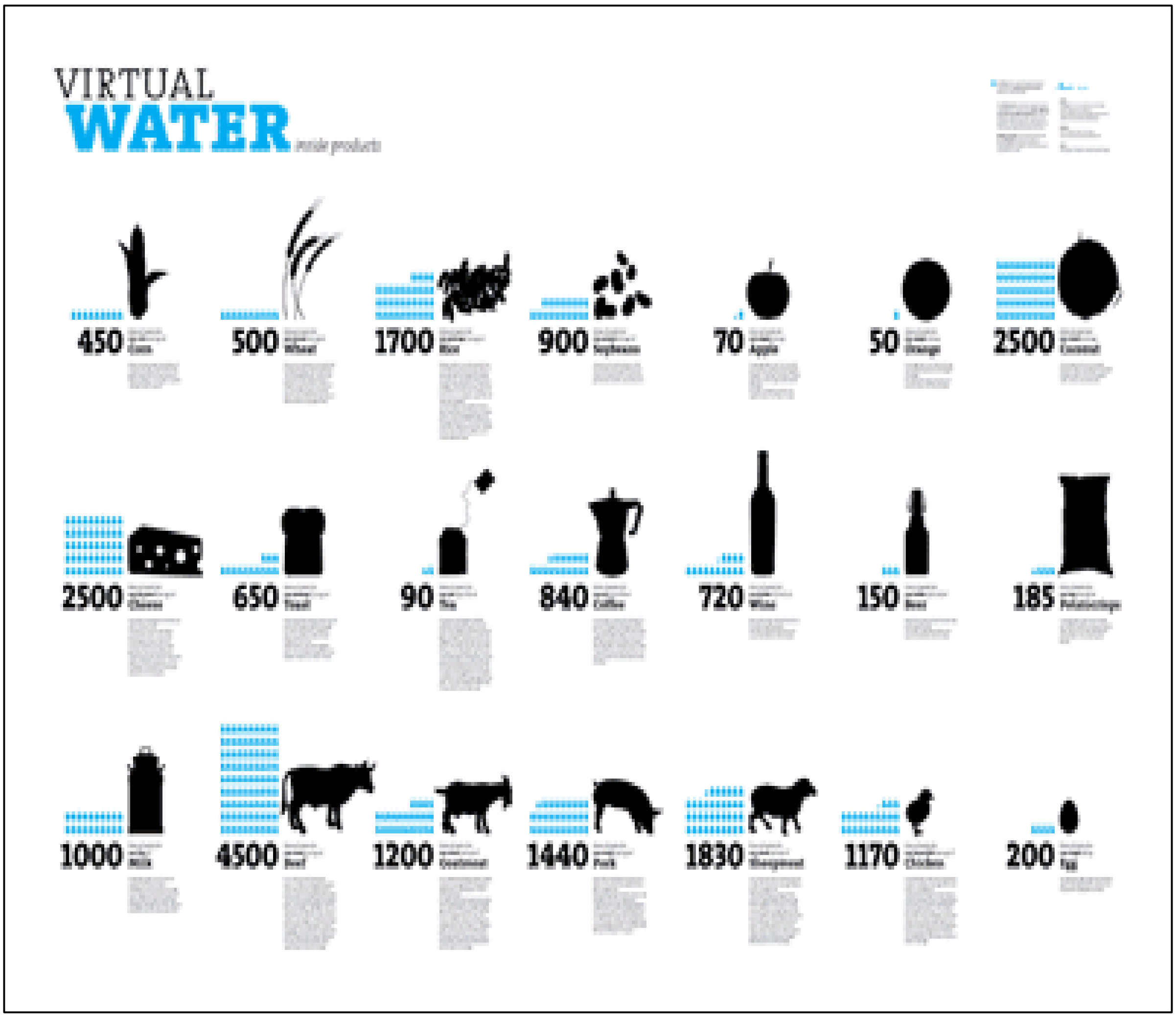


Figure 1: water footprint values for different food items.

Water footprint consumption values (Figure 1) indicate how much water was consumed in the production of food items. At first glance, it is evident that chicken meat has a smaller water footprint than beef meat, and that cheese has a far higher water footprint than eggs. Intuitively the water footprint consumption values indicate that higher nutrition foodstuffs not only take longer to produce, but also require more water. Yet these Water Footprints by themselves do not provide any insight about the risk and enviro-social impact of the water consumption at the site of production. It is possible that the water footprint in the production of eggs in one river catchment is low when considering the availability and quality of water resources in that catchment, but could be high in a catchment where water resources are already stressed. Is it fair to agree that consumers who wish to reduce their sustainability impact should choose to consume foodstuffs with lower water footprints? Is it also fair to expect a CAFO to 'compare and compete' with other similar CAFO's in different regions on water footprint performance? The question that this project is trying to address is if the water footprint tool can be used by an agricultural business to manage water-related risk?

The purpose of the research project is to answer the research question: ***Is there a business case for a CAFO to use Water Footprint Assessment to manage water-related risk?*** Does the resultant measurement provide a useful tool for a CAFO operation that aims to manage their water use more sustainably or equitably, and to reduce costs, maintain the legal obligation for pollution control and strengthen resilience to extreme risks such as drought and competition for resources? This research project applies the Water Footprint Assessment model to the Feedlot and examines if and to what extent the information obtained can be used by an agricultural business operation to manage water-related risk.

Expectations from the Feedlot

The success of this research project depends greatly on the partnership with the feedlot. While the actual Water Footprint Assessment is central to the research project, feedback from the feedlot is critical to answer one of the research questions. The Feedlot should consider the extent to which the Water Footprint Assessment enables the CAFO to achieve its' Water Footprint Goals. The Water Footprint Goals for the Feedlot were jointly developed with Dr Johan van Niekerk and are as follows:

1. Reduce the cost associated with the Water Footprint
2. Optimize water use efficiency in the different parts of the CAFO
3. Reduce the impacts of pollution on the receiving environment
4. Examine the risk posed to the business by the municipal waste water discharge system

Where the Water Footprint Assessment only partially enables the Feedlot to achieve the Water Footprint Goals, discuss the shortcomings and/or potential adjustments which could make the Water Footprint Assessment a robust business risk tool.

The Feedlot collaborated in determining the Water Footprint Goals. After looking at the data and information derived from the Water Footprint Assessment model, are there other business-relevant or appropriate goals which could also be set?

Where the Water Footprint Assessment did not produce useful information, is that due to a problem with the assessment methodology? Would small changes enable more useful information to be produced, for instance by aligning monitoring more closely with the assessment methodology?

Water Footprint Assessment Process

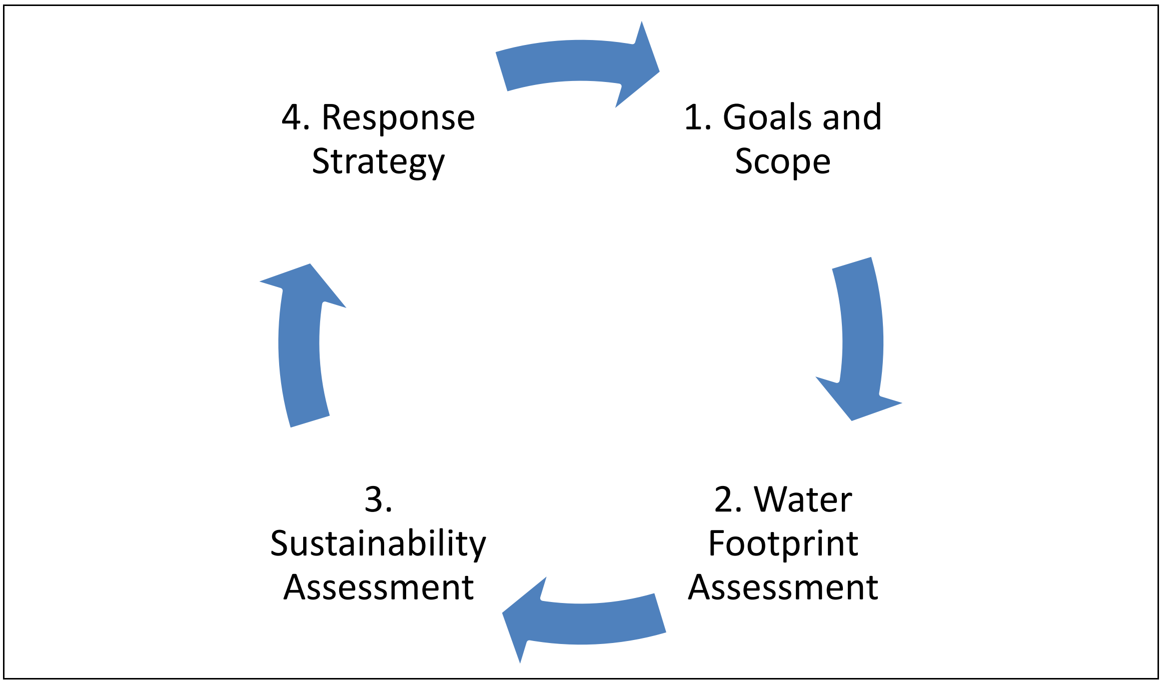


Figure 2: Steps in the Water Footprint Assessment process

Step 1 – Goals and Scope

The Feedlot collaborated to set the Goals and Scope of the Water Footprint Assessment. The Goals of the Water Footprint Assessment are to enable the Feedlot to:

1. Reduce the cost associated with the Water Footprint
2. Optimize water use efficiency in the different parts of the CAFO
3. Reduce the impacts of pollution on the receiving environment
4. Examine the risk posed to the business by the municipal waste water discharge system

The Scope of the Water Footprint Assessment included the following:

1. Blue and grey water footprint – the physical limits of the quaternary catchment (Blesbokspruit catchment). During the course of the assessment the water footprint of manure production was later included in the grey water footprint.
2. Green water footprint – indirect water footprint associated with the production of animal feed outside the CAFO property; and direct water footprint of irrigating fodder crops on the CAFO property.

The research project time period covers Jan 2012 to April 2015.

Step 2 – Water Footprint Assessment

Collect relevant data and calculate the green, blue and grey water footprint of beef cattle according to the Water Footprint Assessment methodology. The grey water footprint associated with waste management practices was calculated according to the Tier 1 Guidelines for Grey Water Footprint Assessment – a more detailed approach.

Step 3 – Sustainability Assessment

To understand the relevance of the water footprint values obtained, it is necessary to contextualize it within the local conditions of the quaternary catchment. The Blue Water Scarcity of the Blesbokspruit Catchment is used to assess the sustainability of the feedlot's water use within the local context.

Step 4 – Response Strategy

The Water Footprint methodology recommends that a response strategy should be developed in order to achieve the Water Footprint Goals.

Schematic Water Footprint Components at the Feedlot

The water footprint components of the feedlot is illustrated below (figure 3).

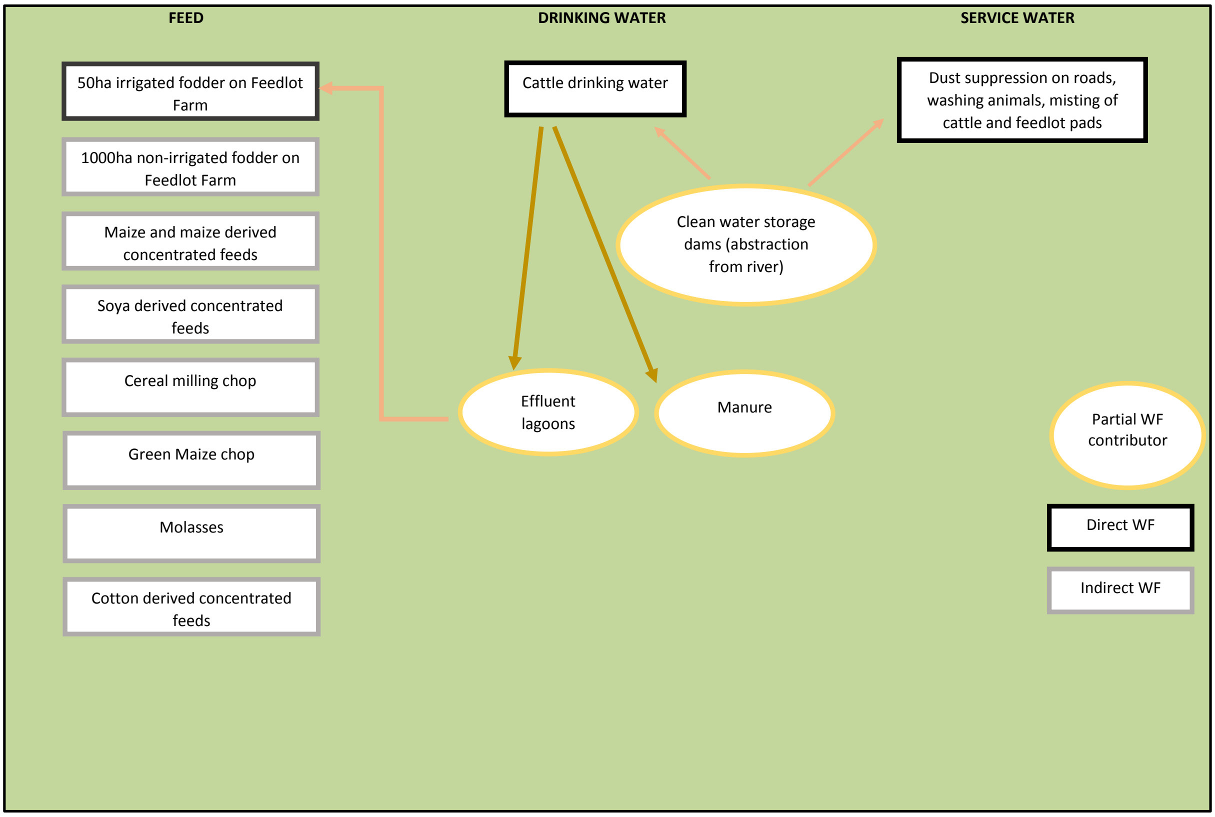


Figure 3: The Feedlot water footprint components

The direct water footprint components include the irrigation of 50ha of fodder on the farm property, drinking water for cattle and service water used on the feedlot. The indirect water footprint components contribute by far the greatest proportion to the water footprint, and consist of the water footprint of production of feeds. The clean water storage dams and effluent lagoons contribute to the green water footprint through evaporation, as well as the grey water footprint of waste management through irrigation (effluent lagoons). Manure disposal contributes to the grey water footprint of waste management.

Water Footprint Assessment

Green, Blue and Grey WF of Beef Cattle

The Water Footprint of farm animals is calculated using the following formula:

$$WF_{[\text{slaughtered animal/month}]} = WF_{[\text{feed/month}]} + WF_{[\text{drink/month}]} + WF_{[\text{serv}]}$$

The first step is to calculate the WF of feed consumed, which is expected to be the largest component of the total water footprint of farm animals.

Feedlot Feed Mix

The feed mix (Table 1 and Table 2) at the Feedlot was derived from information provided by the feedlot, as well as certain industry assumptions on the composition of the cattle feed mix. Values in bold text in Table 1 below were provided by the Feedlot.

Information provided by the feedlot:

Daily average feed per animal = 10kg/animal/day

Average standing population = 130,000 animals

Silage HQ = 10% of total silage

Assumptions:

Therefore: 1,300,000 kg feed/day

Therefore: 39, 000,000 kg feed/month

Therefore silage from other sources = 6930kg/day

The balance of the feed composition is based on the following industry assumptions by Hendy et al 1995: “For dairy cattle in UK, for example, diets typically include 40-50% cereal milling by-products, 25% oilmeals and 20% of other ingredients such as molasses and sugarbeet pulp, though still including some 10-15% cereals (Digest of Feed Facts and Figures 1990-91). Some feeding systems for fattening beef cattle use high proportions of coarse grains as straight concentrates (for example barley in the UK) but in most cases a wide variety of milling and agro-industrial by-products may be incorporated in finishing diets (as in feedlot systems)”.

Further assumptions:

1. Molasses+ gluten feed = 20% of total
2. hominy chop + maize chop = 40% of total
3. wheat straw:wheat bran = 50:50

The feed mix in Table 1 is summarized in the organic feed mix in Table 2, using the following rationale:

1. **Other concentrates** = molasses, Gluten feed (20%) + Cereal milling by-products = green maize chop; Hominy chop (40%) **(Total 60%)** ==> adjusted from Hendy et al (assume 40% chop) to accommodate KB figure for fodder
2. **Oilmeals** = cotton oil cake; soya oil cake **(20%)** = Hendy et al
3. **Cereals** = cotton seed; maize **(5%)** ==> assumption adjusted from 10% given by Hendy to accommodate KB figure for fodder
4. **Roughages** = wheat straw, silage, wheat bran **(15%)** ==> KB figure is 10% fodder

A weakness of the research project is that the feed mix was used as a monthly constant over the entire study period. Variations in the feed mix will affect the water footprint values per month.

TABLE 1: Feed Mix derived from information provided by the feedlot and industry assumptions

Feedlot Feed Mix			
Feed Type		**Daily Quantity (kg)**	**Monthly Quantity (kg)**
Roughages & Crop Residues	**Concentrate Feeds**		
Wheat straw		92 500	2 775 000
Silage HQ		**693**	20 790
Silage from other sources		**6 930**	
	Cotton seed	64 000	1 920 000
	Wheat bran	92 500	2 775 000
Lime		**97**	2 910
	Maize	**1 305**	39 150
	Molasses	260 000	7 800 000
	Gluten feed	**137**	4 110
	Cotton Oil Cake	**135**	4 050
	Hominy Chop (cereal milling	**2 625**	78 750
	Soja Oil Cake	260 000	7 800 000
	Green Maize Chop (cereal milling)	520 000	15 600 000
TOTAL		1 300 922	39 027 660
Total organic feed (kg)		1 300 000	39 000 000

TABLE 2: Organic Feed Categories at the Feedlot

Organic Feed Categories					
Feed Category	**Daily Quantity (kg)**	**Required %**	**Monthly Quantity (kg)**	**Monthly Quantity (ton)**	**Required%**
Cereals	65 305	5	1959150	1959,15	5
Oilmeals	260 135	20	7804050	7804,05	20
Other Concentrates	782 762	60	23482860	23482,86	60
Roughages & Residues	192 623	15	5778690	5778,69	15
TOTAL	1 300 000	100	39 000 000	39000	100

The next step in determining the water footprint feed is to measure the water footprint of production of the main crops, crop by-products and concentrated feeds. A second weakness is that the exact origin of feed ingredients isn't given. For all feed types except molasses, the South African national average water footprint of production was used to compensate for this uncertainty. The water footprint of production for molasses was based on the country average of Swaziland.

Using the water footprint of production of main crops in South Africa and Swaziland (molasses only) (Mekonnen and Hoekstra, 2010) and FAO product fractions, the water footprint for the production of feed consumed at the feedlot per month is given in Table 3:

TABLE 3: Weighted average water footprint of feed

	Weigthed average WF of feed (liter/kg feed)		
	Green	**Blue**	**Grey**
Cereals	253,42	242,17	18,83
Oilmeals	287,07	200,24	5,75
Other Concentrates	79,97	19,66	11,78
Roughages & Residues	42,40	28,40	4,07

This allows one to calculate the first component of the water footprint – the water footprint of feed actually consumed in litre/slaughtered carcass (according to the Water Footprint Assessment methodology used for calculations at a global and national scale) and litre/animal/month (according to my own simplified approach more suited to a local site where more detailed information is available).

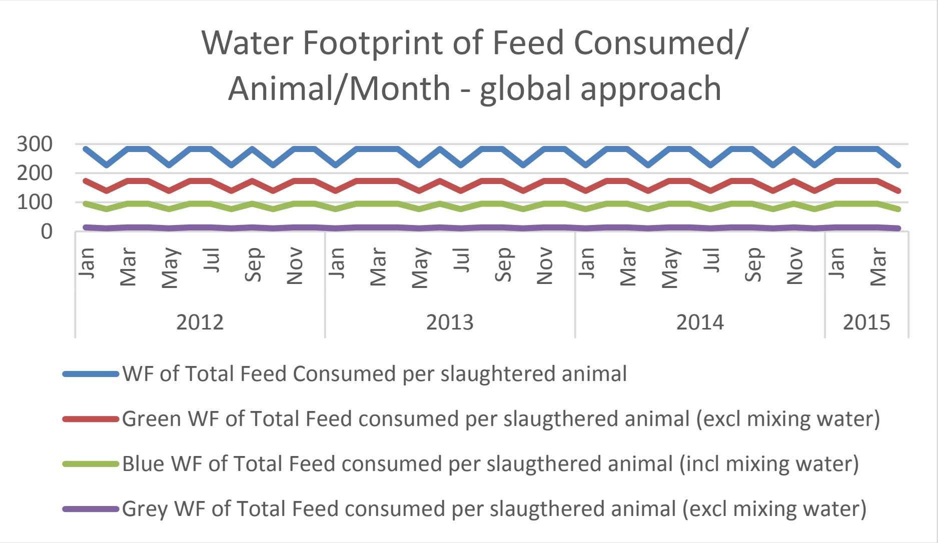
The formula to calculate the WF of feeds consumed by a category of farms animals in a given country (global or national scale), is as follows:

$$WF_{feed} = \frac{\Sigma(Feed[p] \times WF_{prod}[p]) + WF_{mixing}}{\text{Number of slaughtered animals}}$$

Assumptions:

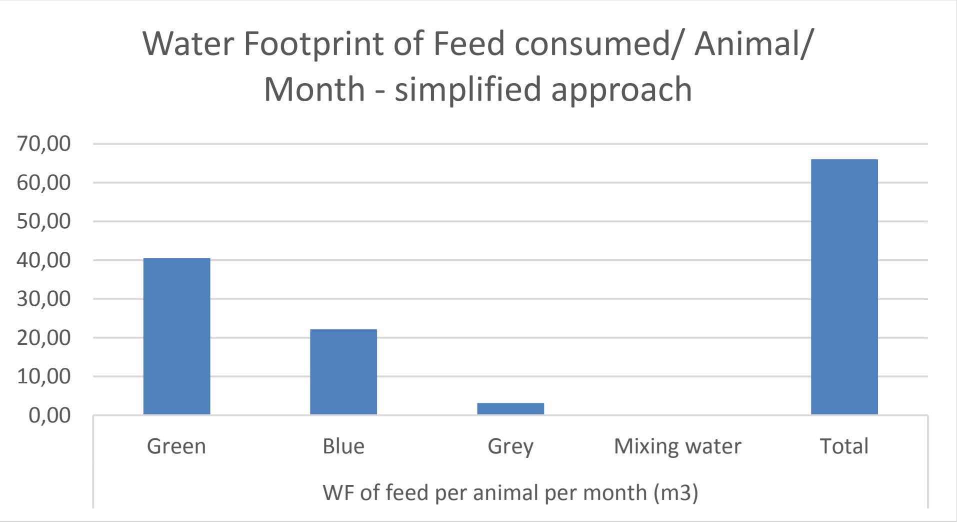
1. Water for mixing = $0,5m^3$/ton concentrate feed (Mekonnen & Hoekstra, 2010a)
2. Carcass weight = 270kg
3. 7000 live cattle slaughtered per week
4. Average nr of cattle at the feedlot: 120,000

Using this approach, the green, blue and grey water footprint varies per month according to the number of animals slaughtered (Graph 1). However, since the feed consumption for the entire feedlot cattle population is divided only by the number of animals slaughtered per month, the water footprint values are overstated.



Graph 1: Green, blue and grey water footprint of the Feedlot's cattle using the global approach by Mekonnen & Hoekstra 2010a.

A simpler and more realist approach is to use the actual amount of feed consumed by the cattle population per month. This approach gives a more realistic of the operational water footprint (graph 2).



Graph 2: Green, blue and grey water footprint of the Feedlot's cattle using a simplified approach.

Continuing using the Water Footprint global methodology, the next step is to determine how much drinking water is consumed to produce 1kg of slaughtered carcass. The drinking water demand per kg slaughtered carcass for the feedlot is 4,26liter/kg carcass. The calculation is based on a constant number of 7000 animals slaughtered per week, and a drinking water demand per animal of 1,15m^3/month. The drinking water demand is based on the following rationale (Table 4):

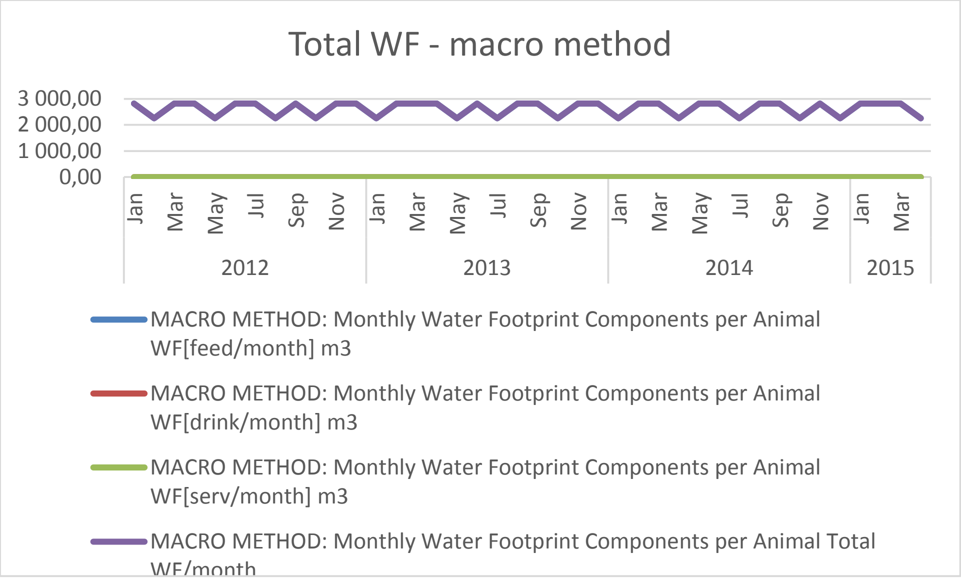
TABLE 4: Rationale used to determine the total drinking water demand per month

Drinking water demand	
Nr of Animals on farm	120 000,00
33% @ 25 - 35 l (30avg per day)	36 000 000,00
33% @ 40 l per day	48 000 000,00
33% @ 45 l per day	54 000 000,00
Total water demand per month (l)	138 000 000,00
Total feedlot drinking water demand per month (m^3)	138 000,00
Monthly drinking water demand per animal (m^3)	1,15

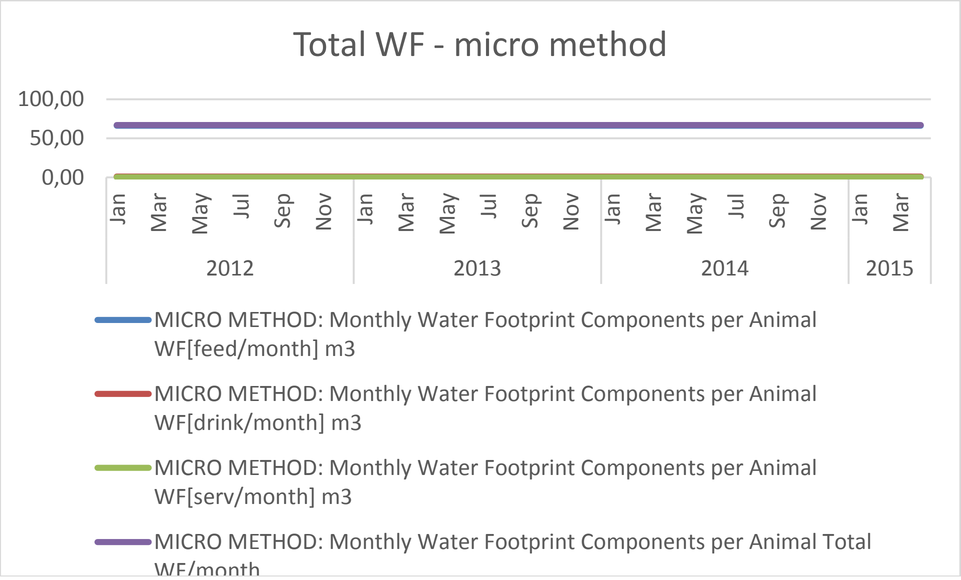
The last component of the animal water footprint is the proportion of service water that is used. This aspect is not monitored at the feedlot. Mekonnen & Hoekstra (2010a) recommend a ratio of 0,8% of the total water footprint is used for service water. In this research project, the service water was estimated as 0,8% of the drinking water consumption, due to the intuitive expectation that the very large feedlot would use higher than average volumes of service water for dust suppression and misting. The service water footprint is estimated to be 0,0043liter/kg slaughtered carcass.

Water Footprint Components of Beef Cattle

The final step adds the three water footprint components to arrive at a total water footprint per kg of slaughtered carcass. Using the global method, the total water footprint is given in Graph 3. The total water footprint is determined using the simplified method is given in Graph 4. The simplified method however does not shed light on monthly variations.



GRAPH 3: total water footprint components using the global method of Water Footprint Assessment based on the total feedlot population and the number of animals slaughtered per month.



GRAPH 4: total water footprint components using the simplified method of Water Footprint Assessment based on the actual monthly consumption of water by the total feedlot population

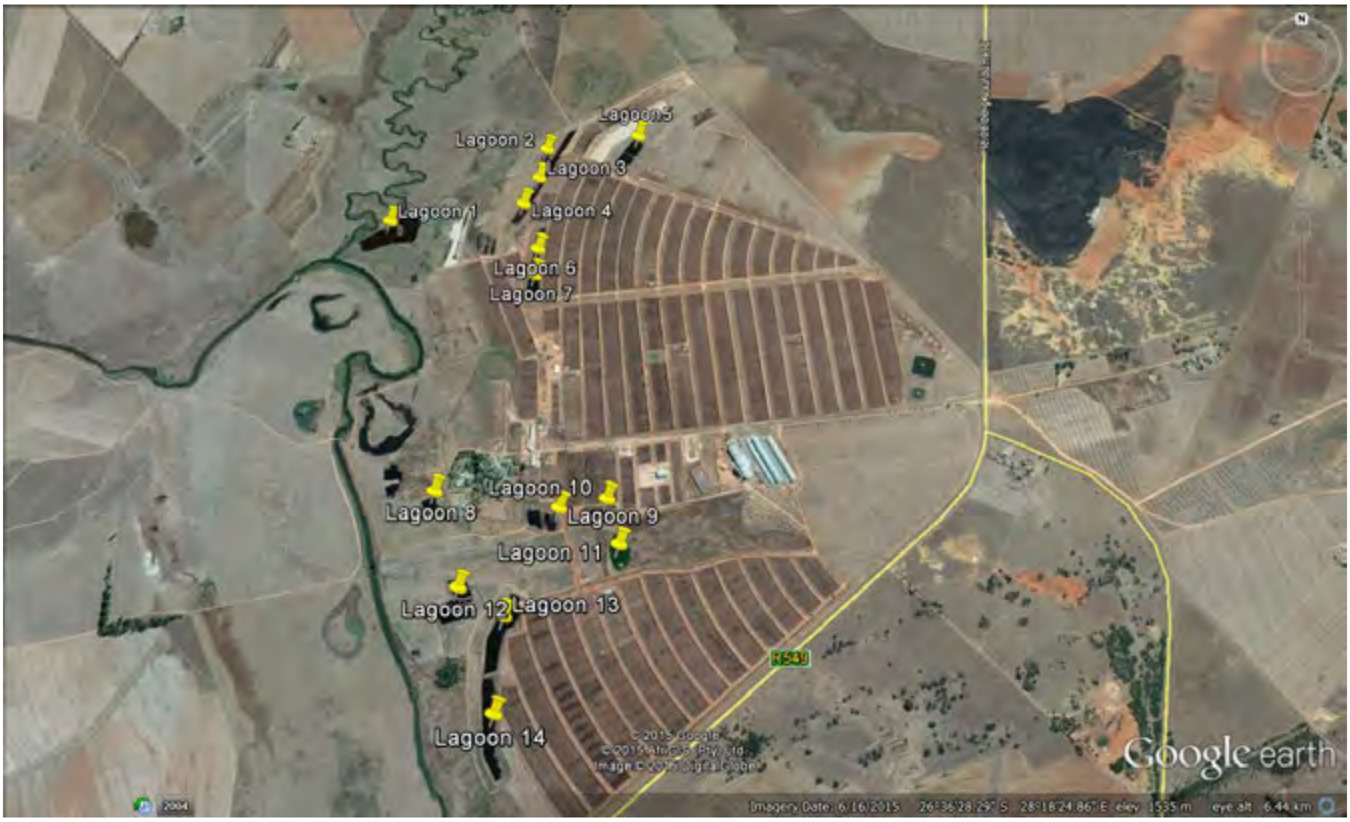
Table 5 below summarizes the weighted average water footprint components of beef cattle for the feedlot. The water footprint of beef cattle can be further broken down into different products, like meat, offal and other valuable products using FAO product fractions.

TABLE 5: Water Footprint components of beef cattle at the Feedlot

Feed component	Feed amount per month (kg/kg carcass)	Weighted average WF of feed per month(liter/kg)			WF (liter/kg carcass)			
		Green	Blue	Grey	Green	Blue	Grey	Total
Cereals	0,259	253,42	242,17	18,83	65,67	62,76	4,88	133,31
Oilmeals	1,032	287,07	200,24	5,75	296,33	206,71	5,93	508,97
Other Concentrates	3,106	79,97	19,66	11,78	248,39	61,08	36,58	346,05
Roughages & Residues	0,764	42,40	28,40	4,07	32,41	21,71	3,11	57,23
Water for feed mixing					0,00	2,20	0,00	2,20
WF related to feed					642,81	354,45	50,50	1 047,76
Drinking Water					0,00	4,26	0,00	4,26
Service Water					0,00	0,00	0,00	0,00
Total WF of Beef cattle (liter/kg carcass)					642,81	358,71	50,50	1 052,02
WF of a 570kg animal, assuming 270kg carcass weight					173 557,71	96 852,96	13 634,68	284 045,35

Grey Water Footprint of Waste Management Practices

The Feedlot has two major waste streams, namely manure and manure effluent. Manure is collected from feedlot pens and stockpiled on the farm, from where it is sold to local farmers for use as fertilizer. Manure effluent is collected in a system of fourteen effluent lagoons which are located downslope from the feedlot operations to intercept manure effluent arising from feedlot pens and prevent it from contaminating the downslope Suikerbosrand River and Blesbokspruit River (map 1). Effluent lagoon levels are managed to prevent spillages. Supernatant water from the lagoons is irrigated onto 50ha of *Erogrostis spp.* some of which is used to supplement the fodder feed at the feedlot and the rest is sold to other feedlots.



MAP 1: Map of effluent lagoons at the Feedlot.

Leaching-Runoff Fractions

The grey water footprint of waste management activities considered the P- and N- inputs from waste materials. Both chemical substances are major agricultural with the potential to cause significant environmental pollution trough leaching and runoff. In an agricultural operation like the feedlot, N- and P- pollution is likely to take place via diffuse pathways. Both N and P can enter the environment through leaching (through the soil strata) and runoff (after rainfall events or irrigation) and it is therefore important to understand the leaching-runoff fractions to determine the potential pollution burden on freshwater resources.

The leaching-runoff fractions of N and P is influenced by several factors. Specific factors that influence the N- and P- leaching-runoff fraction are given in table 6 below.

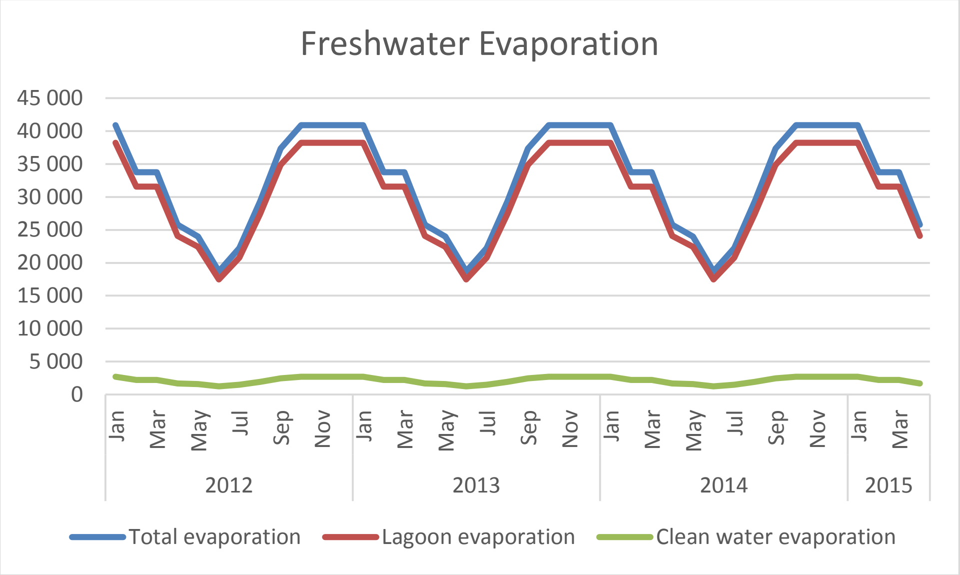
TABLE 6: Factor influencing the leaching-runoff fraction for N and P (Franke et al, 2013)

Nitrogen			Phosphorous		
Category	**Factor**		**Category**	**Factor**	
Environmental Factors	Atmospheric input	N-deposition (g N $m^{-2}yr^{-1}$)	Environmental Factors	Soil	Texture (relevant for runoff)
	Soil	Texture (relevant for leaching)			Erosion
		Texture (relevant for runoff)			P-content (g P m^{-2})
		Natural drainage (relevant for leaching)		Climate	Rain intensity
		Natural drainage (relevant for runoff)			
	Climate	Precipitation (mm)			
Agricultural Practice	N-fixation (kg/ha)		Agricultural Practice	Application rate	
	Application rate			Plant uptake (crop yield)	
	Plant uptake (crop yield)			Management practice	
	Management practice				

Grey water footprint from irrigation

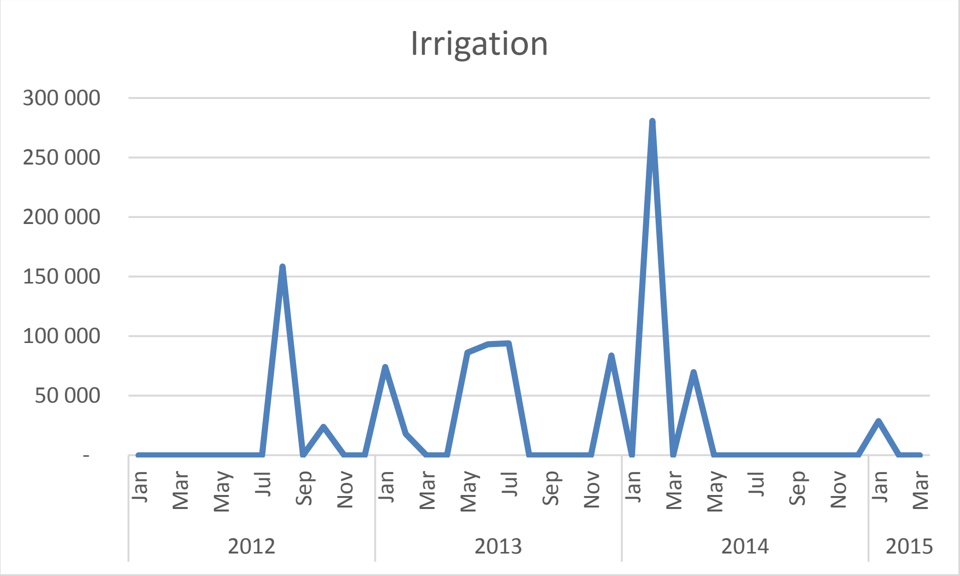
Effluent dam levels are maintained to prevent overflows and spillages into the surrounding environment. Spillages and overflows are a risk during the summer rainfall months. Effluent dam levels are maintained by irrigation of supernatant water onto 50ha of fodder crops.

The feedlot does not actively monitor the volume of water irrigated on land. To estimate the volume and timing of irrigation, the effluent dam level records were compared against expected evaporation (Graph 5) to determine when and what volume of irrigation was done. Evaporation was estimated using the evaporation potential published in the South African Atlas of Agrohydrology and -Climatology (Shulze, 1997), as well as the estimated surface area of the effluent dams (calculated using Google Earth). It is clear that evaporation from effluent dams plays a significant role in the green water footprint of waste management activities, however this aspect was not considered here.



GRAPH 5: Estimate of evaporation from freshwater surfaces over the study period.

The irrigation volumes and timing were estimated using rainfall data for Heidelberg Town, evaporation volumes and data on the effluent dam levels provided by the feedlot (Graph 6).



GRAPH 6: Estimate of irrigation periods and volumes over the study period.

The formula to calculate the grey water footprint is as follows:

$GWF = L/(C_{max} - C_{nat})$

The feedlot does not test the quality of supernatant water before irrigation takes place. Certain assumptions were therefore made about the N- and P- content of irrigation water, based on publications from other feedlots:

N-content of irrigation water:
assume 1630ppm (Ulmann, Mukhtar, 2007) - lagoon characteristics for dry feedlots (supernatent + sludge)
1ppm = 1mg/L
therefore: 1630ppm = 1630 mg/L - 1,63mg/m^3
50ha irrigated
N-uptake for temperate grasslands: 300 kg for dry matter yield of 10 tonnes (Roy et al, 2003)

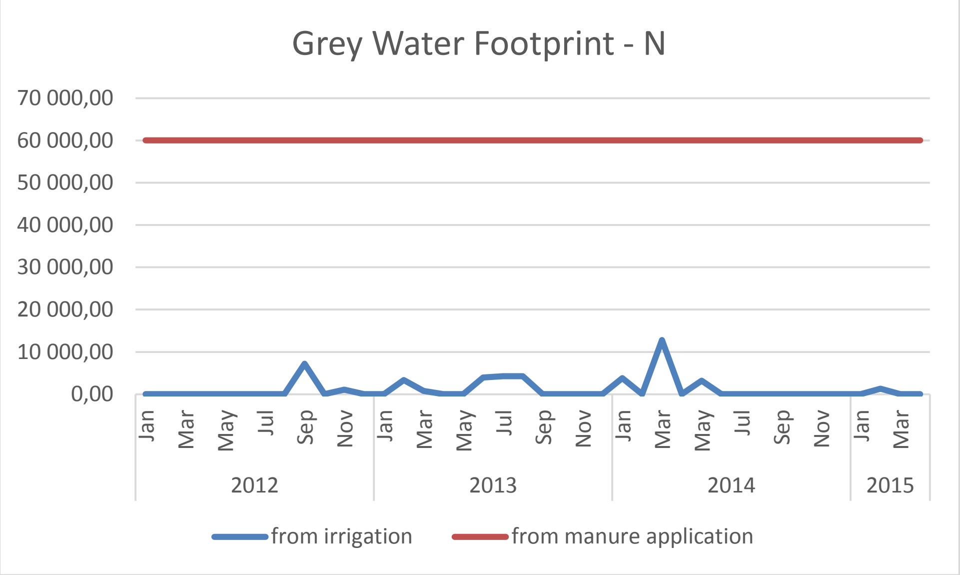
P-content of irrigation water:
assume 376ppm (Ulmann, Mukhtar, 2007) - lagoon characteristics for dry feedlots (supernatent + sludge)
1ppm = 1mg/L
therefore: 376ppm = 376 mg/L - 0,376mg/m^3
50ha irrigated
P_2O_5-uptake for temperate grasslands: 80 kg for dry matter yield of 10 tonnes (Roy et al, 2003)

A weakness of the study is that the N-content and P-content of irrigation water used in the grey water footprint model is likely an overstatement and don’t reflect actual conditions on site. This is due to the fact that the Feedlot irrigates with supernatant water, whereas the reference N-value and P-value used included readings from supernatant water and effluent dam sludge. A weakness of the Tier 1 methodology is that some factors are described as ‘high’, ‘very high’, ‘unknown’, ‘low’ or ‘very low’, without providing a data range within which to quantify the score of the factor. As a consequence, several of the factors scored ‘unknown’ – this will have a significant impact on the results of the assessment if actual scores can be given.
Similarly, certain assumptions were made about the likely N- and P-content of manure:

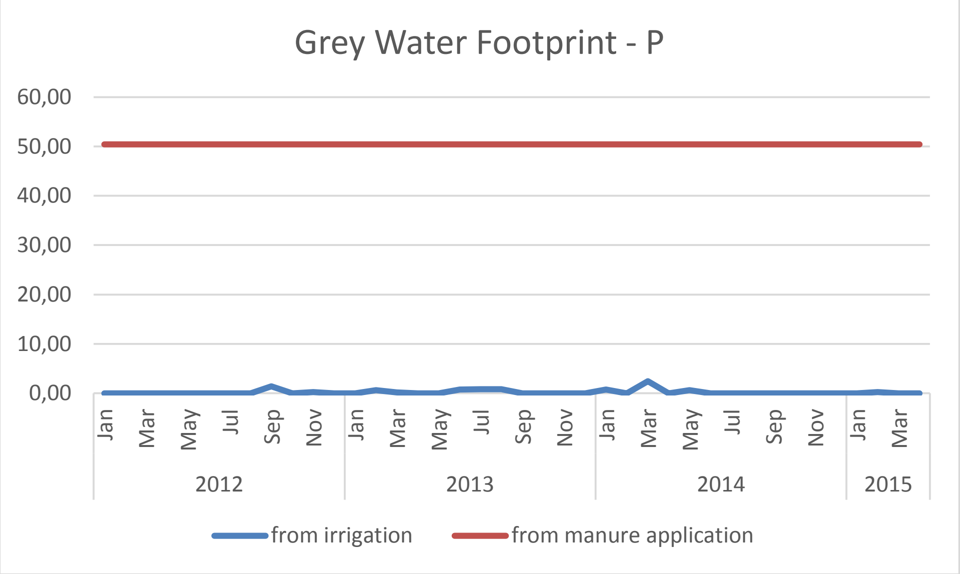
N-content of manure:
3kg manure per animal/day (Dave Ford)
120000 cattle = 3x120000 = 360,000kg manure/day = **10,800 ton manure /month**
N-content = 15,9kg/ton (Hao et al, 2003)
Distribution area for manure:
Dept of Agriculture recommends 5ton/ha for maize under irrigation once a year in the winter (Van Averbeke, W., Yoganathan, S., 2003.)
Therefore: 10800ton/5ton ha^{-1} = **2160 ha is needed for manure distribution per month**

P-content of manure:
3kg manure per animal/day (Dave Ford)
120000 cattle = 3x120000 = 360,000kg manure/day = **10,800 ton manure /month**
N:P is 3,3 ((Parham et al, 2002), therefore P is 15,9/3,3 = 4,82 kg/ton
Distribution area for manure:
Dept of Agriculture recommends 5ton/ha for maize under irrigation once a year in the winter (Van Averbeke, W., Yoganathan, S., 2003.)
Therefore: 10800ton/5ton ha^{-1} = **2160 ha is needed for manure distribution per month**

The results of the grey water footprint from irrigation for N and P is illustrated in the graphs below (Graph 7 & 8).



GRAPH 7: Grey water footprint resulting from irrigation over the study period.



GRAPH 8: Grey water footprint resulting from manure disposal over the study period.

Grey water footprint from manure disposal to land

Manure is collected from feedlot pens and stockpiled on the feedlot property before being sold to local farmers for use as fertiliser. The results of the grey water footprint from manure disposal is illustrated in the graphs above.

Blue Water Scarcity – Blesbokspruit Quaternary Catchment

Blue Water Scarcity essentially is the difference between available blue water resources in a catchment, and demand. Ideally a catchment should be assessed over a period of time to determine periods and locations where demand exceeds availability, in other words where water stress exists. In this research project data provided by the Department of Water Affairs was used to examine the BWS of Blesbokspruit Catchment.

Further Discussion

During the follow-up presentation, the discussion will focus on the Water Footprint Assessment Methodology (Setp 2), Sustainability Assessment (Step 3) and Response Strategies (Step 4) components of the Water Footprint Assessment. The below items and questions will be used to guide the discussion:

1. Data spreadsheets, assumptions and calculations will be discussed.
2. Discuss the current status and future pressure on the Blue Water Scarcity of Blesbokspruit Catchment.
3. How is the feedlot affected by Blue Water Scarcity in the catchment?
4. What contribution does the feedlot make to Blue Water Scarcity within the catchment?
5. What drives the green, blue and grey water footprint components of beef cattle, and of waste management activities?
6. How does the Feedlot's water footprint compare to other studies of beef cattle?
7. How can the feedlot reduce the respective water footprint components?
8. How could the feedlot benefit by reducing the respective water footprint components, and benchmarking water footprint performance against other feedlots?

B1. Audio recording of the Dissertation Workshop

C1. Bovine Water Footprint

Feedlot Feed Mix

Feedlot Feed Mix				
Feed Type		Daily Quantity (kg)	Monthly Quantity (kg)	Monthly Quantity (ton)
Roughages & Crop Residues	Concentrate Feeds			
Wheatstraw		92 500	2 775 000	2 775
Silage HQ		**693**	20 790	21
Silage from other sources		**6 930**	207 900	208
	Cotton seed	64 000	1 920 000	1 920
	Wheatbran	92 500	2 775 000	2 775
Lime		**97**	2 910	3
	Maize	**1 305**	39 150	39
	Molasses	260 000	7 800 000	7 800
	Glutenfeed	**137**	4 110	4
	Cotton Oil Cake	**135**	4 050	4
	Hominy Chop (cereal milling	**2 625**	78 750	79
	Soja Oil Cake	260 000	7 800 000	7 800
	Green Maize Chop (cereal milling)	520 000	15 600 000	15 600
TOTAL		**1 300 922**	**39 027 660**	39 028
Total organic feed (kg)		**1 300 000**	**39 000 000**	39 000
Test total		1 300 922		
RED: given by Feedlot	Black: assumed			

Organic Feed Categories					
Feed Category	**Daily Quantity (kg)**	**required %**	**Monthly Quantity (kg)**	**Monthly Quantity (ton)**	**Required%**
Cereals	65 305	5	1959150	1959,15	5
Oilmeals	260 135	20	7804050	7804,05	20
Other Concentrates	782 762	60	23482860	23482,86	60
Roughages & Residues	192 623	15	5778690	5778,69	15
TOTAL	1 300 000	100	39 000 000	39000	100
Molasses + glutenfeed	260 137	20,01053846			
hominy chop + maixe chop	522 625	40,20192308			

1. **Other concentrates** = molasses, Glutenfeed (20%) + Cereal milling byproducts = green maize chop; Hominy chop (40%) **(Total 60%)** ==> adjusted from Hendy et al (assume 40% chop) to accommodate Feedlot figure for fodder
2. **Oilmeals** = cotton oil cake; soja oil cake **(20%)** = Hendy et al
3. **Cereals** = cotton seed; maize **(5%)** ==> assumption adjusted from 10% given by Hendy to accommodate Feedlot figure for fodder
4. **Roughages** = wheatstraw, silage, wheatbran **(15%)** ==> Feedlot figure is 10% fodder

Hendy et al 1995

For dairy cattle in UK, for example, diets typically include 40-50% cereal milling by-products, 25% oilmeals and 20% of other ingredients such as molasses and sugarbeet pulp, though still including some 10-15% cereals (Digest of Feed Facts and Figures 1990-91). Some feeding systems for fattening beef cattle use high proportions of coarse grains as straight concentrates (for example barley in the UK) but in most cases a wide variety of milling and agro-industrial by-products may be incorporated in finishing diets (as in feedlot systems). In developing countries, the proportion of cereals in concentrates fed to ruminants is very low.

Feedlot given information:
Daily avergae feed per animal = 10kg/animal/day
Average standing population = 130,000 animals
Therefore: 1,300,000 kg feed/day
Therefore: 39, 000,000 kg feed/month

Silage HQ = 10% of total silage
Therefore silage from other sources = 6930kg/day

Assumptions:
1. Molasses+glutenfeed = 20% of total
2. hominy chop + maize chop = 40% of total
2. wheatstraw:wheatbran = 50:50

Water Footprint of Production of Feed Ingredients

	Annual WF Production		
Main Crop	$WF_{GreenProduction}$	$WF_{BlueProduction}$	$WF_{GreyProduction}$
Cotton	1386	3790	91
Wheat (SA national)	1040	230	98
Maize (SA national)	1661	34	131
Sugarcane (Swaziland national)	55	66	0
green maize (SA national)	366	320	70
Soja (SA national)	2739	88	14
Silage HQ (global average)	207	27	20
Silage bought (global average)	207	27	20

Assumptions:

1. WF of low value crop residues = zero (WF attributed to main product) ==> wheatstraw
2. Fraction of $WF_{production}$[main crop] is allocated to the $WF_{production}$[concentrate feed type] ==> (Chapagain & Hoekstra 2010)
3. Country average WF used except for silage HQ; exact origin of bought feeds not known (but within 200km radius)
4. Fodder crops WF used global average (M&H, 2010 - WF of Crops...)
5. Sugar cane used Swaziland country average
6. Assume silage value fraction = 1

			Annual production fraction m^3/ton			Monthly production fraction m3/ton			WF m^3 feed consumed per month		
FEED TYPE	Product Fraction	Value Fraction	WF_{green} Fraction	WF_{blue} Fraction	WF_{grey} Fraction	WF_{green} Fraction	WF_{blue} Fraction	WF_{grey} Fraction	WF_{green}	WF_{blue}	WF_{grey}
Cotton seed	0,63	0,21	291,06	795,90	19,11	24,26	66,33	1,59	46 569,60	127 344,00	3 057,60
Wheatbran	1,00	1,00	1 040,00	230,00	98,00	86,67	19,17	8,17	240 500,00	53 187,50	22 662,50
Molasses	0,05	0,10	5,50	6,60	0,00	0,46	0,55	0,00	3 575,00	4 290,00	0,00
Glutenfeed (wheat)	0,15	0,36	374,40	82,80	35,28	31,20	6,90	2,94	128,23	28,36	12,08
Cotton Oil Cake	0,51	0,51	706,86	1 932,90	46,41	58,91	161,08	3,87	238,57	652,35	15,66
Hominy Chop (maize grouts)	0,11	0,09	149,49	3,06	11,79	12,46	0,26	0,98	981,03	20,08	77,37
Soja Oil Cake	0,79	0,66	1 807,74	58,08	9,24	150,65	4,84	0,77	1 175 031,00	37 752,00	6 006,00
Green Maize Chop	1,00	1,00	366,00	320,00	70,00	30,50	26,67	5,83	475 800,00	416 000,00	91 000,00
Maize	1,00	1,00	1 661,00	34,00	131,00	138,42	2,83	10,92	5 419,01	110,93	427,39
Wheat straw	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Silage HQ	1,00	1,00	207,00	27,00	20,00	17,25	2,25	1,67	358,63	46,78	34,65
Silage bought	1,00	1,00	207,00	27,00	20,00	17,25	2,25	1,67	3 586,28	467,78	346,50

	WF of feed consumed per month (m3)		
FEED CATEGORY	WF_{prod}Green	WF_{prod}Blue	WF_{prod}Grey
Cereals	51 988,61	127 454,93	3 484,99
Oilmeals	1 175 269,57	38 404,35	6 021,66
Other Concentrates	480 484,26	420 338,44	91 089,46
Roughages & Residues	244 444,90	53 702,05	23 043,65
TOTAL	1 952 187,34	639 899,77	123 639,76

	WF of feed (m^3) consumed per month			4-month production cycle WF of feed (m^3) consumed per month			
	Green	**Blue**	**Grey**	**Green**	**Blue**	**Grey**	
Cereals	51 988,61	127 454,93	3 484,99	207 954,45	509 819,70	13 939,95	
Oilmeals	1 175 269,57	38 404,35	6 021,66	4 701 078,26	153 617,42	24 086,65	
Other Concentrates	480 484,26	420 338,44	91 089,46	1 921 937,04	1 681 353,76	364 357,82	
Roughages & Residues	244 444,90	53 702,05	23 043,65	977 779,61	214 808,21	92 174,60	
Total				7 808 749,36	2 559 599,09	494 559,02	10 862 907,47
				71,88	23,56	4,55	
				60,20270396	65,68816852	73,67327315	

Water Footprint of Feed Consumed at the Feedlot per Month

$$WF_{feed} = \frac{\Sigma(Feed[p] \times WF_{prod}[p]) + WF_{mixing}}{\text{Number of slaughtered animals}}$$

m^3/slaughtered animal

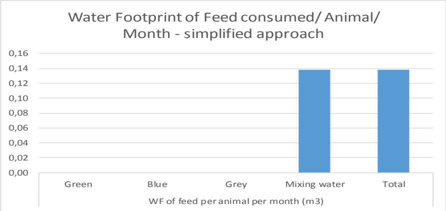
Assumptions:
1. water for mixing = 0,5m^3/ton concentrate feed
2. Carcass weight = 240kg
3. Live weight midpoint= 330kg
4. 130,000 cattle slaughtered per 4-month production cycle
5. Value fraction bovine carcass = 0,87

	Feedlot Total Feed WF per month (m^3)					
Feed category	Monthly feed volume	WF_{prod}Green	WF_{prod}Blue	WF_{prod}Grey	Total Wf_{prod}	WF_{mixing}Month
Cereals	1 959	51 989	127 455	3 485	182 929	980
Oilmeals	7 804	1 175 270	38 404	6 022	1 219 696	3 902
Other Concentrates	23 483	480 484	420 338	91 089	991 912	11 741
Roughages & Residues	5 779	244 445	53 702	23 044	321 191	0
Total	**39 000**	**1 952 187**	**639 900**	**123 640**	**2 715 727**	**16 623**

WF of feed per animal per month (m^3)				
Green	**Blue**	**Grey**	**Mixing water**	**Total**
0,00	0,00	0,00	0,14	0,14

Production cycle	Year	Month	Nr slaughtered animals/cycle	WF of Total Feed Consumed per slaughtered animal (m3)	Green WF of Total Feed consumed per slaugthered animal (excl mixing water) (m3)	Blue WF of Total Feed consumed per slaugthered animal (incl mixing water) (m3)	Grey WF of Total Feed consumed per slaugthered animal (excl mixing water) (m3)
Summer	2012	Jan	130000	84,07	60	20	4
		Feb					
		Mar					
		Apr					
Winter		May	130000	84,07	60	20	4
		Jun					
		Jul					
		Aug					
Winter		Sep	130000	84,07	60	20	4
		Oct					
		Nov					
		Dec					
Summer	2013	Jan	130000	84,07	60	20	4
		Feb					
		Mar					
		Apr					
Winter		May	130000	84,07	60	20	4
		Jun					
		Jul					
		Aug					
Winter		Sep	130000	84,07	60	20	4
		Oct					
		Nov					
		Dec					
Summer	2014	Jan	130000	84,07	60	20	4
		Feb					
		Mar					
		Apr					
Winter		May	130000	84,07	60	20	4
		Jun					
		Jul					
		Aug					
Winter		Sep	130000	84,07	60	20	4
		Oct					
		Nov					
		Dec					
Summer	2015	Jan	130000	84,07	60	20	4
		Feb					
		Mar					
		Apr					

Carcass weight slaugthered per 4-month production cycle (kg)	Feed category	4-month production cycle feed volume (kg)	Feed amount (kg/kg carcass)
31 200 000,00	Cereals	7 836 600	0,25
	Oilmeals	31 216 200	1,00
	Other Concentrates	93 931 440	3,01
	Roughages & Residues	23 114 760	0,74



Drinking Water Footprint

Drinking water demand - winter cycle		Urine (m3)	Drinking water consumed (m3)
Nr of Animals on farm	130 000,00		
33% @ 25 - 35 l (30avg per day)	39 000 000,00		
33% @ 40 l per day	52 000 000,00		
33% @ 45 l per day	58 500 000,00		
Total water demand per month (l)	149 500 000,00		
Total feedlot drinking water demand per month (m^3)	149 500,00		
Monthly drinking water demand per animal (m^3)	1,15		
4-month production cycle per animal (m3)	4,6	4,048	0,552

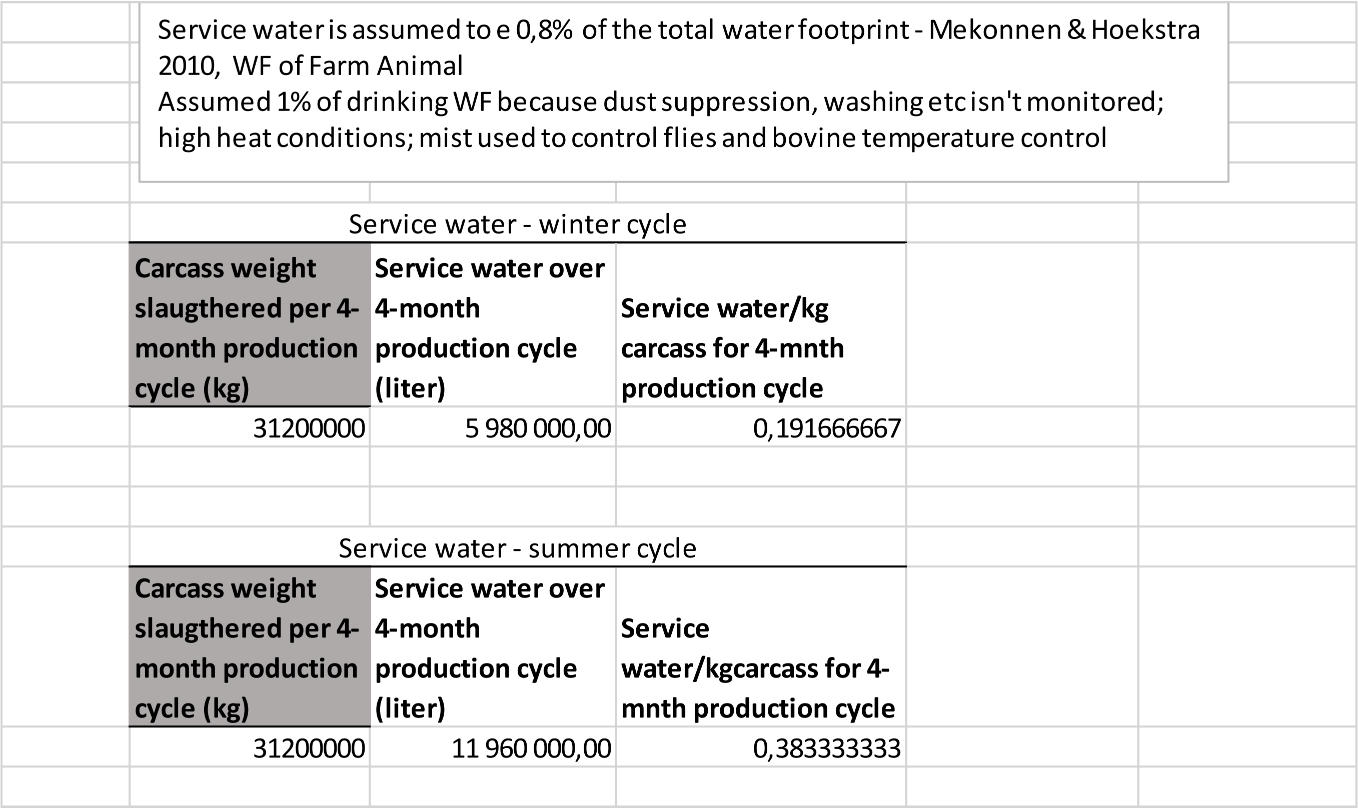
The average water consumption is about 35 l per head. 33% of a
drink 25 - 35 l, 33% drink 40 and 33% drink 45 l. the monthly abs
is about 830 333 cubic meters - Johan van Niekerk (email 11/11/

Carcass weight slaugthered per 4-month production cycle (kg)	**4-month production cycle water demand for**	**Drinking water (liter/kg carcass)**
31200000	598 000 000,00	**19,16666667**

Drinking water demand - summer cycle		Urine (m3)	Drinking water consumed (m3)
Nr of Animals on farm	130 000,00		
33% @ 25 - 35 l (30avg per day)	78 000 000,00		
33% @ 40 l per day	104 000 000,00		
33% @ 45 l per day	117 000 000,00		
Total water demand per month (l)	299 000 000,00		
Total feedlot drinking water demand per month (m^3)	299 000,00		
Monthly drinking water demand per animal (m^3)	2,30		
4-month production cycle per animal (m3)	9,2	8,096	1,104

Carcass weight slaugthered per 4-month production cycle (kg)	**4-month production cycle for feedlot (liter)**	**Drinking water (liter/kg carcass)**
31200000	1 196 000 000,00	**38,33**

Service Water Footprint



Service water is assumed to e 0,8% of the total water footprint - Mekonnen & Hoekstra 2010, WF of Farm Animal
Assumed 1% of drinking WF because dust suppression, washing etc isn't monitored; high heat conditions; mist used to control flies and bovine temperature control

Service water - winter cycle

Carcass weight slaugthered per 4-month production cycle (kg)	**Service water over 4-month production cycle (liter)**	**Service water/kg carcass for 4-mnth production cycle**
31200000	5 980 000,00	0,191666667

Service water - summer cycle

Carcass weight slaugthered per 4-month production cycle (kg)	**Service water over 4-month production cycle (liter)**	**Service water/kgcarcass for 4-mnth production cycle**
31200000	11 960 000,00	0,383333333

Final Calculation of Water Footprint of Beef Cattle

WF[slaughtered animal/production cycle] = WF[feed/production cycle] + WF[drink/production cycle] + WF[serv/production cycle]

The components of the water footprint of beef cattle at Karan Beef Feedlot (4 month winter produdction cycle)								
		Weighted average water footprint of feed (liter/kg feed)			Water Footprint (liter/kg carcass)			
Feed Category	**Feed amount (kg/kg carcass)**	Green	Blue	Grey	Green	Blue	Grey	Total
Cereals	0,25	207 954,45	509 819,70	13 939,95	52 232,56	128 052,98	3 501,34	183 786,88
Oilmeals	1,00	4 701 078,26	153 617,42	24 086,65	4 703 519,21	153 697,18	24 099,16	4 881 315,54
Other Concentrates	3,01	1 921 937,04	1 681 353,76	364 357,82	5 786 228,01	5 061 922,43	1 096 944,06	11 945 094,50
Roughages & Residues	0,74	977 779,61	214 808,21	92 174,60	724 395,55	159 142,31	68 288,26	951 826,12
WF related to Feed					11 266 375,32	5 502 814,91	1 192 832,83	17 962 023,05
Drinking water consumed						19,17		
Service water						0,19		
Total water footprint per 4-month production cycle (liter/kg carcass)					**11 266 375,32**	**5 502 834,27**	**1 192 832,83**	**17 962 042,41**

The components of the water footprint of beef cattle at Karan Beef Feedlot (4 month summer produdction cycle)								
Feed Category	**Feed amount (kg/kg carcass)**	Weighted average water footprint of feed (liter/kg Green	Blue	Grey	Water Footprint (liter/kg carcass) Green	Blue	Grey	Total
Cereals	0,25	207 954,45	509 819,70	13 939,95	52 232,56	128 052,98	3 501,34	183 786,88
Oilmeals	1,00	4 701 078,26	153 617,42	24 086,65	4 703 519,21	153 697,18	24 099,16	4 881 315,54
Other Concentrates	3,01	1 921 937,04	1 681 353,76	364 357,82	5 786 228,01	5 061 922,43	1 096 944,06	11 945 094,50
Roughages & Residues	0,74	977 779,61	214 808,21	92 174,60	724 395,55	159 142,31	68 288,26	951 826,12
WF related to Feed					11 266 375,32	5 502 814,91	1 192 832,83	17 962 023,05
Drinking water consumed						38,33		
Service water						0,38		
Total water footprint per 4-month production cycle (liter/kg carcass)					**11 266 375,32**	**5 502 853,63**	**1 192 832,83**	**17 962 061,77**

Animals spend avg 4 months on the feedlot, in which time their live weight typically increases from 220kg to 450kg. Typical carcass weight is 240kg

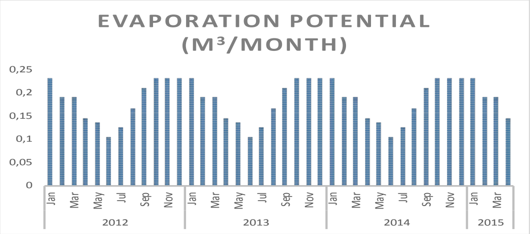
C2. Grey Water Footprint of Waste Management

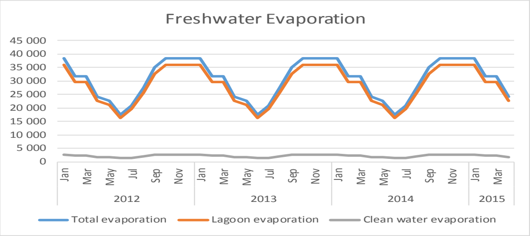
Evaporation

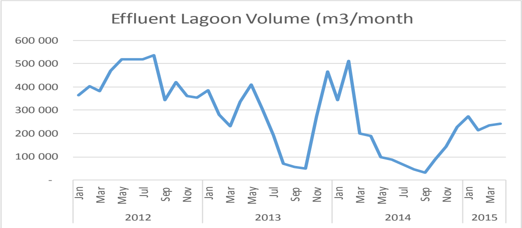
Total clean water surfce area (m2)	11 612,00
lagoon surface area	155 988
Total freshwater surface area (m2)	**167 600**

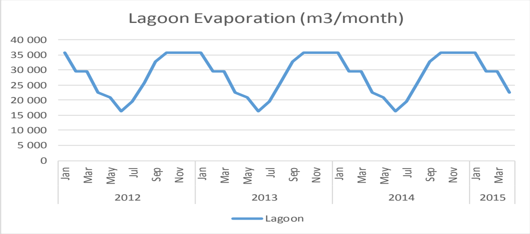
Total annual evaporation (m3)	Avg monthly evaporation (m3)	Water demand/ month (m3)
366 207	30 517	168 517

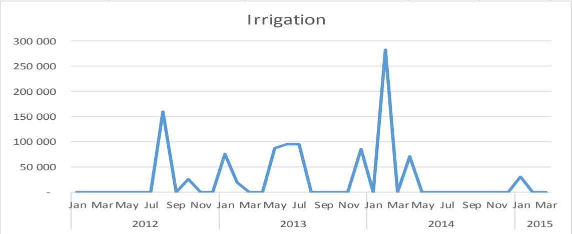
			Water Evaporation (m^3/month)				
		Evaporation Potential (m3/month)	Total	Lagoon	Fresh	**Lagoon Volume**	**Irrigation**
2012	Jan	0,23	38 548	35 877	2 671	365 153	
	Feb	0,19	31 844	29 638	2 206	404 833	-
	Mar	0,19	31 844	29 638	2 206	383 071	-
	Apr	0,145	24 302	22 618	1 684	469 627	-
	May	0,135	22 626	21 058	1 568	520 203	-
	Jun	0,105	17 598	16 379	1 219	520 203	-
	Jul	0,125	20 950	19 499	1 452	520 203	-
	Aug	0,165	27 654	25 738	1 916	537 543	-
	Sep	0,21	35 196	32 758	2 439	344 201	160 584
	Oct	0,23	38 548	35 877	2 671	422 520	-
	Nov	0,23	38 548	35 877	2 671	360 385	26 258
	Dec	0,23	38 548	35 877	2 671	353 160	-
2013	Jan	0,23	38 548	35 877	2 671	387 039	-
	Feb	0,19	31 844	29 638	2 206	281 394	76 006
	Mar	0,19	31 844	29 638	2 206	231 948	19 808
	Apr	0,145	24 302	22 618	1 684	338 070	-
	May	0,135	22 626	21 058	1 568	410 494	-
	Jun	0,105	17 598	16 379	1 219	306 917	87 198
	Jul	0,125	20 950	19 499	1 452	192 872	94 547
	Aug	0,165	27 654	25 738	1 916	71 473	95 661
	Sep	0,21	35 196	32 758	2 439	55 676	-
	Oct	0,23	38 548	35 877	2 671	48 777	-
	Nov	0,23	38 548	35 877	2 671	272 533	-
	Dec	0,23	38 548	35 877	2 671	466 436	-
2014	Jan	0,23	38 548	35 877	2 671	344 508	86 051
	Feb	0,19	31 844	29 638	2 206	513 138	-
	Mar	0,19	31 844	29 638	2 206	200 712	282 789
	Apr	0,145	24 302	22 618	1 684	191 148	-
	May	0,135	22 626	21 058	1 568	98 962	71 127
	Jun	0,105	17 598	16 379	1 219	87 660	-
	Jul	0,125	20 950	19 499	1 452	67 787	374
	Aug	0,165	27 654	25 738	1 916	45 261	-
	Sep	0,21	35 196	32 758	2 439	33 047	-
	Oct	0,23	38 548	35 877	2 671	88 123	-
	Nov	0,23	38 548	35 877	2 671	143 200	-
	Dec	0,23	38 548	35 877	2 671	226 870	-
2015	Jan	0,23	38 548	35 877	2 671	272 571	-
	Feb	0,19	31 844	29 638	2 206	212 272	30 661
	Mar	0,19	31 844	29 638	2 206	234 236	-
	Apr	0,145	24 302	22 618	1 684	242 994	-



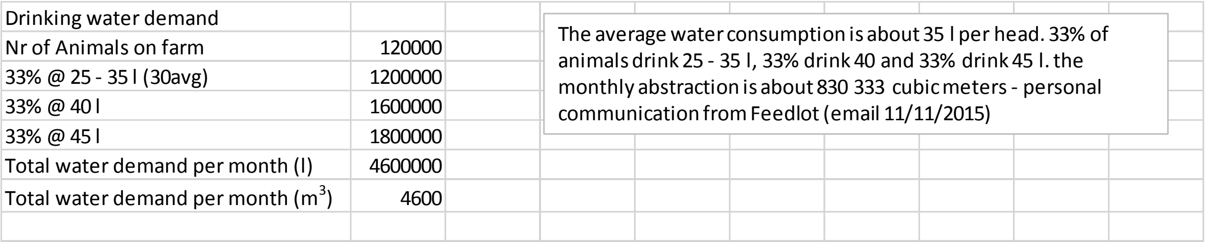








Drinking Water Demand



Drinking water demand	
Nr of Animals on farm	120000
33% @ 25 - 35 l (30avg)	1200000
33% @ 40 l	1600000
33% @ 45 l	1800000
Total water demand per month (l)	4600000
Total water demand per month (m^3)	4600

The average water consumption is about 35 l per head. 33% of animals drink 25 - 35 l, 33% drink 40 and 33% drink 45 l. the monthly abstraction is about 830 333 cubic meters - personal communication from Feedlot (email 11/11/2015)

N-leaching Run-off Potential

NITROGEN LEACHING RUN-OFF POTENTIAL											
Category	**Factor**		**Leaching runoff potential**		**Score (*s*)**					**Results**	
			Weight (*w*)*		**Very low**	**Low**	**No Information available**	**High**	**Very high**		
			α	**β**	**0**	**0,33**	**0,5**	**0,67**	**1**	***s* X*w***	***w***
Environmental Factors	Atmospheric input	N-deposition (g N m^{-2}yr^{-1})	10	10	<0.5	>0.5		<1.5	>1.5	3,3	10
	Soil	Texture (relevant for leaching)	15	15	Clay	Silt		Loam	Sand	10,05	15
		Texture (relevant for runoff)	10	10	Sand	Loam		Silt	Clay	3,3	10
		Natural drainage (relevant for leaching)	10	15	Poorly to very poorly drained	Moderately to imperfectly drained	unknown	Well drained	Excessively to extremely drained	5	10
		Natural drainage (relevant for runoff)	5	10	Excessively to extremely drained	Well drained	unknown	Moderately to imperfectly drained	Poorly to very poorly drained	2,5	5
	Climate	Precipitation (mm)	15	15	0 - 600	600 - 1200		1200 - 1800	>1800	0	15
Agricultural practice	N-fixation (kg/ha)		10	10	0	>0	unknown	<60	>60	5	10
	Application rate		10	0	Very low	Low		High	Very high	0	10
	Plant uptake (crop yield)		5	0	Very high	High	unknown	Low	Very low	2,5	5
	Management practice		10	15	Best	Good		Average	Worst	3,3	10
										34,95	100

Nitrogen	
α_{min}	0,01
α_{avg}	0,1
α_{max}	0,25
C_{max} (mg/l)	3
C_{nat} (mg/l)	0

Equations:

$GWF = L/(C_{max} - C_{nat})$

$L = \alpha \text{ X } Appl$

Appl = Appl.Rate X Area

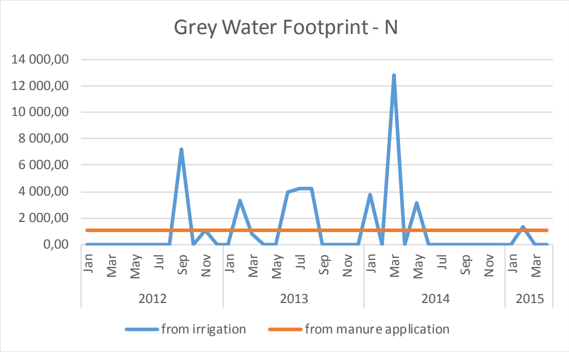
$$\alpha = \alpha_{min} + \frac{\Sigma s_i X w_i}{\Sigma w_i} X (\alpha_{max} - \alpha_{min})$$

$(\alpha_{max} - \alpha_{min})$	$(C_{max} - C_{nat})$
0,24	3

N-Leaching runoff fraction:
0,084

Grey WF - Nitrogen from Irrigation

N-application/month (mg)	N-application rate (mg/ha)	Area (ha)	α	C_{max} - C_{nat} (mg/L)	Load (mg)	GWF - N irrigation (L)
0,00	0,032600	50,00	0,08	3,00	0,00	0,00
0,00					0,00	0,00
0,00					0,00	0,00
0,00					0,00	0,00
0,00					0,00	0,00
0,00					0,00	0,00
0,00					0,00	0,00
0,00					0,00	0,00
258 257,34					21 662,63	7 220,88
0,00					0,00	0,00
38 972,34					3 269,00	1 089,67
0,00					0,00	0,00
0,00					0,00	0,00
120 728,01					10 126,67	3 375,56
29 124,93					2 443,00	814,33
0,00					0,00	0,00
0,00					0,00	0,00
140 385,83					11 775,56	3 925,19
152 031,02					12 752,36	4 250,79
153 181,13					12 848,83	4 282,94
0,00					0,00	0,00
0,00					0,00	0,00
0,00					0,00	0,00
0,00					0,00	0,00
136 434,16					11 444,10	3 814,70
0,00					0,00	0,00
457 783,91					38 398,91	12 799,64
0,00					0,00	0,00
113 690,42					9 536,35	3 178,78
0,00					0,00	0,00
0,00					0,00	0,00
0,00					0,00	0,00
0,00					0,00	0,00
0,00					0,00	0,00
0,00					0,00	0,00
0,00					0,00	0,00
0,00					0,00	0,00
46 815,51					3 926,89	1 308,96
0,00					0,00	0,00
0,00					0,00	0,00



<u>Equations:</u>

GWF = $L/(C_{max} - C_{nat})$

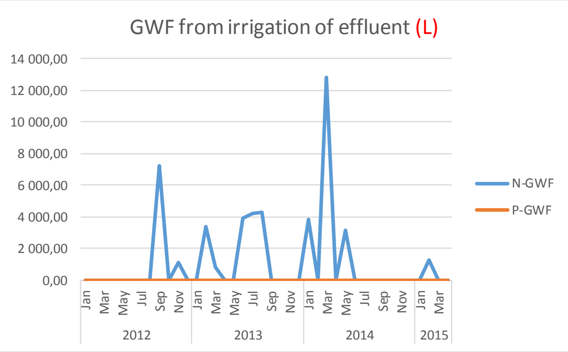
$L = \alpha$ X Appl

Appl = Appl.Rate X Area

$$\alpha = \alpha_{min} + \frac{\Sigma s_i X w_i}{\Sigma w_i} X (\alpha_{max} - \alpha_{min})$$

<u>N-content of irrigation water:</u>
assume 1630ppm (Ulmann, Mukhter, 2007) - lagoon characteristics for dry feedlots (supernatent + sludge)

1ppm = 1mg/L
therefore: 1630ppm = 1630 mg/L - 1,63mg/m³
50ha irrigated

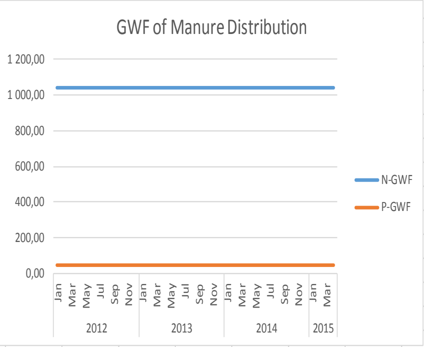


Grey WF Nitrogen - Manure Application to Land

Year	Month	Manure volume (ton/month)	N-content manure (kg/ton)	N-application per month (kg)	Manure application (kg/ha/month)	N-application rate (kg/ha)	Manure distribution Area (ha)	α	$C_{max} - C_{nat}$ (kg/m^3)	Load (kg)	GWF - N manure application (L)
			15,90				2 160,00	0,08	0,24		
2012	Jan	187,20		2,98		0,00				0,25	1 040,28
	Feb	187,20		2,98						0,25	1 040,28
	Mar	187,20		2,98						0,25	1 040,28
	Apr	187,20		2,98						0,25	1 040,28
	May	187,20		2,98						0,25	1 040,28
	Jun	187,20		2,98						0,25	1 040,28
	Jul	187,20		2,98						0,25	1 040,28
	Aug	187,20		2,98						0,25	1 040,28
	Sep	187,20		2,98						0,25	1 040,28
	Oct	187,20		2,98						0,25	1 040,28
	Nov	187,20		2,98						0,25	1 040,28
	Dec	187,20		2,98						0,25	1 040,28
2013	Jan	187,20		2,98						0,25	1 040,28
	Feb	187,20		2,98						0,25	1 040,28
	Mar	187,20		2,98						0,25	1 040,28
	Apr	187,20		2,98						0,25	1 040,28
	May	187,20		2,98						0,25	1 040,28
	Jun	187,20		2,98						0,25	1 040,28
	Jul	187,20		2,98						0,25	1 040,28
	Aug	187,20		2,98						0,25	1 040,28
	Sep	187,20		2,98						0,25	1 040,28
	Oct	187,20		2,98						0,25	1 040,28
	Nov	187,20		2,98						0,25	1 040,28
	Dec	187,20		2,98						0,25	1 040,28
2014	Jan	187,20		2,98						0,25	1 040,28
	Feb	187,20		2,98						0,25	1 040,28
	Mar	187,20		2,98						0,25	1 040,28
	Apr	187,20		2,98						0,25	1 040,28
	May	187,20		2,98						0,25	1 040,28
	Jun	187,20		2,98						0,25	1 040,28
	Jul	187,20		2,98						0,25	1 040,28
	Aug	187,20		2,98						0,25	1 040,28
	Sep	187,20		2,98						0,25	1 040,28
	Oct	187,20		2,98						0,25	1 040,28
	Nov	187,20		2,98						0,25	1 040,28
	Dec	187,20		2,98						0,25	1 040,28
2015	Jan	187,20		2,98						0,25	1 040,28
	Feb	187,20		2,98						0,25	1 040,28
	Mar	187,20		2,98						0,25	1 040,28
	Apr	187,20		2,98						0,25	1 040,28

360 000,00

10 800,00



Equations:

GWF = $L/(C_{max} - C_{nat})$

$L = \alpha \times \text{Appl}$

Appl = Appl.Rate X Area

$$\alpha = \alpha_{min} + \frac{\Sigma s_i \times w_i}{\Sigma w_i} \times (\alpha_{max} - \alpha_{min})$$

N-content of manure:
3kg manure per animal/day (Dave Ford)
Midpoint population weight at Feedlot: 200kg
equals 12kg manure per bovine per day (6% body weight)
equals 10,56kg water
equals 1,44kg dry matter per day

130000 cattle = 1,44x140000 = 187 200kg manure/day = **187,2 ton manure /month**
N-content = 15,9kg/ton (Hao et al, 2003)

Distribution area for manure:
Dept of Agriculture recommends 5ton/ha for maize under irrigation once a year in the winter (Van Averbeke, W., Yoganathan, S., 2003.) ==> more sophisticated approaches use the N in the soiland manure to determine the correct application rate (The Prairie Province's Committee on Livestock Development and Manure Management - Saskatchewan)
Therefore: 10800ton/5ton ha^{-1} = **2160 ha is needed for manure distribution per month**

P-leaching Run-off Fraction

PHOSPHOROUS LEACHING RUN-OFF POTENTIAL												
Category	**Factor**		**Leaching runoff potential**		**Score (s)**					Results		
			Weight (w)*		**Very low**	**Low**	**No information available**	**High**	**Very high**			
			α	**β**	**0**	**0,33**	**0,5**	**0,67**	**1**	s X w	w	
Environmental Factors	Soil	Texture (relevant for runoff)	15	25	Sand	Loam		Silt	**Clay**	4,95	15	
		Erosion	20	25	Low	**Moderate**	unknown	High	Very high	10	20	
		P-content (g P m^{-2})	15	20	<200	200 - 400	unknown	400 - 700	>700	7,5	15	
	Climate	Rain intensity	10	15	Light	Moderate		Strong	Heavy	6,7	10	
Agricultural practice	Application rate		15	0	Very low	Low	moderate	High	Very high	7,5	15	
	Plant uptake (crop yield)		10	0	Very high	High	unknown	Low	Very low	5	10	
	Management practice		15	15	Best	Good		Average	Worst	4,95	15	
										46,6	100	0,466

Phosphorous	
α_{min}	0,0001
α_{avg}	0,03
α_{max}	0,05
C_{max} (mg/l)	10
C_{nat} (mg/l)	0

$(\alpha_{max} - \alpha_{min})$	$(C_{max} - C_{nat})$
0,0499	10

Equations:

GWF = $L/(C_{max} - C_{nat})$

$L = \alpha$ X Appl

Appl = Appl.Rate X Area

$$\alpha = \alpha_{min} + \frac{\Sigma s_i X w_i}{\Sigma w_i} X (\alpha_{max} - \alpha_{min})$$

Assumptions:

1. no information available on rain intensity. Tier 1 guidelines suggest using score 0,5 (therefore use s=0,67 HIGH)

P-leaching run-off fraction:

0,000232534

Grey WF - Phosphorous from Irrigation

Year	Month	Irrigation volume (m3/month)	P-content irrigation water (mg/m^3)	P-application/month (mg)	P-application rate (mg/ha)	Application (mg)	Area (ha)	α	C_{max} - C_{nat} (mg/L)	Load (mg)	GWF - P irrigation (L)
	Jan		0,38	0,00	0,00	0,00	50,00	0,00	10,00	0,00	0,00
	Feb	0,00		0,00	0,00	0,00				0,00	0,00
	Mar	0,00		0,00	0,00	0,00				0,00	0,00
	Apr	0,00		0,00	0,00	0,00				0,00	0,00
	May	0,00		0,00	0,00	0,00				0,00	0,00
	Jun	0,00		0,00	0,00	0,00				0,00	0,00
	Jul	0,00		0,00	0,00	0,00				0,00	0,00
	Aug	0,00		0,00	0,00	0,00				0,00	0,00
	Sep	158 440,08		59 573,47	1 191,47	59 573,47				13,85	1,39
	Oct	0,00		0,00	0,00	0,00				0,00	0,00
	Nov	23 909,41		8 989,94	179,80	8 989,94				2,09	0,21
2012	Dec	0,00		0,00	0,00	0,00				0,00	0,00
	Jan	0,00		0,00	0,00	0,00				0,00	0,00
	Feb	74 066,26		27 848,92	556,98	27 848,92				6,48	0,65
	Mar	17 868,06		6 718,39	134,37	6 718,39				1,56	0,16
	Apr	0,00		0,00	0,00	0,00				0,00	0,00
	May	0,00		0,00	0,00	0,00				0,00	0,00
	Jun	86 126,28		32 383,48	647,67	32 383,48				7,53	0,75
	Jul	93 270,57		35 069,73	701,39	35 069,73				8,15	0,82
	Aug	93 976,15		35 335,03	706,70	35 335,03				8,22	0,82
	Sep	0,00		0,00	0,00	0,00				0,00	0,00
	Oct	0,00		0,00	0,00	0,00				0,00	0,00
	Nov	0,00		0,00	0,00	0,00				0,00	0,00
2013	Dec	0,00		0,00	0,00	0,00				0,00	0,00
	Jan	83 701,94		31 471,93	629,44	31 471,93				7,32	0,73
	Feb	0,00		0,00	0,00	0,00				0,00	0,00
	Mar	280 849,02		105 599,23	2 111,98	105 599,23				24,56	2,46
	Apr	0,00		0,00	0,00	0,00				0,00	0,00
	May	69 748,72		26 225,52	524,51	26 225,52				6,10	0,61
	Jun	0,00		0,00	0,00	0,00				0,00	0,00
	Jul	0,00		0,00	0,00	0,00				0,00	0,00
	Aug	0,00		0,00	0,00	0,00				0,00	0,00
	Sep	0,00		0,00	0,00	0,00				0,00	0,00
	Oct	0,00		0,00	0,00	0,00				0,00	0,00
	Nov	0,00		0,00	0,00	0,00				0,00	0,00
2014	Dec	0,00		0,00	0,00	0,00				0,00	0,00
	Jan	0,00		0,00	0,00	0,00				0,00	0,00
	Feb	28 721,17		10 799,16	215,98	10 799,16				2,51	0,25
	Mar	0,00		0,00	0,00	0,00				0,00	0,00
2015	Apr	0,00		0,00	0,00	0,00				0,00	0,00

Equations:

GWF = $L/(C_{max} - C_{nat})$

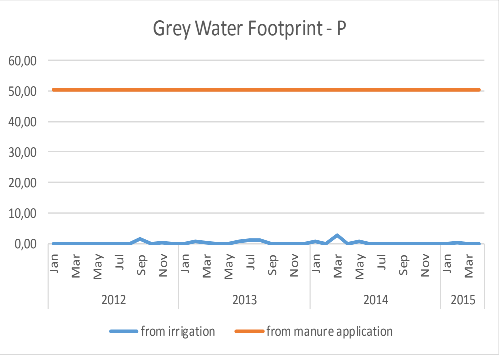
$L = \alpha \text{ X Appl}$

Appl = Appl.Rate X Area

$\alpha = \alpha_{min} + \frac{\Sigma s_i X w_i}{\Sigma w_i} X (\alpha_{max} - \alpha_{min})$

P-content of irrigation water:
assume 376ppm (Ulmann, Mukhter, 2007) - lagoon characteristics for dry feedlots (supernatent + sludge)

1ppm = 1mg/L
therefore: 376ppm = 376 mg/L - 0,376mg/m^3
50ha irrigated



Grey WF Phosphorous from Manure Application to Land

Year	Month	Manure volume (ton/month)	P-content manure (kg/ton)	P-application per month (kg)	Manure application (kg/ha/month)	P-application rate (kg/ha)	Manure distribution Area (ha)	α	C_{max} - C_{nat} (kg/m^3)	Load (kg)	GWF - P manure application (L)
			4,82				**2 160,00**	**0,00**	**0,24**		
	Jan	10 800,00		52,06		0,02				0,01	50,44
	Feb	10 800,00		52,06						0,01	50,44
	Mar	10 800,00		52,06						0,01	50,44
	Apr	10 800,00		52,06						0,01	50,44
	May	10 800,00		52,06						0,01	50,44
	Jun	10 800,00		52,06						0,01	50,44
	Jul	10 800,00		52,06						0,01	50,44
	Aug	10 800,00		52,06						0,01	50,44
	Sep	10 800,00		52,06						0,01	50,44
	Oct	10 800,00		52,06						0,01	50,44
	Nov	10 800,00		52,06						0,01	50,44
2012	Dec	10 800,00		52,06						0,01	50,44
	Jan	10 800,00		52,06						0,01	50,44
	Feb	10 800,00		52,06						0,01	50,44
	Mar	10 800,00		52,06						0,01	50,44
	Apr	10 800,00		52,06						0,01	50,44
	May	10 800,00		52,06						0,01	50,44
	Jun	10 800,00		52,06						0,01	50,44
	Jul	10 800,00		52,06						0,01	50,44
	Aug	10 800,00		52,06						0,01	50,44
	Sep	10 800,00		52,06						0,01	50,44
	Oct	10 800,00		52,06						0,01	50,44
	Nov	10 800,00		52,06						0,01	50,44
2013	Dec	10 800,00		52,06						0,01	50,44
	Jan	10 800,00		52,06						0,01	50,44
	Feb	10 800,00		52,06						0,01	50,44
	Mar	10 800,00		52,06						0,01	50,44
	Apr	10 800,00		52,06						0,01	50,44
	May	10 800,00		52,06						0,01	50,44
	Jun	10 800,00		52,06						0,01	50,44
	Jul	10 800,00		52,06						0,01	50,44
	Aug	10 800,00		52,06						0,01	50,44
	Sep	10 800,00		52,06						0,01	50,44
	Oct	10 800,00		52,06						0,01	50,44
	Nov	10 800,00		52,06						0,01	50,44
2014	Dec	10 800,00		52,06						0,01	50,44
	Jan	10 800,00		52,06						0,01	50,44
	Feb	10 800,00		52,06						0,01	50,44
	Mar	10 800,00		52,06						0,01	50,44
2015	Apr	10 800,00		52,06						0,01	50,44

Equations:

$GWF = L/(C_{max} - C_{nat})$

$L = \alpha \times Appl$

$Appl = Appl.Rate \times Area$

$$\alpha = \alpha_{min} + \frac{\Sigma s_i \times w_i}{\Sigma w_i} \times (\alpha_{max} - \alpha_{min})$$

P-content of manure:
3kg manure per animal/day (Dave Ford)
120000 cattle = 3x120000 = 360,000kg manure/day = **10,800 ton manure /month**
N:P is 3,3 ((Parham et al, 2002), therefore P is 15,9/3,3 = 4,82 kg/ton

Distribution area for manure:
Dept of Agriculture recommends 5ton/ha for maize under irrigation once a year in the winter (Van Averbeke, W., Yoganathan, S., 2003.) ==> more sophisticated approaches use the N in the soiland manure to determine the correct application rate (The Prairie Province's Committee on Livestock Development and Manure Management - Saskatchewan)
Therefore: 10800ton/5ton ha^{-1} = **2160 ha is needed for manure distribution per month**