DRINKING WATER QUALITY AND ITS IMPACT ON THE HEALTH AND PERFORMANCE OF PIGS

INNOVATION PROJECT 2A-118

Final Report prepared for the
Co-operative Research Centre for High Integrity Australian Pork

By

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September 2018

Executive Summary

Water is an essential nutrient for life. It is integral to many physiological functions and if compromised will negatively impact animal performance, health and welfare. Furthermore water is also a biosecurity risk that may harbor and enable the transmission of viruses, bacteria and protozoa. Despite its importance, water is often overlooked and it is no surprise that it is often called 'the forgotten nutrient'. Thus this innovation project sought to develop an understanding of drinking water quality and its management within the Australian Pig Industry and in turn the impacts that it may be having on pig performance, health and welfare.

A total of 57 commercial piggeries participated in this project with each property conducting a self-assessment of farm water delivery and management. Water quality was assessed through the analysis of water samples taken from both the source and the drinker. The most common water source being utilized was bore water. Management practices and infrastructure delivering water from the source to the point of consumption were found to be inconsistent across the farms surveyed with no apparent industry best practice in place or being followed. The water quality of both the source and drinking water was found to be highly variable with many parameters, particularly pH, hardness, chloride, sodium, iron, manganese and microbiological levels, exceeding the acceptable standard. In general, producers did not appear to be routinely testing water quality and as a result had no knowledge of the negative impacts that poor water quality or water management might be having on pig production or the economics of their businesses.

Despite the variability in water quality being offered, the study identified the use of drinking water as a common administration pathway for water-soluble additives, including antibiotics. This delivery route enables a pulsed and targeted delivery of antibiotics which is advantageous as an antimicrobial stewardship tool. However, the findings of this study demonstrated that sub-optimal water quality had detrimental effects on the solubility and stability of commercially available veterinary antibiotics. Furthermore, antibacterial activity was found to be inconsistent. Although preliminary, these findings are of particular importance when considering that the resulting antibiotic dose rate at the drinker may be compromised and in turn the administration dose provided to the pig. The results are indicative that good quality water and management is essential for appropriate antibiotic use and in turn antimicrobial stewardship.

If the preliminary findings of this innovation project were to translate across the broader industry it would suggest that water, its quality and management, represents a significant challenge to the Australian pig industry. Further research is required to quantify the impact of water quality on pig performance, health and welfare however, in the interim, there are several immediate actions identified in this study that Australian producers can take. By implementing these simple steps, producers will be better placed to understand their individual water quality challenges and in turn implement appropriate actions to ensure not only optimal pig productivity, health and welfare but also economic benefits and efficiencies.

Acknowledgements

The author would like to express thanks and gratitude to all industry participants for their important contribution to this study. Indeed, without their invaluable contribution there would have been no study.

The author would like to also acknowledge the valuable contributions made by Dr Steve Little (Capacity$^+$ Ag Consulting), Ms Molly Coleman (Under-Graduate Intern, Ridley) the Ridley team (Mr Joe Edwards, Mr Robert Parkes, Ms Jill Ramsey, Mr Greg Stuart and Mr Andrew Younger), Dr Sue Finch (Department of Statistics, The University of Melbourne), Dr Helen Billman-Jacobe and her team (Department of Veterinary Sciences, The University of Melbourne).

And finally, the Pork CRC for funding this innovation project and for their support and guidance during the project.

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1. Introduction

Water is the first nutrient and an essential component of most, if not all, agricultural production systems. Access to drinking water of a certain physio-chemical and microbiological quality, free of deleterious or toxic substances is imperative for the farm to fork supply chain, traceability and food safety. Despite its importance, there has been limited research on water and in particular the impact of its availability, quality and management on the performance, health and welfare of animals. This is particularly important when considering that drinking water is frequently used to administer water-soluble nutritional additives and veterinary chemical products.

To understand the critical role that drinking water quality can have on the economic viability of an intensive animal production system such as the Australian Pig Industry, we must first understand the role of water as a nutrient.

1.1 Water: The First Nutrient

Water is essential for many physiological functions including the regulation of feed intake and digestion, thermoregulation, mineral homeostasis and nutrient transportation, removal of metabolites, anti-nutritional substances and toxins and, lubrication and protection of the body organs (National Research Council, 1998). Pigs, like other species, need water for tissue maintenance, growth, secretion of water through salivation and lactation, achievement of satiety and behavioral needs. Indeed, water is integral to gut health through a series of complex interactions involving nutrition, immune function and microbiome balance (Sofi et al., 2014). Water also plays an important role in reproduction (Brumm, 2010) particularly in foetal development (Nyachoti & Kiarie, 2010). Urination is the major route for water loss in pigs (National Research Council, 1998), however losses also occur through respiration, evaporation and defecation (Nyachoti, 2004).

The importance of water is highlighted when considering that at birth, 82% of a pig's body weight is water (Brumm, 2010; Feed & Livestock, 2017). By the time the pig has reached 100kg this proportion has decreased to 51-55%. Given the high percentage of water to body weight it is not surprising that changes in drinking water intake can be the first indication of emerging herd or flock health problems (Anderson et al., 2014). Indeed if monitored consistently, daily water usage can be considered as being a more sensitive indicator of animal health and well-being than daily feed intake (Brumm, 2010).

1.2 Water Source, Availability & Management

Australian food animal production systems draw water from many different sources including rivers, irrigation channels, dams, ground water and mains supply. Due to geographical variation and climatic events the volume of supply and the quality of that supply can be highly variable which in itself presents a challenge. The volume of water that a pig will consume will be influenced by a number of factors including, but not limited to, the environment, accessibility, animal physiology, health status and behaviour. In pigs, water intake occurs mainly during feeding, and as pigs eat preferentially at certain times during the day, this creates a 'diurnal drinking pattern'. Bigelow and Houpt (1988) found that 75% of pigs' water intake was associated with their feed intake. Furthermore the way in which water is provided to pigs is important to ensure optimal feed and water consumption (Brumm, 2010; Australian Pork Limited, 2016). Indeed, ambient temperature, the level of competition around the feeder, diet and water flow rate all influence water use and drinking behaviour in pigs (Adam & Voets, 2006; Andersen et al., 2014). Pigs prefer water to be cooler than the ambient temperature. Water management systems including the number and type of drinkers, flow rates and water pressure must be adequate to cover the times of highest use. Growing-finishing pigs may waste up to 60% of the water from a poorly managed nipple drinker (Brooks, 1994). Water wastage is largely influenced by drinker height and water flow rate, as shown by Li et al (2005). Long term inadequate or inconsistent water supply or flow rates can result in increased pig aggression, lowered growth rates and weaning weights, urinary-tract infections and gastric ulcers (Lumb et al., 2017).

Table 1 provides an overview of water management recommendations for pigs including daily water intake. It is evident that adequate quantities of water of a drinkable quality should be made available to meet a pig's physiological needs. Indeed, not doing so would be detrimental given water consumption has been shown to be closely related to feed intake and therefore growth and performance in pigs (Brumm, 2010; Nannoni et al., 2012; Feed & Livestock, 2017). Approximately 2kg of water is required for each kilogram of feed consumed by a grower pig (National Research Council, 1988).

Table 1. Water Management Recommendations for Pigs

Age	Daily Water Intake (L/head)	Flow rate (ml/min)	No. Pigs /Drinker*	Drinker* Height (cm)
Weaners (5-15 kg)	2-3	250-500	10	15-30
Weaners (15-25 kg)	3-5	250-500	10	30-45
Growers (25-45 kg)	5-7	500-1000	10-12	45
Finishers (45-65 kg)	7-9	500-1000	12-15	45-60
Finishers (>65 kg)	9-12	500-1000	12-15	60-75
Lactating sows[#]	20-30	1000-2000	12-15	75-90
Dry sows[#]	10-20	1000	12-15	75-90

*Nipple Drinkers. [#]1 drinker per pig when housed individually.
Table adapted from King (1999), NSW DPI Primefacts (2006), Brumm (2010); APL Fact Sheet (2016)

1.3 Water Quality

Accessibility to a reliable water source is critical but an awareness of the quality of that water is of equal importance. However what does 'water quality' mean and what are the recommended quality standards for optimal pig health and production within the Australian pig industry? Typically, water quality is evaluated based on the analysis of its physical, chemical and microbiological composition. A challenge exists in that most published water quality surveys and resulting standards refer to water for human consumption as opposed to livestock and in turn as it relates specifically to pig production. While the quality of water in reservoirs used for human consumption is constantly monitored, there are no similar comprehensive data-sets on the quality of agricultural water. A comprehensive review by King (1999) provided an overview of the studies conducted by the Queensland and Victorian Governments on ground water. The results of these two studies from the analysis of hundreds of bore water samples showed that the quality of ground water was highly variable but only problematic for livestock in less than 10% of cases. Furthermore, within a given bore, the chemical composition of water remained relatively stable over time. No subsequent studies appear to have been conducted to date. King concluded that surface water from rivers or irrigation sources and mains supply was usually of relatively good quality and unlikely to cause any problems for livestock. In contrast, where ground water is used to supply water to piggeries, water quality may be an issue particularly when one considers the impact of local weather events. Regardless, all water sources should be considered a farm biosecurity risk as they pose a viable entry point and conduit for transmission of water-borne pathogens (e.g. viruses, bacteria, protozoa). It is interesting to note therefore that the Australian Poultry Industry has a well-established guideline around the biosecurity of water (National Water Biosecurity Manual Poultry Production, 2009)

Pigs utilize water from three main sources: feed, drinking and metabolic (Nyachoti & Kiarie, 2010). It has been reported that a poor water supply can lead to lower feed intakes, slower growth rates and urinary tract infections in sows (Australian Pork Limited, 2016) however the available definitions of what constitutes poor water quality in pig production is as varied as it is limited. When given poor quality water, pigs drink excess water causing the animals to excrete excess water, which expends energy that could have been used in growth performance (Nyachoti & Kiarie, 2010).

Recommended Water Quality Standards:
Standards for water quality define acceptable levels of chemical and microbial contaminants. There are many parameters that have been employed to measure water quality. This report attempts to highlight those most frequently used (Table 2). For most water contaminants, there is not a single level at which performance is impacted. This is partly due to the fact that effects on animal performance at any one level vary depending on the presence of other contaminants. Therefore, whenever assessing water quality problems caused by a specific factor, consideration of other factors present is critical (Nyachoti & Kiarie, 2010). Nevertheless, the concept of a prescriptive water quality standard is internationally accepted. Table 3 provides an overview of a number of published water standards for livestock and humans. It was not possible to summarise all the published standards in this table but it is apparent that although many standards exist they are dated or of debatable relevance to the Australian Pig Industry. Even those that are specific for pigs, are highly variable or have no recommended standards for some water quality parameters. So how as an industry should we interpret this and which parameters should we focus on?

Table 2.1. Physical Water Quality Parameters:

Parameter	Description
Colour	• Not a concern in itself unless due to an undesirable contaminant in the water.
Odour	• Fresh water should be almost free of any odours; if present the cause of off-odours should be investigated. • Most likely cause of off-odours is microbiological contamination or the presence of organic compounds.
Turbidity	• A measure of suspended material such as silt, clay or in some cases micro-organisms. • Elevated turbidity may lead to problems with the functionality of the water delivery system, effectiveness of sand filters and/or impair the effectiveness of water disinfection.
Notes	• Of little practical importance as pigs are quite tolerant of unusual colours and tastes in water. • However, extremes should be investigated as they may be symptomatic of underlying problems.

Table 2.2. Chemical Water Quality Parameters:

Parameter	Description
Ammonia	• High levels indicate bacterial contamination (manure).
Nitrates/ Nitrites	• Of concern due to the ability to bind to haemoglobin and form. methaemoglobin however, pigs appear to have a greater resistance and can tolerate higher levels. • Nitrate toxicity leads to high respiration rate, reduced feed intake, poor reproductive performance and reduced Vitamin A utilisation. • High levels may be linked to slurry or fertilizer contamination.
Sulphate	• A naturally occurring mineral in most groundwater sources. • High levels are associated with increased risk of osmotic diarrhoea, pigs appear to adapt so health issues are transient. • Some bacteria can extract the oxygen from sulphate creating a 'rotten egg' odour.
Chloride	• Normally not elevated in either groundwater or surface water. • If high, water will have a metallic taste which does not appear to affect the pig. If associated with Sodium, can result in increased water intake and an increased urine output. • Can impact the activity of some antibiotics.
pH	• pH is a measure of the acidity or alkalinity. • Pigs can tolerate a wide pH range; more likely to impact effectiveness of water soluble additives & metals, sanitation methods e.g. chlorination and cause corrosion in pipes. • pH affects the solubility of certain water-soluble antibiotics.
Total Alkalinity	• A measure of alkaline substances dissolved in the water. • Impacts as per pH.
Iron & Manganese	• Present in ground water in their soluble reduced form (e.g. ferrous, Fe^{+2}). As water is exposed to oxygen it will become oxidised (e.g. ferric, Fe^{+3}) and insoluble. • No known direct health issues associated with elevated levels but can cause water handling problems through the build-up of scale and discolouration. • Iron can support the growth of some bacterial strains. • In combination, Fe and Mn can impact water palatability and the effectiveness of some water-soluble antibiotics.

Parameter	Description
Calcium	• Frequently found dissolved in ground water and well tolerated by pigs. • Can interfere with the effectiveness of tetracycline and phosphorus absorption. • Can cause water handling problems through the build-up of scale.
Magnesium	• Not a concern in itself. • If with sulphate (Epsom salts), it can have laxative effects. • Can cause water handling problems through the build-up of scale.
Potassium	• Not a concern in itself.
Sodium	• If associated with sulphate, it can cause diarrhoea. If associated with carbonate or bicarbonate, can cause alkaline pH. If associated with chloride, can result in increased water intake and an increased urine output. • High salt content affected the gut microbiome, Lactobacillus in particular.
Hardness	• A measure of multivalent cations, primarily calcium and magnesium as carbonates, bicarbonates, sulphates and chlorides. • No known impact on pig health but can impact the effectiveness of some water-soluble antibiotics. • High levels can lead to an accumulation of scale and therefore blockages in water delivery, treatment and heating equipment.
Conductivity	• A measure of the ability of water to conduct an electrical current. • High conductivity suggests a high level of dissolved mineral ions in the water.
Total dissolved solids (TDS)	• Provides a direct measure of total inorganic contaminant content. • A good initial indicator in water quality analysis. • Due mainly to the presence of bicarbonate, chloride and sulphate salts of sodium, calcium and magnesium. • Higher TDS levels are associated with an increased risk of osmotic diarrhoea; only very high levels appear to reduce pig performance.

Table 2.3. Microbiological Water Quality Parameters:

Parameter	Description
E. coli	• Detection is a concern and an indicator of faecal contamination. • Capable of causing detrimental impact on pig health.
Total Coliforms	• Indicative of water system contamination. • Detection may be associated with faecal contamination of water.
Notes	• Of paramount importance, all water sources are a potential biosecurity risk with bacterial survival times far exceeding those in the dry shed or faeces. • Ability of a pig to withstand a bacterial challenge is dependent on its physiological and immunological status. Challenges include *Brachyspira hydoysenteriae*, *E. coli*, *Salmonella* spp, *Mycoplasma* spp, *Cryptospiridium*, *Giardia* etc.

References: Acero et al., (2010); Felix et al., (2016); Grandjean et al., (2005); King (1999); Lumb et al., (2017); Meek (1996); Norte et al., (2018); Nyachoti & Kiarie (2010); Patience (2011); Thacker (2001); Wingender & Flemming (2011)

Table 3. Summary of Published Water Standards. NOTE: *Values shown are the Maximum Acceptable Standards*

Group	Water Quality Parameter (mg/L unless stated)	Human		Livestock		Pigs				
		A	B	C	D	E	F	G	H	Recommended Acceptable Standard
Inorganics	Ammonia (as N)	0.5	-	-	-	-	-	1	1	1
	Nitrate (as N)	50	50	50	20	100	440	100	100	50
	Sulphate (as SO_4)	500	1000	1000	150	1000	-	150	150	200
Chloride	Chloride	-	-	-	100	-	-	250	250	250
pH	pH	-	-	-	6 - 8.5	6.5 - 8.5	-	5.0 - 8.5	6.0 - 8.0	6.0 - 8.0
Alkalinity	Total (as $CaCO_3$)	-	-	-	-	-	-	-	-	300
Heavy Metals	Arsenic	0.0007	0.01	-	0.2	0.2	0.2	-	-	0.2
	Cadmium	0.002	0.003	-	0.01	0.01	0.05	-	-	0.01
	Chromium	0.05	0.05	-	0.1	1	1	-	-	0.05
	Copper	2	2	-	0.2	0.5	0.5	-	-	0.5
	Iron	0.3	-	0.5	0.2	0.5	-	0.5	0.1	0.3
	Lead	0.01	0.01	-	0.05	0.1	0.1	-	-	0.05
	Manganese	0.5	-	-	0.05	-	-	0.1	0.05	0.1
	Mercury	0.001	0.006	-	0.01	0.002	0.01	-	-	0.002
	Nickel	0.02	0.07	-	0.25	1	1	-	-	0.1
	Zinc	3	-	-	5	20	25	-	-	2.0
Alkali Metals	Calcium	-	-	1000	100	1000	-	-	-	500
	Magnesium	-	-	250	50	400	-	-	-	150
	Potassium	-	-	-	20	-	-	-	-	30
	Sodium	-	-	150	50	-	-	400	400	150
Hardness	Equiv. $CaCO_3$	200	-	-	-	180	-	20	10	180
Microbiological (MPN/100ml)	*E. coli*	0	0	200	-	-	-	100	1	50
	Total coliforms	0	0	-	1000	1000	-	100000	100	1000

Table adapted from: A = Australian Drinking Water Guidelines (2011); B = World Health Organisation Water Quality Guidelines (2017); C = NSW DPI, Australia (2006); D = Socha et al., USA (2009); E = R. King, Australia (1999); F = Nutrient Requirements of Swine, USA (1998); G = Pig Health Service, The Netherlands (2015); H = JS Water, The Netherlands (2015); 'Recommended Acceptable Standard' developed in consultation with Dr Steve Little (Capacity+ Ag Consulting).

1.4 Water Treatment & Medication Dosing Systems

As water is fundamental to agricultural production systems it follows that inferior water quality would be detrimental to animal performance, health and welfare, let alone a biosecurity risk. A comprehensive review by Lumb et al (2017) describes the guidance issued by the UK Food Standards Agency regarding the quality of water for food producing animals. UK producers were directed to take adequate measures to ensure the use of potable or clean water whenever necessary to prevent contamination. Clean water was defined as "water that does not contain micro-organisms, or harmful substances in quantities capable of directly or indirectly affecting the health quality of food". Agricultural premises are expected to provide at least 'clean water' to their stock. The challenge to Australian producers is that they are typically reliant on whatever water source is available. Only by establishing what the water quality is can the appropriate actions be subsequently taken, if needed, to provide "clean water" to their stock. When assessing water quality it is important to test both the source and the drinking water. By doing so the results provide an insight in to the health of the water management system and in particular the presence of biofilms.

Biofilms are a mucous-like layer of polymer matrix containing microbiota (bacteria, yeasts, protozoa) that forms on any hard surface and in particular lines the inside of water-pipes (Rashid & Clark, n.d.; Wingender & Flemming, 2011; Lumb et al., 2017). Biofilms can result in odour, colour changes to water, contribute to corrosion and clogging of pipes, water filters and drinkers leading to leakage and poor water flow which can impede water supply (Rashid & Clark, n.d.). Given biofilms contain bacteria there is potential for reduced animal performance and disease outbreak depending on the immune status of the herd. The initial adhesion of biofilms is difficult to prevent and once formed, even harder to remove. The use of some water additives and palatants can be conducive to bacterial growth and in turn support biofilm development. Adherence to a strict cleaning and sanitation regime is paramount to their control and prevention (Martelli et al., 2017; Lumb et al., 2017).

Water quality, access and management should be reviewed as part of an integrated farm management approach when there are on-going animal health or performance issues. Routine testing of water quality will identify if there are issues that require a more permanent solution. Depending on the specific quality problems there are a number of different water treatment systems available. The different systems and their capabilities are shown in Table 4.

Water is commonly used in animal production systems as a delivery mechanism for water soluble additives such as vitamins, minerals, vaccines and medications. The extent to which water use as standard medication delivery practice within the Australian Pig Industry is not known. Water dosing appears to offer some advantages in terms of the strategic and flexible nature of its administration in comparison to in-feed. Specifically, administration via drinking water can provide a faster implementation response time, focused treatment and greater flexibility with regard to dosage. However, particularly when considering delivery of medications, concerns exist around the implementation and management of medication dosing systems. Furthermore, the quality and composition of water including the presence of biofilms must be considered. Indeed, Lumb et al (2017) demonstrated that certain antibiotics become unstable when exposed to high levels of calcium, magnesium and iron. Interaction with other water-soluble products can also results in a loss of stability and in turn efficacy (Dorr et al., 2009). Despite the apparent challenges, the findings of a preliminary farm water quality study conducted in 2016 by Ridley AgriProducts (Ridley) have shown that water medication is viewed favorably by the Australian pig industry. This was in part due to the strategic and flexible nature of its administration compared to in-feed medication delivery.

Table 4. Water Treatment Methods and their Effectiveness against Common Water Quality Problems

Quality Problem	Water Treatment Methods											
	A	B	C	D	E	F	G	H	I	J	K	L
Cl/Cu	●	●			●							
Hardness			○									
H_2S						○	○	○			○	
Fe/ Mn	○	●	●	○	●			●			○	
Pb	○	●			●							
N		●	●		●							
pH												●
Pathogens		●			●			●	●	●	●	○
Pesticides	●	○			●							
Sediment		○		●	○						○	

Table adapted from Socha et al., (2009) in consultation with Dr Steve Little (Capacity^{+} Ag Consulting)
A = Activated Carbon Filtration; B = Reverse Osmosis; C = Ion Exchange Water Softening; D = Sediment Filtration; E = Distillation; F = Aeration; G = De-aeration; H = Continuous Chlorination; I = Ultraviolet Radiation; J = Ozonation; K = Ultra, Micro and Nano Filtration; L = Organic acids/ Acidification.
● = Effective Treatment Method; ○ = Partially Effective Treatment Method

1.6 Aims & Objectives:

From the literature, it can be concluded that water quality and on-going access to water of good quality has the potential to significantly impact animal performance, health and welfare. Aside from being fundamental as a nutrient, drinking water is frequently used as an administration pathway for water-soluble additives such as vaccines and antibiotics. If left unmanaged, water can pose a significant biosecurity risk. A preliminary study by Ridley (2016) indicated that the availability, quality and management of water within the Australian Pig Industry is highly variable and as such is a potential threat to the on-going productivity and sustainability of the Australian Pig Industry.

The aim of this study was to build on these initial observations by developing a greater understanding of the quality and management of drinking water being delivered to pigs on Australian pig farms, and in turn the impacts that it may have on pig performance, health and welfare by specifically targeting the delivery of water-soluble antibiotics in drinking water.

2. Methodology

2.1 Farm Water Survey

To develop an understanding of the quality and management of drinking water within the Australian Pig Industry a Farm Water Survey was initiated. A 'call-out' to industry was made at the commencement of the project with a target of 50 voluntary participants being set. All participants were provided with instructions, a survey questionnaire and relevant equipment to take representative water samples for quality assessment.

The survey consisted of two components, the first being a qualitative paper-based self-assessment form which focused on water management. Specifically, the questionnaire sought to understand:

- Sources of drinking water available for use
- Farm/shed water supply systems in use:
    - Drinker types and configuration
    - Flow rates
    - Cleaning practices
    - Maintenance regimes
- Farm water treatment systems in use
- Farm water dosing systems in use and commonly administered water-soluble additives

The second part of the survey was a quantitative assessment of farm water quality. Representative water samples from the source and shed (drinking water) were taken from all participating farms. The source collection point was defined as the point of entry, or the point of greatest accessibility, as close as possible to the source water or the point at which the water entered the farm. The shed or drinking water collection point was defined as the drinker furthest from the entry pipe to the nominated shed. Where possible, participants were asked to select a grower shed as their nominated shed. At both collection points, water was allowed to run freely before sample collection. Aseptic sample bottles and a collection protocol were provided by a third party NATA accredited laboratory. On collection, all water samples were chilled to 4ºC and transported within 24 hours to the analytical laboratory for the following analysis:

- **General:** Ammonia, Chloride, Hardness, pH, Nitrate, Sulphate, Total Alkalinity
- **Alkali Metals:** Calcium, Magnesium, Potassium, Sodium
- **Heavy Metals:** Arsenic, Cadmium, Chromium, Copper, Iron, Lead, Manganese, Mercury, Nickel, Zinc
- **Microbiological:** *E. coli*, Total Coliforms

Each participant was provided with a copy of their water quality results. At the time of sample collection, participants were also asked to conduct several physical measurements such as drinking water temperature and flow rates.

All survey data was collated and de-identified by the project leader. Statistical analysis was conducted by the Statistical Consulting Centre (School of Mathematics and Statistics, The University of Melbourne). The results of the survey are summarized in Section 3 with greater details being provided in Appendix 2.

2.2 Preliminary Laboratory Studies to Evaluate the Impact of Water Quality on Commonly Used Veterinary Antibiotics

The findings of the Farm Water Survey were used to inform which water-soluble additives including antibiotics were being administered via the drinking water. This preliminary study sought to understand the impact of water quality on their solubility and antibacterial activity.

The findings of the current study were used in combination with those from a preliminary water quality study (Ridley, 2016) to identify veterinary antibiotics administered via drinking water on Australian Pig Farms. In consultation with a major Veterinary Chemical Product distributer, a short-list of commercially available veterinary antibiotic products (Table 5) were sourced. The author would like to state that the short-listing of these products for this study should not be interpreted as a recommendation or otherwise. Full product details were recorded including batch number and expiry date details.

Table 5. Commonly Used Veterinary Antibiotics as Informed by the Farm Water Survey

Commercially Available Veterinary Antibiotic	Active Constituents	APVMA No.
Sol-U-Mox Amoxycillin Soluble Powder*	Amoxycillin Trihydrate	52444
Abbeylinc Antibiotic Soluble Powder	Lincomycin hydrochloride	67803
Abbey TMPS Antimicrobial Soluble Powder*	Trimethoprim sulfadiazine	69475
Linco-Spectin Antibiotic Soluble Powder for Poultry and Swine	Lincomycin monohydrate/ Spectinomycin as the sulphate tetrahydrate	48182
Terramycin 880 Soluble Powder Concentrate	Oxytetracycline hydrochloride	46830
Zamichlor Soluble	Chlortetracycline hydrochloride	81953
Tylovet Tylosin Tartrate Soluble	Tylosin tartrate	54322

*Sol-U-Mox and Abbey TMPS are not registered for use in pigs in Australia. Any use of these antibiotics for pigs in Australia is off-label and is the responsibility of the prescribing veterinarian according to the legislation in the relevant jurisdiction.

The following preliminary laboratory study was conducted by the Department of Veterinary Sciences, The University of Melbourne. For further details, refer to Appendix 3. The results are summarised in Section 3, with greater details being provided in Appendix 3.

Solubility of Commonly Used Veterinary Antibiotics

In the field, water-soluble antibiotics are typically prepared as a concentrated stock solution which is then diluted using a dosing system to achieve the required dose rate at the point of consumption. Using a laboratory scale approach, this preliminary study sought to determine the impact of water quality on the solubility of commercially available antibiotics when prepared as a stock solution or when prepared at the required medication dose (i.e. at the drinker). Four different water types were used, these being ultrapure water (MilliQ) and river, dam and bore farm water. To ensure the farm water samples collected were representative of the 3 different water source types, samples were sent to a third party NATA accredited laboratory for water quality analysis.

Stock (100ml) and drinker (50ml) solutions were prepared by weighing the amount of each individual antibiotic powder to achieve the recommended concentration as per the registered label directions or manufacturer's instructions. MilliQ was the only water type used to prepare the stock solutions whereas all 4 water types were used to prepare the drinker concentration solutions. On addition of the antibiotic product, each solution was agitated using either a vortex (50ml; drinker concentration) or magnetic stirrer (100ml; stock concentration). The time taken for the antibiotic to dissolve was recorded (up to a maximum of 180 seconds). Solutions were then allowed to stand for 5 minutes before visual observations. All solutions were then incubated in the dark for 24 hours at room temperature without agitation. The appearance, pH and amount of particulates in each solution was recorded on preparation and following the 24 hour incubation period.

Particle Size Analysis of Commonly Used Veterinary Antibiotics

The particle size distribution of each veterinary antibiotic product was evaluated using a nested column of sieves (Scienceware™ Mini-Sieve Microsieve Set). Briefly, a 5g subsample was placed in the top section of the sieve column and then agitated on a mechanical shaker for 3 minutes at a setting of 60rpm. The material retained on each sieve section was weighed and expressed as a percentage of the total material recovered. Two subsamples were processed for each product with the exception of Tylovet due to time constraints.

Antibacterial Activity Testing

The disc diffusion method for antimicrobial susceptibility testing was conducted according to the standard disc diffusion method of Bauer et al (1966). The antibacterial activity of each antibiotic was evaluated against antibiotic sensitive *Escherichia coli* ATCC 35218[1] and *Staphylococcus aureus* ATCC9144[2]. Using a fresh overnight bacterial culture, a single colony was picked and mixed in sterile water to ensure a 0.5 McFarland Standard optical density. This solution was used to lawn Oxoid Sensitest agar plates (CM0409, Thermo-Scientific). Excess inoculum was removed and the plates dried for no greater than 15 minutes at room temperature. Antibiotic discs were then applied to the plate, and plates were then incubated at 37ºC for 18 hours after which time they were examined for a zone of inhibition around each applied disc.

Discs were prepared as below using ultrapure MilliQ water as the solute to generate the following test plates:

Table 6. Disc Diffusion Plate Preparation

Plate 1 (2 discs)	Plate 2 (5 discs)	Plate 3 (5 discs)
• Control • Unfractionated Ab, drinker concentration	• Fractionated Ab, no dilution	• Fractionated Ab, x10 dilution

Ab = Antibiotic

Where available, Oxoid antibiotic susceptibility discs were applied as controls to demonstrate sensitivity of the test bacteria.

[1] https://www.atcc.org/~/ps/35218.ashx
[2] https://www.atcc.org/~/ps/9144.ashx

3. Outcomes

3.1 Farm Water Survey

Fifty seven (57) industry participants from five different states (Figure 1) took part in the Farm Water Survey between October 2017 and March 2018. A summary of the results are presented in this section with greater details being provided in Appendix 2.

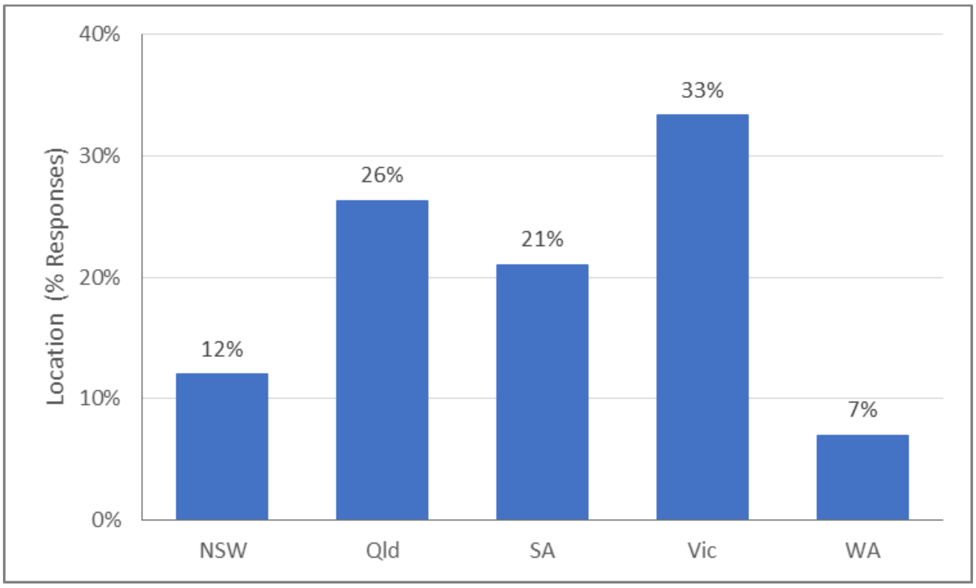

Figure 1. Location of Farm Water Survey Participants

Sources of Drinking Water Available for Use:
Several different types of water sources were being accessed across the 57 piggeries surveyed with bore water being the most common source (Figure 2).

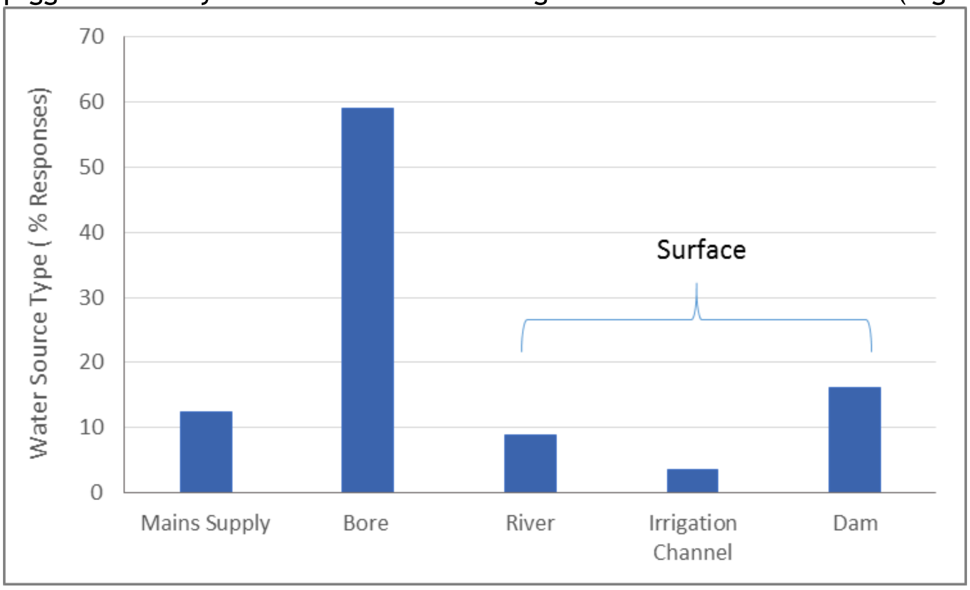

Figure 2. Sources of Drinking Water Available for Use

For the purposes of statistical analysis the sources were classified into three categories: Mains Supply, Bore and Surface (River, Dam, Lake and Irrigation Channel). The majority of participants were heavily reliant on their primary water source with bore water accounting for 60% of supply. Where a secondary source was available it was typically bore water. When asked to rate the hygiene of their primary water source, over 75% of respondents gave a good to excellent rating.

Drinking Water Availability and Water Management:
The survey responses indicated that several different types of drinkers, or combinations of drinkers, were in use within the nominated shed. The most common way water was made available to pigs was through a nipple and bowl combination (26.4% of respondents, Appendix 2). From the responses there appeared to be little consistency to the number, height or positioning of the drinkers within the shed (data not shown due to discrepancies in measurement units reported). Drinker flow rates were provided by 52 of the piggeries surveyed and ranged from 300 to 6,300ml/min (Figure 3) with the most frequently reported flow rates between 2,000 to 2,990ml/min. One outlier was identified with a farm recording a flow rate of 10,333ml/min. This result was verified but has not been included in the figure below.

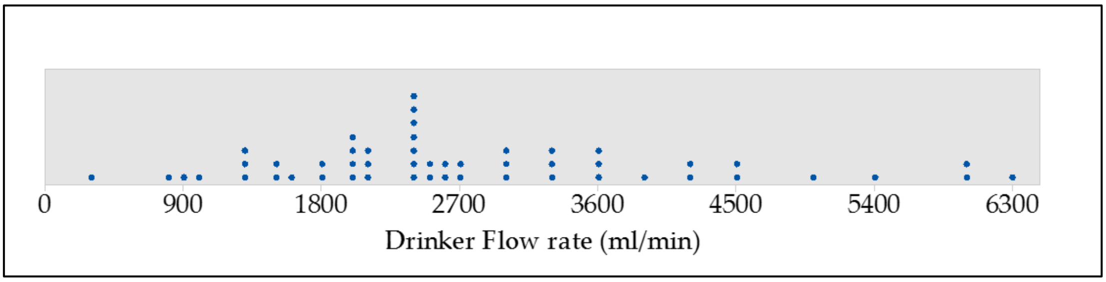

Figure 3. Range of Drinker Flow Rates (ml/min)

Where possible survey participants were requested to select a grower pen for all shed measurements. When compared to the recommended flow rate for grower sheds (500-1000ml/min, Table 1), it was evident that the survey results (Figure 3) exceeded these recommendation in most cases. Indeed, some farm measurements were in excess of the highest recommended flow rate of 2,000ml/min for lactating sows (Table 1). Where it was possible to identify the shed type and pig age, the following flow rate ranges were recorded: Weaners: 1,290 – 6,000ml/min; Growers: 800 – 6,300ml/min; Finishers: 900 – 3,300ml/min and Lactating Sows: 1,300 – 2,000ml/min.

The flow rates measured in this study are highly variable and in many cases in excess of published recommendations. Why this was the case was not investigated in this study but it would be of economic value to the Australian Pig Industry to do so. With this observation in mind, it is interesting to note therefore that over half (56.4%) of respondents indicated that drinker flow rate was checked at least monthly with regular cleaning practices being employed. Indeed, 75% of respondents felt that drinker hygiene was good to excellent with the remaining indicating hygiene was fair to poor. These observations require further investigation to understand the level of water wastage and potential impact on not only pig performance, health and welfare but also the environment.

Water Treatment Systems:
The majority of respondents indicated that they had tested their water in the last 12 months however it was important to note that 13 participants were part of the Ridley study in 2016. As such, many of these repeat participants quoted the Ridley 2016 study as the last time their water was tested. Twelve participants responded that they employed some form of routine water treatment. It was evident from their source water quality results that the water treatment programs had been implemented in response to known and on-going water quality issues. Treatments included, but were not limited to, chlorination, pulsing with organic acids, filtration, reverse osmosis and UV treatment. Benefits of implementing such systems were stated as being improved water management, pig growth rates and health status. These apparent benefits on pig performance and health warrant further investigation.

Water Medication Systems:
The survey findings indicated that over 75% of respondents were using water as a means to administer water-soluble additives and employed a water medication dosing system on farm to do so (Appendix 2). Respondents identified the benefits and challenges of drinking water medication as summarized in Table 7.

Table 7. Benefits and Challenges of Drinking Water Medication

Benefits & Advantages	Challenges & Limitations
Sick pigs continue to drink but may not eat	Equipment: cost, set-up, calibration, on-going maintenance & reliability
Rapid treatment in comparison to in-feed approach	Labour intensive and staff training
Ability to target sick animals	Water wastage
More cost effective and ease of use	Inaccurate dosing and ensuring antibiotics remain in solution

The findings of this survey and in particular the identification of the most commonly administered water-soluble antibiotics was used to inform subsequent laboratory studies (Section 3.2, Appendix 3).

Water Quality:
Water samples from the primary water source and at the point of consumption (drinker in the shed) were collected on the day of the survey. Laboratory analysis provided results across multiple parameters related to water quality with like factors being grouped where possible. All parameters were compared to an acceptable water quality standard for pigs (Table 8) established following a review of the available literature.

The percentage of farms not meeting the acceptable water quality standard for pigs is shown in Figure 4. It was notable that all samples (source and shed) collected from the farms surveyed failed to meet acceptable water quality standards in one or more criteria. Typically the percentage deviation from the standard measured in shed water was reflected and of a comparable level to that in the source water. However, a notable exception to this was observed in the microbiological levels which were detected at higher levels at the point of consumption (shed) compared to those detected at the source (Figure 5; Appendix 2). This result was surprising when considered in the context that over 75% of respondents had rated the hygiene of water at the source water and drinkers as being ‘good to excellent’.

Greater details of individual water quality parameters and the profile of each water source type are provided in Appendix 2 but of the individual water quality parameters pH, hardness, chloride, sodium, iron, manganese, *E. coli* and Total Coliform levels were found to frequently exceed the acceptable water quality standard. It was interesting to note that iron has been reported to support the growth of *E. coli* and Total Coliforms (Grandjean et al., 2005; Wingender & Flemming, 2011; Van Eenige, 2013). This relationship warrants further investigation particularly in the context of the current study observations.

Twelve participants indicated that they routinely conducted some form of water treatment. Assuming that treatment occurred post the source water collection point, it was possible to use this response and the corresponding laboratory analytical data to investigate the impact of water treatment on water quality (Figure 6). Not surprisingly, of the 75% of farms that responded ‘No’ they did not routinely treat water, no significant improvement in water quality or change in the percentage of samples being outside the acceptable water quality standard was observed. In contrast, an impact on water quality parameters was observed in those farms undertaking routine water treatment. It was identified that some parameters were reduced post-treatment compared to the standard (e.g. chloride, alkalinity, heavy metals, alkali metals and hardness) whereas some parameters increased (e.g. pH, ammonia, nitrate, sulphate, *E. coli* and Total Coliforms). Interestingly microbiological levels were higher at the drinker regardless of water treatment or not. The higher microbiological levels may be an indication of poor or ineffective water management between the source and the shed. It is feasible that the higher levels were due to contamination at the drinker by the pigs or water sampling errors however if this was the case it would be anticipated that the results at the drinker would be not as consistent as observed in this study. It was evident from the survey responses that cleaning practices were variable in terms of the cleaning strategies being applied and their frequency. Perhaps the higher microbiological levels in the shed is reflective of the presence of biofilms, a gelatinous layer of polymer matrix containing microbiota (bacteria, yeasts, protozoa) that forms on any hard surface (Rashid & Clark, n.d.; Wingender & Flemming, 2011). It is estimated that 90% of all bacteria live in biofilms (Lumb et al., 2017) with biofilms harboring pathogens such as *E. coli* and *Salmonella* spp. This observation warrants further investigation.

Table 8. Water Quality - An Acceptable Standard for Pigs

Group	Water Quality Parameter (mg/L unless otherwise stated)	Acceptable Standard for Pigs
Ammonia, Nitrate, Sulphate	Ammonia (as N)	≤ 1
	Nitrate (as N)	≤ 50
	Sulphate (as SO_4)	≤ 200
Chloride	Chloride	≤ 250
pH	pH	6.0 to 8.0
Alkalinity	Total As $CaCO_3$	≤ 300
Heavy Metals	Arsenic	≤ 0.2
	Cadmium	≤ 0.01
	Chromium	≤ 0.05
	Copper	≤ 0.5
	Iron	≤ 0.3
	Lead	≤ 0.05
	Manganese	≤ 0.1
	Mercury	≤ 0.002
	Nickel	≤ 0.1
	Zinc	≤ 2.0
Alkali Metals	Calcium	≤ 500
	Magnesium	≤ 150
	Potassium	≤ 30
	Sodium	≤ 150
Hardness	Equiv. $CaCO_3$	≤ 180
Microbiological (MPN/100ml)	*E. coli*	≤ 50
	Total coliforms	≤ 1,000

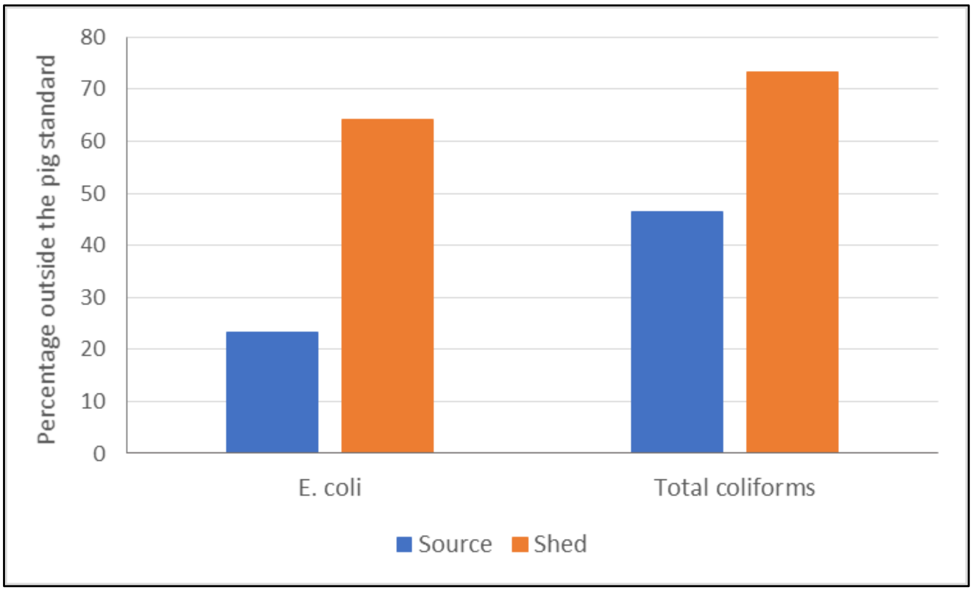

Figure 5. Percentage of Water Samples (Source and Shed) with Microbiological Levels Measured as being Outside the Acceptable Water Quality Standards for Pigs

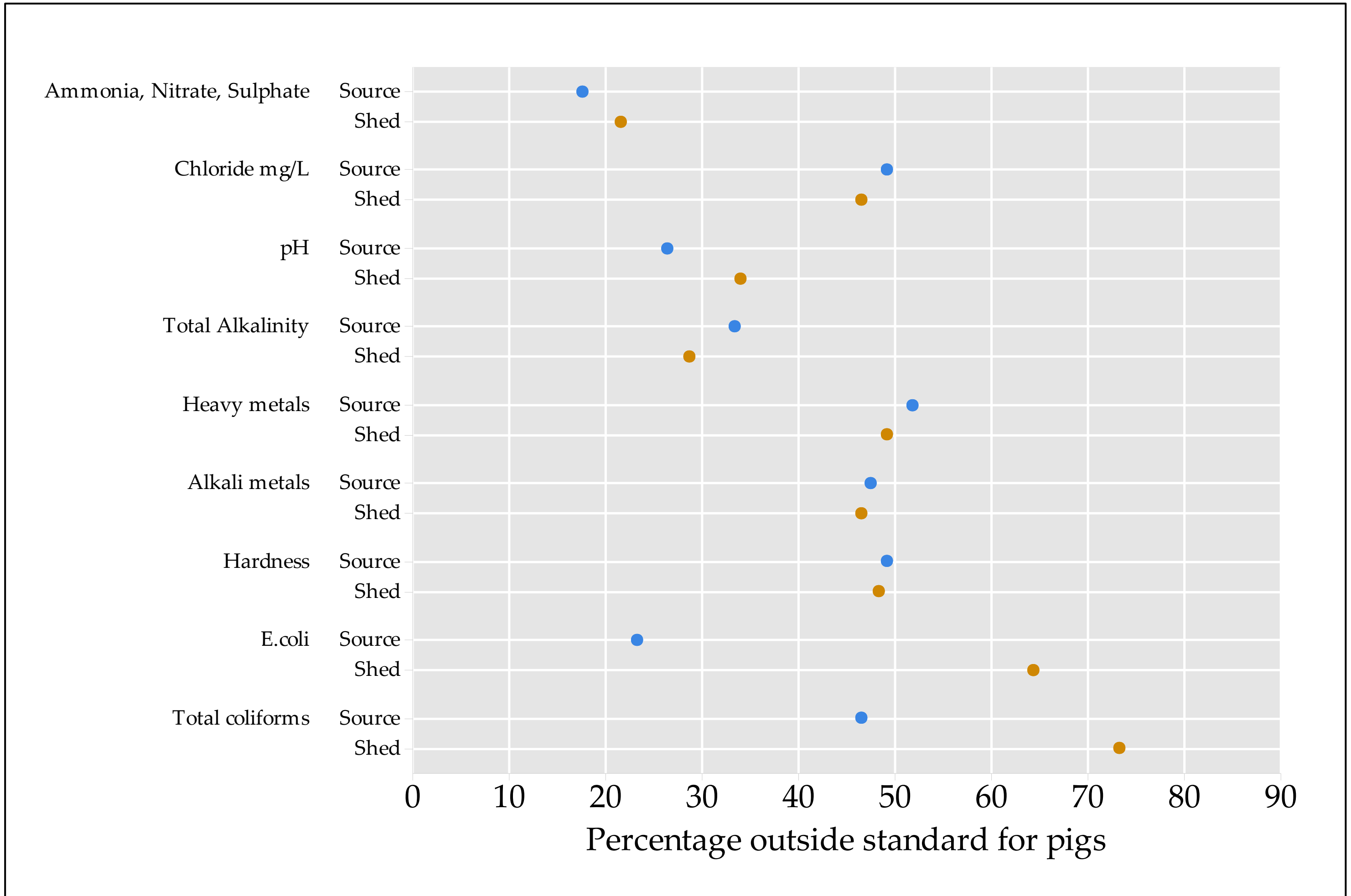

Figure 4. Percentage of Source and Shed Water Samples Outside the Acceptable Water Quality Standards for Pigs

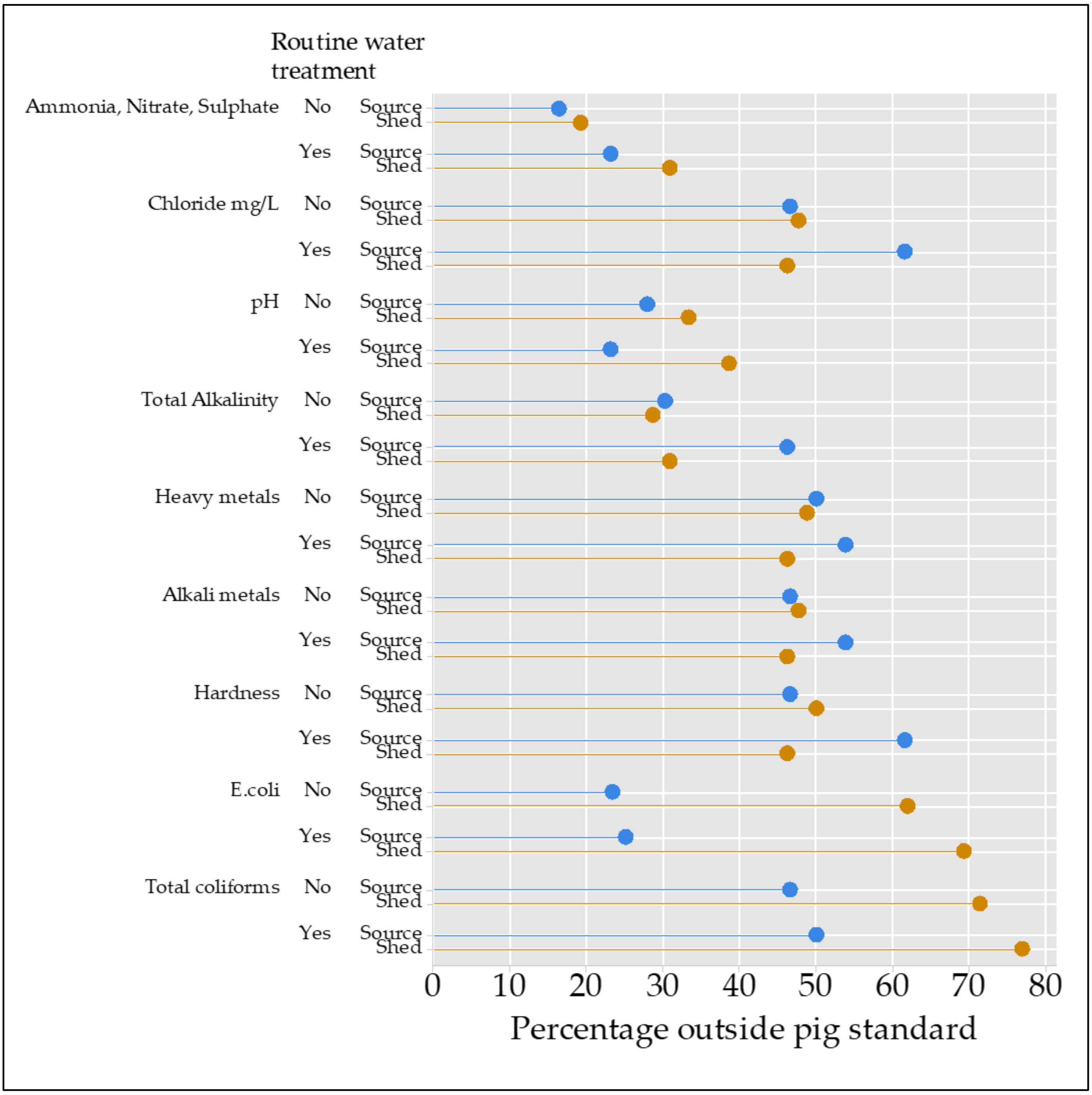

Figure 6: Percentage of Source and Shed Water Samples Outside the Acceptable Water Quality Standards for Pigs According to Routine Water Treatment

3.2 Preliminary Laboratory Studies to Evaluate the Impact of Water Quality on the Solubility of Commonly Used Veterinary Antibiotics

A summary of the findings are provided here with greater detail being provided in Appendix 3.

Solubility of Commonly Used Veterinary Antibiotics: Stock Concentration
Stock solutions were prepared in ultrapure water and the visual appearance recorded before and after a 24 hour incubation period. The results are shown in Table 9. In summary, concentrated preparations of Abbeylinc, Linco-Spectin and Tylovet dissolved to form a clear solution with no insoluble particles observed. In contrast, Sol-U-Mox, Abbey TMPS, Terramycin and Zamichlor did not completely dissolve with insoluble particles being observed in the freshly prepared stock solutions and after the 24 hour incubation.

Table 9. Solubility of Commonly Used Veterinary Antibiotics when Dissolved at Stock Concentration

Antibiotic	Time 0	Time 24h
Sol-U-Mox	Insoluble Particles	Insoluble Particles
Abbeylinc	Soluble	Soluble
Abbey TMPS	Insoluble Particles	Insoluble Particles
Terramycin	Insoluble Particles	Insoluble Particles
Zamichlor	Insoluble Particles	Insoluble Particles
Linco-Spectin	Soluble	Soluble
Tylovet	Soluble	Soluble

Solubility of Commonly Used Veterinary Antibiotics: Drinker Concentration
Using a similar approach, the solubility of antibiotics prepared to drinker concentration in 4 different water types was conducted. With the exception of the dam water, all other water sources were devoid of colour, odour and particulate matter. The turbidity of the dam water impacted the accuracy of the visual observations however, for the purposes of this innovation project and completeness, the dam water results have been included.

All of the commercial veterinary antibiotic products, with the exception of Zamichlor, were observed to have readily dissolved within 2 minutes of preparation. This was seen across all water types tested (Table 10). Following the 24 hour incubation minimal precipitation had occurred in the pure, bore or river water solutions. In contrast sediment accumulation was observed in all of the dam water antibiotic solutions. Images are provided in Appendix 3. It was of note that insoluble particles were also observed in the 'Terramycin – River', 'Sol-U-Mox – Bore' and 'Abbey TMPS – Bore' water solutions (Table 10, Appendix 3).

Table 10. Solubility of Commonly Used Veterinary Antibiotics when Dissolved at Drinker Concentration in Different Water Types

Antibiotic	Drinker Concentration (mg/ml)	Pure		Bore		Dam		River	
		Time to dissolve (secs)	Sediment layer (24h)	Time to dissolve (secs)	Sediment layer (24h)	Time to dissolve (secs)	Sediment layer (24h)	Time to dissolve (secs)	Sediment layer (24h)
Sol-U-Mox	0.123	120*	-	120*	+	120*	-	120*	-
Abbeylinc	0.042	<10	-	<10	-	<10	-	<10	-
Abbey TMPS	0.685	20*	-	20*	+++	30	++	20	-
Terramycin	0.331	20	-	20	-	30	++	30	+
Zamichlor	0.253	45	-	120	-	180	+++	120	-
Linco-Spectin	0.096	<10	-	20	-	25	+	15	-
Tylovet	0.250	<10	-	15	-	15	+	<10	-

*Very fine particles present; Sediment Layer: + = Thin; ++ = Moderate; +++ = Thick

Antibacterial Activity Testing
As shown in the images below all antibiotics tested demonstrated some degree of antibacterial activity however the degree to which they did varied between antibiotics and between preparation categories (Figure 7). The activity across fractions and upon dilution to the levels recommended at the drinker were highly variable and in some cases showed no inhibitory activity.

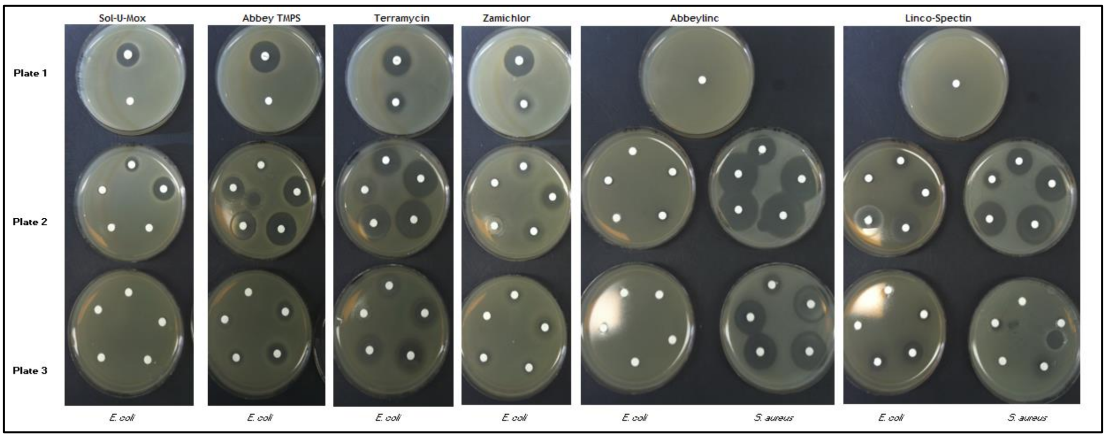

Plate 1 = Control + Unfractionated Ab, drinker concentration; Plate 2 = Fractionated Ab, no dilution; and Plate 3 = Fractionated Ab, x10 dilution

Figure 7. Antibacterial Activity Disc Diffusion Plates Showing Zones of Inhibition of Growth

The findings from this preliminary study warrant further investigation to assist veterinarians when prescribing the most appropriate antibiotics for animal health and welfare. It is recommended that further work is conducted to verify these findings in the laboratory and also investigate the in-field pharmacokinetics of commonly used veterinary chemical products delivered via water. From an antimicrobial stewardship perspective it is imperative that water-soluble antibiotics are delivered at the correct dose via the drinker to ensure maximum health and welfare benefits to the pig and economic value to the producer.

Summary of Results and Interpretation

- Water Quality Survey successfully conducted with the support of 57 industry participants representing 5 different states. Samples of water (source and shed) were collected from all participating properties for laboratory analysis. Bore water was found to be the most common source.

- The accessibility of shed water was extremely inconsistent across the farms surveyed in terms of the type of drinkers, or combinations in use, the number of drinkers per head, their height and their location within the shed including water flow rates. This is surprising given these factors influence behaviour and in turn impact pig performance, health and welfare (Australian Pork Limited, 2016; Brumm, 2010; Li et al., 2005; Gadd, 1988a; Gadd, 1998b). Should this inconsistency be regarded as a lack of awareness of the industry recommendations or perhaps impediments or barriers on farm which prevent their implementation?

- A review of the current literature as part of this study resulted in the development of an Acceptable Water Quality Standard for the Australian Pig Industry. Following completion of the Farm Water Survey all water quality results were compared to this standard. It was found that all farms surveyed failed to meet the Acceptable Water Quality Standard in one or more criteria. It has been demonstrated that water quality can affect feed intake and feed efficiency in pigs (McLeese et al., 1992; Nyachoti & Kiarie, 2010) and, although not within the scope of the current project, the question is now raised as to what the cost of sub-optimal water quality is to the Australian Pig Industry in terms of lost production efficiency, poor pig health or compromised welfare?

- Several water quality parameters were found to exceed the acceptable standard (pH, hardness, Cl, Na, Fe, Mn) but microbiological levels exhibited the most deviation. Interestingly, shed water was significantly more contaminated than the source. This observation was made irrespective of water source. This was surprising given participants rated their water and drinker hygiene as high in the farm water survey. Inconsistency in cleaning and sanitation practices across the farms surveyed was apparent suggesting that these results are indicative of sub-optimal water quality and/ or the presence of biofilm contamination. Aside from being a health risk, water is also a biosecurity risk and so the high microbiological levels reported are concerning. *E. coli* and Total Coliforms should be considered as water quality parameters of concern and their regular monitoring is recommended. Other parameters to consider for regular monitoring include pH, hardness, Cl, Na, Fe and Mn.

- Despite the poor water quality only a relatively small number of participants had implemented water treatment systems. The results from this survey suggest that water treatment systems were variable in how they improved water quality. It is important to recognize that the functionality of the systems at the time of the survey was not known. A number of barriers to invest in the implementation of treatment systems were identified however benefits nominated included improved growth rates and health status. Although anecdotal, these apparent production efficiencies warrant further investigation. In conclusion, physical cleaning and sanitization of the pipe-lines may be the best initial step before investment is made.

- While only a small number of farms had invested in water treatment systems, over 75% of participants administered antibiotics via a dosing medication system. This is surprising given the negative impact that water quality parameters can have on the properties of antibiotics (Dorr et al., 2009, Felix et al., 2016). A number of comments were made around the difficulty in handling water-soluble antibiotics. Although preliminary, the findings of the laboratory study within this report do indicate that poor water quality negatively impacts the effective and appropriate delivery of antibiotics via drinking water. Indeed, the solubility, stability and antibacterial activity properties of several commercially available veterinary antibiotics appeared to be compromised when prepared in water from different sources of varying quality. These initial observation warrant further investigation particularly when viewed through the lens of antimicrobial stewardship.

4. Application of Research

4.1. Potential benefits to cost of production

- Although this study focused on generating an understanding of the quality of water and its management in the Australian Pig Industry, there have been a number of studies which have reported the impact of poor water management (number of drinkers, their heights, flow-rate) and water quality on pig performance (Anderson et al., 2016; Brumm, 2010; Li et al., 2005; Nyachoti & Kiarie, 2010). There is an obvious impact on farm economics if pigs are not able to perform to their genetic potential notwithstanding the economic losses and environmental impacts relating to excessive water wastage or in turn savings if water is managed effectively. This study has raised an awareness of the importance of water quality and the need to test it regularly. Further research is needed to understand the true economic impact of sub-optimal water quality and management on pig performance, health and welfare.

- Research has shown that a drop in water intake which is sustained over 1-3 days is an early indicator of pig health issues (Anderson et al., 2016; Brumm, 2010; Lumb et al., 2017). By closely monitoring pig behaviour and water consumption, Australian producers may have the ability to identify health stresses or resource limitations before they compromise pig performance, health or welfare and in turn farm economics.

- The Farm Water Survey revealed that only 12 participants had implemented a water treatment system but that most farms had a system in place to water medicate. Research is needed to understand water management best practices and determine the most cost-effective water treatments in response to common water quality problems. This information can then be used to ensure appropriate administration of antibiotics in the form of a stewardship decision-making tool. Indeed, by optimising water quality and management it may be possible to reduce reliance on the administration of water-soluble antibiotics. This would be a positive outcome and additionally may reduce a cost of production.

4.2. Ease of Adoption by Producers and Impact of the Research

This study combined with that of Ridley (2016) has raised industry awareness about the importance of water. The impact of water quality and desire to adopt improvements was evident in the response from producers when providing feedback on their individual water quality results particularly when water was determined to be of sub-optimal quality. This study has highlighted our lack of knowledge within a commercial setting and as such more research is required to evaluate the cost-benefit of improving water quality, its management and treatment on the Australian Pig Industry. Given water is a basic input in any production system and the displayed propensity by Australian producers for improvement gains it is anticipated that the following steps could easily be adopted in the interim with far-reaching and quickly realized benefits:

- All Australian Pig Producers should test the quality of the water source and at the point of consumption and compare them to the 'Acceptable Water Quality Standards for Pigs'. Primary parameters to be tested include: Microbiological (*E. coli*, Total Coliforms), pH, hardness, Cl, Na, Fe and Mn.

- It is important that water testing is conducted at regular intervals. If results do not exceed the acceptable standard, then only the microbiological levels need to be regularly monitored. If required, seek expert advice (nutritionist, veterinarian and/or animal health advisor).

- It is imperative that the water system is well-maintained and regularly cleaned. A Water Management Audit is strongly recommended particularly if water quality results consistently exceed the standard. Use of the Survey Questionnaire as a guide to focus on water access and management practices on farm is recommended. As part of this audit the regular testing of flow rate at the drinker should be considered as a quick and easy check to ensure pig water intake is optimised and water wastage is minimised. This is particularly important if water is being used as a pathway for the administration of water-soluble additives such as vaccines and antibiotics.

- Ensure regular and effective cleaning practices are in place that are effective in the removal of biofilms. Regular water quality testing of microbiological parameters and an examination of internal water pipework and associated infrastructure will provide confirmation of effective biofilm removal.

- If the primary water source is unacceptable then treatment is required; treatments may include filtration, ion exchange, reverse osmosis, UV treatment and/or chemical dosing. Acidification is another possible treatment but it is more cost-effective to acidify isolated parts rather than the whole water system.

- If antibiotics are being administered via drinking water, ensure water quality and its management are optimal to drive appropriate delivery fitting with antimicrobial stewardship

5. Conclusion

Water is the first nutrient with the overall efficiency of an animal production facility being intricately linked to the ability to provide a clean and plentiful water supply of optimal mineral, microbiological and chemical composition. The provision and maintenance of water quality is key to preventing adverse health and production effects. Indeed, it may be possible to use water quality as a baseline measure and predictor of animal health. Having a clean and fully functioning water delivery system is important if it is to be used for the delivery of in-water medications (including antimicrobials, vaccines and parasiticides). Clean water is an essential good practice for animal welfare, biosecurity, antimicrobial stewardship and production economics.

The outcomes of this study have shown that the Australian Pig Industry is faced with variable water quality with the economic impacts on productivity and pig health and welfare at this stage unknown. This survey demonstrated that water is indeed, the forgotten nutrient, with inconsistent management and cleaning practices appearing to result in sub-optimal quality at the point of consumption. The microbiological load in the shed was significantly higher than that measured at the source. Considering water is a biosecurity risk these results support the recommendation that farm drinking water should be regularly monitored. Industry guidelines, akin to the Poultry Industry, are needed. An awareness of water quality and in particular microbiological load, coupled with a regular and targeted cleaning program will likely result in significant production efficiency gains. For not much outlay, the returns on investment are attractive and yet, often remain unconsidered as an important part of an integrated farm management approach.

The quantity and quality of drinking water is vital to maintain pig health and ensure they perform to their biological maximum but it is also a valuable pathway to administer water-soluble antibiotics. A large proportion of participants were deemed to be medicating via the drinking water which was shown to be of sub-optimal quality. Many participants commented on the value of drinking water medication and talked about the challenges of preparing a stock solution but did not appear to link this observation to potential water quality issues. Preliminary findings investigated the effectiveness of administering water-soluble antibiotics via the drinking water indicated that water quality had a negative impact. As part of the industry antimicrobial stewardship strategy (Australian Pork Limited, 2017), further research is needed to ensure that water medication administration is an appropriate use of antibiotics.

6. Limitations/Risks

- Although 57 individual producers voluntarily participated in this study, the findings only represent a small part of the industry and a snap-shot in time. Despite being only a small sub-set of data, it was possible to determine from the farms that participated in both this and the Ridley 2016 study that water quality remained relatively consistent over time. It is important to note that consistency means where specific parameters were outside acceptable levels in 2016 they were found to be still outside the standard from the results of the current study.

- The Farm Water Survey questionnaire relied on self-assessment and thus, assumed all participants interpreted the questions in the same way and responded as clearly as possible. Although many issues were ironed out as part of the Ridley 2016 survey, there was still the potential for the misinterpretation of questions. The subjective nature of the responses must be considered before drawing any conclusions and as such there are limitations to the interpretations of the results. A long-term case study approach would resolve some of these uncertainties and provide an understanding of on-going water quality and farm management practices over multiple time-points.

- Part of the Farm Water survey required participants to measure aspects of shed infrastructure such as shed dimensions, drinker heights, distance between drinkers etc. The breadth of results and units used brought into question the validity of some of the observations. Despite this, it was clear that there was inconsistency across the industry in water management and presentation to the animal. The accuracy of water flow rates was reasonably good however there were some outliers which were not presented. However water management practices did appear to be inconsistent across farms with no apparent adherence to an industry standard.

- The water quality assessment was reliant on the participants taking representative samples of both the source and shed water while following all instruction and the samples arriving at the laboratory within 24 hours. Despite this potential for error, the assessment of water quality provided some valuable insights in to the variability of water quality across the industry however how representative this is of on-going water quality issues within the industry remains unanswered. Regardless, a consistent question asked by participants on receipt of their water quality results in comparison to the ‘Acceptable Water Quality Standard for Pigs’ was “What does this mean?” and “What should I do?”

- The results of the preliminary laboratory study were interesting however there are limitations to their interpretation due to the low number of replicates. The study has however raised a number of important research questions for future investigation.

- Statistical analysis was limited due to the nature of the observations and small number of replicates.

- The study did not provide any quantitative data or understanding of what the impact of poor water quality or indeed, what the benefit, if any, of improving water quality is on pig performance, health or welfare. Water treatment systems are expensive and it might be that simple, low cost management, regular cleaning & sanitation programs yield a much higher reward for effort/cost.

- The higher microbiological levels at the drinker in comparison to the source was concerning. It is noted that due to the foraging behaviour of pigs there is an increased risk of drinkers and troughs becoming contaminated, however if this was the sole cause of the contamination observed in this study one would expect the higher microbiological levels observed to be sporadic rather than the consistent results that were detected. Furthermore, it was observed that the microbiological results were consistent across the 13 farms participating in both the current study and that conducted by Ridley (2016). Interestingly, those piggeries that presented with low or acceptable micro-biological levels were found consistently across the two studies. It would be valuable to revisit these farms to understand what their cleaning and water management practices are.

7. Recommendations

As a result of the outcomes from this study, the following recommendations have been made:

- Refresh and/or Develop Industry Fact Sheets on water quality and management. Review of the National Water Biosecurity Manual Poultry Production as part of this recommendation would be valuable, as would the addition of the research findings identified below. Support the release of these Fact Sheets with targeted extension activities to ensure greater awareness and uptake. Australian pig producers can implement some simple steps which can have far-reaching effects on pig performance and quickly realized benefits in terms of the economic outcome of their businesses.

- Further understand which specific water quality parameters provide an indication of water quality and/or are a risk to pig performance within a commercial setting so testing and decision-making can be targeted.

- Quantify the impact of water quality and management on pig productivity, health and welfare in a commercial setting. It is important to understand which quality parameters are fundamental to pig health and performance. General commentary infers that pigs can “tolerate” a wide range of different water qualities but what is the impact of this and how much productivity is being lost? An observational study on specific piggeries as informed by the current survey will assist part-way in answering this question.

- Conduct case studies on selected farms from the survey to establish water management best practices and determine the most cost-effective water treatments in response to common water quality problems.

- Sub-optimal water quality has been shown to have detrimental effects on antibiotic stability and in turn efficacy which is of particular importance when considering the threat of antimicrobial resistance (Australia's First National Antimicrobial Resistance Strategy 2015-2019) and industry antimicrobial stewardship frameworks (Australian Pork Limited, 2017). A valuable next step would be to build on the current laboratory studies to further investigate the effect of water quality and management on appropriate delivery of water-soluble antibiotics to ensure antimicrobial stewardship. In parallel with these laboratory studies, medication delivery must be evaluated in a commercial setting to develop best practice. These findings could be modelled to generate cost-benefit strategies focussing on water management, delivery, quality and antimicrobial stewardship to ensure appropriate administration of antibiotics. When coupled with a medicated in-feed decision-making tool this would be a powerful antimicrobial stewardship model for not only the Australian Pig Industry but also as a transferable model applicable to other animal sectors both domestically and internationally.

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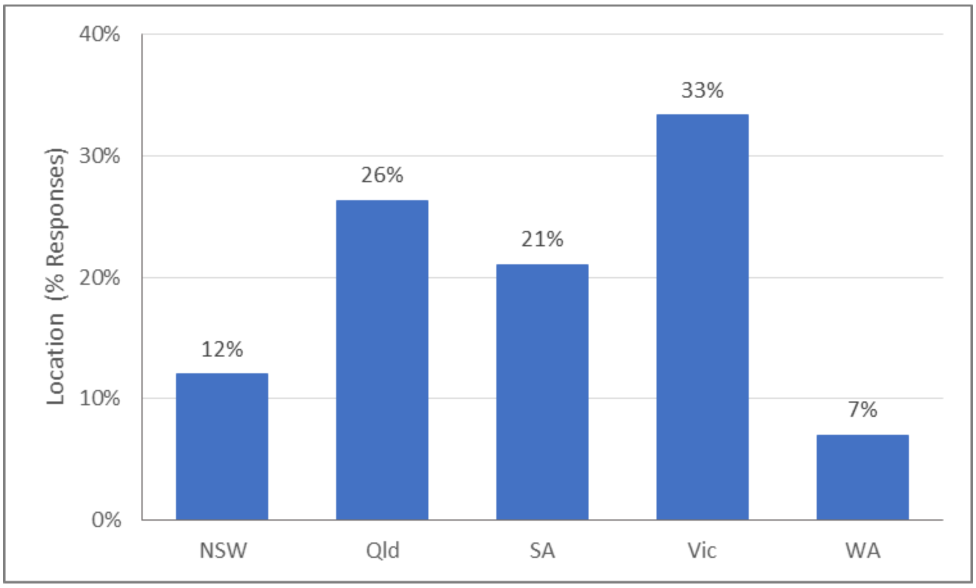
Appendix 2: *Farm Water Quality Survey*

The Farm Water Survey was conducted between October 2017 and March 2018. Detailed responses to the survey questions are summarized below:

Australian State/Territory in which the respondent (piggery) was located:

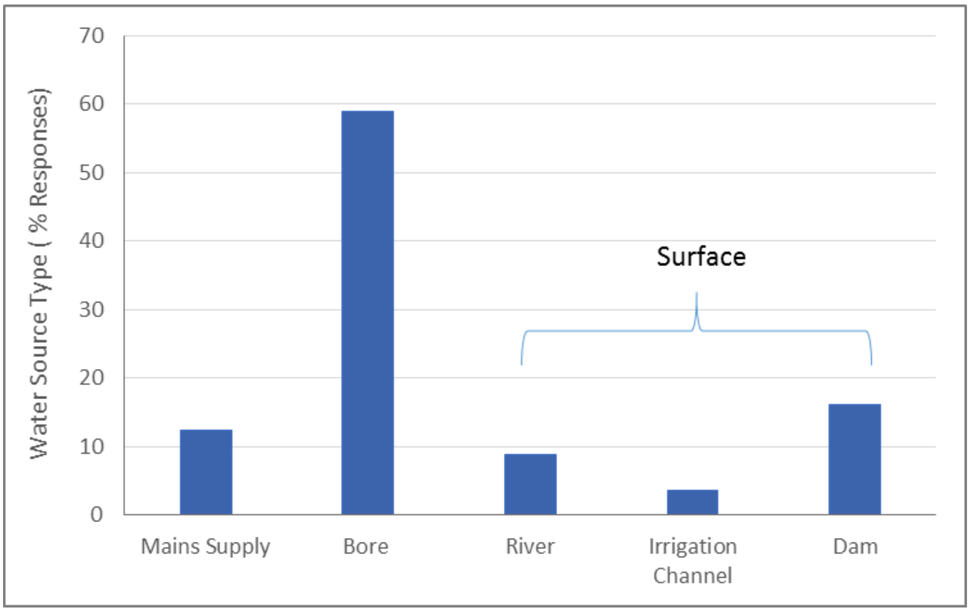
Answer Choices	Location
Australian Capital Territory	0
New South Wales	7
Northern Territory	0
Queensland	15
South Australia	12
Victoria	19
Western Australia	4
Total	**57**

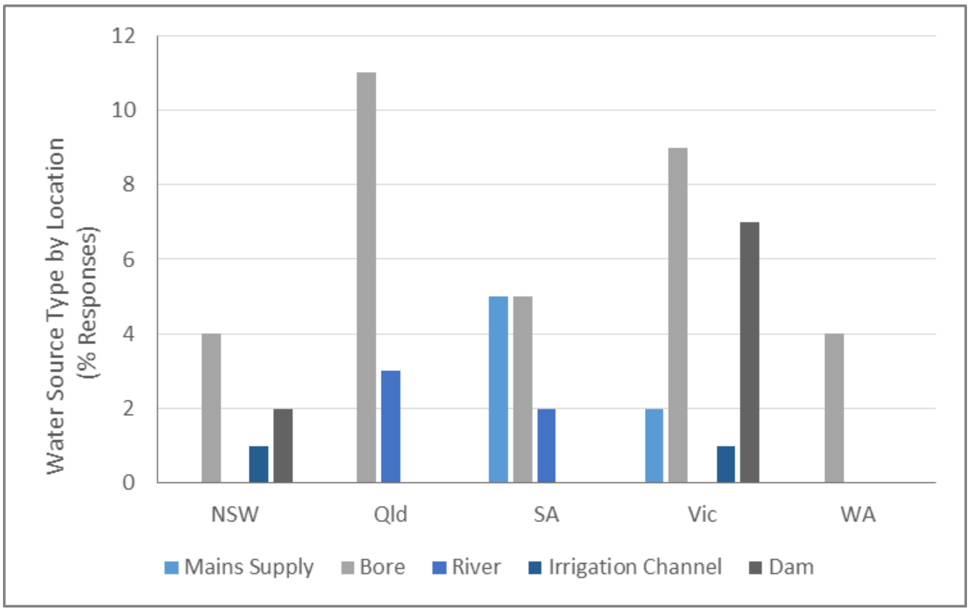


No piggeries responded to the industry call-out from Tasmania, the Australian Capital Territory or the Northern Territories.

Part 1. Source of drinking water available for use
Source(s) of drinking water available:

Answer Choices	Responses (%)	Number of Responses
Mains Supply	12.5	7
Bore	58.9	33
River	8.9	5
Irrigation Channel	3.6	2
Dam	16.1	9
	Answered	56
	Skipped	1



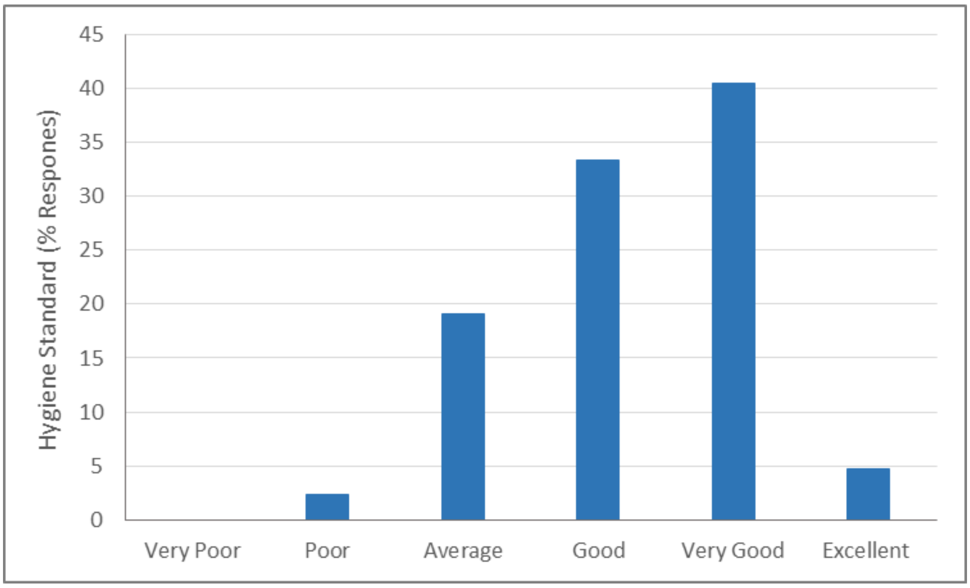


The majority of farms surveyed had one primary water source. The temperature of these sources ranged from 8 to 38°C on the day of the survey. Most farms drawing bore water as their primary source also had a secondary water source available. In all cases, the primary bore was the predominant source of water being utilized.

Rate the hygiene standard of the main water source:

Answer Choices	Responses (%)	Number of Responses
Very Poor	0	0
Poor	2.4	1
Average	19.0	8
Good	33.3	14
Very Good	40.5	17
Excellent	4.8	2
	Answered	42
	Skipped	15

It is important to note that this is a subjective analysis of water source quality, the results of which are interesting when compared to the results of the quantitative water analysis.

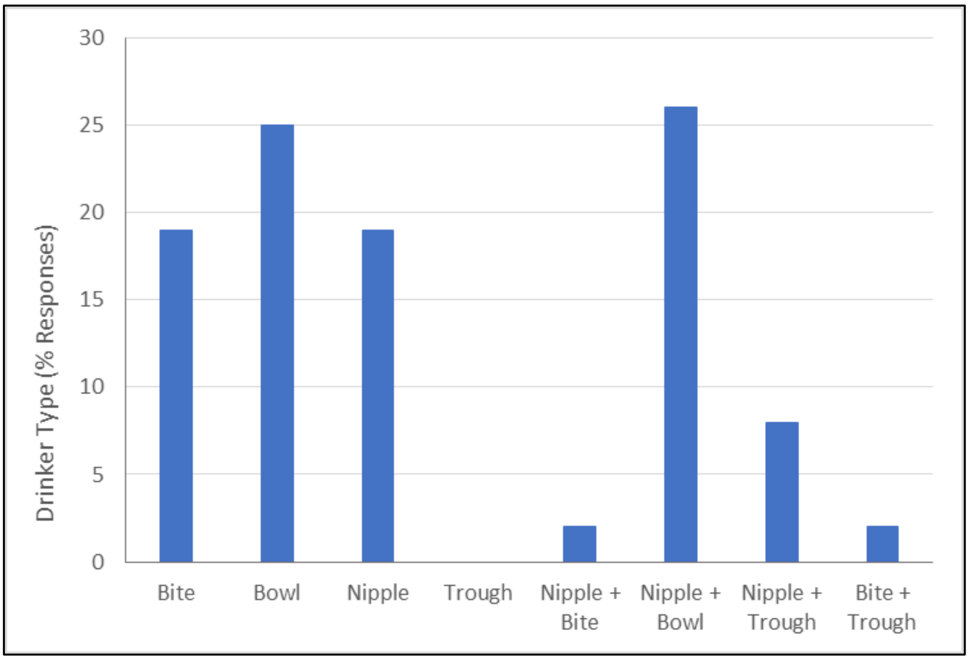


Part 2. Drinking water availability

Participants were asked to select a grower pig pen furthest away from the main drinking water source and then asked to answer a series of questions which focused on pen set-up and in turn drinking water availability. It is important to note that many of the answers given in this part of the survey were subjective and open to error. In addition, not all producers selected a grower shed. The main water pipe from the source to the shed was typically PVC, 50-100mm in diameter and uninsulated. These details were similar for the piping leading from the shed to the drinker with the exception of it being of a smaller diameter (25-50mm).

Type of Drinker. Participants were asked to circle the main drinker type (Nipple, Bite, Bowl or Trough) in use in the nominated shed:

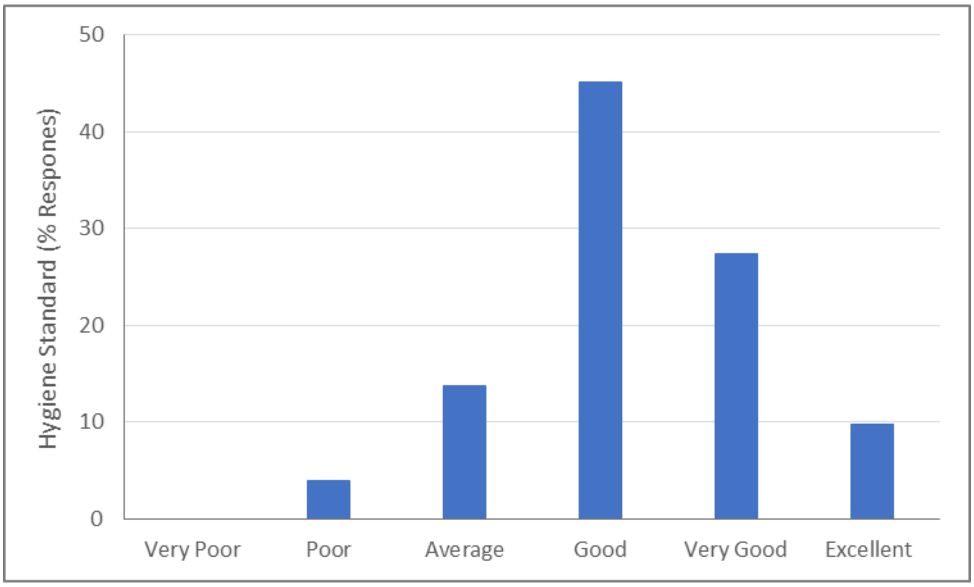
Answer Choices	Responses (%)	Number of Responses
Nipple	18.9	10
Bite	18.9	10
Bowl	25	13
Trough	0	0
Nipple + Bite	1.9	1
Nipple + Bowl	26.4	14
Nipple + Trough	7.5	4
Bite + Trough	1.9	1
	Answered	53
	Skipped	4



Although respondents were asked to circle one drinker type it was evident from the nature of the results that multiple drinker types appear to be in use. Participants were also asked to answer questions on the number of drinkers in the shed, their height and distribution. There was a large variation in responses which requires further investigation in order to provide guidance to the industry.

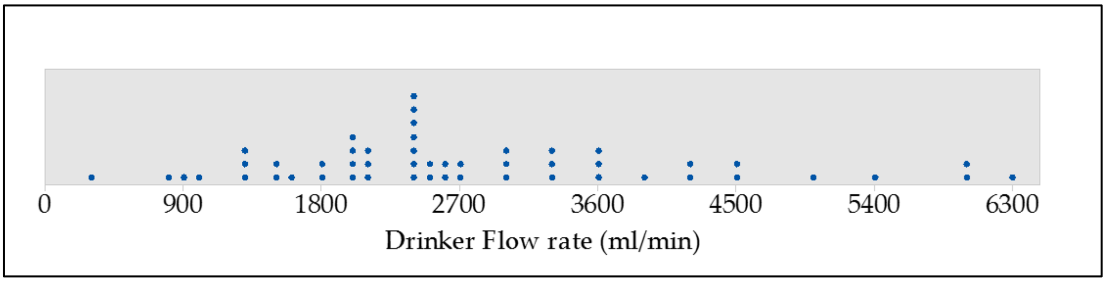
Level of drinker cleanliness:

Answer Choices	Responses (%)	Number of Responses
Very Poor	0	0
Poor	3.9	2
Fair	13.7	7
Good	45.1	23
Very Good	27.5	14
Excellent	9.8	5
	Answered	51
	Skipped	6



Although subjective, over 75% of producers rated drinker hygiene as good to excellent.

Drinker Flow Rate:

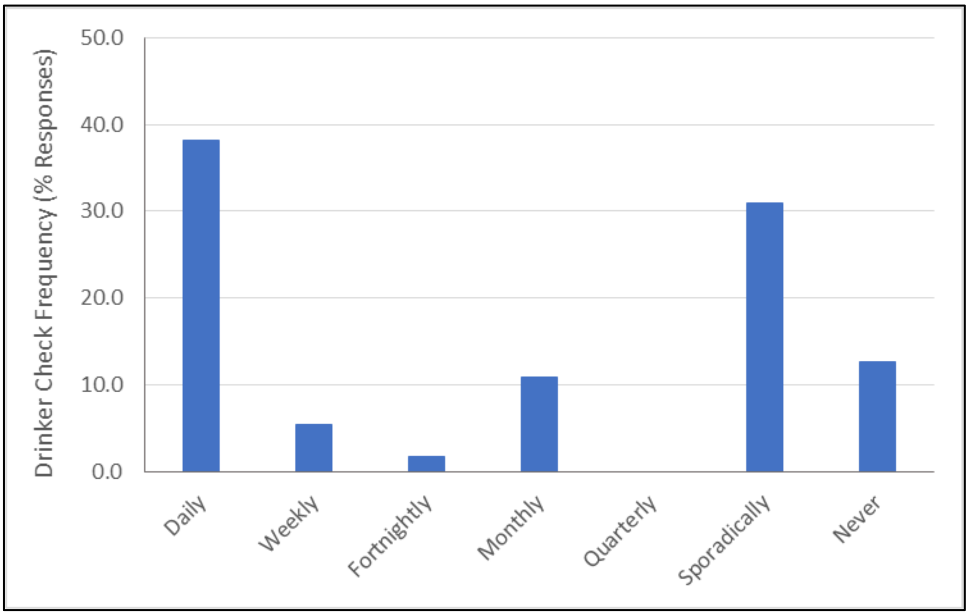


Drinker flow rates were found to be highly variable across the piggeries surveyed as shown below. Each dot represents one piggery. There was no apparent correlation between flow rate and drinker type. Participants were asked questions around water wastage. The majority of respondents indicated that they did not have leaking pipes or infrastructure but did comment that there was water wastage around the drinkers due to pig behaviour.

Part 3. Drinking water system cleaning and maintenance regime

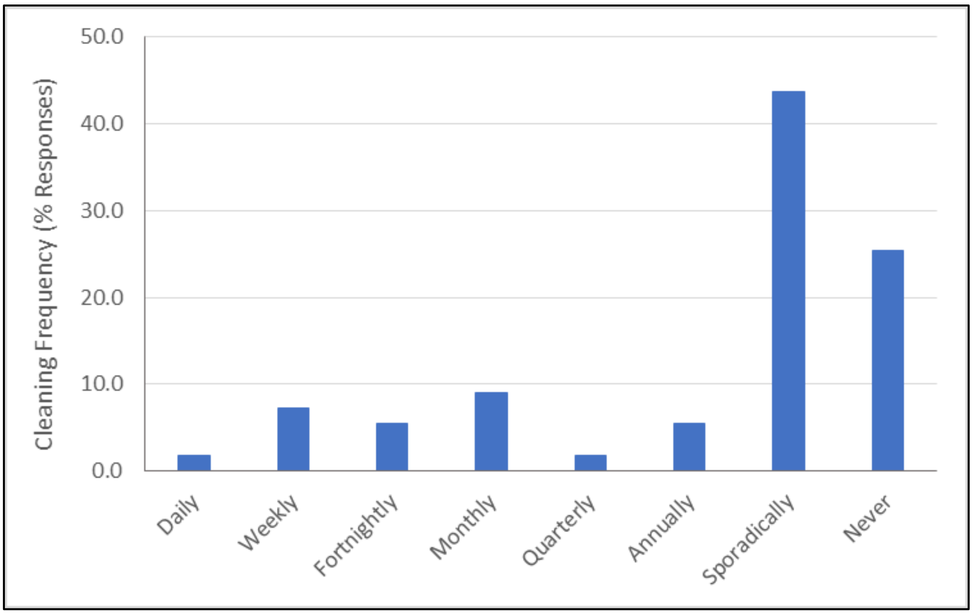
How often are flow rates of drinkers in pens checked?

Answer Choices	Responses (%)	Number of Responses
Daily	38.2	21
Weekly	5.5	3
Fortnightly	1.8	1
Monthly	10.9	6
Quarterly	0	0
Sporadically	30.9	17
Never	12.7	7
	Answered	55
	Skipped	2



How often is the complete water line (including drinkers, pipes and header tanks) cleaned and flushed?

Answer Choices	Responses (%)	Number of Responses
Daily	1.8	1
Weekly	7.3	4
Fortnightly	5.5	3
Monthly	9.1	5
Quarterly	1.8	1
Sporadically	43.6	24
Annually	5.5	3
Never	25.5	14
	Answered	55
	Skipped	2



Where the response ‘sporadically’ was given this was defined as meaning between every batch. The cleaning practices used included:

- Flush with water
- High pressure flush
- Use of organic acids and/or chlorine as a flushing/cleaning agent

If drinker bowls or troughs are used in the pens, are they thoroughly cleaned between each batch of pigs?

Answer Choices	Responses (%)	Number of Responses
Yes	72.9	35
No	27.1	13
	Answered	48
	Skipped	9

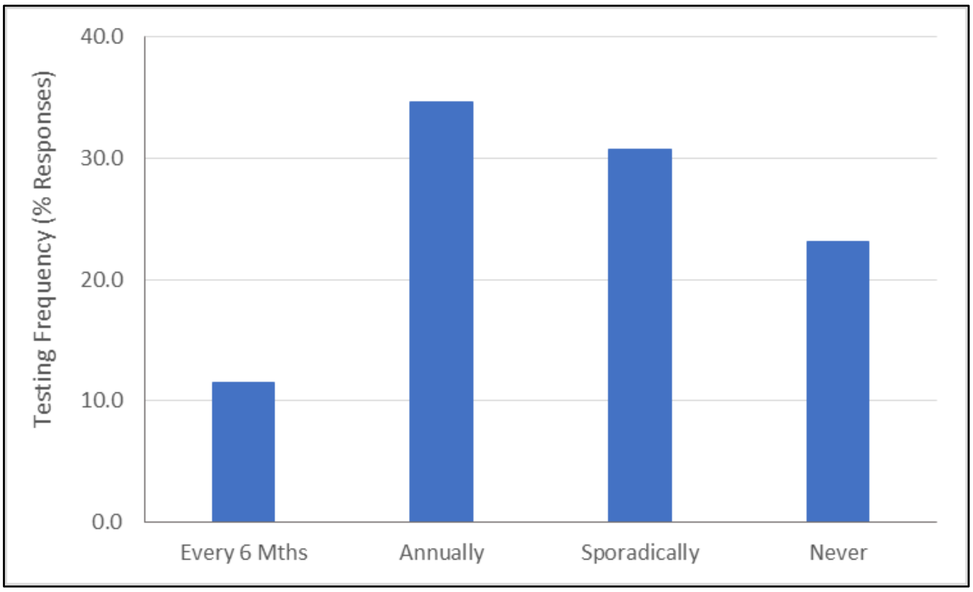
Are header tanks covered to prevent entry/ contamination by birds etc.?

Answer Choices	Responses (%)	Number of Responses
Yes	77.7	33
No	23.3	10
	Answered	43
	Skipped	14

Part 4 Water Quality Testing

Is the quality of farm’s drinking water tested? If yes, how frequently?

Answer Choices	Responses (%)	Number of Responses
Half-yearly	11.5	6
Yearly	34.6	18
Sporadically	30.8	16
Never	23.1	12
	Answered	52
	Skipped	5



Part 5 Water treatment system

Is drinking water routinely treated in any way?

Answer Choices	Responses (%)	Number of Responses
Yes	21.4	12
No	78.6	44
	Answered	56
	Skipped	1

The following list describes the different types of water treatments being applied:

- Chlorination
- Filtration
- Magnetisation
- Pulse with organic acids
- Reverse Osmosis
- Ultra-Violet Light

Survey participants were asked what their main motivation for installing a water treatment system was. It was evident that installation was due to on-going and known water quality issues. When asked what benefits implementation of the system had been only a small number of producers responded. Improved water management, pig growth rates and health status were cited as being benefits and although low in number, these perceived benefits warrant further investigation.

Part 6. Water use to administer medications

Does the farm have a water medication system, which enables antibiotics and other additives to be administered to pigs via drinking water?

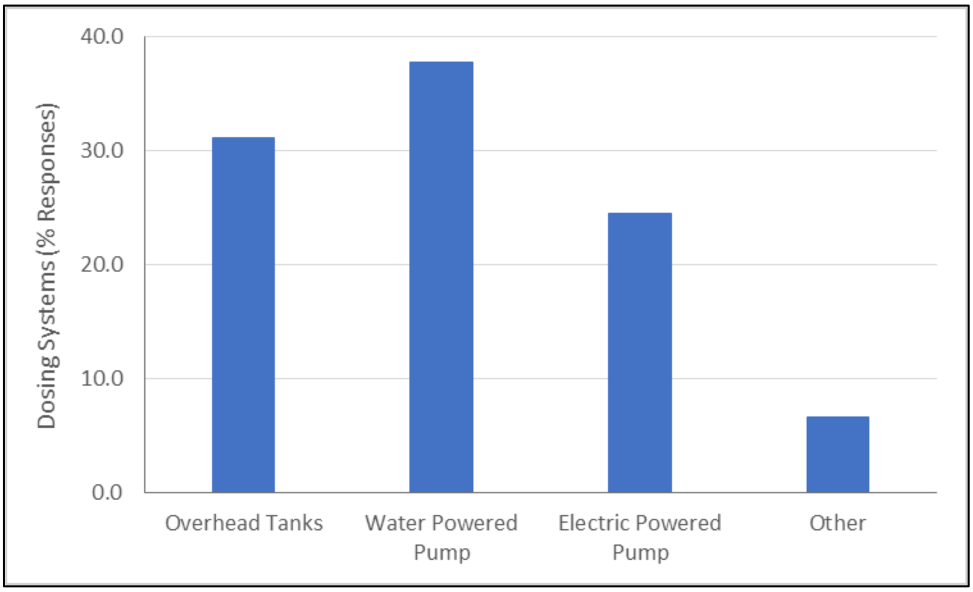
Answer Choices	Responses (%)	Number of Responses
Yes	77.2	44
No	22.8	13
	Answered	57
	Skipped	0

The majority of farms have a water medication dosing system on farm. Of those that did not, the main reasons were:

- Cost of dosing systems
- Preference for in-feed medication
- Inadequate water management infrastructure
- Concerns about water wastage

What dosing system equipment is used?

Answer Choices	Responses (%)	Number of Responses
Overhead tanks for batch mixing	31.1	14
Water powered proportional pumps e.g. Gator, Dosatron	37.8	17
Electric powered, computer controlled dosing pumps e.g. Select 640	24.4	11
Other	6.7	3
	Answered	45
	Skipped	12



Of the 45 participants who responded that they had a dosing system on farm, 41 provided details of which water-soluble antibiotics were being administered via the water medication systems and are listed below:

Amoxycillin	Oxytetracycline
Apramycin	Spectinomycin
Chlortetracycline	Tiamulin
Florfenicol	Tilmicosin
Lincomycin	Trimethoprim/Sulfadiazine
Neomycin	Tylosin

From the survey responses it was determined that the most frequently nominated antibiotic being delivered via drinking water was amoxycillin. This is interesting given its current registration status. Other water-soluble additives delivered included electrolytes, sweeteners, flavours, parasiticides and organic acids. In many cases the pH of the water was being adjusted to assist in preparation of the antibiotic stick solution.

Respondents were asked to comment on the main strengths and weaknesses of medicating pigs via drinking water. Comments summarized below:

Strengths & Advantages	Limitations & Challenges
Sick pigs continue to drink but may not eat	Equipment: cost, set-up, calibration, on-going maintenance & reliability
Rapid treatment in comparison to in-feed approach	Labour intensive and staff training
Ability to target sick animals	Water wastage
More cost effective and ease of use	Inaccurate dosing and ensuring antibiotics remain in solution

Water Quality:

In all cases, water samples from the primary water source and at the point of consumption (drinker in the shed) were collected on the day of the survey. Laboratory analysis provided results for 23 water quality parameters. Where possible like parameters were grouped. All parameters measured were compared to the 'Acceptable Water Quality Standard for Pigs' which was established following a review of the current literature (Table 1). The ranges of parameters measured are shown however, unless stated, the analyses provided in this report are based on detection of any one parameter within a group falling outside the pig standard.

Table 1. Ranges of Water Quality Parameters Measured on Surveyed Australian Pig Farms Compared to the Acceptable Standard for Pigs

Group	Water Quality Parameter (mg/L unless otherwise stated)	Acceptable* Standard for Pigs	Range Observed in the Survey Source	Range Observed in the Survey Shed
Ammonia, Nitrate, Sulphate	Ammonia (as N)	≤ 1	< 0.01 – 4.8	< 0.01 – 19
	Nitrate (as N)	≤ 50	< 0.02 - 86	< 0.02 - 80
	Sulphate (as SO_4)	≤ 200	< 5 - 770	< 5 - 410
Chloride	Chloride	≤ 250	5 - 4600	13 - 2800
pH	pH	6.0 - 8.0	6.2 – 9.3	3.9 – 9.0
Alkalinity	Total As $CaCO_3$	≤ 300	< 20 - 1800	< 20 - 1400
Heavy Metals	Arsenic	≤ 0.2	< 0.001 – 0.059	< 0.001 – 0.043
	Cadmium	≤ 0.01	< 0.0002	< 0.0036
	Chromium	≤ 0.05	< 0.001 - 0.042	< 0.001 - 0.030
	Copper	≤ 0.5	< 0.001 - 0.058	< 0.001 - 0.98
	Iron	≤ 0.3	< 0.05 - 43	< 0.05 - 25
	Lead	≤ 0.05	< 0.001 – 0.049	< 0.001 – 0.34
	Manganese	≤ 0.1	< 0.005 – 1.2	< 0.005 – 1.5
	Mercury	≤ 0.002	< 0.0002	<0.0002
	Nickel	≤ 0.1	< 0.001 -0.02	< 0.001 - 0.086
	Zinc	≤ 2.0	< 0.005 – 0.44	< 0.005 – 1.3
Alkali Metals	Calcium	≤ 500	0.9 - 300	< 1 - 290
	Magnesium	≤ 150	< 0.5 - 470	< 0.5 - 300
	Potassium	≤ 30	< 0.5 – 45	< 0.5 – 45
	Sodium	≤ 150	4.7 - 2300	5.7 - 1500
Hardness	Equiv. $CaCO_3$	≤ 180	< 5 - 2700	< 5 - 1700
Microbiological (MPN/100ml)	*E. coli*	≤ 50	< 1 - > 2400	< 1 - 14000
	Total coliforms	≤ 1,000	< 1 - > 24000	< 1 - > 24000

*Acceptable Standard for Pigs based on a review of the literature and presented in the introduction of this report.

Of concern were the piggeries where parameters (e.g. sulphate, chloride, iron, manganese, magnesium, sodium, hardness, *E. coli* and Total Coliforms) were measured at levels well above those published and recommended in this study as being acceptable (refer to section 1.3). Parameters found to be high in the source were typically also elevated at the drinker. Refer to Section 1.3 for a summary of water quality parameters and impact of high levels. Although out of scope for this

Innovation Project, it would be valuable to revisit the impacted farms to determine if these observations persisted and what the impact on water management and in turn pig health and performance was.

The percentage of farms outside the standard, at the source and at the shed, for each water quality parameter groups are shown in Figure 1 with 95% Confidence Intervals represented in Figure 2. It was apparent that no water quality group for either the source or drinking water samples tested in the survey met the acceptable water quality standards for pigs. Typically, the source and shed sources were of a comparable water quality profile. Indeed in all groups, with the exception of microbiological levels, the percentage of farms outside the quality standard was consistent between the two water sources (Figure 3). Iron, manganese and sodium were typically found to exceed the pig water quality standards (Table 1 & Figure 3). In contrast, microbiological levels while exceeding the pig water quality standards were also found to be significantly higher at the drinker compared to the source or point of entry on to the farm (Figure 4, Table 1).

Table 2 provides a comparative statistical analysis of the microbiological levels in the source and the drinker with *P*-values shown from McNemar's test of the difference of paired proportions.

Table 2. Difference in Percentage of Farms Outside the Acceptable Water Quality Standards for Pigs (Source minus Shed)

Group	% Outside the Standard		% Difference in Farms Outside the Standard (Source - Shed)		
	Source	Shed	Estimate	95% CI	*P*-value*
E. coli	22.82	65.45	-43.64	-61.20, -26.07	< 0.0001
Total coliforms	45.45	72.73	-27.27	-45.39, -9.16	0.004

*McNemar's test of the difference of paired proportions.

As the water source type was known from the farm questionnaire it was possible to group the data into one of three categories: bore, mains supply or surface. This grouping revealed some differences in the water quality profile of the 3 water sources (Figure 5). For example, the chloride standard was exceeded in over 70% of farms surveyed that sourced water from bores, compared with less than 20% of the farms that used surface or mains supply. Typically farms with bore water also exceeded the water quality standards for total alkalinity, alkaline metals and hardness. In contrast farms sourcing surface water typically had heavy metal (62.5%) and Total Coliform (68.8%) levels exceeding the pig water quality standard. Although farms on mains water supply were found to be outside the water quality standards, the percentage of farms was generally lower. Indeed, no farms being supplied by mains water were outside the pig standards for ammonia, nitrate or sulphate (Figure 5). Typically more piggeries sourcing surface or open water exceeded the acceptable standards for microbiological levels compared to those sourcing bore or mains water supply. Given the open nature of surface water sources and the potential of water to be a biosecurity risk, this observation is probably not surprising although the level of contamination is.

Water Treatment
From the survey, 21% of responding participants (12 piggeries) indicated that they routinely conducted some form of water treatment. By using this response and the reciprocal laboratory analytical data it was possible to compare the impact of water treatment, or absence of, on water quality at the drinker (Figure 6).

Of the 79% of farms that responded 'No' they did not routinely treat the drinking water in anyway there was no change in the percentage outside the pig standard either at the source or at the shed. In contrast, routine water treatment did impact the percentage outside the pig standards between the source and the shed. Caution must be taken when making conclusions from this small data sub-set but it was observed that there was a decrease in the percentage outside the pig standard between the source and the shed for chloride, total alkalinity, heavy metals, alkali metals and hardness. In contrast, an increase post-treatment was observed in pH, ammonia, nitrate, sulphate and microbiological water quality parameters. Interestingly microbiological levels were higher at the point of consumption regardless of water treatment or not. Indeed, 47% of farms not routinely conducting water treatment were outside the standard for Total coliforms at the Source, compared with 50% of farms under-taking routine water treatment. The impact and benefits of water treatment on water quality requires further investigation.

Association between Parameters:
A descriptive analysis of the association between specific water quality parameters was under-taken using scatterplots (Figure 7). Aside from identifying interactions between individual parameters, this analysis provided an indication of which subset of parameters should be tested for as a priority when conducting initial water quality testing on farm.

Parameters of interest were:

- pH
- Hardness
- Chloride
- Sodium
- Iron
- Manganese
- Magnesium
- *E. coli*
- Total Coliforms

In summary, the scatterplots show that pH is unrelated to other parameters and should be measured in its own right. Hardness is strongly related to magnesium (r^2 = 0.98) and a choice between these two parameters might be considered. This relationship was apparent in both the source and the shed. Chloride is strongly related to sodium (r^2 = 0.93) and magnesium (r^2 = 0.96) while sodium is also related to magnesium (r^2 = 0.85). As there appears to be a relationship between hardness, chloride, sodium and magnesium it is tangible to suggest that only one of these parameters requires analysis to make an initial determination of water quality on farm. In contrast pH, iron and manganese are not related strongly to other parameters and in terms of testing must be tested in their own right. Similarly there was no apparent relationship or patterns between microbiological levels and the tested parameters (data not shown) indicating that these must be tested in their own right.

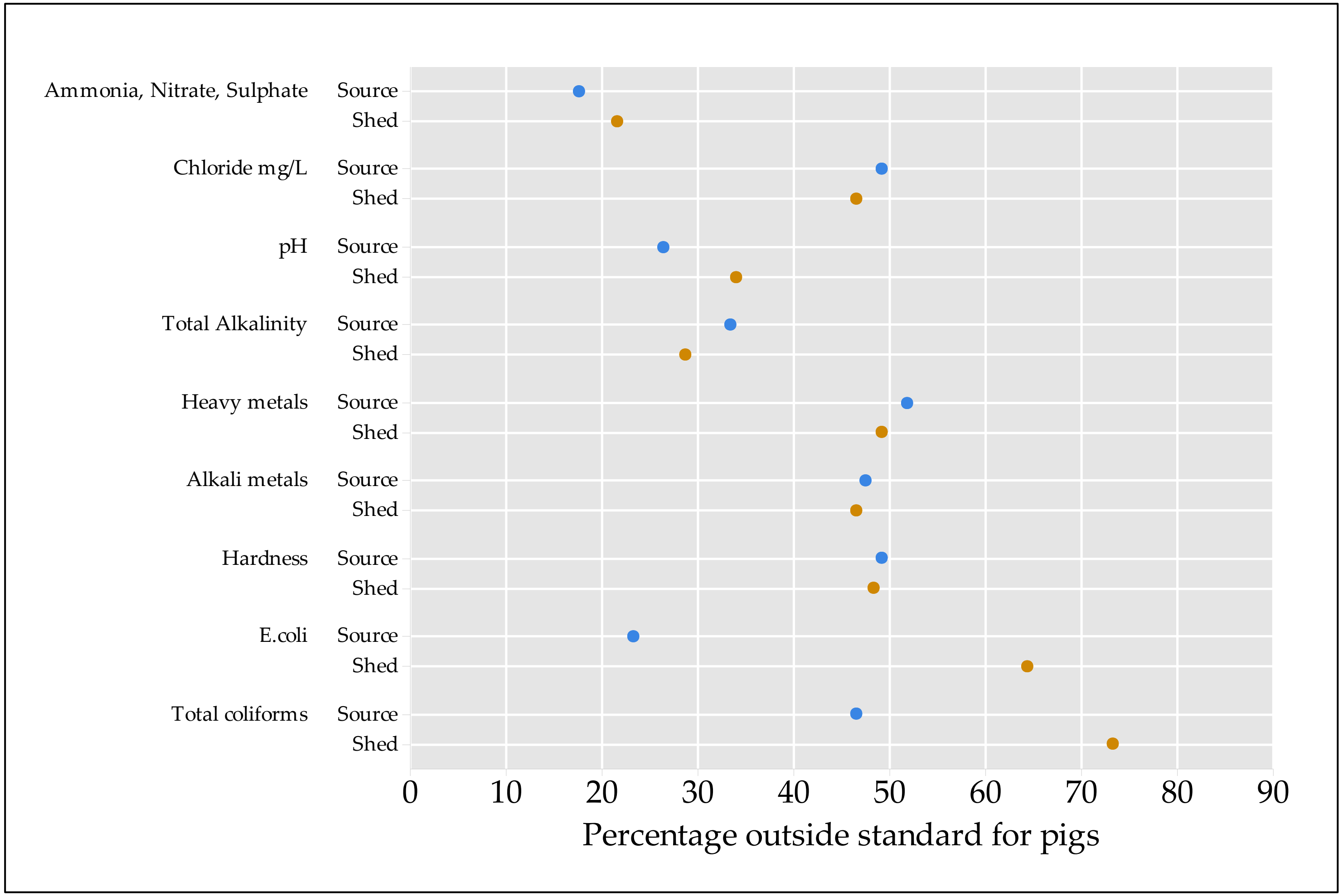


Figure 1. Percentage of Source and Shed Water Samples Outside the Acceptable Water Quality Standard for Pigs

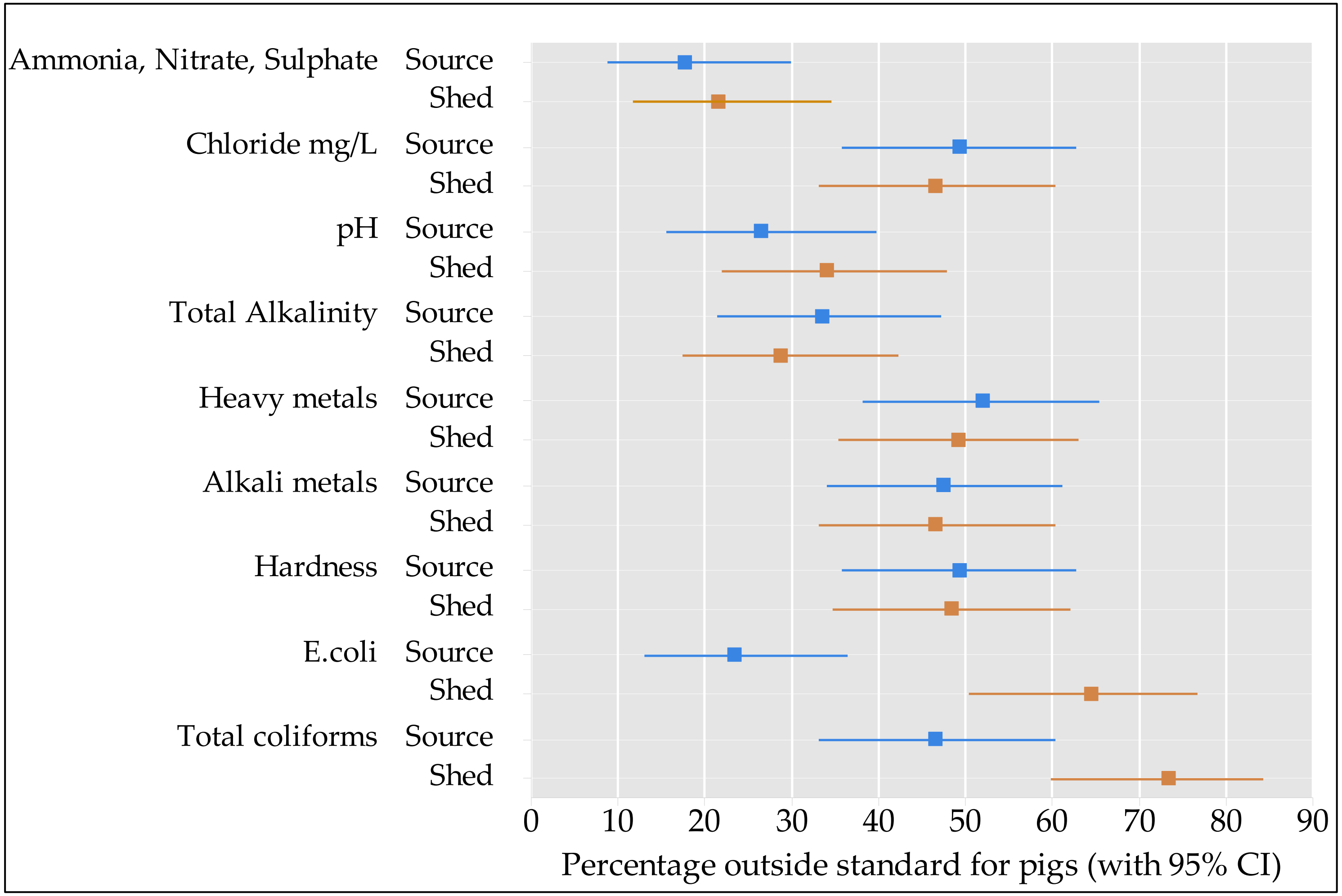


Figure 2. Percentage of Source and Shed Water Samples Outside the Acceptable Water Quality Standard for Pigs with 95% Confidence Intervals Shown.

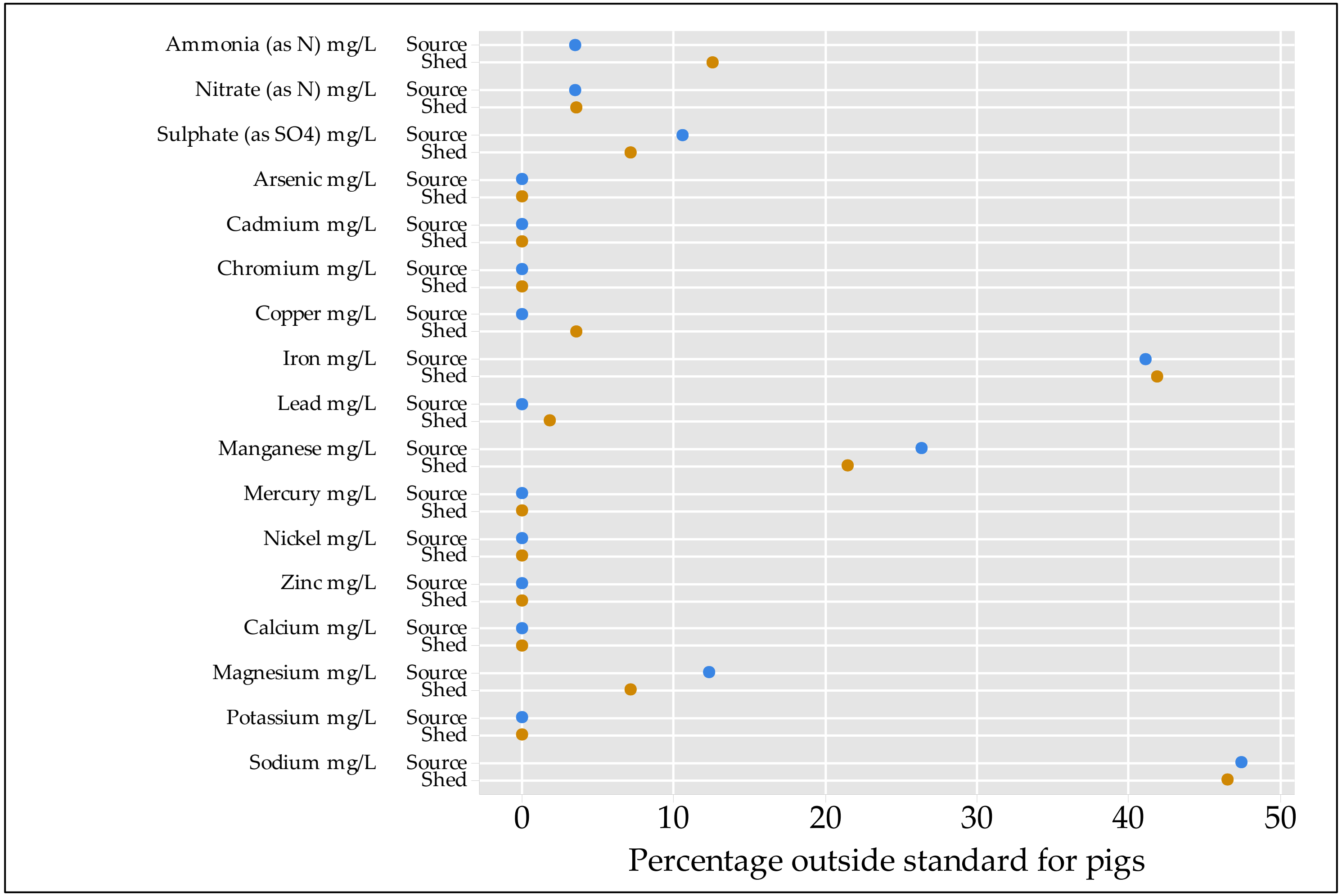


Figure 3. Percentage of Source and Shed Water Samples Outside the Acceptable Water Quality Standard for Pigs. Subset of Individual Water Quality Parameters Shown.

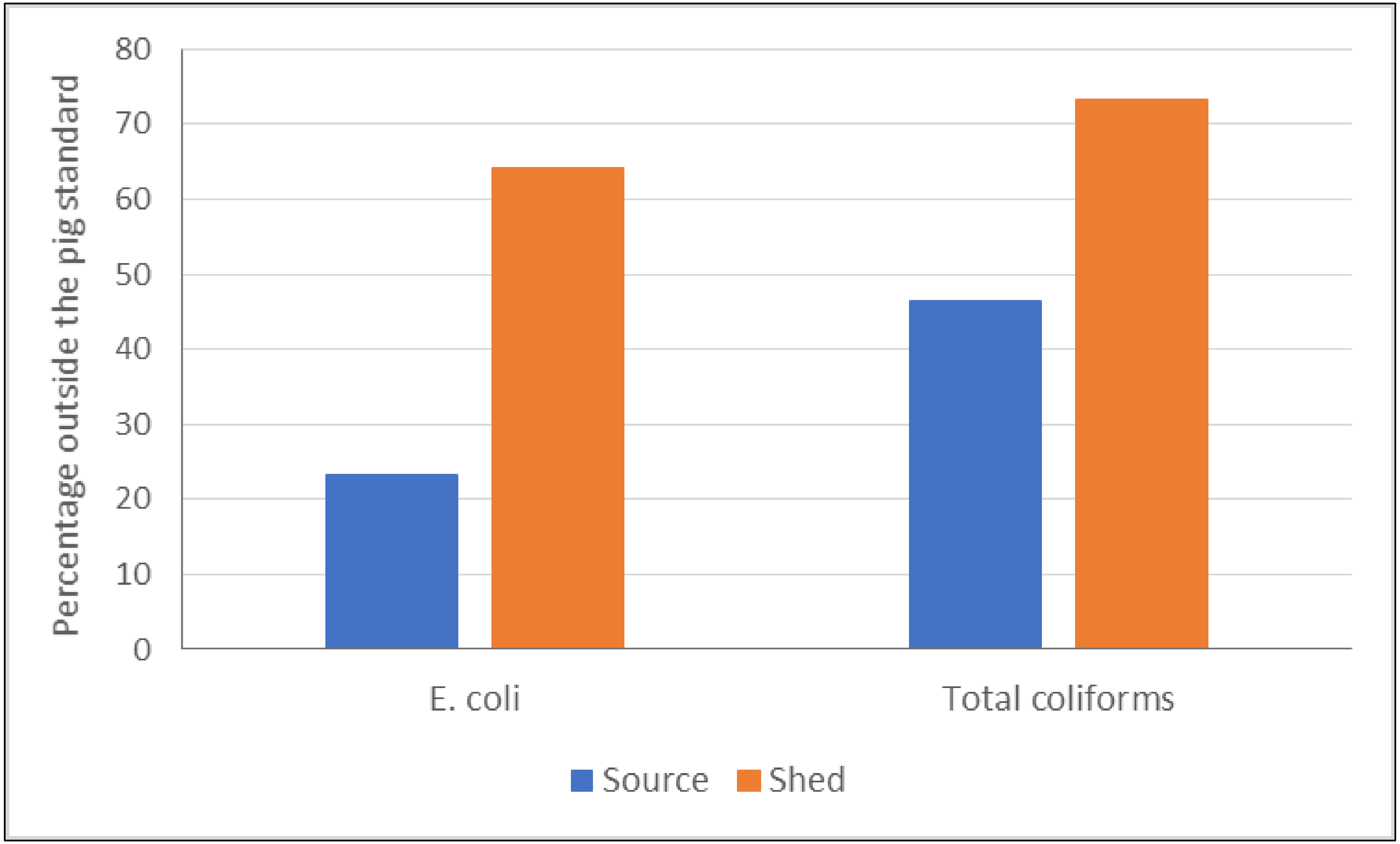


Figure 4. Percentage of Water Samples (Source and Shed) with Microbiological Levels Measured as being Outside the Acceptable Water Quality Standards for Pigs

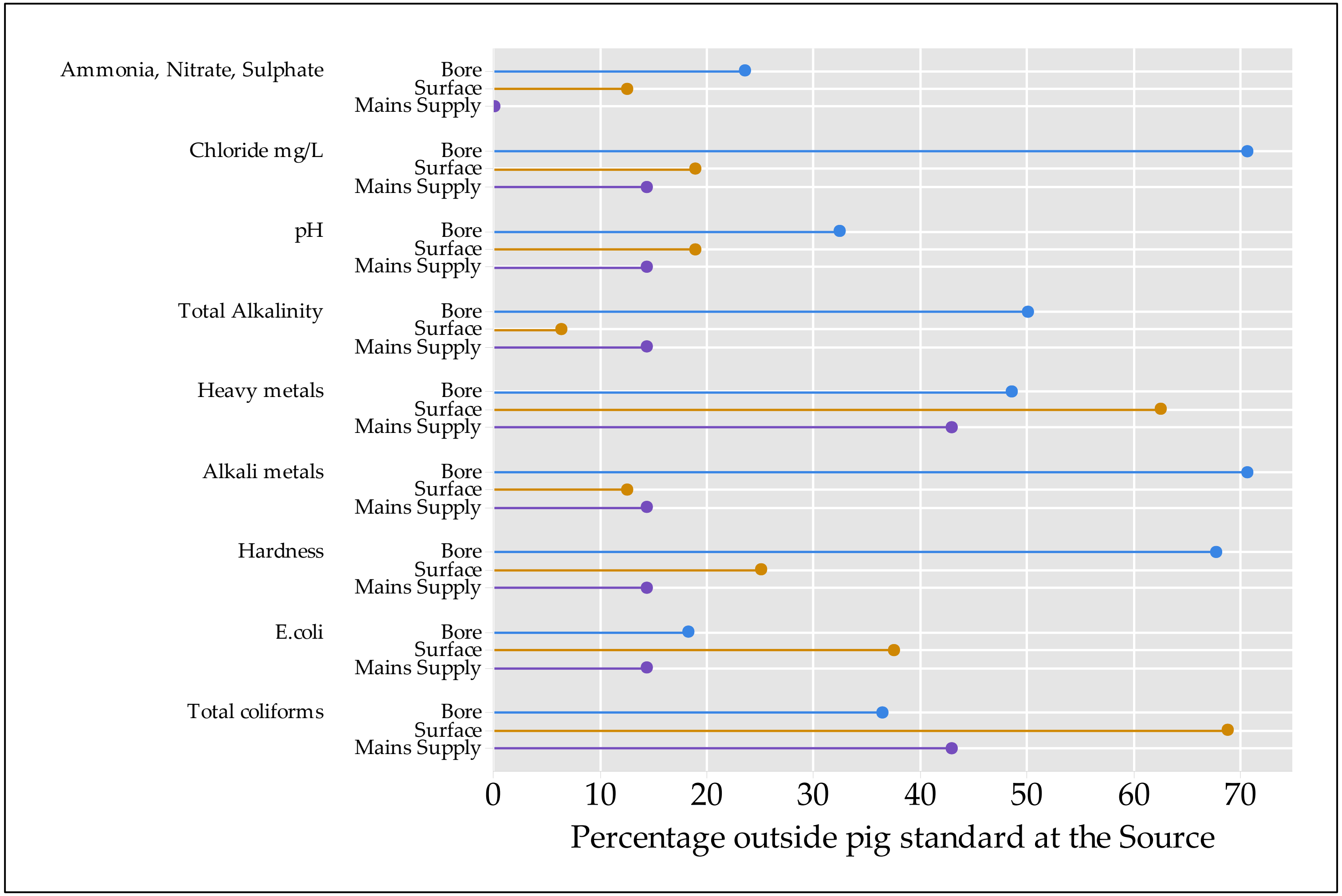


Figure 5. Percentage of Source Water Samples (Bore, Surface or Mains Supply) Outside Acceptable Water Quality Standards for Pigs

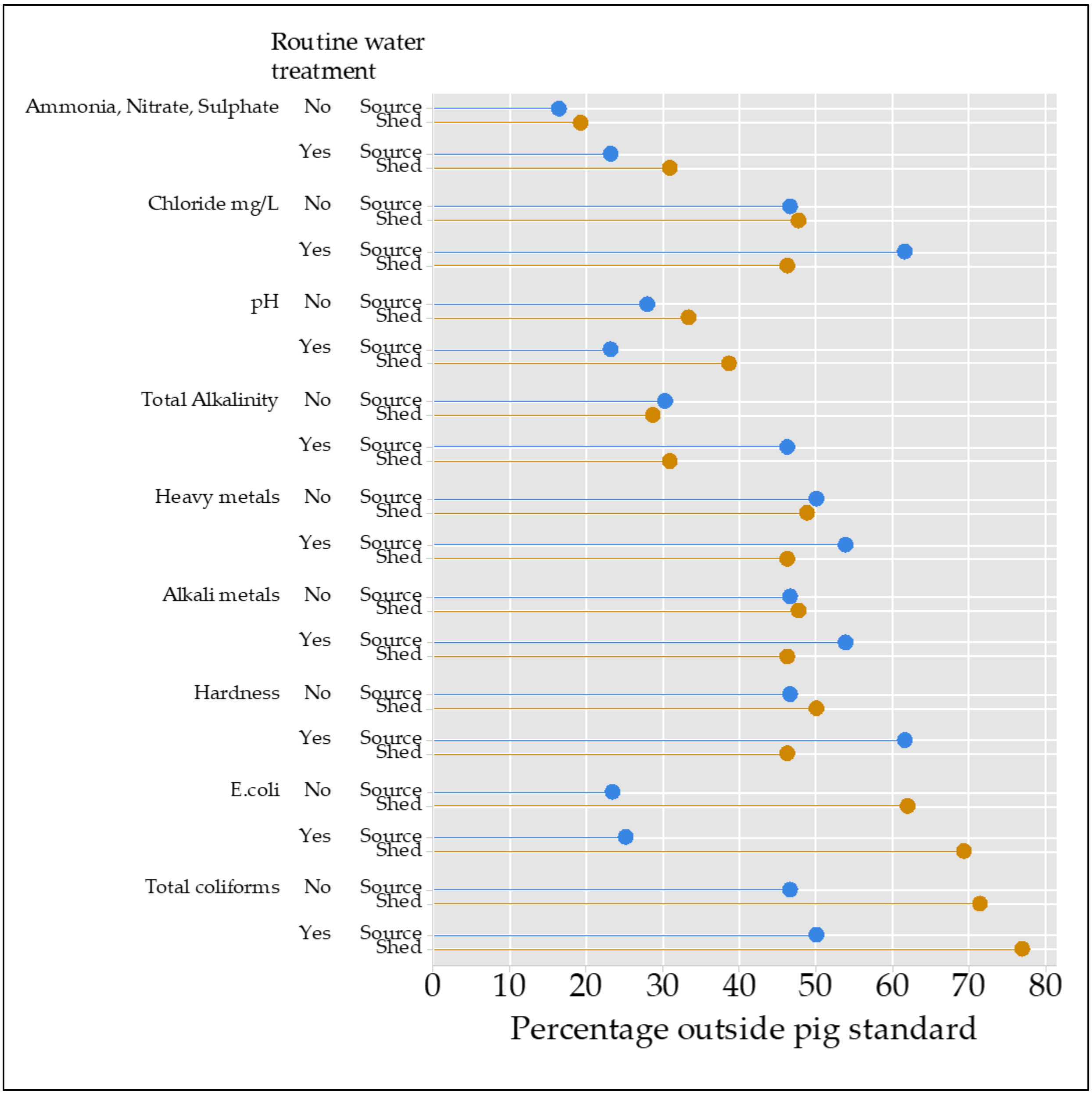


Figure 6. Percentage of Source and Shed Water Samples Outside the Acceptable Water Quality Standards for Pigs According to Routine Water Treatment

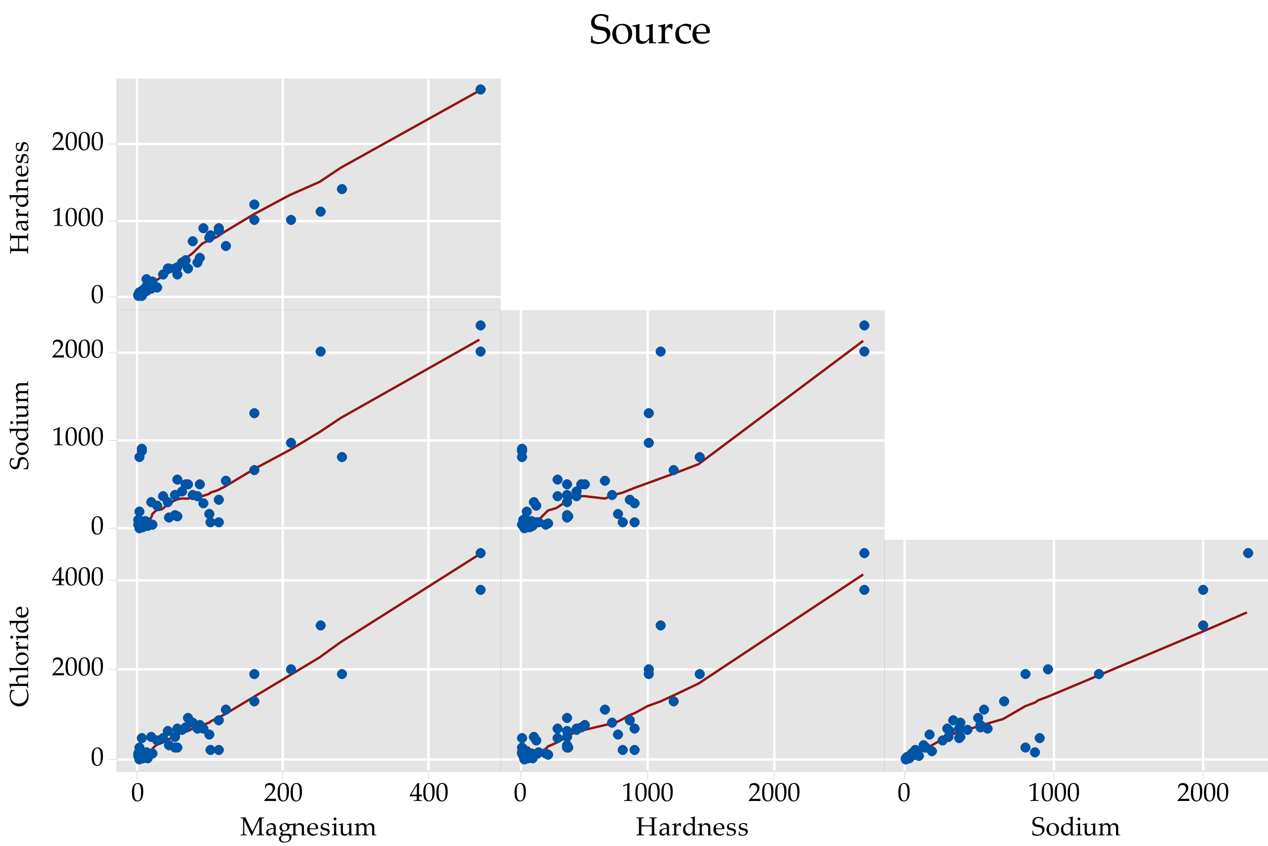


Figure 7. Relationship Between Water Quality Parameters

Appendix 3: *Preliminary Laboratory Studies to Evaluate the Impact of Water Quality on the Solubility of Commonly Used Veterinary Antibiotics*

The findings of the farm survey provided an insight into water medication and which veterinary chemical products were typically administered via the drinking water. Of the 45 participants who responded that they had a dosing system on farm, 41 provided details of which water-soluble antibiotics were being administered. These included:

Amoxycillin
Apramycin
Chlortetracycline
Florfenicol
Lincomycin
Neomycin
Oxytetracycline
Spectinomycin
Tiamulin
Tilmicosin
Trimethoprim/Sulfadiazine
Tylosin

In consultation with a major veterinary products distributor a range of commercially available veterinary products were sourced (Table 1) and all product details were recorded. The selection of these products in this study should not be interpreted as a recommendation or otherwise for their use in veterinary medicine.

Table 1. Commonly Used Veterinary Antibiotics as Informed by the Farm Water Survey

Commercially Available Veterinary Antibiotic	Active Constituents	APVMA No.
Sol-U-Mox Amoxycillin Soluble Powder*	Amoxycillin Trihydrate	52444
Abbeylinc Antibiotic Soluble Powder	Lincomycin hydrochloride	67803
Abbey TMPS Antimicrobial Soluble Powder*	Trimethoprim sulfadiazine	69475
Linco-Spectin Antibiotic Soluble Powder for Poultry and Swine	Lincomycin monohydrate/ Spectinomycin as the sulphate tetrahydrate	48182
Terramycin 880 Soluble Powder Concentrate	Oxytetracycline hydrochloride	46830
Zamichlor Soluble	Chlortetracycline hydrochloride	81953
Tylovet Tylosin Tartrate Soluble	Tylosin tartrate	54322

*Sol-U-Mox and Abbey TMPS are not registered for use in pigs in Australia. Any use of these antibiotics for pigs in Australia is off-label and is the responsibility of the prescribing veterinarian according to the legislation in the relevant jurisdiction.

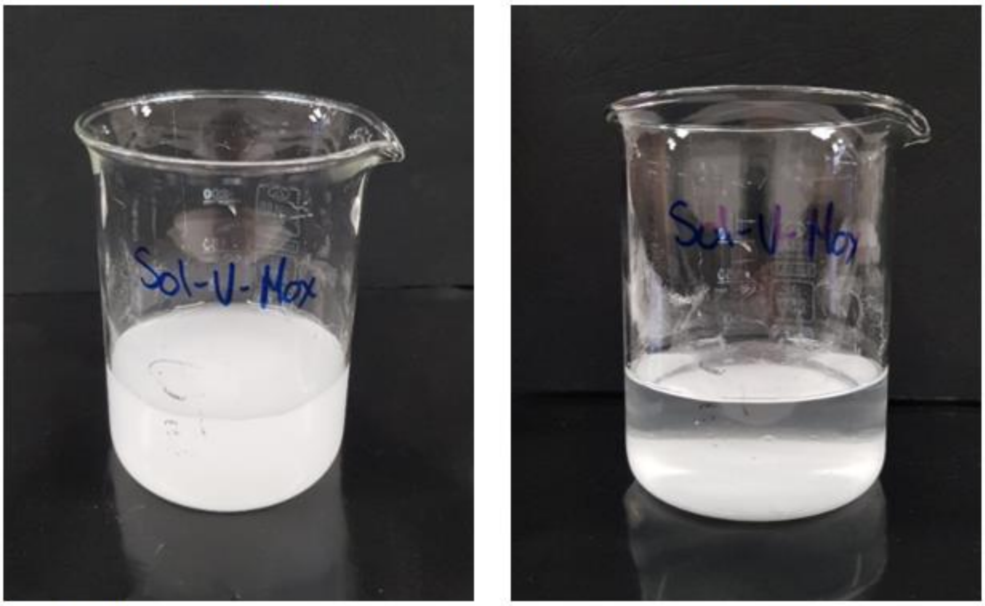
Solubility of Commonly Used Veterinary Antibiotics: Stock Concentration
When administering via drinking water it is common practice, and indeed in line with manufacturer recommendations, to prepare a concentrated stock solution which is then diluted via a medication dosing system to achieve the registered dose at the point of administration, in this case the drinker. Stock solutions were prepared in ultrapure water and the visual appearance recorded before and after

a 24 hour incubation period. The results are shown in Table 2 with images also being captured (Figure 1). In summary, concentrated preparations of Abbeylinc, Linco-Spectin and Tylovet dissolved with no insoluble particles observed. In contrast, insoluble particles were observed in the freshly prepared stock solutions of Sol-U-Mox, Abbey TMPS, Terramycin and Zamichlor after the 24 hour incubation. Interestingly, Terramycin was found to dissolve initially but then appeared to recrystallize and precipitate (Figure 1). The results of this study raise questions about the practicality of manufacturer's directions for use when preparing stock solutions in the field.

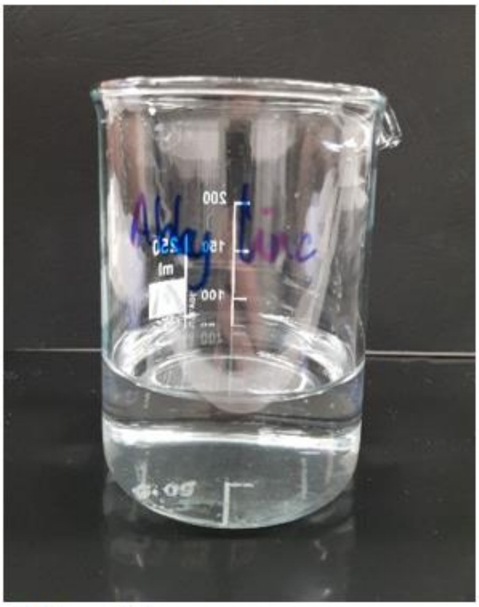
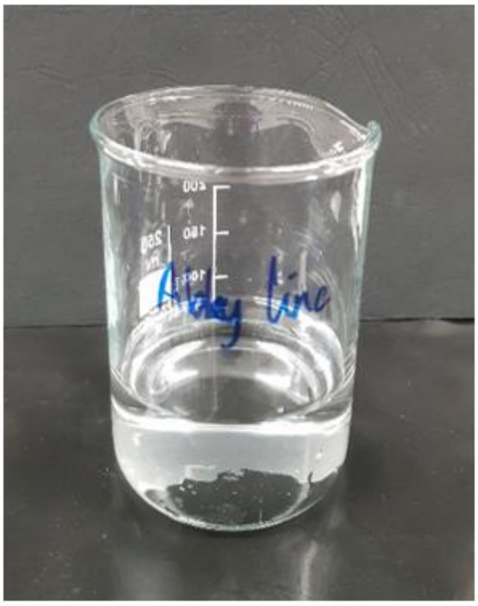
Table 2. Solubility of Commonly Used Veterinary Antibiotics when Dissolved at Stock Concentration

Antibiotic	Time 0	Time 24h
Sol-U-Mox	Insoluble Particles	Insoluble Particles
Abbeylinc	Soluble	Soluble
Abbey TMPS	Insoluble Particles	Insoluble Particles
Terramycin	Insoluble Particles	Insoluble Particles
Zamichlor	Insoluble Particles	Insoluble Particles
Linco-Spectin	Soluble	Soluble
Tylovet	Soluble	Soluble

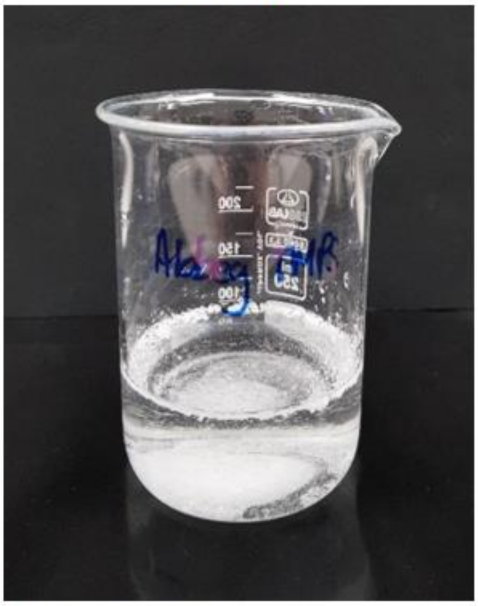
Time 0 Time 24h



Sol-U-Mox

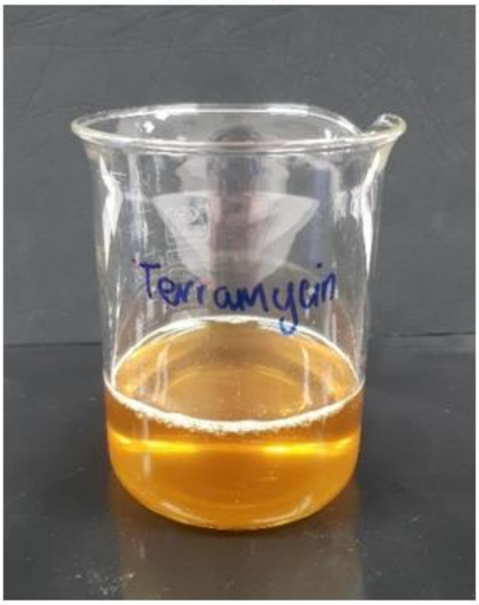
Time 0	Time 24h
	

AbbeyLinc

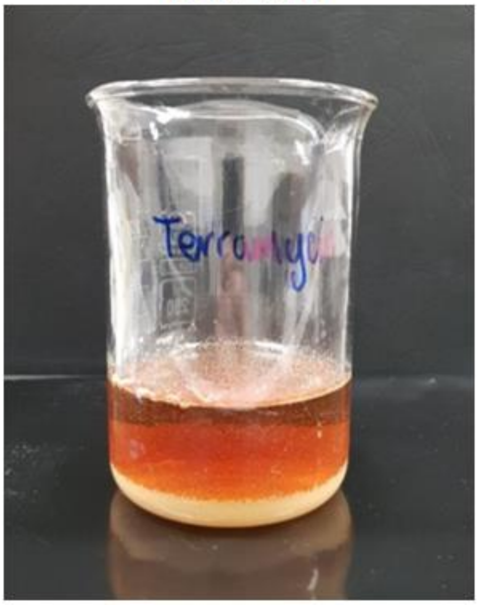
Time 0	Time 24h
	

Abbey TMPS

Time 0

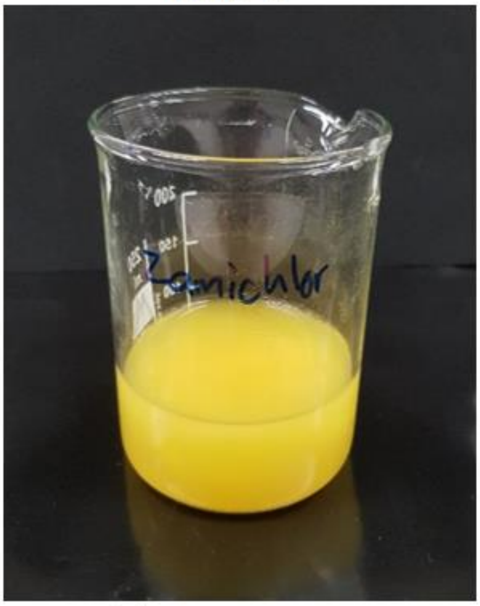


Time 24h

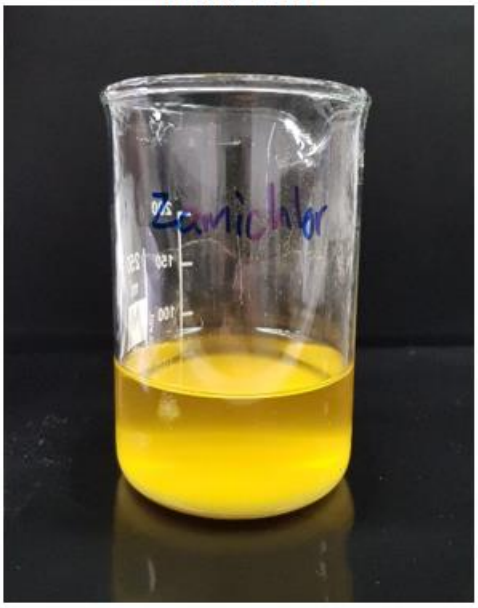


Terramycin

Time 0



Time 24h



Zamichlor

Figure 1. Photographs of Commonly Used Veterinary Antibiotics when Dissolved at Stock Concentration in UltraPure Water

Solubility of Commonly Used Veterinary Antibiotics: Drinker Concentration
Using a similar approach, the solubility of antibiotics prepared to drinker concentration in 4 different water types was conducted. Samples of farm water were collected and sent for third party analysis. Analysis identified several water quality parameters to be elevated in comparison to the acceptable standards for pigs (Table 3). Sodium and chloride levels were more than ten times greater than industry guidelines. The dam water was turbid and exceeded the acceptable standards for iron and manganese. Importantly, these water samples were generally reflective of river, dam and bore water quality characteristics as identified in the farm water survey.

Table 3. Water Quality of Farm Waters Compared to Acceptable Standard for Pigs

Group	mg/L	Bore	Dam	River	Acceptable Standard*
Ammonia, Nitrate, Sulphate	Ammonia (as N)	0.2	0.072	< 0.01	≤ 1.0
	Nitrate (as N)	0.16	0.43	0.08	≤ 50
	Sulphate (as SO_4)	760	< 5	< 5	≤ 200
Chloride	Chloride	3400	44	41	≤ 250
pH	pH	7.3	7.7	7.2	6.0 – 8.0
Alkalinity	Total As $CaCO_3$	470	88	< 20	≤ 300
Heavy Metals	Arsenic	< 0.002	0.005	0.001	≤ 0.2
	Cadmium	<0.0002	<0.0002	<0.0002	≤ 0.01
	Chromium	<0.001	0.007	<0.001	≤ 0.05
	Copper	0.001	0.007	0.001	≤ 0.5
	Iron	0.08	9.6	0.73	≤ 0.3
	Lead	<0.001	0.006	<0.001	≤ 0.05
	Manganese	0.31	0.38	0.02	≤ 0.1
	Mercury	<0.0001	<0.0001	<0.0001	≤ 0.002
	Nickel	0.002	0.008	<0.001	≤ 0.1
	Zinc	0.009	0.025	0.006	≤ 2.0
Alkali Metals	Calcium	290	13	3.7	≤ 500
	Magnesium	440	9.6	3.2	≤ 150
	Potassium	14	9.4	1.3	≤ 30
	Sodium	1800	18	12	≤ 150
Hardness	Equiv. $CaCO_3$	2600	72	22	≤ 180
Microbiological (MPN/100ml)	*E. coli*	< 1	390	19	≤ 50
	Total Coliforms	2400	>2400	870	≤ 1000

*Acceptable Standard for Pigs based on a review of the literature and presented in this report

Visually all water samples, with the exception of the dam water sample, were devoid of colour, odour and were free from any particulate matter. In contrast the dam water was brown, turbid, had an odour and contained particles which readily settled out over 24 hours (Figure 2). Although results are included in this report the turbidity of the dam water does bring in to question the reliability of the visual observations made.

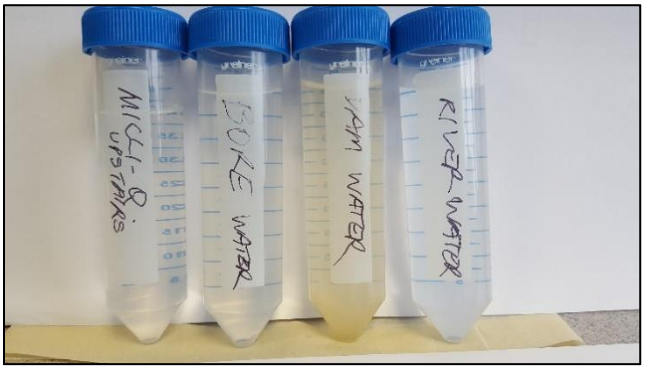


Figure 2. Un-Medicated Water Types Following 24 hour Incubation
Note. Turbid Dam Water

All of the commercial veterinary antibiotic products, with the exception of Zamichlor, were observed to have readily dissolved when prepared at drinker concentration within 2 minutes of preparation. This was seen across all water types tested (Table 4). Following the 24 hour incubation minimal precipitation had occurred in the pure, bore or river water solutions with the exception of Terramycin in river water. In contrast sediment accumulation was observed in all of the dam water antibiotic solutions. It was interesting to note that dam water tended to be much clearer after 24 hours suggesting flocculation of suspended solids had occurred rather than precipitation of the antibiotic.

When these observations are compared it is apparent that the solubility characteristics of each antibiotic differs depending on the concentration of the solution and the water in which it is being prepared. At drinker antibiotic concentration levels, all antibiotics (except Zamichlor) were in solution within 120 seconds and aside from the dam water did not express excess sedimentation across the water types. In contrast, Sol-U-Mox, Abbey TMPS, Terramycin 880 and Zamichlor contained substantial amounts of insoluble material when prepared as a stock solution which sedimented out over the 24 hour incubation period. Abbeylinc, Linco-Spectin and Tylovet in contrast, were very soluble and exhibited no particulate material. These results require further investigation and raise concerns about the practicality of manufacturer’s directions to ensure the required dose is being administered in the field.

Table 4. Solubility of Commonly Used Veterinary Antibiotics when Dissolved at Drinker Concentration in Different Water Types

ID#	Drinker Concentration (mg/ml)	Pure		Bore		Dam		River	
		Time to dissolve (secs)	Sediment layer (24h)	Time to dissolve (secs)	Sediment layer (24h)	Time to dissolve (secs)	Sediment layer (24h)	Time to dissolve (secs)	Sediment layer (24h)
1	0.123	120*	-	120*	+	120*	-	120*	-
2	0.042	<10	-	<10	-	<10	-	<10	-
3	0.685	20*	-	20*	+++	30	++	20	-
4	0.331	20	-	20	-	30	++	30	+
5	0.253	45	-	120	-	180	+++	120	-
6	0.096	<10	-	20	-	25	+	15	-
7	0.250	<10	-	15	-	15	+	<10	-

ID#: 1 = Sol-U-Mox (Amoxycillin), 2 = Abbeylinc (Lincomycin), 3 = Abbey TMPS (Trimethoprim sulfadiazine), 4 = Terramycin (Oxytetracycline), 5 = Zamichlor (Chlortetracycline), 6 = Linco-Spectin (Lincomycin/Spectinomycin), 7 = Tylovet (Tylosin)
*Very fine particles; Sediment Layer: + = Thin; ++ = Moderate; +++ = Thick

pH of Antibiotic Solutions: Drinker Concentration

The pH of the antibiotic solutions (drinker concentration) was determined immediately after preparation of each antibiotic solution (T0) and at the conclusion of the 24 hour incubation period (T24). All un-medicated water sources were close to a neutral pH with differences reflective of the differing buffering capacities (Table 5). No significant change in the pH of the controls over the 24 hour incubation period. In contrast, the pH of antibiotic solutions was shifted in an acidic direction, with the exception of antibiotic Abbey TMPS which became alkaline. This shift was maintained over the 24 hour incubation period and has the potential to impact water palatability and the integrity of the water management system. In comparison to the pure water antibiotic solutions, the shifts in pH in the corresponding farm water antibiotic solutions were not as pronounced. This data suggests that the water sources may have differing buffering capacity as follows: Bore > Dam > River > Pure water.

Table 5. pH of Commonly Used Veterinary Antibiotics when Dissolved at Drinker Concentration in Different Water Types

	Pure		Bore		Dam		River	
	T0	T24	T0	T24	T0	T24	T0	T24
Control*	7.32	6.72	7.23	7.51	7.2	7.3	7.01	7.06
Sol-U-Mox	5.62	5.8	7.1	7.47	6.66	7.15	6.36	6.96
Abbeylinc	5.64	6.11	7.2	7.55	7.04	7.1	6.83	6.94
Abbey TMPS	9.85	9.92	7.96	8.18	9.05	9.17	9.77	9.98
Terramycin	3.35	3.42	6.94	7.13	6.23	6.44	3.86	4.26
Zamichlor	3.38	3.38	6.96	7.29	6.3	6.64	4.1	4.61
Linco-Spectin	5.44	5.72	7.23	7.58	6.99	7.2	6.48	6.8
Tylovet	6.63	6.6	7.67	7.69	7.65	7.81	7.18	7.12

*Control = Non-medicated

The stability of Sol-U-Mox, Terramycin 880 and Zamichlor antibiotic solutions (drinker concentrations) was determined in pure (MilliQ), bore and river water at one hour post-solution preparation and then at the end of the 24 hour incubation period using an in-house developed UV-Vis spectrophotometer methodology. Dam water was found to be too turbid for analysis by this method and was excluded. Although preliminary it was observed that the level of absorbance for Sol-U-Mox when dissolved in pure water did not change over time indicative of good stability (Figure 3). When dissolved in bore or river water however, a reduction in absorbance was observed within 1 hour. A study conducted by Jerzsele & Nagy (2009) observed that amoxycillin was more soluble at alkaline pH than neutral and that its stability in solution was affected by the chemistry of the water. Terramycin 880 and Zamichlor showed no change in absorbance levels across all three water types (Figures 4 and 5). Although preliminary, these observations require further investigation as they are indicative of varying solubility and stability over time and when exposed to a range of water quality parameters representative of the 3 main water source types. Furthermore, what is the impact of these findings in the field and in particular to the administrated dose rate in the field?

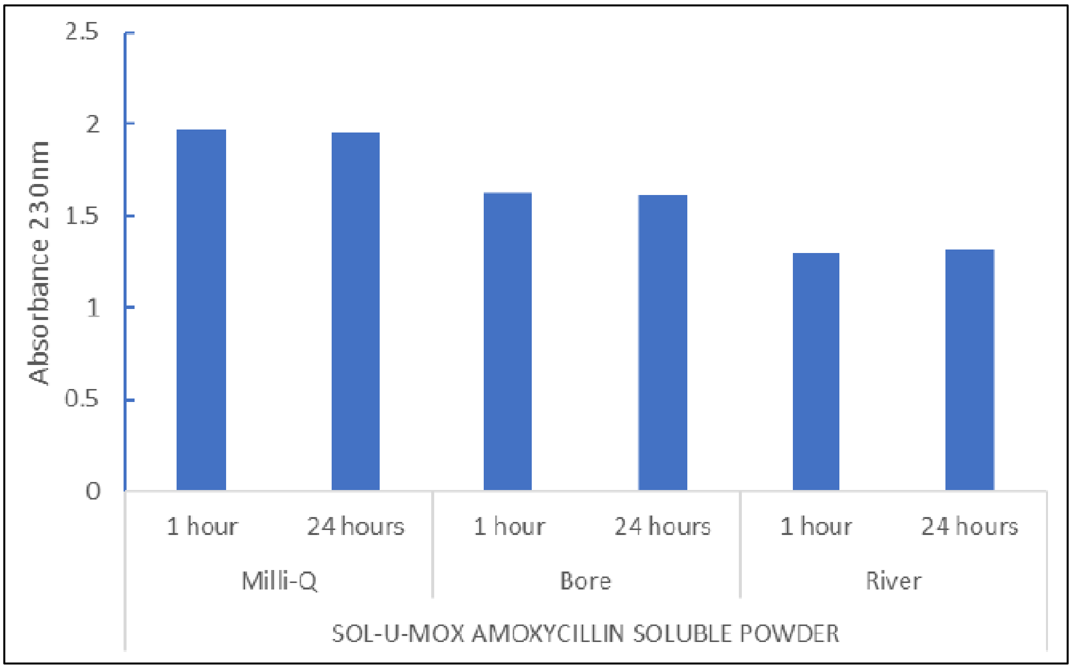


Figure 3. Absorbance (230nm) of Sol-U-Mox Solutions (Pure, Bore and River Water): Drinker Concentration

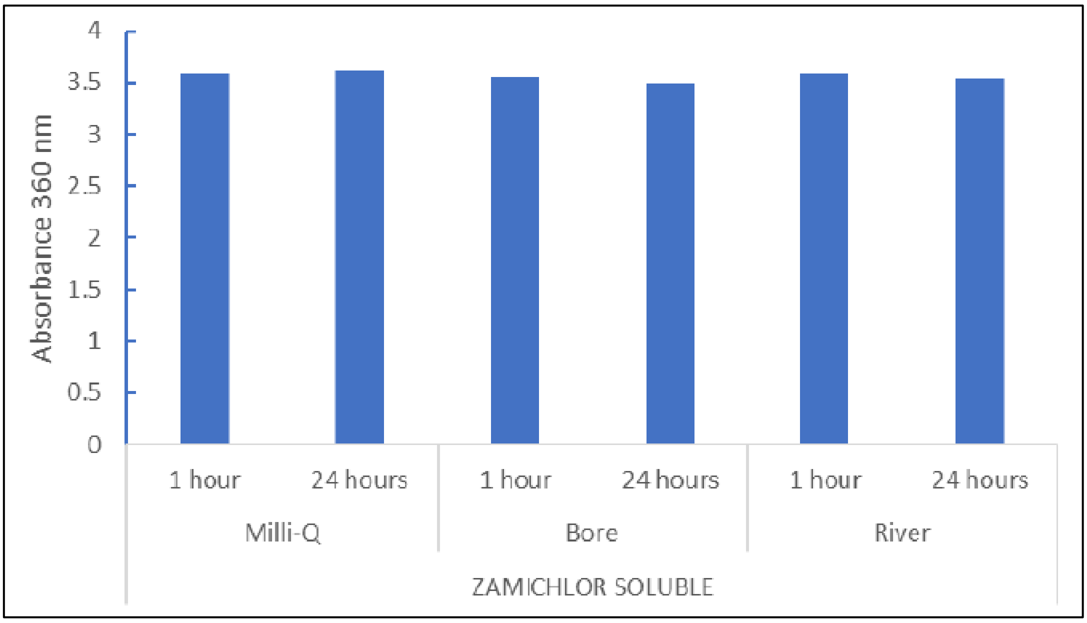


Figure 4. Absorbance (360nm) of Zamichlor Solutions (Pure, Bore and River Water): Drinker Concentration

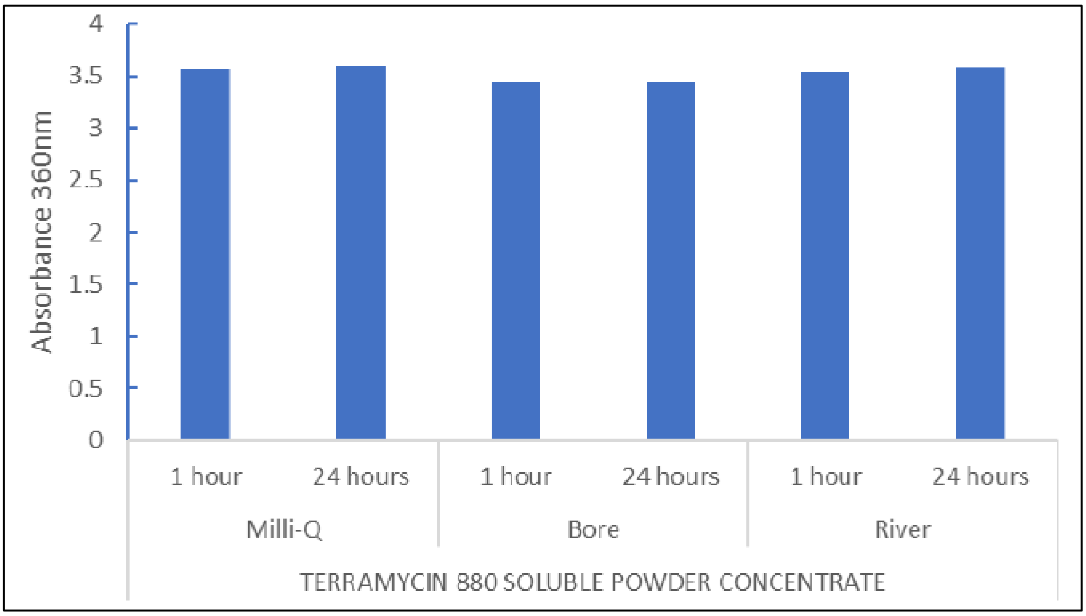


Figure 5. Absorbance (360nm) of Terramycin 880 Solutions (Pure, Bore and River Water): Drinker Concentration

Particle Size Distribution of Commonly Used Veterinary Antibiotics

The particle size distribution of each veterinary antibiotic product was evaluated and is shown in Figure 6. The results were generally consistent across the two subsamples tested however more replicates are required to validate these preliminary findings. Antibiotic Abbey TMPS was difficult to fractionate due to the 'stickiness' of the particles which may in part explain the differences in particle size distribution between sample A and B. It was notable that Sol-U-Mox had a large proportion of particles greater than 500µm whereas the largest particle size in the other antibiotics tested was no greater than 354µm. As only one sample of Tylovet was fractionated the results have not been shown in Figure 6 however the largest fraction was found to be in the >177µm (45.2%).

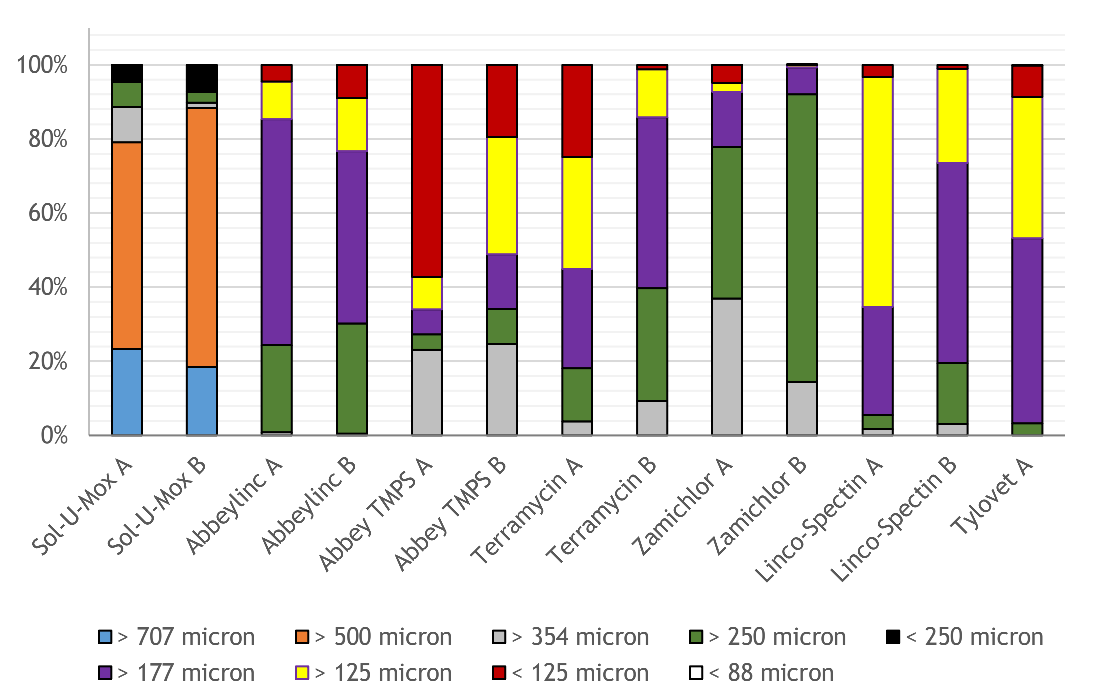


Figure 6. Particle Size Distribution of Commonly Used Antibiotics

Antibacterial Activity Testing

The antibacterial activity of whole and fractionated commercial veterinary antibiotics was using the disc diffusion method. *Escherichia coli* ATCC 35218[1] was used as the Gram-negative test organism for all products and *Staphylococcus aureus* ATCC9144[2] was used as the Gram-positive test strain for Linco-Spectin and Abbeylinc. Tylosin (Tylovet) does not inhibit *E. coli* and was therefore excluded from this experiment. As shown in Figure 7, all antibiotics tested demonstrated some degree of antibacterial activity however the extent to which they did varied. Indeed, the activity across fractions and upon dilution to 'drinker' administration levels was highly variable and in some cases no inhibitory activity was seen. The fractions exhibiting antibacterial activity are shown in Table 6. The inhibitory activity of Sol-U-Mox was clearly evident in discs 1 and 2 which were aliquots of Fraction 1 (>707µm) and Fraction 2 (>500 µm). The observed activity is not surprising given that these two fractions made up over 70% of the product composition. The lack of apparent inhibitory activity in Sol-U-Mox Plate 3 is

[1] https://www.atcc.org/~/ps/35218.ashx
[2] https://www.atcc.org/~/ps/9144.ashx

interesting and requires further investigation. Zamichlor (Chlortetracycline) also exhibited variable activity in that only Fraction 2 demonstrated any inhibitory activity, a result that warrants further investigation.

Table 6. Particle Size Distribution of Tested Antibiotics with the Fraction Containing Antibacterial Activity Indicated

Particle Size Fraction (µm)	SOL-U-MOX	ABBEY TMPS	TERRAMYCIN 880	ZAMICHLOR	ABBEYLINC	LINCO-SPECTIN
> 707	18.46%	-	-	-	-	-
> 500	69.87%	-	-	-	-	-
> 354	1.50%	24.66%	9.22%	14.44%	0.55%	3.11%
> 250	2.85%	9.46%	30.52%	77.64%	29.74%	16.41%
> 177	-	14.77%	46.01%	7.22%	46.39%	54.08%
> 125	-	31.59%	13.02%	0.67%	14.25%	25.36%
< 250	7.32%	-	-	-	-	-
< 125	-	19.51%	1.22%	0.04%	9.07%	1.04%
< 88	-	-	-	-	-	-

Green = Fractions from with antibacterial activity two replicates. Results for fractionated B samples shown

These preliminary findings have raised a number of questions. Further investigation is essential to assure veterinarians, producers and consumers that the most appropriate antibiotics at the right administration dose rates are being used for animal health and welfare. It is recommended that further research be conducted to verify these laboratory findings and if confirmed, an in-field pharmacokinetic study of commonly used veterinary medicines delivered via water is conducted to ensure animals at the drinker are being administered the correct dose.

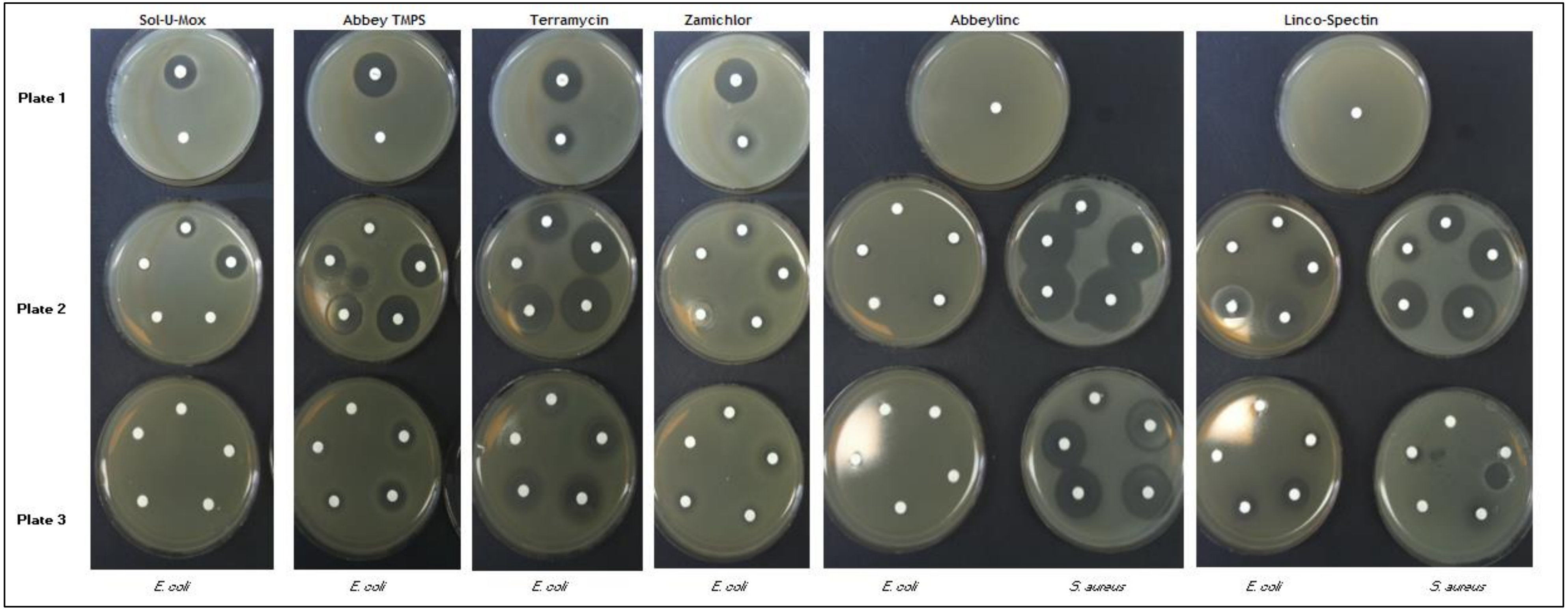


Plate 1 = Control + Unfractionated Ab, drinker concentration; Plate 2 = Fractionated Ab, no dilution; Plate 3 = Fractionated Ab, x10 dilution. Images for fractionated B samples shown

Figure 7. Antibacterial Activity Disc Diffusion Plates Showing Zones of Inhibition of Growth