final report

Project code: B.FLT.1005: Survey of Australian feedlot drinking water quality

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Survey of Australian feedlot drinking water quality

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Executive summary

High concentrations of Total Dissolved Solids (TDS) and salts in drinking water, often exacerbated by drought conditions, have been reported to have a detrimental impact on cattle health and performance. This research investigated water quality parameters including TDS and salts (sodium, calcium, magnesium, potassium, aluminium, zinc, iron, manganese, carbonate, bicarbonate, sulphate, nitrate and nitrite). The project summarised the range of TDS and salts in feedlot drinking water across Australia, thus determining potential impacts on cattle health and production. Additionally, feedlots using surface water sources for drinking water had the cyanobacteria species present identified and quantified. Such a study has not previously occurred in Australia.

The study was split into four parts with this report including over 100 historical water samples taken prior to 2018; 68 feedlot managers/owners completed the survey regarding water use delivered in paper and online format; 82 water samples from April to June 2019 from 58 feedlots were analysed for a suite of parameters. Where multiple water sources were used, the source water was analysed, this occurred for 24 samples. Additionally, water samples that included surface water were analysed for cyanobacteria (27 samples). Feedlots participating in the project were equivalent to over 50% of the licenced cattle feedlots.

Of the 68 feedlots completing the paper based and online survey, the majority (64%) source their cattle drinking water from groundwater. On a per-head basis, the use of groundwater as a drinking water source became even more important, covering two thirds of surveyed feedlot cattle. Surface water from dams and rivers were also a common source of water, and less common sources included reverse osmosis treated water from coal seam gas operations, tank roof water, and irrigation water.

The majority of feedlots (75%) were not aware of any issues with their drinking water quality. Of those that indicated that they had concerns about their water quality, seven feedlots identified cyanobacteria (Blue green algae) and *Escherichia coli* as an issue; four identified turbidity and scale (likely from calcium build up) clogging floats; and four feedlots reported that they now treat water for use in their boiler, but do not treat for cattle, while one feedlot identified high iron as an issue for boiler water.

Among trough water samples analysed for TDS, the majority (86 %) were considered satisfactory for cattle consumption and would not be expected to limit animal performance (≤ 3,000 mg/L). There were, however, cases of poor water quality identified. The highest TDS reported was 11,600 mg/L in groundwater. This water was shandied with surface water and was the maximum in the mixed trough water (5,400 mg/L), which would be expected to limit cattle performance (NASEM, 2016). Chloride was present in the highest concentration of all anions analysed. Nitrate concentrations were highest in the groundwater samples with only one trough sample exceeding the nitrate concentration threshold of 20 mg/L (NASEM, 2016). Sulphate ranged from undetected (<0.3 mg/L sulphur as sulphate) to 575 mg/L, with the highest values in groundwater samples, all samples were below the 1,000 mg/L guideline (ANZEC, 2000). Only 3% of trough samples exceeded the ANZEC (2000) limit of 5 mg aluminium/L. Manganese concentration was highest in surface water samples with 57% to 90% of trough water samples sourced from surface water exceeding the 0.05 mg/L upper-limit guideline (NASEM, 2016). The biological significance of high manganese waters remains

to be elucidated, although water concentrations are well below the Maximum tolerable limit reported for dietary Manganese of 1000 mg/kg dry matter (NASEM, 2016). Two surface water samples were in excess of the trigger value for *Microcystis aeruginosa* (11,500 cells/mL) and were reanalysed and tested for toxins. Only one sample was below a pH 5.1 and one sample above pH of 9.

Several water treatment scenarios were investigated with distributors and installers in Australia with reverse osmosis being the most suitable treatment option. As there are no Australian references for the effect of water quality on the performance of the cattle, Patterson et al. (2004), a publication from the USA, was used for the analysis of benefit and cost of water treatment with reverse osmosis. Treatment with reverse osmosis lead to increased, and more cost-effective, cattle productivity. However, the water used in the article by Patterson et al. (2004) had high sulphate concentrations, so the same responses are unlikely with Australian water. Future research testing water quality in the range of variation experienced by Australian feedlots, in a controlled manner, would allow the industry to determine the most relevant animal production gains and thus the benefits of reverse osmosis.

In conclusion, water quality was determined to be of suitable quality for the majority of feedlots surveyed. Isolated cases of poor water quality were identified. This project is beneficial to the industry as it has yielded a comprehensive understanding of the current sources and quality of feedlot drinking water for a single point in time. Overall, this project will improve feedlot decision-making regarding the conditions when water quality parameters may impact animal health and production in beef cattle feedlots.

Table of contents

1 Background

High concentrations of Total Dissolved Solids (TDS) and salts in drinking water, often exacerbated by drought conditions, can have a detrimental impact on cattle health and performance. This research investigated water quality parameters including TDS and salts (sodium, calcium, magnesium, potassium, aluminium, zinc, iron, manganese, carbonate, bicarbonate, sulphate and nitrate) with the aim to summarise the range of TDS and salts in feedlot drinking water across Australia, thus determining potential impacts on cattle health and production. Participating feedlots supplied historical water quality data, stated water quality concerns, and supplied a drinking water sample which was analysed at a NATA certified laboratory. The research consisted of: (a) summarising historical and current drinking water quality data for TDS and salts, and linking to climatic conditions and feedlot concerns; and (b) a survey of fixed and variable costs of treating different concentrations of the drinking water parameters found in commercial feedlots applied in a benefit/cost analysis (BCA). This project will improve feedlot decision-making regarding the climatic conditions when water quality parameters may decrease production.

With 450 accredited feedlots, the feedlot industry has a value of production of approximately $2.5 billion and employs nearly 30 000 people both directly and indirectly (ALFA, 2018). Feedlots mainly use water for stock (90%), and with the increasing variability of rainfall and prolonged droughts, there has been a shift to more groundwater sources being utilised (MLA, 2017). With 60% of feedlots in Queensland (ALFA, 2018), the feedlot industry is lobbying the Queensland Government to gain access to safe, reliable and sufficient groundwater into the future to support current and future investment in the sector (ALFA, 2017). Increasing competition for water may lead to water quality being compromised, so it is important to review current water quality and define any current and predicted future reductions to productivity and animal health.

TDS has the most straight forward adoption pathway for water quality issues in Australia by using current threshold responses to salts and demonstrating economical water treatments such as shandying. It is hoped this project will lead to discussion and education regarding the importance of ensuring that total salt intake is taken into account from rations and drinking water. Further research, if salts are found to exceed the ANZECC (2000) Guidelines or Nutrient Requirements of Beef Cattle (NASEM, 2016) standards, is to test the ranges of salts for grain fed cattle. Previous research has focused on sodium chloride and grass fed cattle, but in many Australian feedlots this may not be the major salt and modern feedlot rations need to be assessed in conjunction with water quality.

This project links to the Meat Industry Strategic Plan (MISP 2020) priority of improving feedlot productivity and profitability, and the MLA Strategic Plan 2016-2020, in productivity and profitability - production efficiencies in farms and feedlots in water. The project will include a BCA of the concentrations of the water parameters and the climatic conditions leading to any concentrations in excess of the ANZECC (2000) guidelines. Approximations of profit/losses will be defined. In addition, through dissemination of this research and including the impacts of poor drinking water on production, it will increase industry awareness.

Good quality drinking water is essential to cattle health and maximising production and profit with 90% of feedlot water used for drinking. The future of Australian feedlots is threatened in some areas due to drought and pressures from other water users, leading to the use of marginal water. Drought can cause a concentration of salts in surface water, which can decrease cattle health and production. Groundwater in some areas is being over extracted, leading to lower quality water being used. Previous studies have identified the thresholds for health and production impacts for total dissolved solids (TDS) and the individual salts. This project examined historical and current water quality parameters for salts, determined if any samples are in excess of guidelines and, where data permitted, what time of year high salts occur in each feedlot region, and completed a BCA of economical water treatment such as shandying and reverse osmosis. Industry benefits and impacts of this project will potentially include: feedlots with improved gross margins due to decreased penalties at abattoir from more consistent consignments, and improved cattle health and welfare with strengthened social licence of the feedlot industry.

2 Project objectives

- Analyse up to 200 drinking water source samples from individual feedlots in Queensland, New South Wales, Victoria & Tasmania, South Australia, and Western Australia.
- Characterise water quality for feedlot cattle relative to Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2000) and Nutrient Requirements of Beef Cattle (2016) standards
- Determine percentage of Australian feedlots with water quality over specified limits according to each guideline
- Conduct a cost benefit analysis scaled to the size of a 10,000 SCU feedlot to treat water via at least 3 technologies to improve feedlot water quality to 1000, 2000, 3000 mg/L TDS (assuming base water quality at median and maximum TDS from the survey).

3 Methodology

3.1 Historical water quality data

Data for this project includes historical drinking water quality data supplied by 28 participating feedlots and consultants. This data was correlated to climate data for the preceding month including prior rainfall, average minimum and maximum temperature, and evaporation. To ensure anonymity, feedlot data was de-identified and grouped into drinking water extraction from surface water or groundwater from predominately summer and summer dominant rainfall districts in NSW and Qld. This data is relevant to the industry as the majority (78%) of feedlots are in this region. Participation by feedlots in southern and western states further confirms the clear need for the current project. Timing of sampling ranged across the seasons and from 1996 to 2018, with only a small number of surface water samples taken. These samples have been grouped together as surface water and groundwater for this analysis.

3.2 Survey of water sources and treatment

3.2.1 Survey of concerns of feedlot managers about drinking water quality

UNE Human Research Ethics Committee approval was gained for questions asked of feedlot managers in a short survey. The questions included their region, sources of drinking water, and any concerns regarding their drinking water quality. Feedlots were also asked to provide historical water quality data, and were invited to participate in water quality testing. Please see appendix for survey questions, letter to feedlot, email to feedlot and advertisement in ALFA newsletter.

3.2.2 Feedlot selection

To gain feedlot participation across Australia a number of avenues were pursued. Letters were set to 220 feedlots across Australia with follow up phone calls to ensure letters were received and that the feedlot was still operating. Advertisements for the project were placed in the ALFA Newsletter and a detailed explanation of the project in the MLA Quarterly Feed E-Newsletter.

Inclusion criteria for project:

MLA supplied a list of 220 feedlots for this project. All feedlots on the list were invited to participate via an initial letter, with follow up phone calls and emails also conducted to capture the largest possible number of participants. In addition, information about the project was spread to industry via word of mouth from vets and nutritionists and advertisements were placed in MLA and ALFA newsletters.

Exclusion criteria for project:

Managers under 18 years of age were excluded from participating. Of the feedlots invited, funding was available for chemical analysis of feedlot cattle water quality for 200 samples. Since some feedlots had two water sources such as groundwater and surface water, the first 200 water samples from feedlots were to be included and the remainder excluded.

Across Australia, 68 feedlots (29% of feedlots approached) agreed to participate in the project, which is equivalent to 52% of licenced head of cattle (Table 1).

Table 1. The total number of feedlots in each state/region, number of feedlots agreeing to participate in paper based survey; and the number of feedlots that supplied water samples, the number of feedlots that and the percentage participating based on number of feedlots and licenced feedlot head.

Region	No. participating feedlots	Total no. feedlots	% feedlots participating	Head of feedlots participating	Total no. head	% head participating
Northern	40	138	29	431,450	758,890	57
Southern	28	98	29	186,638	433,615	43
Total	68	236	29	618,088	1,192,505	52

Reasons given for not participating included the current drought, which has led to feedlots being too busy or not having any cattle (Table 2). From the mailing list used, 15 feedlots had closed or had the phone disconnected, which may also indicate feedlot closure. Some of the feedlot managers not wishing to participate have participated in previous studies and have not received adequate information regarding the findings. Therefore, in this project, water sample results are being returned to participating feedlots and a letter summarising the findings will be sent to all feedlots who were contacted as part of this project, as well as disseminated through ALFA and MLA newsletters.

Table 2 Reasons given for Australian feedlots not participating in current project

No cattle due to drought	Too busy due to drought	Do not want to be involved	Water is fine do not need to investigate	Selling feedlot	Office and mobile phones disconnected	Closed	**Total**
1	7	16	2	3	7	8	**44**

3.3 Water quality testing

3.3.1 Water sampling

From the feedlots who completed the survey, the first 200 feedlot water sources returning a completed agreement to participate were sent water sampling kits. Where a feedlot used multiple water sources, a kit was sent for each source. Samples of drinking water were collected by feedlot staff from feedlots across Australia in April/May 2019, allowing for a one-time comparison in water quality to be undertaken. The kits were compiled and sent by Symbio Australia, and included instructions on water sampling and return dispatch direct to the NATA-certified Symbio Australia lab in Brisbane. Samples were collected by feedlot staff in 250 mL plastic bottles stabilised with nitric acid for metals and 1L for TDS and a separate opaque bottle for cyanobacteria. Feedlots were instructed to collect a sample at the water source, and a sample at the point where fresh water entered the trough. Sampling instructions are shown in appendices, and included how to take the fresh trough water sample and where feedlots had mixed water sources the water sources were sampled before mixing.

3.3.2 Water analysis

Table 3 summarises the water quality parameters tested and methodologies used by Symbio Australia in this project.

Table 3. Water parameters methodology used by NATA certified laboratory

Test	Method
Mn, Fe, Cu, Zn, Al	ICP-AES - Mn, Fe, Cu, Zn, Al
Major Ions (Ca,Mg,Na,K,Cl,SO_4,Alkalinity, pH, EC, TDS calc)	Calculated from $Ca+Mg+Na+Cl+Alk+Cl+SO_4$
Alkalinity	Calculation from HCO_3, CO_3, OH; APHA 2320 method B
Hardness-Total (as $CaCO_3$)	Calculation from Ca, Mg; APHA 2340 method B
NOx Suite (Nitrate, Nitrite, NOx)	
Ortho-phosphorus by FIA	
Solids (Dissolved)	In-house & APHA 2540 method C
Cyanobacteria	Cyanobacteria ID and Enumeration Potential Toxin Producers ID and Enumeration Cyanobacteria Biovolume Potential Toxin Producers Biovolume

3.4 Statistical analysis techniques

This research used hydrological statistical methods such as those used in flooding studies, by stating the number of times samples exceed threshold salt concentrations based on ANZECC guidelines (2000) and Nutrient Requirements for Beef Cattle (NASEM, 2016). Variability of the water quality in regions was stated using variability index used by the Bureau of Meteorology (BOM, 2018).

3.4.1 Historical water quality data

The mean and standard error the mean (SEM) of water parameters for the historical surface and groundwater samples, and proportion of samples exceeding published thresholds, were calculated.

3.4.2 Current water quality data

Water quality data was collected within two months and related to preceding rainfall, temperature and evaporation information. Data was separated into surface, groundwater and mixed. Feedlot location was separated into 'Northern' (Queensland and New South Wales) and Southern (Victoria, Tasmania, South Australia and Western Australia) regions. The range (minimum and maximum, median) were reported. The proportion of feedlot water sources exceeding moderate and high thresholds for inorganic water quality parameters was calculated. The thresholds were derived from Tables 1-4.

3.4.3 Survey-concerns of feedlot managers about drinking water quality

Data was analysed using the qualitative research method of thematic analysis to summarise occurrence of key words, which were grouped into themes following qualitative research guidelines (Bernard et al., 2016).

3.4.4 Cost-benefit analysis

A cost benefit analysis of water treatment options was conducted. The treatment options considered were flocculation, reverse osmosis, demineralisation and distillation. As information on the animal production impacts of high TDS content is scant for Australia, an animal feeding study by Patterson et al. (2004) in the USA was adapted to take into account more typical Australian productivity. The cost benefit analysis was scaled to the size of a 10,000 SCU feedlot to treat water via four technologies to improve feedlot water quality to 1,000, 2,000, 3,000 mg/L TDS. Initial investigations were conducted using the base TDS concentration at median (841 mg/L) and maximum (3300 mg/L) concentrations from the historical survey TDS data. However, the current study from April to May 2019 found the TDS maximum was 4,044 mg/L for the samples returned on time, but due to transport logistics and feedlot staff being unavailable for various reasons, samples came in late including the three maximum TDS values, including source groundwater supplies of 11,600 mg/L and 5,604 mg/L; and in the trough from groundwater 7,300 mg/L and from mix of groundwater and surface water 5,447 mg/L. Therefore, the maximum used for the BCA was 5000 mg/L, and further research was conducted to find suitable technology for the very high TDS of 7,300 and 11,600 mg/L.

3.5 Standard trigger values for cattle

TDS are all inorganic and organic substances contained in water that can pass through a two micrometre filter (i.e. cations and anions in the water). TDS is considered to be a measure of the inorganic salts dissolved in water, and ranges from less than 1 mg/L in rainwater to 35 000 mg/L in seawater. It can be higher in some natural waters.

TDS can be calculated from Electrical Conductivity (EC) (see Equation 1 (ANZECC, 2000)):

Equation 1 TDS formula: $\text{EC (dS/m)} \times 670 = \text{TDS (mg/L)}$

TDS and TSS are generally thought of as the same, though methods of measurement differ. The published limits of TDS for cattle has been summarised in Table 4, with the limit for some potentially toxic nutrients and contaminants in water summarised in Table 5.

Table 4. Published limits of Total Dissolved Solids (TDS, Salinity) and Total Soluble Solids (TSS) in drinking water for cattle which are equivalent and can be displayed as Solids (Dissolved) in laboratory analysis reports.

Total dissolved solids (TDS) (mg/L) (ANZECC, 2000)	
<4000	**Safe** and no adverse effects on animals expected
4000-5000	Animals may have initial reluctance to drink or there may be some scouring, but **stock should adapt** without loss of production
5000-10000	**Loss of production** and a decline in animal condition and health would be expected. Stock may tolerate these levels for short periods if introduced gradually

Total Soluble Salts (TSS) (NASEM, 2016)	
<1000	**Safe** and should pose no health problems
1000-2999	**Generally safe** but may cause mild temporary diarrhoea in animals not accustomed to the water.
3000-4999	Water maybe refused when first offered to cattle or cause temporary diarrhoea. **Animal performance may be less than optimal** because water intake is not maximised.
5000-6999	Avoid these waters for pregnant or lactating animals. May be offered with reasonable safety to animals where **maximum performance is not required**.
≥7000	These waters **should not be fed to cattle**. Health problems and/or poor production will result.

Table 5 Published trigger values and limits for inorganic and biological water quality parameters for drinking water for cattle. From ANZECC (2000) and NASEM (2016)

Water quality parameter		**ANZECC (2000) Low risk trigger value (mg/L)**	**NASEM (2016) for beef cattle (mg/L)**
Metals/ cations	Aluminium Total)	5	0.5 (Upper-Limit Guideline)
	Calcium (Dissolved)	1000	
	Copper (Total)	1	1.0 (Upper-Limit Guideline)
	Magnesium (Total)	2000	
	Manganese (Total)		0.05 (Upper-Limit Guideline)
	Zinc (Total)	20	5.0 (Upper-Limit Guideline)
Anions	Nitrate (as N) (NO_3 N)	90 (>340 toxic)	0-10: Safe 11-20: Safe in balanced diets 21-40: Could be harmful over long periods 41-100: High risk - possible mortalities >101: Unsafe – possible death
	Nitrite (as N)	>9 hazardous	
	Sulphur (as Sulphate)	1000	
Other	Hardness (Total)		0-60: Soft 61-120: Moderately hard 121-180: Hard >181: Very hard

4 Results

4.1 Sources of cattle drinking water in Australian feedlots

Of the 68 participating feedlots in the survey, the majority source their cattle drinking water from groundwater. As feedlots participating in the study ranged from less than 1000 to over 10000 SCU, the percentage of feedlots using each water source was calculated using the equations below. Water source 'Y' can be substituted for each source (groundwater, surface water (dam), surface water (river) and other).

Equation 2 For each feedlot the percentage of head on water source$_Y$:

(no. head x percentage water source$_Y$ used)/('No. head on water source$_Y$')

Equation 3 Percentage of head on water source$_Y$ (%):

Σ(Equation 2 for each feedlot for water source$_Y$)/Σ(No. head) x 100

On a per-head basis, the use of groundwater as a drinking water source became even more important, covering two thirds of surveyed feedlot cattle (Table 6). Surface water from dams and rivers were a common source of water, and less common sources included reverse osmosis water from coal seam gas operations, shed roof water (tank), and irrigation water (Table 6).

Table 6. Summary of sources for Australian feedlot cattle drinking water for 68 feedlots participating in survey including the percentage and number using each source, and the number of cattle and percentage drinking each water source.

	Region	Groundwater	Surface water (dam)	Surface water (river)	Other*	Total
% water used	Northern	67	17	14	2	100
	Southern	59	12	17	12	100
	Total	64	15	15	6	100
No. feedlots	Northern	30	14	8	4	
	Southern	19	7	5	5	
	Total	49	21	13	9	
% water used based on per head	Northern	72	11	13	4	100
	Southern	50	5	14	30	100
	Total	65	9	13	12	100
No head on each water source	Northern	310,679	49,059	55,424	16,288	431,450
	Southern	93,884	9,180	27,000	56,574	186,638
	Total	404,563	58,239	82,424	72,862	618,088

*Other includes coal seam gas water, municipal raw water supply, tank water, channel water and irrigation water.

4.2 Survey of water quality issues and current water treatment methods identified by feedlots

The majority of feedlots (75%) were not aware of any issues with their drinking water quality. Six feedlots identified that water quality issues may be impacting on cattle performance, and some identified concerns with their water quality but were unsure of the impact on cattle performance. Seven feedlots identified cyanobacteria (blue green algae) or algae, one identified *Escherichia coli* (Table 7) and two identified turbidity. In regard to boilers, two identified scale (likely from calcium build up) clogging floats and one identified iron.

Table 7. Of the 68 feedlots competing the survey, the number of feedlots in Northern (North of 30° South) and Sothern (South of 30° South) regions that identified water quality issues in survey

	Impacts on cattle health, water intake and/or food safety					Boiler
Region	Problems with water quality impacting on performance	Cyanobacteria /algae	Turbidity	Heat from groundwater	*E.coli*	scale/ high iron
Northern	4	5	1	-	1	3
Southern	2	2	1	1	-	-

A number of treatment methods to improve the water quality for cattle and for boilers were mentioned by feedlot managers (Table 8). Treatment methods to improve drinking water quality for cattle included chlorination (five feedlots); addition of copper sulphate blocs to troughs to treat cyanobacteria; storage of hot groundwater in tanks or turkey's nest dams (dam sits on flat ground with round wall) until it cooled before distribution (three feedlots); filtration of turbid water (two feedlots); and aeration of dam to reduce algae production (two feedlots). Four feedlots reported that they treat water for use in their boiler, with three other feedlots stating they are investigating the cost of installing reverse osmosis systems for boilers. The only feedlot with cattle consuming reverse osmosis water was treated water from coal seam gas.

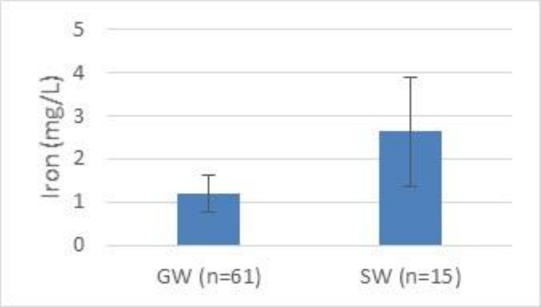
Table 8. Of the 68 feedlots competing the survey, the number of feedlots that identified treatment methods for cattle drinking water or boiler

	Treatment for cattle						Treatment for boiler
Region	Reverse osmosis from coal seam gas	Chlorin-ation	Copper sulphate in troughs (treat algae and cyano-bacteria)	Cool water via tanks or dam	Filtration	Aeration of dam	Reverse osmosis
Northern	1	3	1	2	2	2	3
Southern	-	2	-	1	-	-	1

4.3 Summary of historical data

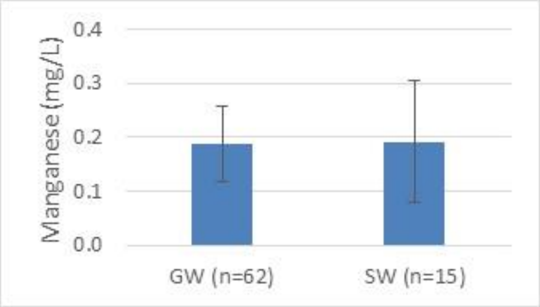
Figure 1 provides historical data for most water parameters. There was insufficient data to report for aluminium and copper. In the figures below groundwater was summarised as GW and surface water was summarised as SW, then a statement is given under the figure if there were samples which exceeded the guidelines identified in Table 9.

a. Iron (Fe)



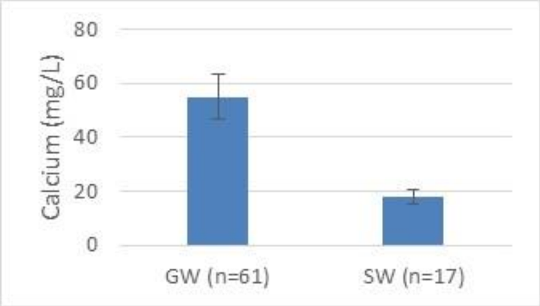
No defined limit for Fe

b. Manganese (Mn)



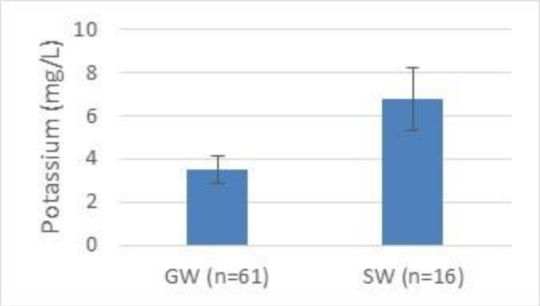
GW and SW exceeded Mn guidelines, see Table 9

c. Calcium (Ca)

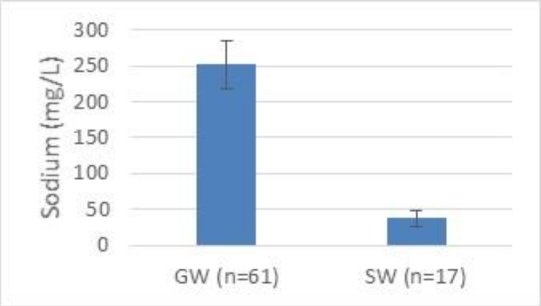


No samples over 1000 mg/L Calcium

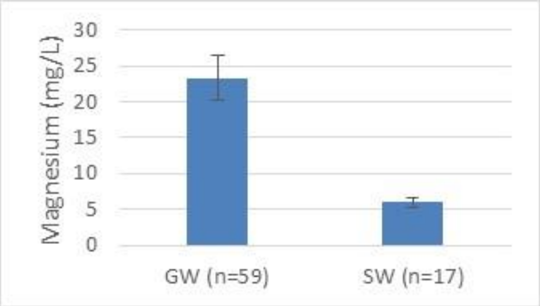
d. Potassium (K)



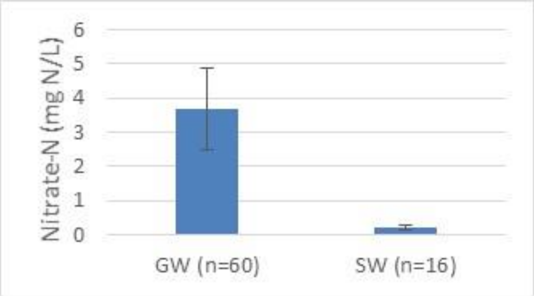
e. Sodium (Na)



f. Magnesium (Mg)

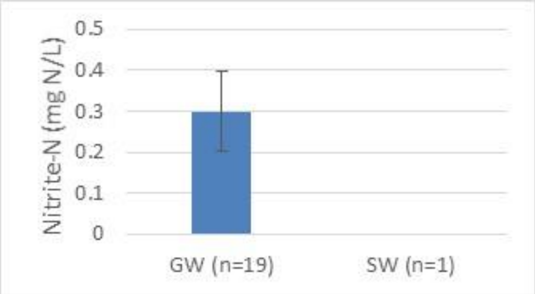


g. Nitrate-N (NO_3^{-1})



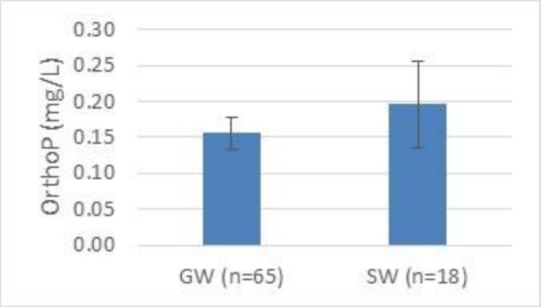
GW exceeded nitrate-N guidelines, see Table 9

h. Nitrite (NO_2^-)

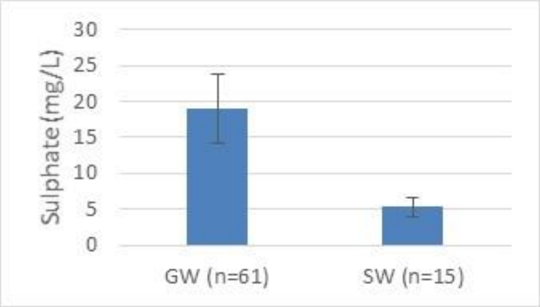


No samples over 9 mg/L nitrite-N;
value for SW was 0 mg/L

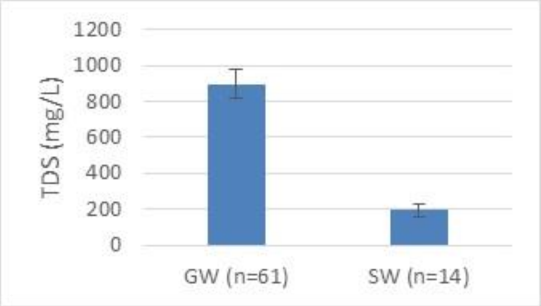
i. Ortho phosphate



j. Sulphate (SO_4^{2-})

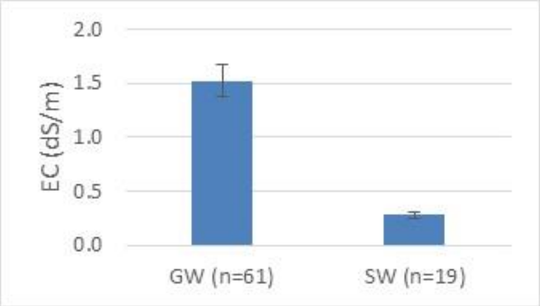


k. Total Dissolved Solids/Salts (TDS)

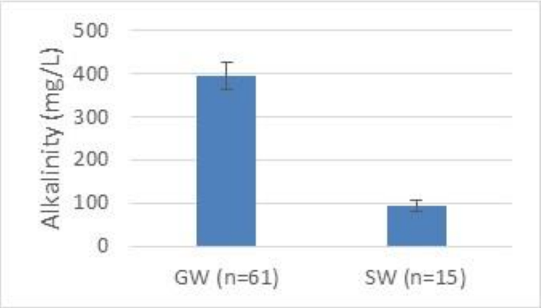


GW exceeded TDS guidelines, see Table 9

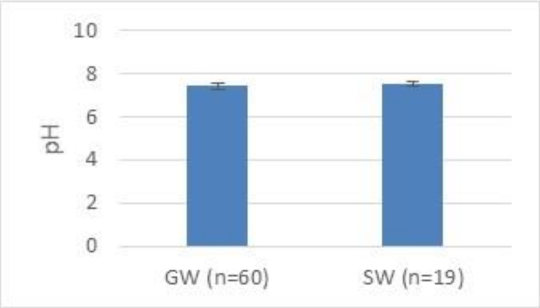
l. Electrical Conductivity (EC)



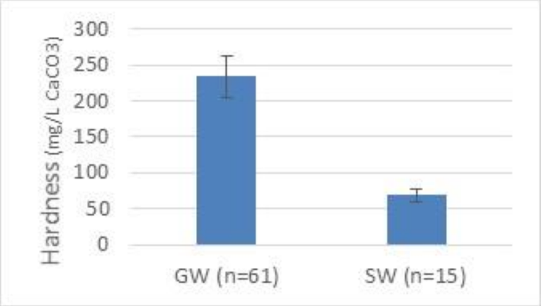
m. Alkalinity



n. pH



o. Hardness



See Table 9

Figure 1. Parameters of historical water samples of groundwater (GW) and surface water (SW) sampled across NSW and Qld.

Table 9. Percentage of historical water samples exceeding guidelines for mineral content of water based on [1]ANZECC and ARMCANZ (2000) Trigger value and/or [2]NASEM (2016) for beef cattle.

Parameter	**Minimum Level/ Trigger value (mg/L)**	**% exceedances from data provided**	
		Ground water	**Surface water**
Calcium[1]	>1000	0	0
Manganese[2]	>0.05	43	47
Nitrate (as N)[2]	>10	8	0
	>20	3	0
	>40	2	0
	>100	0	0
Nitrite (as N)[1]	>9	0	0
Sulphate[1]	>1000	0	0
TDS[2]	>1000	19	0
	>3000	2	0
	>5000	0	0
	>7000	0	0
Hardness[2]	>60	69	47
	>120	57	7
	>180	48	0

4.4 Summary of current data

4.4.1 Total Dissolved Solids (TDS) and salts

TDS was summarised in Figure 2. Among trough water samples analysed for TDS, the majority (86%) were considered satisfactory for cattle consumption and would not be expected to limit animal performance (i.e. TDS ≤ 3,000 mg/L). There were, however, cases of poor water quality identified. The highest TDS (11,600 mg/L) sample was from the groundwater source from a feedlot in the southern region, which is in excess of the highest value of 7,000 mg/L (NASEM, 2016) and summarised in Table 10. This water was shandied with surface water and was the maximum in the mixed trough water (5,400 mg/L), and could still potentially limit cattle performance. Electrical conductivity (EC) is also a measure of dissolved salts and so follows a similar pattern as the TDS results (Table 11). Groundwater had the highest median and maximum values in both the source water and the trough for both TDS and EC. TDS in the source water showed the groundwater and surface water were above the lowest limit of 1,000 mg/L.

In the troughs, the highest readings were in the southern groundwater and mixed samples. For the minimum limit of 1,000 mg/L TDS, the trough water from surface water had no exceedances, whereas the groundwater and mixed types had over a third of samples in excess. ‘Trough All Types’ summarises all trough water samples taken, which gives an overview of the range of TDS in Australian feedlots: 34% of samples were in excess of the minimum of 1,000 mg/L, 14% of samples were in excess of the ‘performance threshold’ of 3,000 mg/L and 2% of samples were in excess of the highest threshold of 7,000 mg/L.

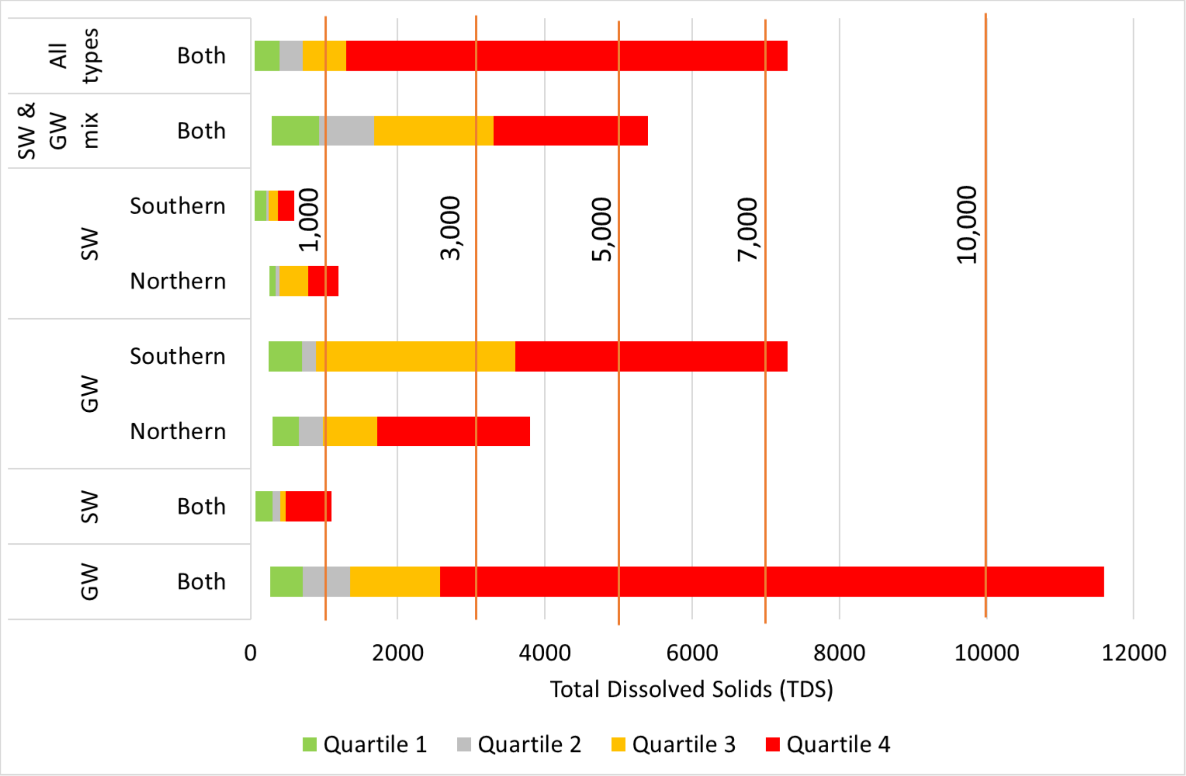


Figure 2. Concentration of Total Dissolved Solids (TDS) in feedlot water including water sampled at the source ('Source', groundwater (GW) and surface water (SW)) that are later mixed or treated before being presented at the trough, and water sampled at the point of trough entry ('Trough', including groundwater, surface water, mixed water and a summary of all types). Results are presented by feedlot location (Northern or Southern Australian regions). Limits from NASEM (2016).

Table 10. Descriptive statistics of the concentration of Total Dissolved Solids (TDS) in feedlot water including water sampled at the source ('Source', groundwater (GW) and surface water (SW)) that are mixed before being presented at the trough, and water sampled at the point of trough entry ('Trough', including groundwater, surface water, mixed water and a summary of all types). Results are presented by feedlot location (Northern or Southern Australia). Percentage of historical water samples exceeding guidelines for mineral content of water based on ANZECC and ARMCANZ (2000) Trigger value and/or NASEM (2016) for beef cattle.

TDS (mg/L)	**Source**		**Trough**					
Type	**GW**	**SW**	**GW**		**SW**		**SW & GW mix**	**All types**
Region	**Nthn & Sthn**	**Nthn & Sthn**	**Nthn**	**Sthn**	**Nthn**	**Sthn**	**Nthn & Sthn**	**Nthn & Sthn**
N	12	12	18	9	10	9	12	58
Minimum	270	70	300	250	260	52	290	52
Median	1,350	400	985	890	395	250	1,682	710
Maximum	11,600	1,100	3,800	7,300	1,200	590	5,400	7,300
% >1000 mg/L	67	8	44	33	10	0	67	34
% > 3000 mg/L	25	0	11	33	0	0	25	14
% > 5000 mg/L	17	0	0	11	0	0	17	5
% > 7000 mg/L	8	0	0	11	0	0	0	2

Table 11. Descriptive statistics of the concentration of Electrical Conductivity (EC) in feedlot water including water sampled at the source ('Source', groundwater (GW) and surface water (SW)) that are mixed before being presented at the trough, and water sampled at the point of trough entry ('Trough', including groundwater, surface water, mixed water and a summary of all types). Results are presented by feedlot location (Northern or Southern Australia).

EC (microS/cm)	**Source**		**Trough**					
Type	**GW**	**SW**	**GW**		**SW**		**SW & GW mix**	**All types**
Region	**Nthn & Sthn**	**Nthn & Sthn**	**Nthn**	**Sthn**	**Nthn**	**Sthn**	**Nthn & Sthn**	**Nthn & Sthn**
N	12	12	18	9	10	9	12	58
Minimum	460	100	440	380	380	120	210	120
Median	1800	445	1450	1400	525	340	1996	1100
Maximum	17000	1600	6200	9900	1900	840	6700	9900

4.4.2 Anions (chloride, nitrate, nitrite, ortho-phosphate and sulphate)

Chloride had the highest concentration of all anions (Table 12); in groundwater chloride ranged from 9 mg/L to 5900 mg/L; and in surface water was present in a lower concentration and ranged from 9 mg/L to 410 mg/L. Within the trough water samples, the maximum concentration of chloride was 3800 mg/L contained in groundwater for the southern region.

Table 12. Descriptive statistics of the concentration of Chloride in feedlot water, including water sampled at the source ('Source', groundwater (GW) and surface water (SW)) that are later mixed or treated before being presented at the trough, and water sampled at the point of trough entry ('Trough', including groundwater, surface water, mixed water and a summary of all types). Results are presented by feedlot location (Northern or Southern Australia).

Chloride (mg/L)	Source		Trough					
Type	GW	SW	GW		SW		SW & GW mix	All types
Region	Nthn & Sthn	Nthn & Sthn	Nthn	Sthn	Nthn	Sthn	Nthn & Sthn	Nthn & Sthn
N	12	12	18	9	10	9	12	58
Minimum	41	13	58	48	22	9	32	9
Median	295	53	220	340	56	34	250	125
Maximum	5,900	410	1,800	3,800	410	140	2,400	3,800

Nitrate concentrations were highest in the groundwater samples, with only two samples exceeding the nitrate concentration threshold of 10 mg/L (Table 13), which is considered 'generally safe in balanced diets with low-nitrate food' (NASEM, 2016). Nitrite concentrations were all below the threshold (NASEM, 2016) and no trends were evident between the surface and groundwater samples (Table 14).

Table 13. Descriptive statistics of the concentration of Nitrate (as N) (NO_3 N) in feedlot water including water sampled at the source ('Source', groundwater (GW) and surface water (SW)) that are later mixed or treated before being presented at the trough, and water sampled at the point of trough entry ('Trough', including groundwater, surface water, mixed water and a summary of all types). Results are presented by feedlot location (Northern or Southern Australia). Percentage of samples exceeding guidelines for nitrate content of water based on NASEM (2016) for beef cattle.

NO_3 (as N) (mg/L)	Source		Trough					
Type	GW	SW	GW		SW		SW & GW mix	All types
Region	Nthn & Sthn	Nthn & Sthn	Nthn	Sthn	Nthn	Sthn	Nthn & Sthn	Nthn & Sthn
N	12	12	18	9	10	9	12	58
Minimum	<0.005	<0.005	0.006	0.068	0.005	<0.005	0.008	<0.005
Median	0.305	0.115	0.185	0.690	0.175	0.230	0.257	0.245
Maximum	11.000	1.800	23.000	5.700	0.780	2.200	2.300	23.000
% >10	8	0	6	0	0	0	0	2
% >20	0	0	6	0	0	0	0	2

Table 14. Descriptive statistics of the concentration of Nitrite (as N) in feedlot water including water sampled at the source ('Source', groundwater (GW) and surface water (SW)) that are later mixed or treated before being presented at the trough, and water sampled at the point of trough entry ('Trough', including groundwater, surface water, mixed water and a summary of all types). Results are presented by feedlot location (Northern or Southern Australia). Percentage of samples exceeding guidelines for nitrite content of water based on National Research Council (2016) for beef cattle.

NO_2 (as N) (mg/L)	Source		Trough					
Type	GW	SW	GW		SW		SW & GW mix	All types
Region	Nthn & Sthn	Nthn & Sthn	Nthn	Sthn	Nthn	Sthn	Nthn & Sthn	Nthn & Sthn
N	12	12	18	9	10	9	12	58
Minimum	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Median	<0.005	0.014	<0.005	<0.005	0.004	<0.005	0.023	<0.005
Maximum	0.530	0.150	0.200	0.029	0.023	0.056	0.160	0.2
% >9	0	0	0	0	0	0	0	0

As NO_x is the addition of nitrate and nitrite it followed the trends above, with groundwater showing the highest concentrations. There is no limit in NO_x for cattle, but for slightly disturbed ecosystems over 73% of samples from each water type exceeded the trigger value (Table 15).

Table 15. Descriptive statistics of the concentration of NO_x (as N) in feedlot water including water sampled at the source ('Source', groundwater (GW) and surface water (SW)) that are later mixed or treated before being presented at the trough, and water sampled at the point of trough entry ('Trough', including groundwater, surface water, mixed water and a summary of all types). Results are presented by feedlot location (Northern or Southern Australia). Percentage of exceedances above the trigger value for south-east Australia reservoirs in slightly disturbed ecosystems [1]ANZECC (2000:3.3-10).

NO_x (as N) (mg/L)	Source		Trough					
Type	GW	SW	GW		SW		SW & GW mix	All types
Region	Nthn & Sthn	Nthn & Sthn	Nthn	Sthn	Nthn	Sthn	Nthn & Sthn	Nthn & Sthn
N	12	12	18	9	10	9	12	58
Minimum	0.005	0.011	0.006	0.068	0.006	<0.005	0.011	<0.005
Median	0.525	0.125	0.255	0.690	0.190	0.230	0.330	0.270
Maximum	11.000	1.900	23.000	5.700	0.800	2.200	2.300	23.000
% >0.010[1]	75	100	94	100	90	89	100	95

Orthophosphate ranged from not detectable (<0.005 mg/L) to 0.403 mg/L in groundwater from the northern region. There is no limit in orthophosphate for cattle, but for slightly disturbed ecosystems, which is related to algae growth, all but two samples exceeded the trigger value (Table 16).

Table 16. Descriptive statistics of the concentration of ortho-phosphate (ortho-PO_4 (as P)) in feedlot water including water sampled at the source ('Source', groundwater (GW) and surface water (SW)) that are later mixed or treated before being presented at the trough, and water sampled at the point of trough entry ('Trough', including groundwater, surface water, mixed water and a summary of all types). Results are presented by feedlot location (Northern or Southern Australia). Percentage of exceedances above the trigger value for south-east Australia reservoirs in slightly disturbed ecosystems [1]ANZECC (2000).

Ortho-P (as P) (mg/L)	Source		Trough					
Type	GW	SW	GW		SW		SW & GW mix	All types
Region	Nthn & Sthn	Nthn & Sthn	Nthn	Sthn	Nthn	Sthn	Nthn & Sthn	Nthn & Sthn
N	12	12	18	9	10	9	12	58
Minimum	0.023	<0.005	0.020	0.018	0.008	0.005	0.025	0.005
Median	0.071	0.067	0.059	0.075	0.036	0.042	0.085	0.061
Maximum	0.370	0.330	0.400	0.200	0.400	0.380	0.270	0.400
% >0.005[1]	100	83	100	100	100	89	100	98

Sulphate ranged from undetected (<0.3 mg/L sulphur as sulphate) to 575 mg/L, with the maximum values in groundwater samples, but the lowest concentration of sulphate was in groundwater from the northern region (Table 17).

Table 17. Descriptive statistics of the concentration of sulphate in feedlot water including water sampled at the source (‘Source’, groundwater (GW) and surface water (SW)) that are later mixed or treated before being presented at the trough, and water sampled at the point of trough entry (‘Trough’, including groundwater, surface water, mixed water and a summary of all types). Results are presented by feedlot location (Northern or Southern Australia). Percentage of occurrences concentration of sulphate in feedlot water exceeded arbitrary thresholds. Percentage of exceedances above the threshold based on [1]ANZECC (2000).

Sulphate (mg/L)	Source		Trough					
Type	GW	SW	GW		SW		SW & GW mix	All types
Region	Nthn & Sthn	Nthn & Sthn	Nthn	Sthn	Nthn	Sthn	Nthn & Sthn	Nthn & Sthn
N	12	12	18	9	10	9	12	58
Minimum	0.4	2.2	<0.3	3.5	0.8	2.3	2.6	<0.3
Median	24.1	7.3	15.4	58.3	4.6	16.1	23.8	15.8
Maximum	575.0	47.0	181.0	490.0	17.8	50.0	313.0	490.0
% >1000[1]	0	0	0	0	0	0	0	0

4.4.3 Cations and hardness

Of the cations, sodium had the highest concentration, with the groundwater source samples having the highest concentrations (Figure 3 and Table 18).

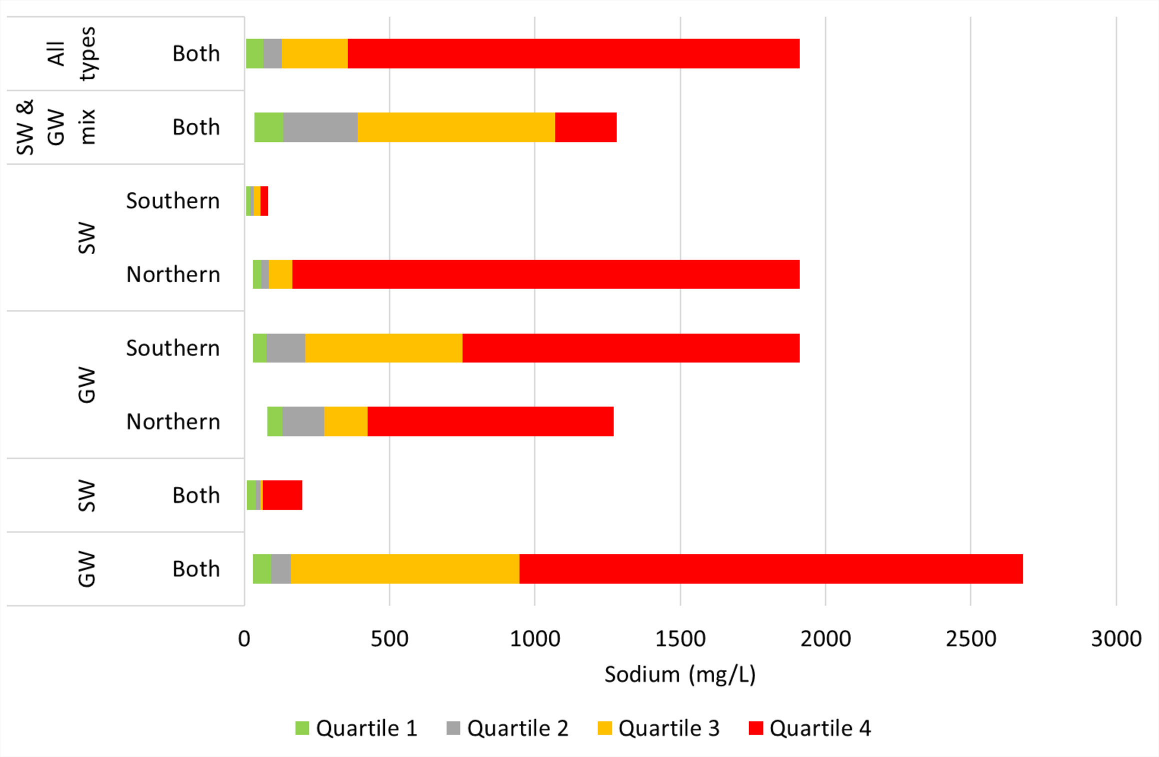


Figure 3. Sodium concentration in feedlot water including water sampled at the source (‘Source’, groundwater (GW) and surface water (SW)) that are later mixed or treated before being presented at the trough, and water sampled at the point of trough entry (‘Trough’, including groundwater, surface water, mixed water and a summary of all types). Results are presented by feedlot location (Northern or Southern Australia).

Table 18. Descriptive statistics of the concentration of sodium in feedlot water including water sampled at the source ('Source', groundwater (GW) and surface water (SW)) that are later mixed or treated before being presented at the trough, and water sampled at the point of trough entry ('Trough', including groundwater, surface water, mixed water and a summary of all types). Results are presented by feedlot location (Northern or Southern Australia). Percentage of occurrences concentration of Sodium in feedlot water exceeded arbitrary thresholds. Percentage of exceedances above the threshold based on [1]Raisbeck et al. (2008), with arbitrary values of 2000 and 3000 mg/L Na added to compare data.

Sodium (mg/L)	Source		Trough					
Type	GW	SW	GW		SW		SW & GW mix	All types
Region	Nthn & Sthn	Nthn & Sthn	Nthn	Sthn	Nthn	Sthn	Nthn & Sthn	Nthn & Sthn
N	12	12	18	9	10	9	12	58
Minimum	31	9.1	79	30	29	6.6	35	6.6
Median	160	55	275	210	76	33	390.8	130
Maximum	2680	200	1270	1910	330	83	1280	1910
% >1000[1]	18	0	5	11	0	0	42	12
% >2000	9	0	0	0	0	0	0	0
% >3000	0	0	0	0	0	0	0	0

Potassium concentrations showed no clear trends between types, ranging from undetectable (1 mg/L) to 95.00 mg/L (Table 19).

Table 19. Descriptive statistics of the concentration of Potassium in feedlot water including water sampled at the source ('Source', groundwater (GW) and surface water (SW)) that are later mixed or treated before being presented at the trough, and water sampled at the point of trough entry ('Trough', including groundwater, surface water, mixed water and a summary of all types). Results are presented by feedlot location (Northern or Southern Australia).

Potassium (mg/L)	Source		Trough					
Type	GW	SW	GW		SW		SW & GW mix	All types
Region	Nthn & Sthn	Nthn & Sthn	Nthn	Sthn	Nthn	Sthn	Nthn & Sthn	Nthn & Sthn
N	12	12	18	9	10	9	12	58
Minimum	1.4	1.1	1.1	1.9	4.8	0.9	2.5	0.9
Median	5.1	8.0	3.2	3.7	11.0	4.0	9.1	5.6
Maximum	95.0	21.0	13.0	58.0	22.0	7.2	48.0	58.0

Calcium ranged in concentration from 1.08 mg/L to 170 mg/L, with the maximum concentrations occurring in groundwater. No water sources exceeded the maximum trigger value from ANZECC (2000) for cattle (Table 20).

Table 20. Descriptive statistics of the concentration of Calcium in feedlot water including water sampled at the source ('Source', groundwater (GW) and surface water (SW)) that are later mixed or treated before being presented at the trough, and water sampled at the point of trough entry ('Trough', including groundwater, surface water, mixed water and a summary of all types). Results are presented by feedlot location (Northern or Southern Australia). Percentage of exceedances above the threshold based on [1]ANZECC (2000).

Calcium (mg/L)	Source		Trough					
Type	GW	SW	GW		SW		SW & GW mix	All types
Region	Nthn & Sthn	Nthn & Sthn	Nthn	Sthn	Nthn	Sthn	Nthn & Sthn	Nthn & Sthn
N	12	12	18	9	10	9	12	58
Minimum	1.1	4.2	1.7	18.0	12.0	4.6	1.1	1.1
Median	51.0	21.5	25.0	38.0	19.0	20.0	43.0	23.0
Maximum	170.0	38.0	170.0	90.0	37.0	59.0	150.0	170.0
% >1000[1]	0	0	0	0	0	0	0	0

Magnesium ranged in concentration from being below detection limit (<0.05 mg/L) to 390.00 mg/L, with the maximum concentrations in groundwater (Table 21). There is no limit for cattle for magnesium in water supply.

Table 21. Descriptive statistics of the concentration of magnesium in feedlot water including water sampled at the source ('Source', groundwater (GW) and surface water (SW)) that are later mixed or treated before being presented at the trough, and water sampled at the point of trough entry ('Trough', including groundwater, surface water, mixed water and a summary of all types). Results are presented by feedlot location (Northern or Southern Australia). Percentage of exceedances above the threshold based on [1]ANZECC (2000).

Magnesium (mg/L)	Source		Trough					
Type	GW	SW	GW		SW		SW & GW mix	All types
Region	Nthn & Sthn	Nthn & Sthn	Nthn	Sthn	Nthn	Sthn	Nthn & Sthn	Nthn & Sthn
N	12	12	18	9	10	9	12	58
Minimum	0.2	1.5	0.0	12.0	5.0	4.2	0.0	0.0
Median	23.0	11.5	15.0	48.0	13.5	8.6	15.8	17.5
Maximum	390.0	48.0	150.0	240.0	58.0	40.0	190.0	240.0
%>2000	0	0	0	0	0	0	0	0

The highest hardness values occurred in the groundwater with 44 to 78% of trough groundwater being higher than 180 mg/L, which is rated as very high hardness (Table 22).

Table 22. Descriptive statistics of the concentration of hardness in feedlot water including water sampled at the source ('Source', groundwater (GW) and surface water (SW)) that are later mixed or treated before being presented at the trough, and water sampled at the point of trough entry ('Trough', including groundwater, surface water, mixed water and a summary of all types). Results are presented by feedlot location (Northern or Southern Australia). Percentage of samples exceeding guidelines for mineral content of water based on [1]NASEM (2016) for beef cattle.

Hardness (mg/L)	Source		Trough					
Type	GW	SW	GW		SW		SW & GW mix	All types
Region	Nthn & Sthn	Nthn & Sthn	Nthn	Sthn	Nthn	Sthn	Nthn & Sthn	Nthn & Sthn
N	12	12	18	9	10	9	12	58
Minimum	6	17	5	93	49	29	5	5
Median	260	104	140	320	113.5	84	230	135
Maximum	2,000	290	1,000	1,100	330	310	1,100	1,100
% >180[1]	50	17	44	78	10	11	50	40

4.4.4 Metals (aluminium, iron, manganese and zinc)

Aluminium concentration ranged from undetectable to 18 mg/L in trough samples from a mixed surface and groundwater sample. Of the trough samples, up to 40% exceed the upper-limit guideline for aluminium from the NASEM (2016) of 0.5 mg/L and ten samples were over 5 mg/L (Table 23).

Table 23. Descriptive statistics of the concentration of aluminium in feedlot water including water sampled at the source ('Source', groundwater (GW) and surface water (SW)) that are later mixed or treated before being presented at the trough, and water sampled at the point of trough entry ('Trough', including groundwater, surface water, mixed water and a summary of all types). Results are presented by feedlot location (Northern or Southern Australia). Percentage of exceedances above the threshold based on [1]NASEM (2016) and [2]ANZECC (2000).

Aluminium (mg/L)	Source		Trough					
Type	GW	SW	GW		SW		SW & GW mix	All types
Region	Nthn & Sthn	Nthn & Sthn	Nthn	Sthn	Nthn	Sthn	Nthn & Sthn	Nthn & Sthn
N	12	12	18	9	10	9	12	58
Minimum	<0.05	<0.05	<0.05	<0.05	0.10	<0.05	<0.05	<0.05
Median	<0.05	0.10	0.00	<0.05	0.42	0.06	0.10	<0.05
Maximum	0.34	7.60	0.28	1.80	12.00	1.10	18.00	18.00
% >0.5[1]	0	42	0	11	40	33	17	17
% >5[2]	0	8	0	0	10	0	8	3

There are no trigger values for iron, but of note were the two surface water samples with concentration of and 36 and 39 mg/L (Table 24).

Table 24. Descriptive statistics of the concentration of iron in feedlot water including water sampled at the source ('Source', groundwater (GW) and surface water (SW)) that are later mixed or treated before being presented at the trough, and water sampled at the point of trough entry ('Trough', including groundwater, surface water, mixed water and a summary of all types). Results are presented by feedlot location (Northern or Southern Australia).

Iron (mg/L)	Source		Trough					
Type	GW	SW	GW		SW		SW & GW mix	All types
Region	Nthn & Sthn	Nthn & Sthn	Nthn	Sthn	Nthn	Sthn	Nthn & Sthn	Nthn & Sthn
N	12	12	18	9	10	9	12	58
Minimum	<0.01	<0.01	<0.01	<0.01	0.23	<0.01	<0.01	<0.01
Median	0.03	1.47	0.06	<0.01	1.20	0.99	0.27	0.22
Maximum	2.90	8.90	1.60	0.67	36.00	6.80	39.00	39.00

Manganese concentration was highest in surface water samples where 56% to 90% of trough water samples that included surface water (Table 25) exceeded the 0.05 mg/L upper-limit guideline (NASEM, 2016).

Table 25. Descriptive statistics of the concentration of manganese in feedlot water including water sampled at the source ('Source', groundwater (GW) and surface water (SW)) that are later mixed or treated before being presented at the trough, and water sampled at the point of trough entry ('Trough', including groundwater, surface water, mixed water and a summary of all types). Results are presented by feedlot location (Northern or Southern Australia). Percentage of samples exceeding guidelines for mineral content of water based on [1]NASEM (2016) for beef cattle.

Manganese (mg/L)	Source		Trough					
Type	GW	SW	GW		SW		SW & GW mix	All types
Region	Nthn & Sthn	Nthn & Sthn	Nthn	Sthn	Nthn	Sthn	Nthn & Sthn	Nthn & Sthn
N	12	12	18	9	10	9	12	58
Minimum	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01
Median	0.01	0.11	<0.01	<0.01	0.44	0.06	0.07	0.03
Maximum	0.31	1.20	0.62	0.08	9.70	0.23	1.20	9.70
% >0.05[1]	25	67	22	11	90	56	67	47

Zinc concentration in the water samples were below the detection limit for many of the samples and only one of the samples, which was the groundwater source which when mixed with surface water, was under the 5 mg/L upper-limit guideline (NASEM 2016) (Table 26).

Table 26. Descriptive statistics of the concentration of zinc in feedlot water including water sampled at the source ('Source', groundwater (GW) and surface water (SW)) that are later mixed or treated before being presented at the trough, and water sampled at the point of trough entry ('Trough', including groundwater, surface water, mixed water and a summary of all types). Results are presented by feedlot location (Northern or Southern Australia). Percentage of samples exceeding guidelines for mineral content of water based on [1]NASEM (2016) for beef cattle.

Zinc (mg/L)	Source		Trough					
Type	GW	SW	GW		SW		SW & GW mix	All types
Region	Nthn & Sthn	Nthn & Sthn	Nthn	Sthn	Nthn	Sthn	Nthn & Sthn	Nthn & Sthn
N	12	12	18	9	10	9	12	58
Minimum	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Median	<0.02	0.01	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Maximum	7.60	0.10	0.67	0.42	0.30	0.02	0.36	0.67
% >5[1]	8	0	0	0	0	0	0	0

4.4.5 pH

The pH of the water ranged from acidic 4.9 to alkaline 9.0 (Table 27), with one sample below the pH of 5.1 and one above 9.0 that can potentially cause issues for cows as proposed by Adams and Shape (1995).

Table 27. Descriptive statistics of the concentration of pH in feedlot water including water sampled at the source ('Source', groundwater (GW) and surface water (SW)) that are later mixed or treated before being presented at the trough, and water sampled at the point of trough entry ('Trough', including groundwater, surface water, mixed water and a summary of all types). Results are presented by feedlot location (Northern or Southern Australia). Percentage of exceedances above and below the threshold for pH causing problems for cattle based on [1]Adams and Shape (1995).

pH	Source		Trough					
Type	GW	SW	GW		SW		SW & GW mix	All types
Region	Nthn & Sthn	Nthn & Sthn	Nthn	Sthn	Nthn	Sthn	Nthn & Sthn	Nthn & Sthn
N	12	12	18	9	10	9	12	58
Minimum	4.91	6.31	6.80	6.92	7.40	6.87	5.22	5.22
Median	7.72	7.82	7.90	7.56	8.24	7.31	7.94	7.84
Maximum	8.40	8.64	9.04	8.04	8.56	8.17	8.61	9.04
% <5.1[1]	8	0	0	0	0	0	0	0
% >9.0[1]	0	0	5	0	0	0	0	2

4.4.6 Alkalinity

Alkalinity is measured as bicarbonate, carbonate, hydroxide and the total alkalinity. No samples had detectable amounts of alkalinity as hydroxide. Alkalinity as carbonate was not detected in the majority of samples, with the highest values in groundwater (Table 28). The highest carbonate concentration in Southern samples was 12 mg/L in the Source groundwater, and in the Northern samples 62 mg/L from trough groundwater. However, in surface water in the Northern region, the highest carbonate concentration was 21 mg/L but was undetectable in the Southern region.

Maximum values for alkalinity as bicarbonate and total alkalinity were highest for groundwater and mixed trough water samples (Table 29 and Table 30). On further investigation, the maximum values in each region were from groundwater with the maximum in the Northern groundwater 1800 mg/L bicarbonate and 1850 mg/L total alkalinity and 322 mg/L bicarbonate and 322 mg/L total alkalinity in the Southern region. Surface water maximum in the Northern region (480 mg/L bicarbonate and 480 mg/L total alkalinity) was higher than the maximum Southern groundwater, again showing geological differences.

Table 28. Descriptive statistics of the concentration of Alkalinity Carbonate (as $CaCO_3$) in feedlot water including water sampled at the source ('Source', groundwater (GW) and surface water (SW)) that are later mixed or treated before being presented at the trough, and water sampled at the point of trough entry ('Trough', including groundwater, surface water, mixed water and a summary of all types). Results are presented by feedlot location (Northern or Southern Australia).

Alkalinity Carbonate ($CaCO_3$)	Source		Trough					
Type	GW	SW	GW		SW		SW & GW mix	All types
Region	Nthn & Sthn	Nthn & Sthn	Nthn	Sthn	Nthn	Sthn	Nthn & Sthn	Nthn & Sthn
N	12	12	18	9	10	9	12	58
Minimum	<1	<1	<1	<1	<1	<1	<1	<1
Median	<1	<1	<1	<1	<1	<1	<1	<1
Maximum	46	15	62	<1	21	0	28	62

Table 29. Descriptive statistics of the concentration of Alkalinity Bicarbonate (as $CaCO_3$) in feedlot water including water sampled at the source ('Source', groundwater (GW) and surface water (SW)) that are later mixed or treated before being presented at the trough, and water sampled at the point of trough entry ('Trough', including groundwater, surface water, mixed water and a summary of all types). Results are presented by feedlot location (Northern or Southern Australia).

Alkalinity Bicarbonate ($CaCO_3$)	Source		Trough					
Type	GW	SW	GW		SW		SW & GW mix	All types
Region	Nthn & Sthn	Nthn & Sthn	Nthn	Sthn	Nthn	Sthn	Nthn & Sthn	Nthn & Sthn
N	12	12	18	9	10	9	12	58
Minimum	5	13	95	50	93	33	4	4
Median	290	118	392	269	186	83	296	277
Maximum	1800	219	588	322	480	226	1112	1112

Table 30. Descriptive statistics of the concentration of Alkalinity Total (as $CaCO_3$) in feedlot water including water sampled at the source ('Source', groundwater (GW) and surface water (SW)) that are later mixed or treated before being presented at the trough, and water sampled at the point of trough entry ('Trough', including groundwater, surface water, mixed water and a summary of all types). Results are presented by feedlot location (Northern or Southern Australia).

Alkalinity Total ($CaCO_3$)	Source		Trough					
Type	GW	SW	GW		SW		SW & GW mix	All types
Region	Nthn & Sthn	Nthn & Sthn	Nthn	Sthn	Nthn	Sthn	Nthn & Sthn	Nthn & Sthn
N	12	12	18	9	10	9	12	58
Minimum	5	13	95	50	93	33	4	4
Median	290	118	392	269	186	83	302	280
Maximum	1850	229	629	322	480	226	1142	1142

4.4.7 Cyanobacteria

Feedlots with trough water containing surface water (rivers, dams and irrigation channels) were sent an additional bottle to collect trough water to be analysed for cyanobacteria. For feedlots where the trough water was from mixed sources including surface water, an additional bottle for cyanobacteria was sent to collect a samples of the surface water source. Surface water samples showed a wide range of cyanobacteria species, including those classified as Potentially Toxic Phytoplankton (Table 31).

Table 31. From 13 northern and 7 southern feedlots, 20 trough water samples containing surface water were tested for cyanobacteria. Where trough water was mixed (7 samples (4 northern and 3 southern feedlots)), the Source SW (surface water) was sampled. Source SW (surface water) and trough samples. Reported in the table are the number (N) of samples containing cyanobacteria. Samples containing Potentially Toxic Phytoplankton (PTP) are highlighted.

			Measured (cells/mL)		
Cyanobacteria Identification		*N*	Minimum	Median	Maximum
Anabaenopsis spp.	Source SW	1			79,224
	Trough	1			650
Aphanocapsa spp. <2um	Source SW	4	866	3,308	70,384
	Trough	10	233	13,084	258,000
Aphanocapsa spp. >2um	Source SW	3	950	983	1,600
	Trough	4	300	775	1,983
Aphanothece spp.	Trough	1			916
Aphanothece spp. <2um	Source SW	1			28,225
	Trough	1			1,150
Arthrospira spp.	Source SW	1			101,536
	Trough	1			1,916
Cuspidothrix issatschenkoi	Trough	1			2,783
Cyanocatena imperfecta	Trough	5	100	1,500	114,000
Cyanogranis libera	Source SW	2	200	3,225	6,250
	Trough	5	100	250	1,350
Cylindrospermopsis raciborskii (PTP)	Source SW	1			1,845,332

	Trough	1			2,980
Dolichospermum circinale (PTP) (formerly named *Anabaena circinalis*)	Trough	1			290
Dolichospermum spp. (straight)	Trough	1			1,333
Geitlerinema spp.	Source SW	1			500
	Trough	4	266	958	5,150
Glaucospira laxissima	Trough	1			1,033
Gloeothece spp.	Trough	1			2,350
Merismopedia spp. <2um	Source SW	1			1,064
	Trough	3	200	5,200	8,100
Merismopedia spp. >2um	Trough	2	2,200	2,750	3,300
Microcystis aeruginosa (PTP)	Source SW	1			6,000
	Trough	2	140,777	224,927	309,076
Oscillatoria spp.	Trough	1			350
Planktolyngbya limnetica	Trough	5	233	333	2,300
Planktolyngbya microspira	Trough	1			266
Pseudanabaena limnetica	Source SW	1			9,000
Pseudanabaena spp.	Trough	1			3,616
Raphidiopsis mediterranea (PTP)	Source SW	1			3,396,000
	Trough	1			235
Romeria spp.	Trough	1			27,000
Sphaerospermopsis reniformis	Source SW	1			55,400
	Trough	1			5,475
Unidentified Nostocales	Source SW	1			3,332
	Trough	3	200	900	4,466
Unidentified Oscillatoriales	Source SW	1			5,332
	Trough	1			1,166

Within the Phylum Cyanobacteria, Table 32 shows the SW (surface water source) had the highest cells/mL for each Order. Table 33 shows that two trough water samples were in excess of the trigger value for *Microcystis aeruginosa* (11,500 cells/mL) from feedlots Northern 4 and Northern 5. Of the two feedlots with water samples in excess of the trigger value for *Microcystis aeruginosa,* follow up sampling was conducted where the cyanobacteria was again identified and then sampled for biotoxins (Table 34). The trigger value for microcystin toxin is 2.3 µg/L (expressed as microcystin-LR toxicity equivalents), and as shown in Table 34 all samples were below the trigger level.

Table 32. Samples were collected from 27 feedlots of Source SW (surface water) and trough samples which include surface water, but can include samples mixed. Summary of Phylum Cyanobacteria and Orders for samples containing cyanobacteria.

Cyanaobacteria Identification		Measured (cells/mL)			
		N	Minimum	Median	Maximum
Total Chroococcales	SW	5	1816	5996	105842
	Trough	13	233	8100	580576
Total Cyanophytes	SW	5	2316	6000	5501152
	Trough	15	300	8100	595286
Total Nostocales	SW	1			5379288
	Trough	4	200	5120	8872
Total Oscillatoriales	SW	2	500		115868
	Trough	9	233	733	27000

Table 33. Samples containing Potentially Toxic Phytoplankton (PTP) compared to guidelines for algae content of water based on [1]ANZECC and ARMCANZ (2000) trigger value. Feedlots labelled where N and S indicated northern and southern regions.

Cyanobacteria Identification		Measured (cells/mL)			Samples in excess of threshold
		N	Minimum	Maximum	N
Cylindrospermopsis raciborskii (PTP)	SW	1		1,845,332 (Feedlot N1)	No trigger value available
	Trough	1		2,980 (Feedlot N2)	No trigger value available
Dolichospermum circinale (PTP)	Trough	1		290 (Feedlot N3)	No trigger value available
Microcystis aeruginosa (PTP)	SW	1		6,000 (Feedlot S1)	0
	Trough	2	140,777 (Feedlot N4)	309,076 (Feedlot N5)	2
Raphidiopsis mediterranea (PTP)	SW	1		3,396,000 (Feedlot N1)	No trigger value available
	Trough	1		235 (Feedlot N5)	No trigger value available

Table 34. Summary of the follow up samples containing Potentially Toxic Phytoplankton (PTP) compared to guidelines for algae content of water based on [1]ANZECC and ARMCANZ (2000) trigger value. In addition, as Feedlot N5 treats trough with copper sulphate a water sample from the trough as well as the fresh water coming into the trough were sampled.

Cyanobacteria Identification	Feedlot N5		Feedlot N4	Samples in excess of threshold
	Enumeration (cells/mL)			N
	In trough	Trough	Trough	
Cylindrospermopsis raciborskii (PTP)		50		No trigger value available
Microcystis aeruginosa (PTP)	7,595	47,750	17,300	2
Raphidiopsis mediterranea (PTP)	360	460		No trigger value available
Biotoxins	Concentration (µg/L)			N
Anatoxin-a	<0.1	<0.1	<0.1	No trigger value available
Cylindrospermopsin	0.2	0.2	0.2	No trigger value available
Deoxycylindrospemopsin	0.8	0.7	<0.1	No trigger value available
Nodularin	<0.2	<0.2	<0.2	No trigger value available
Saxitoxin	<0.5	<0.5	<0.5	No trigger value available
Neosaxitoxin	<1.0	<1.0	<1.0	No trigger value available
Microcystin-RR	<0.2	<0.2	<0.2	Below trigger value
Microcystin-YR	0.3	<0.2	<0.2	Below trigger value
Microcystin-LR	<0.2	<0.2	<0.2	Below trigger value
Microcystin-Total	<0.6	<0.6	<0.6	Below trigger value

5 Discussion

5.1.1 TDS and salts

TDS and salts have been shown to decrease cattle production. With the expansion of feedlotting into new areas, there is a need to survey feedlots across Australia to determine the concentration of TDS and salts in their drinking water. In the current project, feedlots were also asked to provide historical data where available. How often feedlot drinking water exceeds ANZECC (2000) guidelines or Nutrient Requirements of Beef Cattle (2016) standards for feedlots in Australia was previously unclear. Cattle production losses of 10% have been recorded (Rasby and Walz, 2011), which could be costing the industry millions of dollars. Previous studies have shown that high concentrations of salts in feedlot drinking water can lead to a decrease in feed intake, health and performance of beef cattle. *Ad libitum* water supply is essential for maximal cattle production. In Australian feedlots, water is supplied from surface and groundwater. Salts concentrate during drought conditions, and with climate change predictions of increasing length of droughts this issue will be exacerbated (Harrington and Cook, 2014:20).

Feedlot water supply is mainly from surface water and groundwater, with groundwater usually having a higher salinity. Feedlots currently use the Australian water guidelines (ANZECC, 2000) and Nutrient Requirements of Beef Cattle (NASEM, 2016). The thresholds for salinity measured as TDS differ between the two sources and is summarised in Table 4, but it is widely accepted high salinity water can be unpalatable to cattle and can cause liveweight losses (Ray, 1986 cited in NASEM, 2016).

However, TDS is an undifferentiated collection of ions and is a ‘very poor indicator of animal health’ as a high TDS value may not cause any health impacts to an animal due to the specific ions being harmless, and vice versa. Thus, Raisbeck et al. (2008) propose a limit of 500 mg/L TDS, and if water exceeds this level a full water analysis should be conducted to identify, quantify and evaluate the contribution ions to ensure health impacts are not occurring.

The objective of this project was to determine how to treat water with high TDS, so this measure was used. Among trough water samples analysed for TDS, the majority (86%) were considered satisfactory for cattle consumption and would not be expected to limit animal performance (i.e. TDS ≤ 3,000 mg/L). In the current study, two samples were in excess of the highest threshold of 7000 mg/L (NASEM, 2016). The highest (11600 mg/L) occurred in the source groundwater, and the second highest (7300 mg/L) occurred in the trough water derived from groundwater. Both feedlots were from the southern region. Unfortunately, these samples were late being reported by the laboratory and so were not used for the benefit cost analysis; at the time of completing the cost benefit analysis, the highest value was 4044 mg/L.

Feedlots require optimal performance of cattle, and as a TDS over 3000 mg/L can impact cattle performance, in this project a TDS of 1000, 2000 and 3000 mg/L are being used as the minimum criteria for the water treatment options in the benefit cost analysis.

As TDS is a non-specific measure, it is important to also examine the individual salts (ions and ionic compounds) in the water such as nitrate, sulphate, sodium, chloride, calcium, magnesium and other salts.

5.1.2 Anions - chloride, nitrate, nitrite, phosphorus and sulphate

No limits have been determined for the anion chloride (Cl^-), which along with sodium is essential for maintaining the acid-base balance and regulating the osmotic pressure in bodily fluids (Raisbeck et al., 2008). Chloride was the anion in the highest concentration in the water samples taken in the current project.

Although nitrates are not poisonous to cattle, in the rumen they are converted to nitrites which can be absorbed into the bloodstream causing haemoglobin to generate metheamoglobin. Methaemaglobin does not bind to oxygen, so the oxygen carrying capability of the blood is reduced. Although cattle can be gradually introduced to increasing levels of nitrate, water over 100 mg/L needs to be managed as part of the cattle's diet (Rasby and Walz, 2011).

Nitrate concentrations in excess of 20 mg/L have been recorded in many Australian groundwater samples, with a small proportion in excess of 100 mg/L. Levels of nitrate under 10 mg N/L (and 9 mg N/L nitrite) in drinking water should not be harmful to animal health (ANZECC, 2000:9.3), with one groundwater source at 11 mg N/L and the groundwater trough water sample of 23 mg N/L at another feedlot.

Phosphorus along with calcium is essential for bone formation, with 80% in bones and the remainder in soft tissues. There are no published limits to phosphorus concentration in water (NASEM, 2016:112).

Sulphate has been found in elevated levels in excess of ANZECC guidelines during droughts in surface waters, leading to cattle deaths. ANZECC (2000) recommend less than 1,000 mg/L sulphate, and levels above 2,000 mg/L can cause chronic and acute health concerns. In a study in South Dakota, drought conditions lead to elevated TDS and sulphate concentrations, which lead to death of steers from polioencephalomalacia (PEM). PEM is caused by high levels of sulphur being ingested and leads to blindness, seizures and coma. Sulphur in the rumen reduces to hydrogen sulphide gas, a toxic compound, which can be inhaled following eructation from the rumen. Patterson et al. (2004) fed 300 kg steers grass hay and wheat middlings, a high protein ration with 52% crude protein. With increasing drinking water TDS and sulphate concentrations, the average daily gain (ADG), dry matter intake (DMI) and gain to feed ration declined quadratically ($P < 0.05$); and water intake declined linearly ($P < 0.01$). Water with TDS of 4720 mg/L and 2919 mg/L of sulphate showed performance reductions. At higher TDS of 7,000 mg/L, 4,654 mg/L, 48% of cattle had PEM, with 33% mortality. For TDS/sulphate of 1,226/441 and 2,933/1,725 respectively, which are within the ANZECC Guidelines (ANZECC, 2000), the ADG was 0.81, 0.75 kg/day; DMI 9.43, 9.35 kg/day; and gain/feed of 0.086, 0.080 (Patterson et al., 2004), showing a decrease in production with increasing TDS and sulphate. This was also confirmed by Weeth and Hunter (1971) who found, for young cattle, growth rate was reduced at 1,462 mg/L sulphate or higher; and feed intake was reduced with 2,814 mg/L sulphate. Such high sulphate concentrations in Australia is uncommon. Because sulphate is an important component of TDS in the USA, TDS thresholds based on USA data may not be applicable to Australian conditions, which are likely to contain a much lower proportion of TDS as sulphate. Therefore, a re-evaluation of thresholds of TDS for Australian cattle and diets may be warranted.

5.1.3 Cations - sodium, potassium, calcium and magnesium

Sodium is an essential extracellular cation (Na^+), which, along with chloride (Cl^-), maintains the acid-base balance and regulates the osmotic pressure in bodily fluids (Raisbeck et al., 2008). In a review Raisbeck et al. (2008) noted that dietary sodium needs to be taken into account when determining the limit of sodium in drinking water. Chronic health effects leading to decreased production have been observed in dairy cows supplied with drinking water containing 1,000 mg Na/L. In another study, beef heifers were minimally affected by drinking water containing 1,600-2,000 mg Na/ L, but this study was conducted in a cool climate. A limit was proposed of 1,000 mg Na/L with serious health effects over 5,000 mg Na/L (Raisbeck et al. 2008). There may be a need to re-evaluate Na thresholds under heat stress conditions.

Potassium is the third highest mineral in concentration in cattle being the major cation in intracellular fluid. It is important for the acid-base balance, regulating osmotic pressure, nerve transmission and certain enzyme reactions (NASEM, 2016). Concentrations in the current study ranged from undetectable (<0.05 mg/L) to 0.403 mg/L.

Calcium is the most abundant mineral in cattle with 98 % of endogenous stores held in bones and teeth and the remainder in plasma (NASEM, 2016:110). Magnesium is essential for animal health such as activating enzymes and maintaining electrical potentials across nerves and muscle membranes (NASEM, 2016:114). Both high calcium and magnesium intake can cause phosphorus deficiency and decrease production. The Ca:P ration is an important dietary formulation standard for maintenance of cellular function. Up to 1,000 mg Ca/L in water is acceptable if calcium is the dominant cation and dietary phosphorus is adequate. But if cattle have high sodium and magnesium in drinking water, or if calcium is added to feed, the level of tolerable calcium may be reduced. Similarly, to calcium, excess magnesium can lead to phosphorus deficiency, scouring, lethargy, lameness and decreased feed intake and performance. Currently, a limit is not clearly set, but up to 2,000 mg Mg/L is acceptable in drinking water (ANZECC, 2000:4.3, 9.3). None of the water samples in the current study exceeded the limits for calcium or magnesium. Groundwater samples had higher maximum concentrations of calcium and magnesium than the surface water samples.

5.1.4 Metals – aluminium, iron, manganese and zinc

Excessive concentrations of aluminium in drinking water can cause phosphorus deficiency, but if phosphorus levels are high, the impacts of aluminium can be compensated. There is substantial variation in current guidelines, with ANZECC standards currently set at 5 mg/L of aluminium in drinking water (ANZECC, 2000:9.3), whereas the upper limit is 0.5 mg/L by NASEM (2016). In the current study, the maximum trough water sample was 17.59 mg Al/L, which is over 30 times the limit. Over 50% of the trough samples exceeded the upper limit of 0.5 mg/L, so is something requiring further investigation.

Iron, manganese and zinc are essential animal nutrients usually found in low concentrations in water. Iron is an essential component of a number of proteins involved in oxygen transport or utilisation (NASEM, 2016). It is an essential nutrient and poses a low risk to cattle, so trigger values have not been defined for iron, but high levels can lower palatability. In regions with high concentrations of iron in water or forage, cattle may require copper to be added to the diet as excessive iron intake depletes copper. The maximum tolerable concentration of iron is 500 mg/kg

DM (NASEM, 2016). In the current study, the highest concentration was 38.7 mg/L in surface water, and in these cases the nutritionist should check the overall intake of iron. NASEM (2016) note iron toxicity causes diarrhoea, metabolic acidosis, hypothermia and decreased gain and feed intake.

Manganese is required as a component and activator of a number of enzymes (NASEM, 2016). Although no trigger value has been assigned in the ANZECC Guidelines (2000:9.3), the NASEM (2016) upper limit is 0.05 mg/L. In the current study, manganese concentration was highest in surface water samples with 57% to 100% of trough water samples exceeding 0.05 mg/L upper-limit guideline (NASEM (2016). The biological significance of high manganese waters remains to be elucidated, although water concentrations are well below the Maximum tolerable limit reported for dietary Manganese of 1000 mg/kg dry matter (NRC, 2016).

Zinc is rarely found above 0.01 mg/L in natural waters, but can be higher due to galvanised tanks and zinc coated plumbing; concentrations in drinking water should be less than 20 mg/L zinc (ANZECC, 2000:9.3) and NASEM (2016) suggest an upper limit of 5.0 mg/L.

5.1.5 pH and alkalinity

pH is determined by the quantity of hydrogen ions where a pH of 7 is neutral, less than 7 is acidic and greater than 7 is alkaline. 'It is defined as the negative logarithm of the hydrogen ion concentration of the solution' (ANZECC, 2000). As pH controls the solubility and concentrations of elements in water, it is an important factor when considering water treatments and palatability for cattle (Raisbeck et al., 2008).

Guidelines for cattle have not been developed for pH, so it is suggested to use the pH developed for humans of 6.5 to 8.5 as a guide (NASEM, 2016:157). The human ranges were developed to protect plumbing from corrosion rather than as a health criteria (Raisbeck et al., 2008). Adams and Sharpe (1995) suggested a pH of less than 5.1 and above 9.0 can cause harm to cattle, based on literature and field experiences. In a review document for Wyoming livestock and wildlife, Raisbeck et al. (2008) found the lower limit of 5.5-6.5 and 7.5-9.0 are excessively conservative. A limit of 3.0 to 7.0 would not cause any pathophysiological issues; however, feedlot cattle maybe an exception as their high soluble carbohydrate ration leads to a marginally acidotic rumen (Raisbeck et al., 2008). Therefore, the limit of Adams and Sharpe (1995) was used in the current project. In the current study, only one sample was below pH of 5.1 and no samples were above pH of 9. In the historical data, there were four groundwater samples that were less than 5.1, with the lowest being 3.7 for pH.

Alkalinity is related to the water's buffering capacity, in other words the capacity of the water to resist changing pH reported as bicarbonate, carbonate, hydroxide and the total alkalinity in mg/L of $CaCO_3$. Alkalinity as carbonate was not detected in the majority of samples, with the highest values of 62 mg/L in Northern groundwater and 12 mg/L in Southern groundwater. In surface water the highest value was 21 mg/L as carbonate in Northern region, and was undetected in Southern surface water samples. This trend followed for both bicarbonate and total alkalinity most probably due to differences in geology between regions.

5.1.6 Cyanobacteria

Phytoplankton species naturally occur in Australian streams and include tiny photosynthetic organisms such as diatoms and Cyanobacteria. They respond to an increase in nutrient levels in the water with blooms. The water samples collected in this project showed a very high percentage of exceedances above the trigger value for south-east Australian reservoirs in slightly disturbed ecosystems for NO_x and orthophosphate. NO_x is a combination of nitrate and nitrite, which are forms of nitrogen, vegetation and include algae that take up nitrate as it is soluble. Orthophosphate, as a form of phosphorus, is taken up by vegetation including algae, and when above the threshold concentrations for reservoirs indicates the potential to contribute to algal blooms (ANZECC, 2000:3.3).

Of the 20 feedlot trough samples containing surface water, 15 samples contained cyanobacteria, and of those, 4 feedlots had potentially toxic phytoplankton in their troughs. A further two feedlots that mixed their water had cyanobacteria in their source water.

With the increased prevalence of blue green algae (cyanobacteria) due the weather conditions in March 2019, as noted by the Victorian Chief Veterinarian (Miller, 2019), this project was expanded to include quantifying algae in surface water samples. Toxic blooms caused by blue green algae (cyanobacteria) have been recorded in Australia since 1878 at Lake Alexandrina by *Nodularia spumigena* (Hallegraeff, 1992). There are 40 species of cyanobacteria which are toxic as they produce a diverse range of secondary metabolites such as heptotoxins, neurotoxins, saxitoxins, lipopolysaccaride endotoxins (Saker et al., 1999). In 1959, over 300 sheep, 5 cattle and 1 horse were killed by cyanobacteria at Lake Bonney in South Australia (Hallegraeff, 1992).

In the current study, *Cylindrospermopsis raciborskii*, a potentially toxic phytoplankton, was detected in two samples with the highest 1,845,332 cells/mL. *Cylindrospermopsis raciborskii* is common and widespread in reservoirs in northern Australia (McGregor et al. 2011). There is no trigger value for this species in cattle, but in 1979 a bloom in the drinking water reservoir on Palm Island in Queensland caused an outbreak of hepatoenteritis in 148 people (Hallegraeff, 1992) and has been attributed since to the alkaloid cylindrospermopsin (Ohtani et al., 1992 cited in Saker et al., 1999).

Deaths of three cows and ten calves were reported near a farm dam in northwest Queensland with a monoculture of C*ylindrospermopsis raciborskii* (Saker et al., 1999). This appears to be the first report of cattle deaths being attributed to C*ylindrospermopsis raciborskii*. Following on, Shaw et al. (2004) investigated two cattle poisoning events in Northwest (45 cattle) and Central (10 cattle) Queensland, and found after exposure of less than 10 days, concentrations above 1 mg/L of cylidrospermopson in drinking water lead to cattle deaths. Affected cattle had pale mottled livers, distended gall bladders and were lethargic 3 to 4 days before dying. In humans, due to a lack of data, no guideline value has been set by Australia, but due to the known toxicity, relevant health authorities should be notified (HMRC & NRMMC, 2011 p. 327).

Raphidiopsis mediterranea, a potentially toxic phytoplankton, is morphologically similar to *Cylindrospermopsis raciborskii*, so it had not been frequently identified in Australian waters. In 2011 an Australian study with a samples of *Raphidiopsis mediterranea* from a reservoir in Queensland showed it can produce cyanotoxins (McGregor et al., 2011). In the current study, 3,396,000 cells/mL of *Raphidiopsis mediterranea* was identified in the source dam water, which was mixed with groundwater before cattle consumption, diluting the prevalence of *Raphidiopsis mediterranea* to 235 cells/mL at the trough. There is no trigger value for *Raphidiopsis mediterranea*, for human health or cattle, and it is not mentioned in the Australian Drinking Water Guidelines (2011).

Dolichospermum circinale (formerly named *Anabaena circinalis*), a potentially toxic phytoplankton, was detected in one sample at 290 cells/mL. This algae caused contamination of 1200 km of the Darling River system, killing sheep, cattle and wildlife, and contaminating water supplies for many rural towns (Hallegraeff, 1992). *Dolichospermum circinale "*tends to proliferate in calm, stable waters, particularly in summer when thermal stratification reduces mixing”. Blooms usually occur in late spring to early autumn. For humans, less than 2,000 cells/mL can produce offensive tastes and odour. Management to reduce *Dolichospermum circinale* is to minimise nutrients it the water source, with treatment details in the Australian Drinking Water Guidelines (HMRC & NRMMC, 2011 p. 342).

Microcystis aeruginosa, a potentially toxic phytoplankton, has a trigger value of 11,500 cells/mL; which was exceeded in two samples in the current project. Microcystin is a hepatotoxic polypeptide, most commonly produced from *Microcystis aeruginosa but can be produced from Dolichospermum* spp. Microcystin is water soluble, and so is unable to easily penetrate biological membranes, and thus enters the bloodstream of mammals from the intestine and concentrate in the liver causing hepatoenteritis. Microcystin is very stable chemically and can remain intact after boiling, but is naturally biodegraded by naturally occurring aquatic bacteria in lakes. Microcystin half-life is 5 to 20 days (HMRC & NRMMC, 2011 p. 332).

5.1.7 Treatment to reduce Cyanobacteria

It is well known that in temperate parts of Australia cyanobacteria blooms occur from late Spring to early autumn (HMRC & NRMMC, 2011). Treatment methodologies will be dependent on the species, stage of growth, and concentration of the cyanobacteria and biotoxins. It is anticipated feedlot managers will seek advice of nutritionists, veterinarians or environmental scientists when deciding on the most appropriate treatment.

The Australian Drinking Water Guidelines (HMRC & NRMMC, 2011) state the “first line of defence against cyanobacteria is catchment management to minimise nutrient inputs to source waters”. To minimise growth of cyanobacteria, maintain flow of regulated rivers, avoid stratification by mixing (avoid large temperature differential between top and bottom of dam), and if required, careful use of algaecide, being aware decaying cyanobacteria can release toxins that can persist for months (HMRC & NRMMC, 2011). It may be toxic to aquatic plants and animals, and there may be a withholding period before stock can drink the water. If adding ferric alum to farm dams to restrict cyanobacteria grown, it should only be used for prevention. A novel approach is to float in a mesh bag 100 g of barley straw per 1000 L of water, taking up to one month to work but lasting 6 months (WA DPIRD, 2018). In a study in Alabama (Wilson et al., 2018), of 41 livestock drinking dams found, 80% contained measureable microcystin. They found by the cattle having access to walk into the dams and thus increase turbidity mediated the high concentrations of nutrients including phosphorus and nitrogen. However, in Australia many dams have been fenced and cattle are watered from troughs to reduce nutrient contamination (NSW Government, 2011), thus going back to the Australian Drinking Water Guidelines of minimising nutrients inputs to the source water.

5.2 Technologies to reduce TDS

Initial results from historical data were within the acceptable range for TDS, and as the highest sample was 4,000 mg/L using the data that had been processed we used the limit of 5,000 mg/L. However, two of the final water samples that were processed had TDS of 7,300 and 11,600 mg/L, so a different reverse osmosis technology was required that can treat higher TDS.

Numerous water treatment technologies are available for a range of water quality parameters. As stipulated by industry, in this project TDS was used to indicate the salt load for the cattle. Technologies that were investigated for suitability to treat water to reduce TDS to acceptable levels for drinking water for feedlot cattle are summarised in Table 35, and those that may be viable are described in detail below. The authors advise feedlot managers to seek advice from their animal nutritionist and/or veterinarian to examine the diet holistically to determine if minerals are exceeded, whilst taking into account other climatic factors such as heat stress and TDS of water before investing in water treatment technologies.

Table 35 Summary of water treatment methodologies, contaminants removed and if should be investigated further for reducing TDS. From [1]Olkowski (2009)

Treatment options	Contaminant removed	Reduces Total Dissolved Solids
Chlorination	Bacteria, oxidise metals[1]	No
Coagulation	Particles, arsenic, iron, manganese[1]	No, only part of TDS reduced
De-mineralisation (deionised water)		Yes
Distillation		Yes
Ion exchange (softening)	Hardness, iron <2 mg/L[1]	Not as effective at TDS levels in current study
Ozonation	Bacteria, oxidise metals[1]	No
Reverse osmosis	TDS, sulphates, hardness, arsenic, manganese[1]	Yes
Slow sand filter	Iron, arsenic[1]	No
Ultra violet	Bacteria[1]	No
Shandying*	Dilution with lower TDS water if available	Potentially yes, dependent on source water

*Shandying is mixing of different sources of water such as surface and groundwater.

5.2.1 Demineralisation (deionisation of water)

Demineralisation refers to the removal of dissolved solids; however, it is commonly used to refer specifically to ion exchange to remove nearly all the ionic minerals in the water. Ion selective membranes are used so the positive ions are attracted to the negative electrode, and vice versa for negative ions. The cation resins will remove calcium (Ca^{2+}), iron (Fe^{3+}), magnesium (Mg^{2+}), manganese (Mn^{2+}), potassium (K^{+}), and sodium (Na^{+}); and anion resins will remove alkalinity (CO_3^{2-},

HCO^{3-}), chloride (Cl^-), nitrate (NO^{3-}), sulphates (SO_4^{2-}) and silica (SiO_2). This level of water processing is used in high pressure boilers. Although this level of cation and anion removal may not be required for feedlot cattle drinking water, the technology was considered as it could be used to shandy with the water source to reduce overall TDS of the cattle drinking water. However, when Australian suppliers were contacted to discuss the suitability of their technology for Australian feedlots they stated it would not be suitable.

Three types of demineralisation technologies were investigated: ion exchange, ion absorption and electrochemical desalination. Ion exchange is a water softening process that replaces valance positive two ions with 'softer' single valance ions. This technology is typically applied to processing water with an equivalent ion constituent range of 150 mg/L to 300 mg/L calcium carbonate ($CaCO_3$). As ion exchange does not result in a substantial decrease in overall TDS and constraints on treating very hard water, the suppliers contacted considered the technology would have limited applications in the intensive livestock industry. Ion absorption is used on already potable water (<60 µS/cm) to further reduce the ion constituents to near zero. Ion absorption is not suitable in this application.

A new technology that looks to have promising future applications in reducing TDS of brackish water is electrochemical desalination. This technology is a membrane desalination process in which ions are transported through selective ion permeable membranes from a cationic solution to anionic solution under the influence of an electrical potential gradient. A supplier was contacted but was unable to provide details of the technology within the time frame of this research project.

5.2.2 Distillation

In distillation processing, water is boiled to produce water vapour, which then condenses on a cool surface before transforming back into liquid water. As the dissolved salts (cations and anions) are unable to vaporise they remain in the boiling solution which concentrates into in a hyper saline solution and needs to be disposed. This level of water processing is used to treat human drinking water. Although this level of cation and anion removal may not be required for feedlot cattle drinking water, similarly to demineralisation this technology was considered as it could be used to shandy with the water source to reduce overall TDS of the cattle drinking water. However, when two Australian suppliers were contacted to discuss the suitability of their technology for Australian feedlots they stated it would not be suitable due to the volume of water requiring processing and it would almost certainly not be cost effective when compared with other available technologies.

5.2.3 Reverse Osmosis

Reverse osmosis processing forces water under pressure through a synthetic membrane of microscopic pores of 0.0001 micro metres. As the salts, metals and non-organic contaminants are larger than the membrane's pores they are held back and form a hyper saline solution that then needs to be disposed. The water passes through the membrane and thus reduces the TDS and salinity.

Reverse osmosis units are being installed across Australia in feedlots to treat water before use in steam flaking mill, and in the current survey four feedlots stated they were using reverse osmosis. For water with a TDS of less than 5,000 mg/L one type of unit can be used, whereas for higher TDS a unit designed for sea water is required. Therefore, in the benefit cost analysis below both types of machines were used.

5.2.4 Shandying

Shandying is the process of mixing clean water with drinking water to reduce concentrations of dissolved solids, soluble solids, and other minerals and salts. Clean water may be sourced from groundwater, surface water, or treated water sources. In addition, when using a technology to treat water only a portion of the water needs to be treated and then 'shandied' back with raw water to gain the TDS level required.

5.2.5 Coagulation

Addition of ameliorates such as aluminium sulphate (alum) neutralises the change on the particles and cause the particles to combine into a floc that is removed either by filtration or the settling. It is used in livestock operations to remove fine particulates, arsenic, iron, manganese and organics to make chlorination more effective (Olkowski, 2009). Coagulation was investigated in the current project but it was determined by the supplier to be largely ineffectual on dissolved ions.

5.2.6 Model assumptions

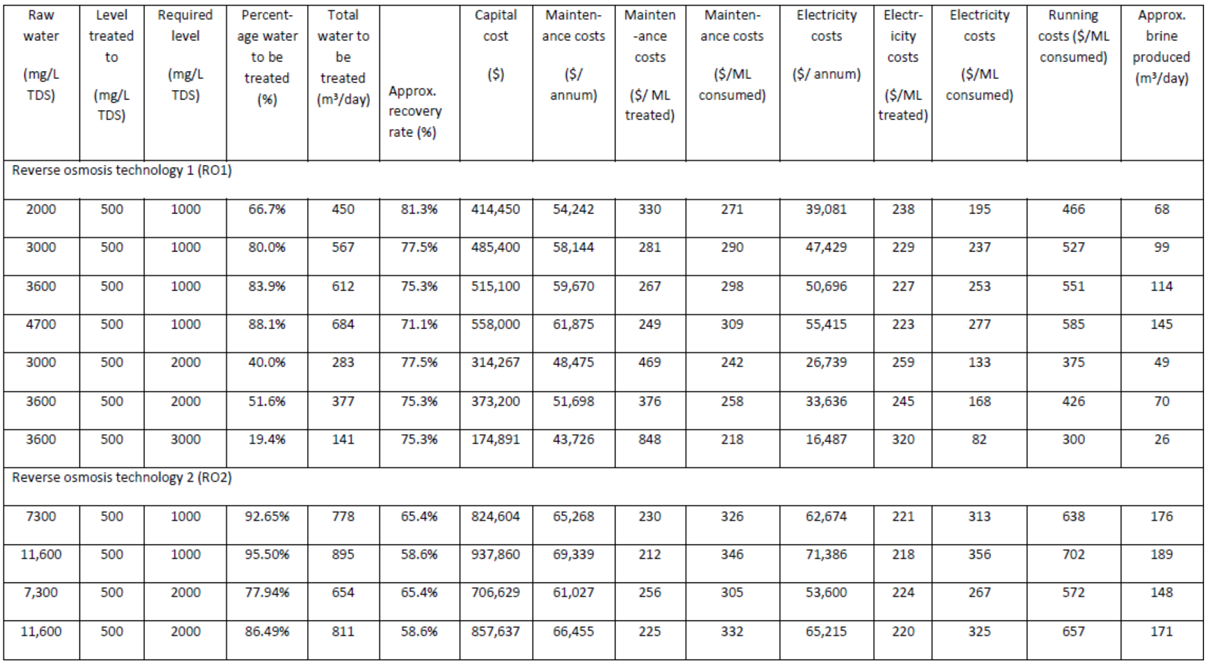
Model assumptions include:

1. Use of Patterson et al. (1995) for the performance of the cattle, although this refers to a publication from the USA as there are no Australian references for this particular information. It should be noted this study had water with sulphate concentrations much higher than the water in the current study (maximum was 575 mg SO_4/L); however, in a study collating over 70,000 groundwater samples from grazing land in Western Australia, Northern Territory and Queensland the maximum sulphate level was 57,000 mg SO_4/L (Kurup et al., 2011). It is unknown if the benefits outlined in Patterson et al. (1995) will occur in Australia when decreasing TDS due to differences in mineralogy, so additional animal trials are required to determine benefits of reducing TDS for Australian mineral proportions.
2. Installation costs include travel, materials and labour; but may vary depending on site.
3. Costs for electricity are assumed to be from the electricity grid at 0.27624 c/kWh (Canstar Blue, 2019).
4. Costs per litre treated are extrapolated from costs obtained for 10- 820 m^3/day system.
5. Costs are based on a water requirement of 454 kg finisher cattle at 26°C of 54.9 L/day for cattle watered with mid-level TDS (NASEM, 2016). Therefore 549 m^3 per day for 10,000 head.
6. Due to the site specific nature of brine disposal costs including the environmental monitoring, brine disposal have been excluded but should be factored into full analysis.

Where ultrafiltration and reverse osmosis is being used already for boiler water the costs may be reduced by the instillation of a larger unit at time of renewal of infrastructure. To reduce the cost of electricity, on site renewable energy such as a solar plant or wind turbine could be installed to treat water during the day and store water at night in tanks which would then be distributed through the feedlot overnight. Also a shandy could be investigated where only a proportion of the water is treated and is then mixed back with the raw water to reduce the TDS.

Reverse osmosis relies on filters to remove the salts and with increasing salt concentration the percentage of salt removed decreases. A typical recovery rate of a TDS of <1,000 is about 85%, 5,000 TD is 70% recovery and 10,000 is 60% (Pers. Comm. M. Lowry, Premise 2019). Two different types of reverse osmosis technologies were required for this study RO 1 (for TDS up to 5000 mg/L) and RO2 (for RO above 5000 mg/L and is used for sea water >35 000 mg/L). Using costings acquired by interviewing suppliers of reverse osmosis equipment Table 36 was developed where water was treated to 500 mg/L TDS.

Table 36. Indicative calculations for water requirement of 549 m^3 each day with two reverse osmosis technologies (RO1 for <5000 mg/L TDS and RO2 for >5000 mg/L TDS) for 10000 SCU/yr feedlot



Raw water (mg/L TDS)	Level treated to (mg/L TDS)	Required level (mg/L TDS)	Percent-age water to be treated (%)	Total water to be treated (m^3/day)	Approx. recovery rate (%)	Capital cost ($)	Mainten-ance costs ($/ annum)	Mainten-ance costs ($/ ML treated)	Mainten-ance costs ($/ML consumed)	Electricity costs ($/ annum)	Electr-icity costs ($/ML treated)	Electricity costs ($/ML consumed)	Running costs ($/ML consumed)	Approx. brine produced (m^3/day)
Reverse osmosis technology 1 (RO1)														
2000	500	1000	66.7%	450	81.3%	414,450	54,242	330	271	39,081	238	195	466	68
3000	500	1000	80.0%	567	77.5%	485,400	58,144	281	290	47,429	229	237	527	99
3600	500	1000	83.9%	612	75.3%	515,100	59,670	267	298	50,696	227	253	551	114
4700	500	1000	88.1%	684	71.1%	558,000	61,875	249	309	55,415	223	277	585	145
3000	500	2000	40.0%	283	77.5%	314,267	48,475	469	242	26,739	259	133	375	49
3600	500	2000	51.6%	377	75.3%	373,200	51,698	376	258	33,636	245	168	426	70
3600	500	3000	19.4%	141	75.3%	174,891	43,726	848	218	16,487	320	82	300	26
Reverse osmosis technology 2 (RO2)														
7300	500	1000	92.65%	778	65.4%	824,604	65,268	230	326	62,674	221	313	638	176
11,600	500	1000	95.50%	895	58.6%	937,860	69,339	212	346	71,386	218	356	702	189
7,300	500	2000	77.94%	654	65.4%	706,629	61,027	256	305	53,600	224	267	572	148
11,600	500	2000	86.49%	811	58.6%	857,637	66,455	225	332	65,215	220	325	657	171

Using the experiment by Patterson et al. (2004) which demonstrated the impact of TDS and sulphate concentrations on steer response in South Dakota experiment the table was developed and Australian costs inserted (See Table 37). Patterson et al. (2004) showed an Average Daily Gain (ADG) of 0.81 kg/day at 1200 mg/L TDS down to 0.67 kg/day for 4700 mg/L TDS; in Table 37 it was assumed the ADG would be the industry standard of 2 kg/day for TDS of 1200 mg/kg and 17% depression of ADG, and 9% depression of Dry Matter Intake (DMI).

Table 37. Impact of TDS and sulphate concentrations on steer response (Patterson et al. 2004) in South Dakota experiment, adapted to Australian costs ([1]Mid was calculated using linear relationship; [2]ADG assumed as 2 kg/day for lowest TDS and depression percentage from experiment applied for other treatments)

Treatment	Low (1200 mg/L TDS)	Mid[1] (2000 mg/L TDS)	High (3000 mg/L TDS)	Very high (4700 mg/L TDS)	Highest (7268 mg/L TDS)
Initial Wt (kg)	291	291	291	291	291
Final Wt (kg)	375	372	368	360	322
ADG (kg/d)	0.81	0.78	0.75	0.67	0.28
DMI (kg/d)	9.43	9.39	9.35	8.60	5.98

Treatment Response		low-mid	low-high	low-very high	highest-low
% depression ADG		4	7	17	66
% depression DMI		0	1	9	37

Head/pen	240				
Ration Cost ($/t As-Fed)	340				
Ration DM (%)	75				
Ration Cost ($/t DM)	453.33				
DOF (d)	120	*Experimental dates*		*23/05/2002*	*4/09/2002*
HCW Price ($/kg)	5.5				

Treatment	low	mid	high	very high	Highest
TDS (mg/kg)	1,226	2,080	2,933	4,720	7,268
Sulphate (mg/kg)	441	1,083	1,725	2,919	4,654
ADG[2] (kg/d)	2.00	1.93	1.85	1.66	0.69
DMI (kg/d)	9.43	9.39	9.35	8.60	8.60
Feed Cost ($/hd)	513	511	509	468	468
Final BW (kg)	531	522	514	491	373
Dressing Percent (%)	53	53	53	52	51
HCW (kg)	282	277	271	257	189
Mortality (%)	0	0	0	0	33
Final head/pen	240	240	240	240	160
HCW (kg /pen)	67,681	66,397	65,113	61,789	30,257
Feed cost ($/pen)	123,120	122,617	122,114	112,224	112,224

Table 38 shows the summary of the benefit cost analysis for reducing TDS in varied amounts such as 4700 to 1000 mg/L TDS using the two technologies.

Table 38 Indicative benefit cost analysis using Patterson et al. (2004) data with Australian costings using Reverse Osmosis Technology 1 (<5000 mg/L) for 10000 SCU/yr feedlot

	Treat 2000mg/L TDS to 1000 mg/L	Treat 3000mg/L TDS to 1000 mg/L	Treat 3600mg/L TDS to 1000 mg/L	Treat 3000mg/L TDS to 2000 mg/L	Treat 3600mg/L TDS to 2000 mg/L	Treat 3600mg/L TDS to 3000 mg/L	Treat 4700mg/L to 1000 mg/L
Gain HCW (kg/hd)	5.35	10.70	15.89	5.35	10.54	5.19	24.55
Percentage underweight (%)	0.9	1.8	2.6	0.9	1.7	0.8	4
Extra HCW Revenue ($/hd)	29.43	58.85	87.39	29.43	57.96	28.54	135.03
Extra Feed Cost ($/hd)	-2.10	-4.19	-19.58	-2.10	-17.48	-15.38	45.40
Extra returns ($/hd)	31.52	63.05	106.97	31.52	75.44	43.92	89.63
Extra returns ($/pen)	**7,566**	**15,132**	**25,672**	**7,566**	**18,106**	**10,540**	**21,510**
Benefit, $/10,000 SCU/yr (where fed for 120 days)	958,877	1,917,755	3,253,579	958,877	2,294,701	1,335,824	2,726,103
Reverse osmosis	Treat 2000mg/L TDS to 1000 mg/L	Treat 3000mg/L TDS to 1000 mg/L	Treat 3600mg/L TDS to 1000 mg/L	Treat 3000mg/L TDS to 2000 mg/L	Treat 3600mg/L TDS to 2000 mg/L	Treat 3600mg/L TDS to 3000 mg/L	Treat 4700mg/L to 1000 mg/L
Installation costs ($ upfront)	414,450	485,400	515,100	314,267	373,200	174,891	558,000
Installation costs amortised 15 years ($/yr)	27,630	32,360	34,340	20,951	24,880	11,659	37,200
Running costs ($/ML)	466	527	551	375	426	300	585
Cattle water consumption (L/hd/d)	55	55	55	55	55	55	55
Treatment costs ($/10000 hd/yr)	93,323	105,573	110,366	75,215	85,334	60,213	117,290
Total costs ($/10000 hd/yr)	120,953	137,933	144,706	96,166	110,214	71,872	154,490
Treatment costs ($/hd/yr)	9	11	11	8	9	6	12
Total costs ($/hd/yr)	12	14	14	10	11	7	15
Total marginal benefit ($/10,000 SCU/yr)	837,924	1,779,822	3,108,873	862,712	2,184,487	1,263,951	2,571,613
Total marginal benefit ($/head/yr)	83.79	178	311	86	218	126	257
Total marginal benefit ($/hd turned off)	28	59	102	28	72	42	85

Table 39 Indicative benefit cost analysis with Australian costings using Reverse Osmosis Technology 2 (>5000 mg/L) [1]using Patterson et al. (2004) data for 7300 mg/L TDS for both 7300 and 11600 mg/L TDS scenarios for 10000 SCU/yr feedlot

	Treat 7300 mg/L to 1000mg/L)	Treat 11600 mg/L to 1000mg/L)[1]	Treat 7300 mg/L to 2000mg/L)	Treat 11600 mg/L to 2000mg/L)[1]
Gain HCW (kg/hd)	93.00	93.00	87.64	87.64
Percentage under weight	14	14	13	13
Extra HCW Revenue ($/hd)	511.47	511.47	482.05	482.05
Extra Feed Cost ($/hd)	43.31	43.31	43.31	43.31
Extra returns ($/hd)	468.17	468.17	438.74	438.74
Extra returns ($/pen)	112,360	112,360	70,234	70,234
Benefit, $/10,000 SCU/yr (where fed for 120 days)	14,240,113	14,240,113	13,345,031	13,345,031
Reverse osmosis	Treat 7300 mg/L to 1000mg/L)	Treat 11600 mg/L to 1000mg/L)	Treat 7300 mg/L to 2000mg/L)	Treat 11600 mg/L to 2000mg/L)
Installation costs ($ upfront)	824,604	937,860	706629	857637
Installation costs amortised 15 years ($/yr)	54,974	62,524	47,109	57,176
Running costs ($/ML)	638	702	572	657
Cattle water consumption (L/hd/d)	55	55	55	55
Treatment costs ($/10000 hd/yr)	127,942	140,725	114,627	131,670
Total costs ($/10000 hd/yr)	182,916	203,249	161,736	188,846
Treatment costs ($/hd/yr)	13	14	11	13
Total costs ($/hd/yr)	18	20	16	19
Total marginal benefit ($/10,000 SCU/yr)	14,057,197	14,036,864	13,183,296	13,156,185
Total marginal benefit ($/head/yr)	1,406	1,404	1,318	1,316
Total marginal benefit ($/hd turned off)	462	461	433	433

This benefit cost analysis has been generated to provide an indicative assessment of the benefits and costs of using reverse osmosis to treat drinking water at a 10,000 SCU feedlot. Before investing in reverse osmosis technology a detailed site specific assessment would be required on a case by case basis to ensure the feedlot benefits of adopting this technology can be achieved.

The cost benefit analysis above, showing a decrease in performance with increasing TDS was formulated using results from the USA with much higher sulphate levels than usually recorded in Australia. But other studies have found a decrease in some performance indicators with high saline water, such as Ray (1986) who found water with a TDS of 5000 mg/L reduced cattle gain on a high-roughage diet. However, Ray (1989) indicated this experiment was confounded with seasonality and adoption to saline water leading to another experiment on feedlot steer calves in the USA where "saline water ingestion tended to be more detrimental during periods of heat stress". Domínguez et al. (2007) found for pre-weaning Holstein calves well water (1469 mg/L TDS) treatment with Inverse Osmosis Water reduced the TDS by 93% to 107 mg/L TDS and reduced the bacteriologic count by 98%. Calves receiving Inverse Osmosis Water had 26% higher dry matter intake, 23% higher daily gain and 10% higher body weight than the calves given untreated well water due to the reduction in salts and bacterial load for pre-weaning calves.

Further research needs to be conducted with Australian cattle breeds, modern feedlot rations and mineral composition of water, as if such a high level of return was possible as outlined in Patterson et al. (2004) then it is assumed this would have been adopted previously. The minerals comprising the TDS component of Australian feedlots is often sodium, chloride and carbonate, all minerals added to the diets of feedlot cattle. Therefore, water treatment to reduce salts during times of animal stress maybe beneficial; however, simply taking into consideration the salts in the water when formulating feedlot diets may give greater production gains. Feedlot managers, nutritionists and veterinarians should continue to examine the concentration of minerals in the drinking water of Australian feedlots as in some cases these exceeded national guidelines. In these cases, instead of reducing the TDS of the water it will be important to remove the mineral.

Feedlots should also examine drinking water for cyanobacteria, especially from spring until summer. Simple management techniques such as the use of barley straw have been suggested as a preventative measure early in the cyanobacteria growing season.

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7 Appendix

7.1 Information for participants

Dear feedlot manager

We wish to invite you to participate in this University of New England (UNE) and Meat & Livestock Australia (MLA) project funded in consultation with Australian Lot Feeders Association (ALFA). UNE and Premise Agriculture are service providers to MLA for this research project.

This project aims to summarise the quality of feedlot drinking water across Australia and determine potential impacts on cattle health and production. The most common water quality issues will then be evaluated to ascertain the most cost effective treatment methods to minimise impacts on production. The survey should not take more than 10 minute to complete. By your feedlot supplying a cattle drinking water sample and answering three questions about water quality at your feedlot, your water sample will be analysed at a NATA certified lab for free. The first 200 respondents to this survey will have their water samples analysed.

Confidentiality	Any personal details gathered in the course of the study will remain confidential. No individual or feedlot will be identified by name in any publication of the results. All data will be summarised and grouped in regions/states/areas to ensure individual identification of feedlots cannot be made. Where feedlots agree to be quoted a pseudonym will be used to ensure anonymity is maintained.
Participation is Voluntary	Please understand that your involvement in this study is voluntary and we respect your right to stop participating in the study at any time without consequence and without needing to provide an explanation.
Use of Information	Water quality data and questionnaire information will be summarised and reported to MLA and ALFA and academic journal articles and conference presentations. It is expected to be completed by April 2019. At all times, we will safeguard your identity by presenting the information in a way that will not allow you or your feedlot to be identified.
Upsetting Issues	It is unlikely that this research will raise any personal or upsetting issues but if it does you may wish to contact Lifeline on 13 11 14.
Storage of Information	I will keep all hardcopy of surveys in a locked cabinet in my office at the University of New England. Any electronic data will be kept on cloud.une.edu.au, UNE's centrally managed cloud server managed by the research team. It will also be kept on a password protected computer in the same location. Only the research team will have access to the data.
Disposal of Information	All the data collected in this research will be kept for a minimum of five years after submission the final report to MLA, after which it will be disposed of by deleting relevant computer files, and destroying or shredding hardcopy materials.
Approval	This project has been approved by the Human Research Ethics Committee of the University of New England (Approval No. HE18-279, Valid to 4/12/19).
Researchers Contact Details	Feel free to contact the team with any questions about this research by email at rrg@une.edu.au or by phone on 02 6773 2025.

Complaints	Should you have any complaints concerning the manner in which this research is conducted, please contact: Mrs Jo-Ann Sozou, Research Ethics Officer, Research Services UNE, Armidale, NSW 2351, Tel: (02) 6773 3449, Email: ethics@une.edu.au

7.2 Consent form for participants

Feedlot Water Quality Project Form

I, ____(name),
_______________________________________ (feedlot name),
___________________________________ (position at feedlot),
have read the information contained in the Information Sheet for Participants and any questions I have asked have been answered to my satisfaction. Yes/No

I am older than 18 years of age and agree to participate in this activity, realising that I may withdraw at any time. Yes/No

I agree that research data gathered for the study may be quoted and published using a pseudonym. Yes/No

I agree to collect and return feedlot cattle drinking water for analysis for this project. I understand data will be summarised and de-identified before reporting.
Yes/No

I agree to supply historical feedlot cattle drinking water analysis. I understand data will be summarised and de-identified before reporting.
Yes/ No/ Not applicable

_______________________________________ ___________________________

Participant signature Date

7.3 Questionnaire

Feedlot Water Quality Project Form

Feedlot name ____

(Not released outside the project)

Source of drinking water

What is the major source of cattle drinking water for your feedlot?

Source	% contribution to total drinking water
Groundwater (underground water)	
Surface water (dam)	
Surface water (river)	
Coal seam gas water	
Town water	
Roof water (tank)	
Other, please specify	

Water quality

In the past decade have you had instances where your water quality (salinity, algae, silt, etc) has led to a decrease in cattle health or production? Please circle Yes No

If yes please describe the instance including visible indicators and water tests.

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Water treatment

Does your feedlot currently process (filter, reverse osmosis, chlorinate, etc) or are you considering processing your cattle's drinking water? Please explain your situation.

____

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____

Trough water sample

With the arrival of your Kit (esky) you should find a set of bottles and a prepaid Toll return freight form to Symbio Laboratories Brisbane.

Prior to sampling day

1. Freeze iceblocks for at least one day.

2. To avoid your water sample being delayed in transport to the laboratory it is best to take your sample on Monday or Tuesday.
    a. Please phone the number on the prepaid Toll form in your Kit.
    b. Choose the best day and book pickup.
    c. Any issues please contact Symbio Laboratories (1300 703 166).

3. If possible, place esky in cool room.

4. Print '**Analysis Request Form**' that was attached to your email and place in esky.

On the day of sampling

1. Write on bottles with ball point or waterproof pen.
    a. Sample description - 'trough' (see '**Analysis Request Form**')
    b. Include feedlot name on bottle
    c. Date and time sampled

2. Place frozen iceblocks in esky.

3. Identify the first drinking water trough in the line from the water source.

4. Empty the trough by removing the ‘plug’ to allow the water to flow through the trough flushing outlet or equivalent. Clean any debri from around the water inlet to make sure you get a ‘clean’ sample.

5. Use the float to adjust the flow. Fill the bottle.
   Take care with the bottle that has acid preservative not to spill on yourself, wear safety glasses and do not to overfill.

6. Squeeze container to remove air.

7. Place in bottles in esky, make sure ‘**Analysis Request Form**’ is included.

8. Seal with packing tape or similar.

9. Have esky ready for Toll to collect or if needed drop off.

For feedlots with mixed water sources

For feedlots with mixed drinking water sources surface (dam and river) water and/or groundwater, you have been sent additional bottles. Please repeat as above ensuring a fresh running sample is taken of the water source.

Please see ‘**Analysis Request Form**’ for the ‘sample description’ to be placed on the sample bottles for each water source.

Water quality thresholds for cattle drinking water

This document outlines published trigger and threshold limits for several water quality parameters for cattle drinking water using the following two references:

- ANZECC (2000). *Australian and New Zealand Guidelines for Fresh and Marine Water Quality Vol 1*, Australian and New Zealand Environment and Conservation Council, Agriculture and Resource Management Council of Australia and New Zealand.

- National Academies of Sciences, Engineering, and Medicine (2016). Nutrient Requirements of Beef Cattle, 8th Edition, National Academy Press, Washington D.C.

This document is for information only.

Please consult a nutritionist or veterinarian when interpreting your water quality assessment results and in making decisions on action.

Table 40 Published trigger values and limits for some inorganic and biological water quality parameters for drinking water for cattle. From ANZECC (2000) and NASEM (2016)

Water quality parameter		ANZECC (2000) Low risk trigger value (mg/L)	NASEM (2016) for beef cattle (mg/L)
Metals/ cations	Aluminium Total)	5	0.5 (Upper-Limit Guideline)
	Calcium (Dissolved)	1000	
	Copper (Total)	1	1.0 (Upper-Limit Guideline)
	Iron (Total)	not sufficiently toxic	
	Manganese (Total)	not sufficiently toxic	0.05 (Upper-Limit Guideline)
	Zinc (Total)	20	5.0 (Upper-Limit Guideline)
Anions	Nitrate (as N) (NO_3 N)	90 (>340 toxic)	0-10: Safe 11-20: Safe in balanced diets 21-40: Could be harmful over long periods 41-100: High risk - possible mortalities >101: Unsafe – possible death
	Nitrite (as N)	>9 hazardous	
	Sulphur (as Sulphate)	1000	
Other	Hardness (Total)		0-60: Soft 61-120: Moderately hard 121-180: Hard ≥181:Very hard

Table 2. Published limits of Total Dissolved Solids (TDS, Salinity) and Total Soluble Salts (TSS) in drinking water for cattle which are equivalent and displayed as Solids (Dissolved) in your report.

Total dissolved solids (salinity) (mg/L) (ANZECC, 2000)	
<4000	**Safe** and no adverse effects on animals expected
4000-5000	Animals may have initial reluctance to drink or there may be some scouring, but **stock should adapt** without loss of production
5000-10000	**Loss of production** and a decline in animal condition and health would be expected. Stock may tolerate these levels for short periods if introduced gradually

Total Soluble Salts (TSS) (NASEM, 2016)	
<1000	**Safe** and should pose no health problems
1000-2999	**Generally safe** but may cause mild temporary diarrhoea in animals not accustomed to the water.
3000-4999	Water maybe refused when first offered to cattle or cause temporary diarrhoea. **Animal performance may be less than optimal** because water intake is not maximised.
5000-6999	Avoid these waters for pregnant or lactating animals. May be offered with reasonable safety to animals where **maximum performance is not required**.
≥7000	These waters **should not be fed to cattle**. Health problems and/or poor production will result.

Table 3 Trigger values and limits for algae water quality parameters for cattle drinking water. From ANZECC (2000)

Water quality parameter		**ANZECC (2000) Low risk trigger value (mg/L)**
Biological	Algae – (Cyanobacteria ID and Enumeration; Potential Toxin Producers ID and Enumeration; Cyanobacteria Biovolume; Potential Toxin Producers Biovolume)*	Microcystis exceeding 11 500 cells/mL; and/or concentrations of microcystins exceeding 2.3 µg/L (expressed as microcystin-LR toxicity equivalents)*

*** Please note: for surface water samples tested for algae**

B.V. is Biovolume – this is the volume of algae per litre of sample

PTP is the Potentially Toxic Phytoplankton – to determine if toxins are produced further analysis is required. Please contact Symbio Laboratories for clarification.