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1   Summary

Livestock production in Australia and New Zealand relies on surface water, groundwater and reclaimed water supplies. All water for livestock must be fit-for-purpose and adhere to the relevant regulatory and technical requirements.

The *Livestock drinking water guidelines* provide recommended values for biological, chemical and radiological substances that may occur in livestock drinking water (Table 1.1). The guideline values are based on the current evidence and literature, with preference given to data from Australia and New Zealand.

If levels of the substance in drinking water are below these values, there should be little risk of harmful effects on animal health. Indeed, many of the ions and metals in drinking water are essential for animal health, but can be toxic at higher levels.

The values may not be appropriate for all stock types, ages and feeding systems. For example, young livestock or non-ruminant species may be more sensitive to some substances. In addition, higher concentrations may sometimes be tolerated (e.g. aluminium concentrations higher than the given value may be tolerated if dietary phosphorus levels are adequate).

If values are exceeded, potential management actions include water treatment, changes to water sources, changes to livestock diet, or veterinary treatment. The action to be taken will depend on the risk level, which will in turn depend on the type of substance and the livestock species and age. Regular assessment of water quality and livestock health are important to ensure producers continue to provide the water quality that is essential for successful livestock production.

Table 1.1 Summary of guideline values for livestock drinking water

Substance		Guideline value	Notes
Biological parameters	Cyanobacteria	Toxin-producing cyanobacteria <0.4 mm³/L, (equivalent to 5,000 cells/mL of *Microcystis aeruginosa*, or 1 µg/L of total microcystins-LR)	Algal blooms should be treated as toxic; remove livestock from the water source until the algae are identified and toxicity is determined
	Pathogens and parasites	<100 cfu/100 mL (median value) of *E. coli*	*E. coli* is a critical indicator to manage pathogenic infection risk
Main ions of concern	Calcium	<1,000 mg/L	If dietary phosphorus levels are adequate
	Magnesium	<500 mg/L (ruminants in general) <250 mg/L (lactating cows and ewes with lambs) <125 mg/L (poultry)	
	Nitrate and nitrite	<100 mg/L nitrate and <10 mg/L nitrite (livestock in general) <25 mg/L (poultry) <400 mg/L (cattle)	Levels of nitrate tolerance are lowest in poultry, medium in pigs and highest in cattle
	Sulfate	<500 mg/L (livestock in general) <250 mg/L (poultry)	Pigs may tolerate higher levels
	Total dissolved solids (salinity)	<500 mg/L	

Metals and metalloids	Aluminium	<5 mg/L <3.6 mg/L (chickens)	If dietary phosphorus levels are adequate
	Arsenic	<0.025 mg/L	Level should not be exceeded
			Arsenic is a carcinogen; assessments should be conservative and consider the potential accumulation of arsenic in edible tissues
			Consider all factors in assessing the risk of toxicity (e.g. bioavailability, levels in feed)
	Beryllium	<60 µg/L	
	Boron	<5 mg/L	
	Cadmium	<0.01 mg/L	Level should not be exceeded
			Consider all factors in assessing the risk of toxicity (e.g. bioavailability, levels in feed)
	Chromium (III) or Chromium (VI)	<0.05 mg/L	
	Cobalt	<1 mg/L	
	Copper	<0.5 mg/L (sheep) <1 mg/L (cattle) <5 mg/L (pigs) <5 mg/L (poultry)	If livestock diets are high in copper, the concentration in drinking water should be reduced
	Fluoride	<2 mg/L	If livestock feed also contains fluoride, the guideline value should be reduced to 1.0 mg/L
	Iron	No guideline value (not sufficiently toxic)	
	Lead	<0.1 mg/L	Level should not be exceeded
			Lead is accumulative, and livestock health problems may begin at 0.05 mg/L
			Consider all factors in assessing the risk of toxicity (e.g. bioavailability, levels in feed)
	Manganese	<10 mg/L	
	Mercury	<0.002 mg/L	Level should not be exceeded
			Assessments should be conservative and consider the potential accumulation of mercury in edible tissues
			Consider all factors in assessing the risk of toxicity (e.g. bioavailability, levels in feed)
	Molybdenum	<0.01 mg/L	If dietary copper levels are low, molybdenum is toxic at lower concentrations
	Nickel	<1 mg/L	
	Selenium	<0.02 mg/L	Level should not be exceeded

			Consider all factors in assessing the risk of toxicity (e.g. bioavailability, levels in feed)
	Uranium	<0.2 mg/L	
	Vanadium	<0.1 mg/L	Level should not be exceeded
			Consider all factors in assessing the risk of toxicity (e.g. bioavailability, levels in feed)
	Zinc	<20 mg/L	
Pesticides and other organic contaminants		Guideline values for specific chemicals used in pesticides are provided in fact sheets attached to the Australian Drinking Water Guidelines	
Radionucleotides		<5 Bq/L (radium 226) <5 Bq/L (radium 228) <2.5 Bq/L (uranium 238) <1 Bq/L (gross alpha) <5 Bq/L (gross beta excluding k-40) <10 Bq/L (thorium 230/232/228)	Levels of radioactivity in livestock drinking water are unlikely to be a direct threat to animal health

The guideline values are usually presented as concentrations that should not be harmful to animal health if they are not exceeded. For example, 'Aluminium concentrations <5 mg/L in livestock drinking water should not be harmful to animal health.'

However, several metals and metalloids are highly toxic at very low levels. For arsenic, cadmium, lead, mercury, selenium and vanadium, the guideline values are instead presented as concentrations that are hazardous to animal health if they are exceeded. For example, 'Total arsenic concentrations >0.025 mg/L in livestock drinking water may be hazardous to stock health.' This indicates that caution must be taken with these substances, and management action may be needed even if levels are very low.

Other contaminants are emerging as potential concerns and will be captured in future editions of these guidelines. These include various substances used in industry, farms and households, such as endocrine-disrupting chemicals, per- and polyfluoroalkyl substances (PFAS), and pharmaceuticals and personal care products.

2   Introduction

Good water quality and sufficient water quantity are essential for successful livestock production. Livestock production in Australia and New Zealand relies on surface water, groundwater and reclaimed water supplies.

Poor-quality water may reduce animal production and impair fertility. In extreme cases, livestock may die. Contaminants in drinking water can produce residues in animal products (e.g. meat, milk, eggs), adversely affecting saleability and/or creating human health risks.

2.1   Water quality

Many factors influence the suitability of water for livestock watering.

Requirements and tolerances of contaminants may differ between monogastric and ruminant animals; between animal species (generally tolerances decrease in the order sheep, cattle, horses, pigs, poultry); and by animal condition and stage of growth. Moreover, stock accustomed to good-quality water can initially suffer ill effects or refuse to drink water of poorer quality, but may adjust if introduced gradually.

Surface water quality (e.g. streams and dams) is influenced by catchment land use (e.g. agriculture, mining and other industries), geology, topography, soil type and climate. Groundwater, which is used as livestock drinking water throughout Australia and in parts of New Zealand, may contain large quantities of dissolved salts, metals or other pollutants (e.g. pesticides), depending on the soil and rock of the surrounding area and factors such as rainfall, evaporation, vegetation, land use and topography. Reclaimed water used for livestock is commonly derived from wastewater and mining.

Animal industries themselves may impair water quality downstream (e.g. through faecal contamination), highlighting the need for an integrated approach to land and water management in rural catchments.

2.2   Water quantity

If water has any contaminants, the amount of contaminant ingested by livestock will depend on how much water they drink.

Daily water intake varies widely among different forms of livestock. It is also influenced by various factors, such as:

- season and weather (warmer weather increases water intake)
- livestock diet (livestock eating dry feed are likely to have higher water needs)
- breed of animals (larger breeds may have higher water needs)
- age of animals (growing animals typically have higher water needs than mature animals)
- water quality (livestock may drink less if water quality is poor, for example if the water has high levels of salinity)
- lactation (a lactating female needs at least 50% more water than a dry animal)
- recent conditions (water intake can increase dramatically if animals are allowed unrestricted access following a period of deprivation).

Temperatures have the largest effect on water intake, and thus the livestock water requirements vary between Australian states. The Victorian average and peak (summer) daily water requirements for various Australian livestock species are given in Table 2.1, but hotter and drier areas are likely to have higher water requirements.

Table 2.1 Livestock water requirements

Livestock	Average daily consumption	Peak daily consumption (summer)
Sheep	**Litre/head**	**Litre/head**
Nursing ewes on dry feed	10.0	14.0
Mature sheep on dry pasture	6.0	10.0
Fattening lambs on dry pasture	4.0	6.0
Mature sheep on green pasture	3.5	4.9
Fattening lambs on green pasture	1.1	1.5
Cattle	**Litre/head**	**Litre/head**
Dairy cows, lactating	150.0	210.0
Dairy cows, dry	80.0	112.0
Beef cattle	80.0	100.0
Calves	55.0	70.0
Horses	**Litre/head**	**Litre/head**
Working	55.0	77.0
Grazing	35.0	49.0
Pigs	**Litre/head**	**Litre/head**
Brood sows	45.0	63.0
Mature pigs	20.0	28.0
Grower	12.0	16.8
Poultry	**Litre/100 birds**	**Litre/100 birds**
Laying hens	33.0	46.0
Pullet	18.0	25.0
Turkeys	55.0	77.0

Source: https://agriculture.vic.gov.au/farm-management/water/farm-water-solutions/managing-farm-water-supplies

2.3   Water assessment

Producers should assess and monitor livestock drinking water to determine its safety. However, it is not economically viable to regularly sample livestock water for screening purposes. The frequency will vary from situation to situation:

- If the water source is groundwater or surface water, screening may be required when:
    - a known contamination has occurred
    - historical data suggest the water body is at high risk for a specific contamination
    - there are visual symptoms of contamination (e.g. algal bloom)
    - livestock discomfort is observed (e.g. reluctance to drink, lethargy, scouring).

- If a use agreement or permit is being sought to use reclaimed water for livestock watering, the water needs to be sampled before use so that the background concentrations of possible contaminants can be established. The water should then be regularly tested to establish the variation in the concentration of constituents over time.

- Where salinity is known to be the major contaminant, frequent low-cost sampling and analysis should be undertaken.

The guideline values in this section are neither meant to be considered in isolation nor are they absolute values to be adhered to. Rather they are guideline values (i.e. a starting point for each specific situation) from which the weight of evidence is built up.

Weight of evidence (Figure 2.1) is accumulated by comparing the measured concentration of a substance in drinking water with the guideline value (Weight of evidence 1); by comparing with historical background data for the water source (Weight of evidence 2); and by considering the livestock species, the agricultural production system (e.g. cattle for beef or for dairy) and water intake for the specific conditions (Weight of evidence 3). Once the weight of evidence has been accumulated, a risk management plan can be developed (e.g. see Table 3.4).

This method is recommended for various contaminants; however, it may be less useful for the assessment of pathogen risk, because the source of the pathogen is an important factor to determine the level of risk.
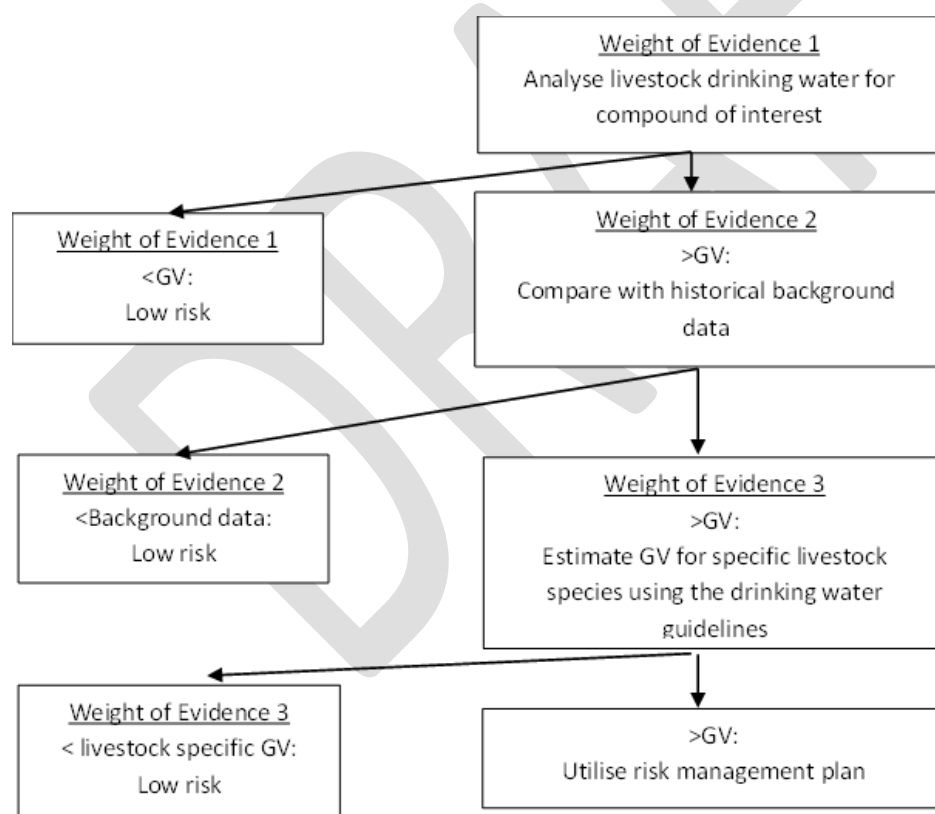
Source: The approach of weight of evidence is also detailed on the Australia & New Zealand Guidelines for Fresh & Marine Water Quality web page (ANZ, 2018)

Figure 2.1 Weight of evidence approach to risk management for livestock drinking water

3   Guideline values

The guidelines for livestock drinking water cover biological, chemical (including ions, metal and metalloids, and pesticides and other organic contaminants) and radiological substances that may affect animal health, whether from surface or groundwater sources.

The water quality guideline values are the recommended values for which there should be little risk of adverse effects on animal health, even with long-term daily intake (i.e. chronic use). If the level of a substance in livestock drinking water exceeds a guideline value, it is advisable to investigate further to determine the level of risk.

Information used to determine the guideline values was sourced from the current literature and evaluated for relevance, with preference given to data from Australia and New Zealand. Much of the information was based on field observations rather than rigorous experimentation. In several cases, guideline values have been calculated using data on chronic and toxic effects on animals, taking into consideration animal weights, percentage intake from water, and safety factors for data not specific to the species.

The guidelines values focus on stock health and performance. However, producers may also need to meet the requirements of other guidelines – in particular, guidelines around food and export safety, and bioaccumulation of contaminants in animal tissue. Relevant guidelines include:

- Primary Production and Processing Standards of Food Standards Australia New Zealand
- Maximum Residue Limits of Food Standards Australia New Zealand
- Maximum Residue Limits of the Australian Pesticides and Veterinary Medicines Authority.

The research for these Livestock drinking water guidelines has focused on the most common livestock produced in Australia: cattle, sheep, pigs and poultry. Producers who raise other species (e.g. alpaca, deer, bison) are advised to investigate species-specific tolerances and sensitivities to substances.

Other domestic animals may also be exposed to livestock drinking water, such as working dogs. These guidelines do not include information on other domestic animals, but they may be covered in future editions. Producers should take care to keep other animals away from any water that is suspected to be contaminated.

3.1 Biological parameters

Substances in livestock drinking water can be of biological origin, including algae, pathogens and parasites. These substances can be hazardous to animal health.

3.1.1 Cyanobacteria (blue–green algae)

Algal blooms should be treated as toxic, and livestock should be removed from the water source until the algae are identified and the toxicity is determined.

Identification, enumeration and cyanotoxin assessment should be triggered when levels of all cyanobacteria known to produce toxins are >0.4 mm³/L, which is equivalent to 5,000 cells/mL of* Microcystis aeruginosa*, or 1 µg/L of total microcystins-LR.

Source

Cyanobacteria (blue–green algae) are naturally occurring microorganisms that closely resemble algae in morphology, habitat and photosynthetic ability. Some cyanobacteria can produce toxins.

Cyanobacteria are a component of the natural plankton population in healthy surface water supplies. However, they can become hazardous when present in large numbers (blooms or mats), and various factors can contribute to blooms and the accumulation of cytotoxins in water. For example, phytoplanktonic blooms typically occur on warm days with light-to-calm winds (summer to autumn) in neutral-to-alkaline water containing elevated levels of inorganic phosphorus and nitrogen, although blooms are possible at other times (Carmichael 1994); for example, in South Australian conditions, benthic cyanobacterial growth peaks in autumn and spring (Gaget et al. 2020). More than one cyanobacteria species can be associated with a bloom (Ressom et al. 1994).

Most of the research reported in the literature concerning algal blooms and cyanotoxicity refers to phytoplanktonic cyanobacteria. However, it is now recognised that benthic cyanobacteria can release cytotoxins and may have caused livestock deaths in several countries (Quiblier et al. 2013).

Phytoplanktonic cyanobacteria are found as single cells or in clumped or filamentous colonies. Cyanobacteria can move vertically through water by adjusting their buoyancy (Ressom et al. 1994). In Australia, the most common genera of cyanobacteria associated with known animal poisoning incidents are *Microcystis* (clumped), *Dolichospermum* (previously known as *Anabaena)*, and *Nodularia* and *Raphidiopsis* (previously known as *Cylindrospermopsis*; filamentous) (Queensland Water Quality Task Force 1992, Jones 1994, Jones & Orr 1994, Steffensen et al. 1998).

Benthic cyanobacteria (e.g. *Phormidium*, *Pseudanabaena* and *Oscillatoria*) tend to occur in shallow, clear waterbodies. They attach to a substrate (e.g. rock, sediment) below the water surface, forming mats that can separate and rise to the surface where they may accumulate as scum and be eaten by animals (Quiblier et al. 2013).

Effects on animal health

The toxins associated with cyanobacteria generally only affect livestock if they directly ingest cells (either in the water or as dried mats left on the shore), or drink water where the death of cells has released toxins into the water.

The effect on livestock depends on the type of cyanobacteria and associated toxin:

- Worldwide, the most common cyanobacterial toxin is microcystin, a hepatotoxin that is produced predominantly by the genus *Microcystis*, but also by species of *Fischerella* (Cirés et al. 2014) and *Nostoc* (Gaget et al. 2017). Though there are some differences between livestock types, microcystin poisoning symptoms typically include weakness, lethargy, anorexia, paleness,

diarrhoea, and sometimes mental derangement. In serious cases, animals suffer general distress, muscle tremors and coma, followed by death within a few hours to a few days. Animals, particularly cattle, that survive hepatotoxicosis may suffer from photosensitisation resulting in cows refusing to suckle their young (Carmichael & Falconer 1993).

- The hepatotoxin nodularin, which is produced by *Nodularia spumigena*, has also affected domestic animals in Australia (Steffensen et al. 1998). Nodularin can also be produced by *Iningainema pulvinus* – an algae species that lives at the lowest levels of water bodies such as lakes (benthic zone) (McGregor & Sendall 2017).

- The neurotoxins produced by *Dolichospermum circinale* are a group of closely related alkaloids known as saxitoxins, which can also be produced by species of the benthic genus *Heteroscytonema* (Sendall & McGregor 2018). When ingested by animals, these toxins restrict message transmission between neurons, which affects muscle tissues, including those required for breathing. Death is almost always due to respiratory failure (Negri et al. 1995, Steffensen et al. 1998). Water containing *D. circinale* at 50,000 cells/mL caused the death of sheep in central New South Wales (Negri et al. 1995). Since the neurotoxins act more rapidly, their effects are more obvious than the effects of hepatotoxins (in cases where both are present) (Carmichael & Falconer 1993).

- Cylindrospermopsin is a cytotoxic alkaloid produced by several cyanobacterial genera, including *Cylindrospermopsis*, *Aphanizomenon*, *Umezakia*, *Anabaena* (now *Dolichospermum*), *Lyngbya*, and *Raphidiopsis* (van der Merwe 2015). This toxin affects the liver, kidney, small intestine and lungs of animals, which can result in death (Hawkins et al. 1996).

There have been few toxicological trials carried out to determine safe levels of intake of cyanobacterial cells or toxins for domestic animals. In experiments with bloom material of *Microcystis aeruginosa*, Falconer et al. (1994) showed there was no adverse effect on the livers of pigs supplied with 280 µg toxins/kg/day via drinking water over 44 days. Long-term effects of ingestion of lower levels of toxins are not well understood.

Not all cyanobacteria blooms appear to be hazardous to animals because (Carmichael & Falconer 1993):

- the bloom may have low concentrations of toxins

- livestock are not equally susceptible to algal intoxication – species, age and sex affect susceptibility, and monogastric animals are less sensitive than ruminants and birds

- the amount of toxin consumed may be small and/or countered by the amount of food in the animal's gut.

Derivation of guideline values
Establishing guideline values based on the health of animals is difficult because:

- not all blooms appear to be toxic, and toxic and non-toxic blooms of the same species have been found

- the toxicity per cell can vary over time (weeks to months), making it difficult to relate cell numbers to toxicity (toxin levels)

- different toxin-producing and non–toxin-producing cyanobacterial species can appear and disappear over time (days to weeks)

- insufficient toxicological data are available for all toxins.

In addition, an implicit assumption in devising guidelines and recommendations is that toxic concentrations of cyanotoxins are only associated with a visible bloom. This does not take into account other potential sources:

- In some species, the cyanobacteria population can also be distributed throughout the water column.

- Cyanotoxins persist after a bloom has dissipated – once toxins are released into the water by the death of the cyanobacteria cells, it may take weeks for toxins to be degraded by naturally occurring bacteria (Carmichael 1994, Jones & Orr 1994). The photo-degradation of microcystin-LR toxins in full sunlight can take as little as 2 weeks or longer than 6 weeks depending on the presence of water-soluble cell pigments (Corbel et al. 2014).

- Cyanotoxins can persist in the dried scum that is the remains of blooms, and livestock can eat the scum. Jones et al. (1995) reported that scums of *M. aeruginosa* that dry on the shores of lakes may contain high concentrations of microcystin-LR for several months.

Accurate and sensitive methods for the determination of cyanotoxins in water are available. However, due to their cost, they are not commonly used in a monitoring framework.

The 1 µg/L total microcystin-LR trigger level has been adopted in South Africa (DWAF 1996) for livestock. A subchronic action level of 0.9 µg/L has been adopted in California (CEPA 2012). The Australian Drinking Water Guidelines (as distinct from livestock drinking water) value is 1.3 µg/L of total microcystins-LR toxicity equivalents (NHMRC & NRMMC 2011).

There are insufficient data available to derive guideline values for other cyanobacteria species, but several other toxin-producing genera are known from Australian freshwaters (e.g. *Anabaena* spp., *Cylindrospermopsis raciborskii, Nostoc linckia*) (e.g. Sydney Catchment Authority 2010). Therefore, detection of any level of cyanobacteria in livestock drinking water should be considered significant and should trigger management action.

Microcystin

The following calculations and assumptions were used to derive a guideline value for microcystin-LR toxicity equivalents. (Other microcystins include microcystin-LA, microcystin-RR and microcystin-YR. While the most extensive toxicological information is available for the LR congener, the LA, RR and YR congeners appear to have similar toxicological effects (CEPA 2012)). They are based on the principles adopted by the United States Environmental Protection Agency (Belluck & Anderson 1988, cited by Hamilton & Haydon 1996) and the World Health Organization (Falconer et al. 1999). The example given in Equation 3.1 is for pigs; data for other livestock are in Table 3.1.

Equation 3.1

$$\text{guideline value} = \frac{\text{LOAEL x animalweight}}{\text{maxdailywaterintake x safetyfactor}} = \frac{100\mu\frac{\frac{g}{kg}}{day}\text{x}110\text{kg}}{\frac{15\text{L}}{day}\text{x}45} = 16.3\,\mu\text{g/}\quad\text{L}$$

Where:

- 100 µg microcystin-LR toxicity equivalents/kg/day per body weight is the lowest observed adverse effect level (LOAEL) for pigs fed over 44 days (Falconer et al. 1994, Kuiper-Goodman et al. 1999)

- 110 kg is the upper weight of pigs going to market

- 15 L/day is the peak consumption of water for pigs at this stage of development

- 45 is the safety factor to allow for the less than lifetime study, varying susceptibilities of animals and deriving a no observed effect level (NOEL) from the LOEAL of the pig study.

Table 3.1 Data for deriving guideline values for microcystin-LR toxicity equivalents

Livestock	Body weight (kg)	Peak water intake (L/day)	Safety factor					Microcystin (µg/L)[a]	Equivalent cell concentration (cells/mL)
			Less than lifetime	Inter-species variation	Intra-species variation	LOAEL to NOEL	Total		
Cattle	800.0	85.0	3	5	3	5	225	4.2	21,000
Sheep	100.0	11.5	3	5	3	5	225	3.9	19,500
Pigs	110.0	15.0	3	1	3	5	45	16.3	81,500
Chickens[b]	2.8	0.4	3	5	3	5	225	3.1	15,500
Horses	600.0	70.0	5[c]	5	3	5	375	2.3	11,500

a Assuming 0.2 pg total microcystins/cell (Falconer et al. 1994).
b These values can be taken to represent all poultry, since all poultry has a similar body weight:water intake ratio.
c Horses generally live longer than other livestock.

Using this approach (Equation 3.1, Table 3.1), estimated guideline values for microcystin-LR toxicity for different livestock range from 2.3 µg/L to 16.3 µg/L. A study conducted on growing pigs exposed to microcystins over 44 days concluded that no adverse effect was observed at concentrations lower than 1 µg/L (Falconer et al. 1994), which could represent the guideline value.

Other cyanotoxins
There are presently insufficient animal toxicity data available to derive guideline values for cyanotoxins other than microcystins in livestock drinking water.

CEPA (2012) conducted toxicity assessments on microcystins, anatoxin-a and cylindrospermopsin; the findings for livestock drinking water are summarised in Table 3.2.

Table 3.2 Subchronic action level for toxins, beef and dairy cattle

Cattle	Microcystin (µg/L)	Anatoxin-a (µg/L)	Cylindrospermopsin (µg/L)
Dairy	0.9	40	5
Beef	3.0	100	20

Source: CEPA (2012)

Monitoring and management
Monitoring of algal blooms and cell levels in drinking water is an important component of livestock management. However, neither the presence nor the absence of cells or an algal bloom in drinking water is an accurate indicator of drinking water quality. Hence, the diagnostic procedure is based on prevention and a risk management plan.

Cell biovolume
In guidelines for algal blooms in livestock water and several worldwide guidelines for human drinking water, guideline values are sometimes expressed in terms of cells/mL or colonies/mL. This approach could be misleading in certain circumstances because different cyanobacteria have different cell sizes. Values may be better expressed as a cell biovolume in mm³/L. For example, NHMRC (2008) suggested that a cell biovolume of ≥4 mm³/L could be applied for unknown cyanobacterial populations in recreational water (in terms of human impact).

The effect of using cell numbers versus cell biovolume can be illustrated by considering 178,000 cells/mL of 2 common *Microcystis* species that occur in Australia: *M. aeruginosa* (which has large cells) and *M. flos-aquae* (which has small cells). When 178,000 cells/mL are converted into mm^3/L, the result for *M. aeruginosa* is 15.49 mm^3/L (nearly 4 times higher than the guideline value recommended by NHMRC (2008) for recreational water) whereas the result for *M. flos-aquae* is 3.8 mm^3/L (below the recreational water guideline value recommended by NHMRC (2008)). The value of 178,000 cells/mL of *M. flos-aquae* was found in Class A recycled water stored in a dam and a tank on the Northern Adelaide Plains (Kelly & Stevens 2001); no toxicity problems were observed when using the water for crop irrigation.

For microcystin-producing species other than *M. aeruginosa*, notifications and alerts should be based on cell biovolumes. In all cases, cell numbers in water should be used only as preliminary signals and as guidelines for toxin testing to enable assessment of potential health risks.

For assessing cyanobacteria other than *M. aeruginosa* (i.e. containing microcystins), the approximate cell biovolume equivalent of 4 mm^3/L for the total of all cyanobacteria is recommended (NHMRC 2008).

The Australian Drinking Water Guidelines (NHMRC & NRMMC 2011) recommends that a notification procedure for the presence of cyanobacteria be developed by water and health authorities. A tiered framework should be considered; for example, for *M. aeruginosa*:

- Initial notification to health authorities could be provided when cell concentrations of *M. aeruginosa* reach 30% of the cell concentration equivalent to the guideline value of 1.3 µg/L microcystin (2,000 cells/mL or cell biovolume 0.2 mm^3/L).

- An alert could be provided when cell numbers are equivalent to the guideline value (6,500 cells/mL or cell biovolume 0.6 mm^3/L).

The Australian Drinking Water Guidelines have equivalent notification procedures for *Raphidiopsis raciborskii*, *Nodularia* and *Anabaena*.

Prevention

To minimise monitoring and laboratory analyses, waterbodies are initially graded according to their susceptibility to algal blooms, as suggested by GWRC (2004) and NHMRC (2008). The weight of evidence for establishing the likelihood of cyanobacteria build-up is in Table 3.3.

Table 3.3 Likelihood of cyanobacterial growth

Likelihood of cyanobacterial growth	History of previous algal blooms	Water temperature planktonic/benthic (°C)	Total phosphorus (µg/L)	Thermal stratification
Rare	No	<15/<12	<10	None
Unlikely	Yes	15–20/12–15	<10	Infrequent
Possible	Yes	20–25/15–20	10–25	Occasional
Likely	Yes	>25/20–20	25–100	Frequent and persistent
Certain	Yes	>25/>25	>100	Frequent and persistent/strong

Source: Adapted from GWRC (2004)

Table 3.3 is used in Step 1 of the risk management plan (Table 3.4). Further weight of evidence can be accumulated by considering site-specific conditions (e.g. the livestock species, production system and water intake).

Water considered high risk would have a more rigorous monitoring plan at high-risk times of the year than those considered low risk.

Risk management plan
Table 3.4 outlines a cyanobacteria risk management plan that can be adapted for individual conditions. It is based on a plan created by TEPA (2011) for wastewater.

A separate risk management plan should be derived for benthic cyanobacteria because their growth and toxin release appears to be affected by different factors or different levels of factors. For example, temperature is just as important for benthic cyanobacteria as for planktonic species. However, they have been observed to release cytotoxins at temperatures lower than those observed for toxin release by planktonic cyanobacteria (Mez et al. 1997). New Zealand developed interim guidelines for benthic cyanobacteria in fresh waters used for recreation in 2009 (Wood et al. 2009); these were updated in 2022 (Puddick et al. 2022).

Table 3.4 Example of cyanobacteria risk management plan

Alert level	Monitoring actions[a]	Observations	Response actions for high-risk or deteriorating situations
Identification of high-risk waterbody	• Establish frequency and extent of previous algal blooms • Establish susceptibility of the water to algal blooms	• Assess using Table 3.3.	• Proceed to 'Surveillance'
Surveillance	• Establish colour and clarity of water when there is no algal bloom (take photograph) • Visually monitor water appearance monthly • Monitor livestock for signs of discomfort • Consider increasing monitoring frequency at key risk periods (e.g. summer, after heavy rain on sandy soils)	• Coloured/cloudy water • Small surface scum or algal blooms/mats • Animal discomfort (particularly clinical signs of liver and neurological damage)	• Keep livestock away from water source (e.g. use electric fence if water source is in paddock required for fodder) • Increase frequency of monitoring • Contact local advisers for up-to-date information • Proceed to 'Low Alert'
Low alert	• Increase visual monitoring frequency, choosing the time interval according to the severity of the algal bloom (e.g. fortnightly, weekly)	• Increasing size and depth of algal blooms/mats	• Proceed to 'Medium alert' • Keep livestock away from water source (e.g. use electric fence if water source is in paddock required for fodder)
Medium alert	• Increase visual monitoring frequency (e.g. weekly, bi-weekly) • Identify and enumerate cyanobacterial species and cell biovolume of all cyanobacteria where a known toxin producer is dominant • Consider undertaking toxin testing, noting that some laboratories may only undertake toxin testing if sufficient numbers of toxin-producers have been confirmed	• Continued increase in area and depth of algal blooms/mats	• Seek specialist advice • Conduct risk assessment based on cyanobacterial species identified; levels of cyanotoxins; livestock species; and livestock maturity • If cell biovolume ≥0.9 mm^3/L or ≥2.3 µg/L microcystin or 11,500 cells/mL *Microcystis*, proceed to 'High alert'
High alert	• Monitor livestock for clinical signs of liver or neurological	• Continued increase in area and depth of algal blooms/mats	• If ≥10 µg/L microcystin or cell biovolume ≥4 mm^3/L for all

Alert level	Monitoring actions[a]	Observations	Response actions for high-risk or deteriorating situations
	damage (if stock has not been isolated from the water source as per the precautionary action for 'Low alert') • Increase visual monitoring frequency (e.g. bi-weekly, daily) • Undertake toxin testing		cyanobacteria known to produce toxins, or >50,000 cells/mL *Microcystis*, proceed to 'Immediate action'
Immediate action	• If not done at previous alert levels, isolate water source from livestock • Continue frequent visual monitoring • Once there are no visual signs of algal blooms persisting in the water column, or the results of cell biovolumes are <0.4 mm³/L, undertake a toxin analysis to confirm the water is safe for livestock to consume	• Bloom well established with visible scums/mats, or in decay	• Source alternative water • Implement management plan • Liaise with local specialists • When sample colour and clarity is similar to control samples taken in absence of a harmful algal bloom, revert to 'Low Alert'

a Monitoring actions also include collection and analysis of historical information when necessary.

3.1.2 Pathogens and parasites

E. coli *is a critical indicator for managing risk for human and non-human infection by pathogens, and is therefore used as the guideline value. Drinking water for livestock should contain <100 cfu/100 mL (median value) of* **E. coli***.*

Source
Microbial pathogens can be transmitted to livestock from drinking water supplies that are contaminated by animals, humans and their faeces. The risk of contamination is greatest in surface water (e.g. dams, watercourses) that is directly accessible by livestock or that receives run-off or drainage from intensive livestock operations or human waste. The incidence of groundwater contamination by pathogens is generally low, particularly for deep bores and wells. Some shallow groundwater supplies have the potential to be contaminated, particularly in sandy soils.

Pathogens may be of particular concern if reclaimed water from sewage systems is used as livestock drinking water.

Effects on animal health
Bacterial infections in livestock often reduce growth and cause morbidity and sometimes mortality (Smith et al. 1974). In water supplies, the bacteria of most concern are the enteric bacteria *Escherichia coli* and *Salmonella* spp., and to a lesser extent *Campylobacter jejuni*, *C. coli*, *Yersinia enterocolitica* and *Y. pseudotuberculosis*. Other bacteria known to affect livestock and that may be transmitted through water supplies include:

• *Aeromonas hydrophila* (gastroenteritis, septicaemia and wound infections)

• *Bacillus anthracis* (anthrax)

• *Burkholderia pseudomallei* (melioidosis)

• *Clostridium* spp. (botulism and tetanus)

• *Helicobacter pylori* (gastric and duodenal ulcers)

- *Klebsiella* spp. (meningitis, pneumonia, sepsis)

- *Legionella* spp. (Legionnaires' disease)

- *Leptospira* spp. (leptospirosis)

- *Listeria monocytogenes* (listeriosis)

- *Mycobacterium* spp. (such as *M. bovis*, *M. avium* subsp. *avium*, *M. avium* subsp. *paratuberculosis;* responsible for pulmonary or gastrointestinal diseases such as Johne's disease in ruminants)

- *Pseudomonas* spp. (mastitis).

- *Shigella* spp. (shigellosis).

Several livestock diseases can be caused by waterborne viruses; for example, water supplies have been implicated in transmitting Newcastle disease in poultry (Animal Health Australia 2022).

Well-managed livestock usually has a relatively low incidence of parasitic infections. Most parasites do not cause mortality directly; instead, they reduce growth rates and vitality, increasing the susceptibility to fatal infectious diseases (MLA 2023).

Several livestock parasites, including helminths (worms) and protozoa, spend part of their lifecycles in water, and faecal contamination of water is the usual means of introduction. Parasitic diseases of concern in Australia include:

- cysticercosis in cattle (beef measles) caused by *Taenia saginata* (a tapeworm that affects humans) (Arundel 1972)

- cysticercosis in pigs caused by *Taenia solium,* which can be transmitted between pigs and humans and causes cysts in muscles and the brain

- *Cryptosporidium parvum* – experiments with lambs have shown that the minimum infectious dose of the protozoan *C. parvum* may be as little as one oocyst and that the infection may be waterborne (Blewett et al. 1993)

- *Giardia* spp. – weight loss in livestock has been reported from infection with the protozoan *Giardia* (Olson et al. 1995).

Trematodes such as fasciola and schistosomes can cause liver and biliary system damage that affects the health of the animal and can prevent livers being sold for human consumption.

Waterborne pathogens and parasites can also affect human health. High prevalence of pathogens in a herd could lead to high numbers of pathogens in meat, increasing the risk of disease for human consumers.

Derivation of guideline values
The National Water Quality Management Strategy guidelines for pathogens in drinking water (ARMCANZ, ANZECC & NHMRC 2000) were based on:

- the best available scientific evidence

- international practice in reclaimed water use

- a consensus of local practice demonstrated to be safe.

In particular, the guidelines considered:

- the methods and information used to develop guidelines from the World Health Organization (WHO 1989) and the United States Environmental Protection Agency (USEPA 1992)

- local guidelines adapted to local conditions and socio-economic factors (Hespanhol & Prost 1994).

In addition, the management and use of reclaimed water from sewage systems are important components of the National Water Quality Management Strategy. Pathogen guidelines for livestock drinking water have been proposed in the Australian Guidelines for Water Recycling (NWQMS 2006).

Monitoring and management

It is generally not feasible nor warranted to test livestock drinking water for the presence of the wide variety of waterborne microbial pathogens (bacteria, viruses, protozoa and helminths) that may affect stock health. Instead, tests to detect faecal contamination are used to indicate the possible presence of microbial pathogens. Faecal contamination is detected by testing for *E. coli*, which is the recommended primary indicator because of its presence in warm-blooded animals (NHMRC & NRMMC 2011).

Drinking water for livestock should contain <100 cfu/100 mL (median value) of *E. coli*. In testing for *E. coli*, it is recommended that a median value of *E. coli* is used, based on several readings over time from a regular monitoring program. Investigations of likely causes are warranted when 20% of results are >4 times the median guideline level (ARMCANZ, ANZECC & NHMRC 2000), unless it is clear from the monitoring program that the background in the stream is already carrying an unacceptable bacterial load.

Managing water supplies to minimise contamination is the best strategy for protecting livestock from waterborne microbial pathogens. Effective measures include:

- preventing livestock access to watercourses

- minimising the drainage of water containing animal or human waste to surface water and groundwater

- locating high-density animal areas (e.g. dairy platforms and indoor/outdoor pig farms) away from watercourses

- safeguarding water sources during adverse weather events (e.g. droughts and flooding events).

3.2 Main ions of concern

Salts are chemical compounds formed from positive and negative ions. When the salts are dissolved in water, the bond between the ions breaks. Many inorganic salts (salts without a carbon–hydrogen bond) are essential nutrients for animal health, but elevated concentrations of some compounds in drinking water may have chronic or toxic effects in livestock.

Unless otherwise stated, the guideline values relate to the total concentration of the constituent, irrespective of whether it is dissolved, complexed with an organic compound, or bound to suspended solids. Measured concentrations from unfiltered samples should be used to compare with the guideline values. Further assessment of risk should consider the bioavailability and solubility of the constituent, including results from filtered samples.

Monitoring and management
Livestock drinking water should be monitored and regularly assessed for contaminants of concern. Further information is available in the Australian and New Zealand Water Quality Management Framework, particularly the Monitoring section.

In particular, water should be tested if:

- any adverse health or growth effects are noticed in livestock

- warm weather causes high rates of evaporation, which can increase the concentration of ions of concern.

Actions to be taken will depend on the results of testing. If levels are increased but not yet unsafe, increased monitoring is recommended. If levels exceed guideline values or adverse health or growth effects are noticed, keep stock away from the water source.

3.2.1 Calcium

Calcium concentrations <1,000 mg/L in drinking water should not be harmful to animal health, if calcium is the main cation present and if dietary phosphorus levels are adequate. In the presence of high concentrations of magnesium and sodium, or if calcium is added to feed as a dietary supplement, the level of calcium tolerable in livestock drinking water may be less.

Source
Calcium is found in natural waters over a wide range of concentrations. The concentration of calcium in water is closely related to the geology of the catchment areas, because the calcium comes from weathering of minerals such as gypsum, limestone and dolomite. Calcium contributes to the hardness of the water and may cause scaling problems in pipes, troughs and fittings.

Effects on animal health
Calcium is an essential element in animal nutrition. However, high calcium concentrations may cause calcious formations in the body, or phosphorus deficiency by interfering with phosphorus absorption in the gastrointestinal tract (Mulhearn 1964). It can also contribute to poor growth, soft bones, fractures and infertility (Agriculture Victoria 2023).

Long-term intake by sheep of water containing approximately 1,100 mg/L of calcium had no adverse effect on health and wool production, although the calcium concentration in plasma increased while the sodium concentration in plasma decreased (Peirce 1960).

Derivation of guideline values
The ANZECC (1992) guideline for calcium has been retained in the absence of new contradicting information. Agriculture Victoria (2023) recommends a maximum level of 1,000 mg/L of calcium for

water in stock containment areas. The guideline value of 1,000 mg/L is consistent with guidelines developed in Canada (CCME 2005) and South Africa (DWAF 1996). However, in the presence of high concentrations of magnesium and sodium, or if calcium is added to feed as a dietary supplement, the level of calcium tolerable in drinking water may be less (Olkowski 2009).

3.2.2 Magnesium

For ruminants, magnesium concentrations <500 mg/L in drinking water should not be harmful to health. However, for lactating cows and ewes with lambs, concentrations should be <250 mg/L.

For poultry, magnesium concentrations in drinking water should be <125 mg/L; higher concentrations may have a laxative effect. Also, if sulfate levels are high, poultry performance may be affected at magnesium concentrations >50 mg/L.

Source
The concentration of magnesium in natural waters varies from <1 mg/L to >1,000 mg/L, depending on catchment geology (Meybeck 1979, Galvin 1996, APHA, AWWA & WEF 1998). Magnesium contributes to the hardness of water and may cause scaling problems in pipes, troughs and fittings.

Effects on animal health
Magnesium is an essential element in animal nutrition and is required in large amounts. However, in very high doses magnesium can cause scouring and diarrhoea, lethargy, lameness, decreased feed intake and decreased performance.

Drinking water containing magnesium at concentrations up to 2,000 mg/L has been found to have no adverse effects on cattle. Work by CSIRO in Queensland suggests that Brahman steers can tolerate magnesium concentrations in drinking water up to 2,000 mg/L with no adverse effects (GS Harper pers. comm.). Several earlier studies have reported possible adverse effects on livestock from drinking water containing magnesium at concentrations of 250 mg/L and higher (Peirce 1960, Saul & Flinn 1978, 1985, VIRASC 1980). However, it is not clear whether the reported effects were due to magnesium or other issues such as salinity or other ions (e.g. sulfate).

High magnesium concentrations in water are generally associated with high concentrations of total dissolved salts (TDS). This means that problems attributed to magnesium may instead be due to high TDS concentrations. Flinn (1980) showed that concentrations of 400–600 mg/L magnesium were typically found in water containing 8,000–12,000 mg/L TDS, which is at the upper limit of tolerance by livestock. The findings of Saul and Flinn (1985) also seem to support this.

Derivation of guideline values
Information about recommended limits for magnesium in livestock drinking water on animal health varies. The ANZECC (1992) guidelines (based on Flinn 1984) gave the upper limit of 600 mg/L for magnesium for all livestock, but this is no longer supported. Agriculture Victoria (2003) recommends a maximum level of 500 mg/L of magnesium for water in stock containment areas.

Canadian guidelines (CCME 2005) do not include a magnesium guideline for livestock drinking water. In South Africa, the target water quality range is between 0 mg/L and 500 mg/L, with adverse chronic (for ruminants) and acute (for non-ruminants) effects occurring at concentrations of 500–1,000 mg/L (DWAF 1996). For poultry, the suggested maximum acceptable concentration of magnesium in drinking water is 125 mg/L (Watkins 2008, cited in MSU 2013).

The UN Food and Agriculture Organization (FAO; Ayers & Westcot 1994) provides the following table of suggested limits for magnesium in drinking water for livestock.

Table 3.5 Suggested limits for magnesium in livestock drinking water

Livestock	Maximum magnesium level (mg/L)
Adult sheep on dry feed	500
Beef cattle	400
Ewes with lambs	250
Dairy cattle	250
Horses	250
Pigs	250
Poultry	250

Source: Ayers & Westcot 1994

3.2.3   Nitrate and nitrite

Nitrate concentrations <100 mg/L and nitrite concentrations <10 mg/L in livestock drinking water should not be harmful to animal health.

However, tolerance varies between animals. Generally, levels of nitrate tolerance are lowest in poultry, medium in pigs and highest in cattle:

- *For poultry, adverse effects are expected at nitrate concentrations >25 mg/L. Poultry may tolerate higher nitrate concentrations in drinking water if nitrate concentrations in feed are not high.*

- *For cattle, adverse effects are expected at nitrate concentrations >400 mg/L nitrate. Stock may tolerate higher nitrate concentrations in drinking water if nitrate concentrations in feed are not high.*

Source

Nitrate and nitrite are oxidised forms of nitrogen, both of which can occur naturally in water, though nitrate is generally predominant. Nitrate is usually present in unpolluted streams at concentrations <1 mg/L (Meybeck 1982). Higher concentrations are often associated with over-use of nitrogen fertilisers and manures, intensive livestock operations, and/or leaks from septic systems and municipal wastes. Typically, elevated nitrite concentrations are found only under anoxic conditions (e.g. where water is polluted by organic waste).

Groundwater may contain elevated nitrate concentrations due to natural processes (Lawrence 1983), but more typically, high nitrate concentrations in groundwater are associated with contamination. Nitrate concentrations >20 mg/L have been reported in many Australian groundwaters, with a small proportion showing concentrations >100 mg/L nitrate (Lawrence 1983, Keating et al. 1996).

Animals are likely to be at higher risk of nitrate/nitrite poisoning through consumption of pastures, forages and feeds containing high concentrations of nitrate than from their water supplies. Over-fertilising plants with nitrogen fertilisers, poultry litter or animal manures can lead to excessive nitrate accumulation in plants. Plants under stress (e.g. from drought, or a lack of adequate nutrition or sunlight) may also accumulate nitrate.

Effects on animal health

Both nitrate and nitrite can cause toxicity to animals, with nitrite being 10–15 times more toxic than nitrate (Case 1963). Nitrate and nitrite can cause vomiting, convulsions and death (Agriculture Victoria 2023).

Toxicity is increased when nitrate is reduced to nitrite, which is an intermediate product of the reduction of nitrate to ammonia by bacteria in the rumens of sheep and cattle and, to some degree, in the cecum of horses. Non-ruminants (pigs and chickens) are less susceptible as they rapidly eliminate nitrate in the urine (Thompson 2022). However, excess nitrate intake can also lead to absorption of nitrate and nitrite, which will cause toxicity.

Nitrite is absorbed into the bloodstream, where it converts haemoglobin to methaemoglobin, thus reducing the oxygen-carrying capacity of the blood and causing eventual suffocation due to a lack of oxygen in body tissues. Symptoms of acute poisoning include increased urination, restlessness and cyanosis, leading to vomiting, convulsions and death.

Rumens of animals previously fed high nitrate diets have an increased tolerance. Toxicity also depends on the rate of consumption, with slow intake and a balanced ration reducing toxicity (Crowley 1985).

Livestock vary in their sensitivity to nitrate and nitrite.

- Winks (1963) reported death of calves and cattle in Queensland from drinking water containing 2,200 mg/L nitrate. He suggested a toxic nitrate concentration for cattle as between 300 mg/L and 2,200 mg/L. In dairy cows, nitrate concentrations up to 180 mg/L in drinking water did not increase the concentration of nitrate in milk (Kammerer et al. 1992).

- Seerley et al. (1965) concluded that drinking water containing approximately 300 mg/L nitrate-N had no effect on the health of pigs or sheep and that levels of nitrite-N <100 mg/L over 105 days did not adversely affect pig health. Anderson and Stothers (1978) similarly reported no ill effects in weanling pigs after 6 weeks of drinking water containing approximately 1,300 mg/L nitrate. Sorensen et al. (1994) found no effect on early weaned piglets and growing pigs from water containing up to 2,000 mg/L nitrate or up to 17 mg/L nitrite. In experiments carried out in Queensland, pigs raised from 20 kg to 80 kg showed no decrease in performance and no adverse health effects when given water containing up to 500 mg/L nitrate or up to 50 mg/L nitrite (McIntosh 1981). A national survey of pig farms in the United States showed no association between animal health or performance and drinking water containing up to 460 mg/L nitrate (Bruning-Fann et al. 1996).

- Poultry are very sensitive to nitrate. Blake and Hess (2001) report poultry performance may be affected by 3–20 mg/L of nitrate. Fairchild and Ritz (2009) state a limit of 25 mg/L of nitrate for poultry water; however, they note that concentrations up to 600 mg/L have been shown to have no adverse effect on poultry health.

Derivation of guideline values

Confusion can arise concerning guideline values for nitrate and nitrite because concentrations are sometimes reported on the basis of their respective nitrogen (N) contents: nitrate-N (NO_3 N) and nitrite-N (NO_2-N). The conversions are as follows:

- 1 mg/L nitrate-N = 4.43 mg/L nitrate

- 1 mg/L nitrite-N = 3.29 mg/L nitrite.

Because ingestion of nitrite leads to a more rapid onset of toxicity than ingestion of nitrate, the guideline value for nitrite is lower than that for nitrate.

The total dietary intake of nitrate by livestock should be considered when interpreting the guideline values. High nitrate concentrations in the water supply may indicate that nitrate concentrations in locally grown feed may also be elevated.

The NRC (2005) noted that in ruminants, diets containing more than 5,000 mg/kg nitrate (dry matter) may result in toxicity. Rumen bacteria have been suggested to provide a good buffer against nitrate toxicosis; however, this makes the derivation of a maximum tolerable intake difficult, given the broad range of dietary conditions. Also, ammonia toxicosis in ruminants is a risk if the rate of ammonia production exceeds the capacity of microorganisms in the rumen to use it to form amino acids.

Nitrate guideline values for different species were estimated using Equation 3.2 (ANZECC/ARMCANZ 2000) and based on the NRC (2005) dietary recommendations. The calculated guideline values are shown in Table 3.6.

Equation 3.2

$$\text{Guideline value} = \frac{\text{MTDL} \times \text{PFI} \times \text{ proportion of water contribution}}{\text{WIR} \times \text{SF}}$$

Where:

- MTDL is the maximum tolerable dietary level (mg/kg feed)

- PFI is the peak food intake (kg feed/day)

- 0.2 is the proportion of water contribution

- WIR is the water intake rate (L/day)

- SF is the safety factor.

Table 3.6 Calculated guideline values for nitrate in livestock drinking water

Livestock	Maximum nitrate in feed (dry matter) (mg/kg)[a]	Safety factor[b]	Nitrate guideline value (mg/L)
Cattle	5,000	1	235
Sheep	10	1	209
Poultry	50	1	25[c]

a Based on NRC (2005) assumed maximum intake of nitrate in feed.
b No safety factor was included in these calculations.
c This value from Blake and Hess (2001).

NRC (1974) provides the following information about concentrations in cattle drinking water.

- Concentrations of <10 mg/L of nitrate as nitrogen (i.e. nitrate-N) or <44 mg/L of nitrate (NO_3) are generally considered safe.

- Concentrations of 10–100 mg/L (nitrate-N) or 44–443 mg/L (NO_3) are questionable.

- Concentrations of >100 mg/L (nitrate-N) or 443 mg/L (NO_3) are generally considered unsafe.

A target water quality range of 0–100 mg/L of nitrate is supported by the South African Livestock Drinking Water guidelines (DWAF 1996). Canada has set a guideline value of 100 mg/L for nitrate and 10 mg/L for nitrite (CCME 2005). Agriculture Victoria (2023) recommends a maximum level of 1,500 mg/L of nitrate for water in stock containment areas.

Concentrations higher than 200 mg/L may be toxic to monogastrics, and concentrations >400 mg/L increase the potential for adverse effects for ruminants. Nitrate concentrations of 100–200 mg/L for monogastrics and 200–400 mg/L for ruminants may have toxic effects on pregnant livestock. For non-pregnant animals, these ranges may be tolerated. In the United States, NRC (1974) set a range of

221–660 mg/L of nitrate for risk and death to cattle. The calculated guideline values are in the lower part of this range for ruminants.

3.2.4 Sulfate

Sulfate (measured as SO$_4$) concentrations <500 mg/L in livestock drinking water should not be harmful to animal health. The exception to this is poultry, where 250 mg/L of sulfate in drinking water is the maximum concentration.

For cattle, adverse effects may occur at sulfate concentrations >500 mg/L, especially in feedlot, young or lactating animals or in dry, hot weather when water intake is high. These effects may be temporary and may cease once stock become accustomed to the water. Chronic exposure effects seem to start at sulfate concentrations of 1,000 mg/L. Chronic or acute health problems are expected at concentrations of 1,500–2,000 mg/L, and adverse acute effects are expected at >2,000 mg/L.

Pigs appear to tolerate higher sulfate concentrations (2,650 mg/L).

Source
Sulfate is found in most natural waters in the form of calcium, iron, magnesium and sodium salts as a result of the dissolution of sulfate-bearing minerals in soils and rocks. Sulfate can occur naturally at concentrations up to thousands of milligrams per litre, particularly in groundwater. Domestic and industrial wastewater such as treated sewage effluent and mine contaminated water can contain high concentrations of sulfate. Tannery wastes and other industrial discharges also contain high concentrations of sulfate, and the use of alum (usually a hydrated double sulfate salt of aluminium) as a flocculant may increase the concentrations of sulfate in stock drinking water.

Under anoxic conditions, bacteria in water can reduce sulfate to sulfide, which releases hydrogen sulfide, causing an unpleasant taste and odour and increasing the potential for corrosion of pipes and fittings.

Note: 1 mg/L sulfate-S = 2.99 mg/L sulfate.

Effects on animal health
Sulfate is an essential element in animal nutrition, but excessive concentrations of sulfate in water typically cause diarrhoea in livestock. However, animals generally avoid water containing high sulfate concentrations in favour of water containing lower concentrations, where available (Weeth & Capps 1972).

A sulfate concentration of 1,000 mg/L in drinking water can cause diarrhoea in young animals (Church 1979). Higher concentrations of sulfate may be tolerated, depending on the type and age of livestock and the principal cations associated with the sulfate ion, but loss of production may be expected (CCREM 1987, 2005).

Pigs and poultry can tolerate higher levels of sulfate than cattle or sheep (Olkowski 2009, Meays & Nordin 2013). Weaning pigs showed no significant effect on performance after drinking water containing up to 2,400 mg/L of sulfate for 20 days (although scouring was reported), but performance was reduced at 4,880 mg/L of sulfate (McLeese et al. 1992).

Improvements in dairy cattle productivity and health were reported when their source of drinking water was changed from deep-well water containing 1,500–2,500 mg/L of sulfate to surface water containing less than 1,000 mg/L of sulfate (CCREM 1987). Hereford cattle showed decreased water and food consumption, weight loss and diuresis when consuming water containing 3,380 mg/L of sulfate (Weeth & Hunter 1971). Cattle feedlot performance declined with sulfate concentrations

greater than 583 mg/L (Loneragan et al. 2001), and water intake declined linearly as magnesium sulfate concentrations in cattle water increased (Grout et al. 2006). However, this effect was not observed when sodium was the accompanying cation rather than magnesium. The authors attributed the difference to the functional roles played by the 2 cations and an aversion to consumption due to the bitter taste of the magnesium sulfate. NRC (2005) recommended a limit of 600 mg/L of sulfate in drinking water for cattle being fed high-concentrate diets such as in feedlots.

Brahman steers fed diluted coal mine pit water containing approximately 2,000 mg/L of sulfate showed no reduction in performance over 46 days when progressively adapted to the high sulfate concentrations under controlled experimental conditions (Robertson et al. 1996). Similarly, beef steers showed no ill effects when introduced gradually to water containing 2,000 mg/L of sulfate, but their water and dry matter intake reduced when exposed to drinking water containing 4,000 mg/L of sulfate (Harper et al. 1997). Body weight gains for lactating cows and their calves were significantly reduced by drinking water containing 1,300 mg/L of sulfate, but not at 630 mg/L (Hunter et al. 2002).

Very high concentrations of sulfate in drinking water (7,200 mg/L) have been associated with an outbreak of polioencephalomalacia in cattle, with symptoms including depression, ataxia, cortical blindness, dysphagia and death (Hamlen et al. 1993).

Derivation of guideline values

The NRC (2005) recommendation for total dietary sulfur intake is between 0.3% and 0.5% for various species. This value is determined given the potential for sulfur to be toxic to animals, and notes that many animals are exposed to sulfate in water as opposed to food.

The NRC (2005) maximum tolerable sulfur concentrations were used to calculate indicative guideline values using the Equation 3.2. The calculated guideline values are shown in Table 3.7.

Table 3.7 Calculated guideline values for sulfate in livestock drinking water

Livestock	Maximum S⁻ in feed (%)[a]	Safety factor[b]	Guideline value S (mg/L)	Guideline value SO_4^{2-} (mg/L)
Pigs	0.4	1	155	464
Cattle	0.3 (high-concentrate)	1	141	422
	0.5 (high-forage diet)	1	235	704
Sheep	0.3 (high-concentrate)	1	125	374
	0.5 (high-forage diet)	1	209	626
Poultry	0.4	1	100	300

Note: Sulfate limits were calculated based on sulfur constituting 33.4% of sulfate.
a Based on NRC (2005) assumed maximum dietary intake of sulfur in feed.
b No safety factors were considered in this assessment as long-term effects were not considered.

Based on these results, a guideline value of 500 mg/L is recommended for all livestock except for poultry, for which a guideline value of 250 mg/L is recommended. Agriculture Victoria (2023) recommends a maximum level of 1,000 mg/L of sulfate for water in stock containment areas. Canada recommends a water quality guideline of 1,000 mg/L sulfate for livestock (CCME 2005); however, this level may cause health problems for ruminant livestock, especially when combined with dietary sources (Meays & Nordin 2013).

Interactions with dietary copper and molybdenum should also be taken into account when deciding if water with high sulfate concentrations is suitable for livestock drinking water.

3.2.5   Total dissolved solids (salinity)

Total dissolved solids (TDS) concentrations <500 mg/L in drinking water should not be harmful to animal health.

Salinity is used as a convenient guide to the suitability of water for livestock watering. However, TDS should not be measured in isolation. Individual ion concentration should be included where possible to better assess the suitability or palatability of water for stock. In particular, the concentration of calcium, magnesium, nitrate/nitrite and sulfate ions may need monitoring, especially if using groundwater, as they can cause purgative or toxic effects (DPIRD 2021). If a water has purgative or toxic effects, especially if the TDS concentration is >2,400 mg/L, the water should be analysed to determine the concentrations of specific ions.

Source
TDS is a measure of all inorganic salts dissolved in water. TDS are any ions smaller than 2 μm including chlorides, carbonates, nitrates and sulfates of calcium, magnesium, sodium, and potassium. The mass of dissolved salts in water is a measure of salinity.

Salts are derived from the weathering of the Earth's crust and are transported and cycled in the broader environment through rainfall and the movement of water. The concentration of TDS in natural waters ranges widely, from <1 mg/L in rainwater to 35,000 mg/L in seawater. The TDS of natural waters reflects the geology of source areas; the major contributing ions are typically the cations calcium, magnesium, sodium and potassium, and the anions bicarbonate, chloride, sulfate and, in some cases, nitrate.

Surface waters generally have lower TDS concentrations than groundwaters. In streams, TDS can increase through the continual addition of salts from both natural weathering processes and human activities, such as discharges of domestic and industrial effluents and run-off from urban and rural areas. TDS concentrations in surface water storages such as dams, lakes and water troughs can increase due to evaporation, particularly if they are not flushed regularly with fresh water. In still water, water at the lower levels (bottom of the storage) can have much higher salinity, and these levels can be exposed by evaporation.

Effects on animal health
Water with high TDS concentrations can cause physiological problems and sometimes death in land animals. Animals under physiological stress (e.g. due to pregnancy, lactation, rapid growth or temporary water deprivation) are particularly susceptible to mineral imbalances and salt poisoning. However, unless they have been previously deprived of water, animals can drink moderate amounts of highly saline water for a few days without being harmed (Ayers & Westcot 1994).

Livestock generally find high-salinity water unpalatable. Urolithiasis (kidney stones) in ruminants is often associated with reduced water intake owing to poor palatability (Beggs 2014). In north Queensland it is seen in steers and wethers on bore water and mineral supplements towards the end of dry season.

Water of marginal quality can cause gastrointestinal symptoms and reduce weight gain and milk or egg production. However, to some extent, livestock can physiologically acclimatise to high-salinity water when the concentration is adjusted over several weeks.

In dairy cattle, reduced milk production and body weight gain have been reported at TDS concentrations of 4,360 mg/L (Challis et al. 1987), 3,574 mg/L (Solomon et al. 1995) and 2,696 mg/L (Jaster et al. 1978). Saul and Flinn (1985) reported losses in animal production when Hereford heifers were introduced to water containing TDS concentrations of 5,000–11,000 mg/L.

The tolerance of sheep to saline drinking water may depend on the type of forage consumed. Sheep raised in pens were shown to tolerate up to 13,000 mg/L TDS (Peirce 1966, 1968a). However, with sheep raised on pasture, lambs experienced:

- diarrhoea, mortality and decreased body weight gains at 13,000 mg/L of TDS

- reduced body weight gains and wool production at 10,000 mg/L of TDS (Peirce 1968b).

In chickens, the incidence of eggshell defects (thin and cracked shells) significantly increased as mineral salts intake increased (Balnave & Scott 1986). Municipal water supplemented with 250 mg/L of sodium chloride doubled the rate of shell defects, and 2,000 mg/L added to drinking water resulted in defects in up to 50% of all eggs (Balnave & Yoselwitz 1987, Brackpool et al. 1996). The adverse effect of drinking the saline water even for short periods during early laying was not overcome when the water supply was replaced with lower-salinity water (Balnave & Zhang 1998). Equivalent concentrations of sodium chloride in feed did not adversely affect eggshell quality (Yoselwitz & Balnave 1989).

While increased water consumption and some initial diarrhoea are common when pigs are introduced to water containing >4,000 mg/L of TDS, concentrations as high as 6,000 mg/L of TDS are unlikely to adversely affect pigs that have become accustomed to the water (Robards & Radcliffe 1987, Williams 1990). Concentrations >7,000 mg/L are considered unfit for pigs, and this threshold is lower (5,000 mg/L) for pregnant and lactating pigs (van Heugten 2000).

Derivation of guideline values
Salinity (TDS) is used throughout Australia as a guide to the suitability of livestock drinking water.

Table 3.8 summarises the salinity guidelines for livestock (from ANZECC 1992), and Table 3.9 summarises the guidelines for pigs. These guidelines are broadly consistent with those recommended in Canada (CCREM 2005) and South Africa (DWAF 1996), although there are some differences in TDS concentration ranges for different types of livestock. In Canada, the maximum TDS concentration recommended as safe for livestock consumption is 10,000 mg/L (CCREM 2005).

Table 3.8 Guideline values for total dissolved solids in livestock drinking water

Livestock	Total dissolved solids (mg/L)		
	No adverse effects expected	Livestock may be reluctant to drink May be some scouring Livestock should adapt without loss of production	Loss of production Decline in livestock condition and health Livestock may tolerate for short periods if introduced gradually
Beef cattle	0–4,000	4,000–5,000	5,000–10,000
Dairy cattle	0–2,400	2,400–4,000	4,000–7,000
Sheep	0–4,000	4,000–1, 000	10,000–13,000[a]
Horses	0–4,000	4,000–6,000	6,000–7,000
Pigs	0–4,000	4,000–6,000	6,000–7,000
Poultry	0–2,000	2,000–3,000	3,000–4,000

Source: Adapted from ANZECC (1992)
a Sheep on lush green feed may tolerate up to 13,000 mg/L of TDS without loss of condition or production.

Table 3.9 Guideline values for total dissolved solids in drinking water for pigs

Total dissolved solids (mg/L)	Effect
<1,000	No risk
1,000–2,999	Satisfactory for pigs, but may cause slightly reduced feed intake and, in pigs not adapted to it, mild diarrhoea
3,000–4,999	Satisfactory for pigs, but likely to cause reduced feed intake and may cause reduced health, temporary diarrhoea and temporary refusal of water
5,000–6,999	Reasonably safe for pigs, but unfit for pregnant and lactating pigs
>7,000	Unfit for pigs and not recommended for use

Source: Adapted from van Heugten (2000)

TDS is sometimes expressed as total dissolved ions (TDI), which is a summation of the concentrations of inorganic ions present in water, but unlike TDS, it does not include any other substances (e.g. organic compounds) that may also be dissolved in the water.

For convenience, TDS is often estimated from electrical conductivity (EC). An approximate conversion of EC to TDS is:

- EC (dS/m) x 670 = TDS (mg/L)

- EC (µS/cm) x 0.67 = TDS (mg/L).

3.3 Metals and metalloids

Many metal elements are essential nutrients for animal health, but elevated concentrations of some compounds may cause chronic or toxic effects in livestock. Stock can tolerate many metal elements in drinking water if there are not high levels in the diet, because accumulation in the body depends on the amount ingested from both food and water sources.

Unless otherwise stated, the guideline values relate to the total concentration of the constituent, irrespective of whether it is dissolved, complexed with an organic compound, or bound to suspended solids. Measured concentrations from unfiltered samples should be used to compare with the guideline values. Further assessment of risk should consider the bioavailability and solubility of the constituent, including results from filtered samples.

Monitoring and management
Livestock drinking water should be monitored and regularly assessed for contaminants of concern. Further information is available in the Australian and New Zealand Water Quality Management Framework, particularly the Monitoring section.

In particular, water should be tested if:

- any adverse health or growth effects are noticed in livestock

- warm weather causes high rates of evaporation, which can increase the concentration of metals and metalloids

- levels of metals and metalloids may have been affected by local changes or events such as new development or mining, or new roads and increased traffic.

Actions to be taken will depend on the results of testing. If levels are increased but not yet unsafe, increased monitoring is recommended. If levels exceed guideline values or adverse health or growth effects are noticed, keep stock away from the water source.

3.3.1 Aluminium

Aluminium concentrations <5 mg/L in livestock drinking water should not be harmful to animal health. Concentrations <3.6 mg/L are recommended for chickens.

Source
Aluminium is found in abundance in the geosphere (8% in the Earth's crust) in complexes with oxygen, fluorine and silicone. Aluminium compounds are very stable and are contained in all soils, mostly in alumino-silicate minerals, although aluminium may be present in an ion-exchangeable form in acidic soils (Scott-Fordsmand & Peterson 1995).

Aluminium is usually present in natural waters in concentrations below 1 mg/L, except in areas with low soil pH (acidic), where the aluminium content may be as high as 10 mg/L, due to the increased solubility of aluminium oxides and clay minerals (Galvin 1996). The bioavailability and toxicity of aluminium is generally greatest in more acidic solutions (Campbell & Stokes 1985). The use of alum and other aluminium-based flocculants (used in water treatment to promote clumping of fine particles into 'floc' that can then be readily separated from the water) may also increase concentrations of aluminium in water supplies.

Effects on animal health
High levels of aluminium react with phosphorus in the intestine of animals to form a non-absorbable complex, thus affecting phosphorus absorption and metabolism and resulting in phosphorus deficiency (NRC 1980). Symptoms of phosphorus deficiency include reduced growth, soft bones and

fractures, and infertility (Agriculture Victoria 2023). Ruminants may be less susceptible than monogastrics, since organic anions in the rumen may prevent the aluminium precipitating with phosphate (Thompson et al. 1959, cited by NRC 1980).

Animals, particularly ruminants, may tolerate high concentrations of aluminium if there is sufficient phosphorus in the diet to compensate for the effects of aluminium. Where aluminium concentrations in drinking water exceed 5 mg/L (3.6 mg/L for chickens), livestock intake of phosphorus in the diet should be investigated.

No adverse effects were observed when aluminium sulfate was fed to sheep and cattle at concentrations of 1,215 mg/kg (Bailey 1977), or when aluminium chloride was added to feed for steers at concentrations of 1,200 mg/kg (Valdivia et al. 1978). Based on these results, NRC (1980, 2005) set the maximum tolerable concentration of aluminium in the diet of livestock as 1,000 mg/kg.

Chicks and turkeys showed no effects when fed 486 mg/kg. There is no information on the tolerance of pigs to aluminium (Cakir et al. 1978, cited by NRC 1980).

Derivation of guideline values

The ANZECC (1992) guideline value of 5 mg/L has been retained and is supported by the calculation of a theoretical guideline value based on a toxicological approach using data from the literature and assumptions as detailed below. The example in Equation 3.3 is for cattle; data for other livestock are provided in Table 3.10.

Equation 3.3

$$\text{Guideline value} = \frac{\text{NOEL x dailyfeedintake x proportionwater}}{\text{maxdailywaterintake x safetyfactor}}$$

$$= \frac{(1200 \text{ mg/kg})/\text{day x 20 kg x 0.2}}{85 \text{ L/day x 10}} = 5.6 \text{ mg/L}$$

Where:

- 1,200 mg/kg is the concentration of aluminium in the diet for cattle fed over 84 days used as the NOEL (Valdivia et al. 1978)

- 20 kg/day is an estimate of the average daily feed intake of cattle at this weight, assuming they consume approximately 2.5% of their body weight in feed

- 0.2 is the proportion of aluminium attributed to the intake of water

- 85 L/day is the peak water consumption

- 10 is the safety factor for possible long-term effects and tissue accumulation.

Based on this approach, estimated guideline values for various types of livestock range from 3.6 mg/L to 5.6 mg Al/L (Table 3.10), consistent with a guideline value of 5 mg/L for all livestock. Agriculture Victoria (2023) recommends a maximum level of 5 mg/L of aluminium for water in stock containment areas. The guideline is also consistent with the Canadian (CCREM 2005) and South African (DWAF 1996) guideline values for aluminium in livestock drinking water of 5 mg/L. The Canadian and South African guidelines also indicate that much higher concentrations of aluminium may be tolerated.

Table 3.10 Calculated guideline values for aluminium in drinking water

Livestock	Concentration (mg/kg)[a]	Daily feed intake (kg/day)	Peak water intake (L/day)	Safety factor[b]	Guideline value (mg/L)
Cattle	1,200	20.0	85.0	10	5.6
Sheep	1,215	2.4	11.5	10	5.1
Poultry[c]	486	0.15	0.4	10	3.6

a From summary of toxic responses of animals to aluminium concentrations in feed in NRC (1980, 2005).
b Safety factor for possible long-term effects and tissue accumulation.
c Calculated for chickens; all poultry have a similar body weight to water intake ratio; hence, these values represent all poultry.

3.3.2 Arsenic

Total arsenic concentrations >0.025 mg/L in livestock drinking water may be hazardous to stock health.

Source
Arsenic is a naturally occurring element that is widely distributed in the Australian environment. It exhibits complex chemical and environmental behaviours as it can exist in a number of oxidative states (Rajakovic & Rajakovic-Ognjanovic 2018).

Arsenic occurs naturally in surface waters at low concentrations, generally <0.01 mg/L. Higher concentrations are found in some groundwaters and as a result of local mining or industrial activities (Fergusson 1990, Galvin 1996). The potential sources of arsenic for farm animals, in order of contribution, are food, drinking water, soil and air (Olkowski 2009).

Arsenic is used in several industrial processes. It is no longer used as insecticide in sheep dips, but organic forms of arsenic are included in some herbicide formulations (see PubCRIS).

Animal health
Arsenic and inorganic arsenic compounds are classed as a Group 1 carcinogen by the International Agency for Research on Cancer. The toxicity of arsenic depends, to a large extent, on the form in which it occurs: inorganic arsenic is more toxic than organic arsenic; trivalent inorganic arsenic (arsenite) is more toxic than the pentavalent form (arsenate).

Symptoms of arsenic intoxication include acute effects such as diarrhoea, incoordination, and anaemia (Agriculture Victoria 2023). Monogastrics (pigs and poultry) are more susceptible than ruminants and horses.

Although the level of arsenic in animal tissue increases proportionally with the amount ingested, it does not accumulate in tissue and is efficiently excreted (NRC 1980, 2005). Arsenic increases excretion of selenium, which may lead to selenium deficiency (Olkowski 2009).

NRC (1980) set a maximum tolerable dietary concentration of 50 mg/kg in feed for inorganic forms of arsenic and 100 mg/kg in feed for organic forms of arsenic. This was reduced in NRC (2005) to 30 mg/kg diet for both forms of arsenic to recognise the variability between species in their tolerance of arsenic.

Rosas et al. (1999) reported that dairy cattle in Mexico grazed on forage and given drinking water from wells naturally contaminated with arsenic (0.007–0.422 mg/L) could transfer arsenic to milk. In 10% of the milk samples tested, arsenic was greater than the 10 ng/g limit suggested by the International Dairy Federation. However, in Argentina, where dairy cattle were drinking water ranging from 0.04 mg/L to2.5 mg/L of arsenic, only one milk sample showed an exceedance of the

international standard. This suggests that arsenic accumulates differently in cattle depending on local conditions.

Chickens and ducks drinking well water with a concentration of 0.122 mg/L of arsenic had significantly higher levels of arsenic in feathers, litter and eggs than those of birds in a control zone with water at 0.011 mg/L of arsenic (Rana et al. 2014). Feed and grain were also contaminated with arsenic in the contaminated zone. Subclinical sufferings of chicken and duck were prevalent in arsenic endemic areas, reflected in alterations in haemato-biochemical indices (Rana et al. 2014).

Significantly different toxicity was observed between different arsenic species administered to chickens. Arsenic(III) resulted in an LD50 value of 4.89 mg/kg, while arsenic(V) up to 40 mg/L did not result in mortality, but did decrease sperm quality and fertilisation (Lin et al. 2002). Often, only total arsenic is analysed in livestock drinking water; therefore, the guideline value is suitably conservative to account for the variable toxicities if no speciation values are specified.

Derivation of guideline values

Because arsenic and inorganic arsenic compounds are classed as Group 1 carcinogens, it is important to be conservative around the potential toxicity and accumulation of arsenic in some edible tissues. In 1993, Canada revised its arsenic guideline concentration to 0.071 mg/L, and in 2005 it was further revised to 0.025 mg/L (CCME 2005; see CCME arsenic fact sheet). The limit of 0.025 mg/L is also recommended by the FAO (Irrigation and Drainage Paper 61, Tanji & Kielen 2002). Similarly, the limit of 0.02 mg/L is recommended in the United States (USDA 2009). Agriculture Victoria (2023) recommends a maximum level of 0.5 mg/L of arsenic for water in stock containment areas.

Beede (2012) suggested the maximum upper concentration of arsenic in livestock drinking water should be 0.2 mg/L, which is in line with that suggested by van Heugten (2000) for pigs. However, NRC (2005) recommends a limit of 0.05 mg/L for arsenic in cattle drinking water, which is more in line with the guidelines in Canada and the United States. Fairchild and Ritz (2009) report that a maximum concentration for poultry water is 1 mg/L.

Following the precautionary principle, it is recommended that the total arsenic guideline value be 0.025 mg/L.

3.3.3 Beryllium

There are insufficient data to set guideline values for beryllium in livestock drinking water. The guideline value of <60 μg/L from the Australian Drinking Water Guidelines (NHMRC & NRMMC 2011) is adopted as a precautionary level, but concentrations as high as 100 μg/L (for cattle) may be tolerated (Watts et al. 2016).

Source

Beryllium is commonly found in silicate and oxide minerals, predominantly as beryl, a beryllium aluminium silicate. The silicate and carbonate forms are insoluble in water and are generally bound tightly to sediments.

Beryllium may occur in water supplies through the weathering of catchment rocks containing feldspar or it may be deposited from the atmosphere, predominantly as a result of burning fossil fuels.

The concentration of beryllium in freshwater is usually <1 μg/L (Galvin 1996); one exception was found in Saudi Arabia, with water samples presenting an average beryllium concentration of 1.24 μg/L (Vaessen & Szteke 2000). However, there are limited data on beryllium concentrations in water except from the United States, where a survey was carried out to support possible regulation. Based on the United States Environmental Protection Agency's STORET database for 1960–1988, the

geometric mean concentration of total beryllium in surface waters was estimated to be 70 ng/L (WHO 2009).

Groundwater in Germany contained an average beryllium concentration of 8 ng/L (WHO 2009).

Animal health

Beryllium is generally poorly absorbed from the gastrointestinal tract, and toxicity due to ingestion is low (WHO 1984). Livestock eliminate most beryllium quickly in urine and faeces (ATSDR 2002). Additionally, beryllium does not occur at sufficient levels in natural waters to cause harm to livestock (Dunbar & Miller 2002).

Long periods of exposure to beryllium have been reported to cause cancer in laboratory animals (ATSDR 2002). Mice and rats fed with a beryllium concentration (as beryllium sulfate) of 0.43 mg/L over their lifespan showed no effect in growth and longevity, but some leukemias and tumours were observed (Schroeder & Mitchener 1975a, 1975b). In another study, rats fed with beryllium concentrations of 5 mg/kg, 50 mg/kg and 500 mg/kg in their feed showed no carcinogenic responses related to beryllium (WHO 1984).

Derivation of guideline values

Beryllium was classified as a Group 1 carcinogen by the International Agency for Research on Cancer (IARC 1993). However, in a review of the limited toxicity data available for animals, IPCS (1990) indicated that ingestion of beryllium in the water supply for long periods caused no ill effects.

A chronic duration oral maximum residue limit (MRL) of 0.002 mg/kg/day was derived for beryllium (WHO 2009). The MRL is based on a chronic dog feeding study in which groups of 10 dogs were exposed to beryllium sulfate in the diet for 143–172 weeks (Morgareidge et al. 1976). Ulcerative lesions of the small intestine were observed in 9 out of 10 dogs exposed to the highest dose (500 ppm; 12 mg/kg/day and 17 mg/kg/day for the males and females, respectively); similar lesions were observed in 1 out of 10 dogs exposed to 50 ppm (1 mg/kg/day). No gastrointestinal effects were observed at the lower doses.

FAO (Ayers & Westcot 1994) and Canada have a guideline value of 0.1 mg/L of beryllium for livestock drinking water. In Australia, the guideline value for beryllium in human drinking water is 60 µg/L (NHMRC & NRMMC 2011).

3.3.4 Boron

Boron concentrations <5 mg/L in livestock drinking water should not be harmful to animal health. If the concentration of boron in livestock drinking water >5 mg/L, the total boron content of the livestock diet should be investigated.

Source

Boron is present in the environment as borates and borosilicate minerals, such as borax associated with salt deposits in saline lakes, borate and aluminium borosilicate. Boron is commonly associated with saline hydrogeological conditions.

Boron concentrations in unpolluted waters are generally <0.1 mg/L (Galvin 1996). Boron concentrations in groundwater may be higher, though are normally <4 mg/L (Hart 1974). Pesticides and fertilisers containing boron are a potential source of contamination of farm water supplies.

Animal health

Boron dissolved in water or contained in food is rapidly absorbed from the gastrointestinal tract in animals and excreted in urine.

Green and Weeth (1977) reported that boron concentrations of 150 mg/L in drinking water for cattle resulted in reduced hay consumption and a loss of weight. The tolerance concentration of boron was estimated to be between 40 mg/L and 150 mg/L. NRC (1980, 2005) suggested a maximum tolerable level of 150 mg/kg (as borax) in the diet of cattle, and presumed that this value should be reasonable for other types of livestock.

Derivation of guideline values

The following calculations and assumptions (Equation 3.4, Table 3.11), based on the principles adopted by the World Health Organization (Albanus et al. 1989, cited by Hamilton & Haydon 1996), were used to derive a guideline value. Based on this approach, guideline values for various types of livestock range from 5.8 mg/L to 11.3 mg/L. The calculation in Equation 3.4 is for cattle; data for other livestock are in Table 3.11.

Equation 3.4

$$\text{Guideline value} = \frac{\text{MTDL x dailyfeedintake x proportionwater}}{\text{maxdailywaterintake}}$$

$$= \frac{150 \text{ mg/kg/day x 20kg x 0.2}}{85 \text{ L/day}} = 7 \text{ mg/L}$$

Where:

- MTDL is the suggested maximum total dietary level of 150 mg/kg/day of boron in the animal diet (NRC 1980, 2005)

- 20 kg/day is an estimate of the average daily feed intake of cattle at this weight, assuming they consume approximately 2.5% of their body weight in feed

- 0.2 is the proportion of boron attributed to the intake of water

- 85 L/day is the peak consumption rate of water by cattle.

A safety factor for possible long-term effects was not included in the calculations because there is little likelihood of long-term effects due to boron ingestion (NRC 1980, 2005).

Table 3.11 Calculated guideline values for boron in livestock drinking water

Livestock	Body weight (kg)	Peak water intake (L/day)	Peak feed intake (kg/day)	Guideline value (mg/L)
Cattle	150.0	85.0	20.0	7.0
Pigs	110.0	15.0	2.9	5.8
Sheep	100.0	11.5	2.4	6.2
Poultry[a]	2.8	0.4	0.15	11.3
Horses	600.0	70.0	20.0	8.6

a Calculated for chickens; all poultry have a similar body weight to water intake ratio; hence, these values represent all poultry.

A value of 5 mg/L of boron has been proposed for livestock use in Canada (CCREM 2005) and South Africa (DWAF 1996). Although this is somewhat contrary to evidence in Green and Weeth (1977), the values calculated in Table 3.11 support the 5 mg/L value.

3.3.5   Cadmium

Total cadmium concentrations >0.01 mg/L in livestock drinking water may be hazardous to animal health.

Source

Cadmium is readily soluble in nitric acid, but only slowly soluble in hydrochloric and sulfuric acid and insoluble in basic (alkaline) solutions. Salts of cadmium with strong acids are readily soluble in water, whereas cadmium sulfide, carbonate, fluoride and hydroxide are less soluble. In the presence of organic material, cadmium has a high affinity for thiol and hydroxyl groups, for example, proteins, enzymes and other essential compounds (Scott-Fordsmand & Pedersen, 1995).

Cadmium concentrations in surface waters are usually extremely low (<0.001 mg/L). In unpolluted streams, cadmium occurs predominantly in association with suspended particulate matter, rather than in a dissolved state.

Concentrations of cadmium in groundwaters may be slightly higher in some areas (Fergusson 1990).

Industrial wastewater, metallurgical industries and fertilisers that contain cadmium as an impurity can be sources of cadmium released into the environment. Corrosion of galvanised tanks, pipes and solders can contaminate water supplies with cadmium. The solubility of cadmium in water increases with decreasing pH (increasing acidity).

Effects on animal health

Cadmium is toxic to both animals and plants at low concentrations. Usually, only a small amount of the total cadmium intake by livestock comes from drinking water, with most coming from food. Nevertheless, cadmium concentrations in drinking water for livestock should be restricted because of its toxic and possibly teratogenic, mutagenic and carcinogenic effects (CCREM 1987, CCME 1996).

Anaemia, abortions, stillbirths and reduced growth were observed in animals given cadmium in doses of 1–160 mg/kg (Supplee 1961, Powell et al. 1964, Miller et al. 1967, Doyle et al. 1974).

Miller (1971) reported that only a small part of the ingested cadmium in ruminants was absorbed, with most absorbed cadmium going to the kidney and liver. Taking into consideration the accumulation in liver and kidney and long-term exposure, NRC (1980) set a concentration of 0.5 mg/kg as the maximum tolerable dietary intake; NRC (2005) increased this to 10 mg/kg for all livestock to recognise that the 1980 levels were based on human health concerns and not on toxicity to animals.

Toxic concentrations of cadmium can be passed to the consumer if they ingest the liver and kidneys of livestock, because of the accumulation of cadmium in these organs.

Derivation of guideline values

The ANZECC (1992) guideline value of 0.01 mg/L for cadmium (based on Hart 1982) has been retained until more information becomes available from animal feeding trials. This value is consistent with guidelines developed for cadmium in South Africa (DWAF 1996). A value of 0.08 mg/L is recommended in Canada (see CCME cadmium fact sheet).

3.3.6 Chromium

Chromium(III) and chromium(VI) concentrations <0.05 mg/L in livestock drinking water should not be harmful to animal health.

Source

Total chromium concentrations in natural unpolluted water are generally very low (<0.025 mg/L) (Galvin 1996). Most surface waters contain between 0.001 and 0.010 mg/L of chromium (WHO, 2003).

Chromium occurs in the environment in 2 forms: trivalent chromium (chromium(III)) and hexavalent chromium (chromium(VI)). Studies in lake water showed that the ratio of chromium (III) to chromium (VI) is affected by the amount of organic matter and dissolved oxygen (ANZG, 2021).

In general, the chromium content of surface waters reflects the extent of industrial activity. Chromium may enter water supplies through the waste of various industrial processes in which it is used (alloy, tanning, textile dyes, pigments, glazes and treated timber) (Subramanian et al., 2003).

Effects on animal health

Chromium(III) is essential to mammal nutrition as it is required for carbohydrate and lipid metabolism. Chromium supplementation has been found to improve performance in poultry and ruminants (Rajalekshmi et al. 2008). Salts of chromium(III) are poorly absorbed by the gastrointestinal tract, whereas the absorption rate of chromium(VI) is much higher. Chromium accumulates in animal tissues; however, some studies show that chromium was removed from most organs 140 days after exposure (Kapoor et al. 2022).

There is a lack of studies that tested chromium toxicity in larger livestock; the toxicity studies that were found were about mice, rats, poultry, dogs and rabbits. Chromium(VI) is more toxic to animals than chromium(III)(NRC 1980, WHO 1984, CCREM 1987).

Abdel-Rahman et al. (2012) noted male rabbits administered 0.14 mg/kg of chromium(VI) had significantly increased levels of serum urea and creatinine, and histopathological and histomorphometrical changes in the kidneys. Apostoli et al. (2013) injected approximately 0.07 mg/kg of chromium(III) into New Zealand white rabbits and found no adverse effects. Stout et al. (2009) fed rats between 5 mg/L and 180 mg/L of sodium dichromate dihydrate in drinking water in a 2 year study and showed that carcinogenicity evolved in chromium-treated rats and mice. For this concentration range, the average daily ingested dose was between 0.2 mg/kg and 5.9 mg/kg body weight. This was the first lifetime study to demonstrate increased carcinogenicity effects of chromium(VI) in rats, generally at concentrations greater than 2.4 mg/kg body weight. Adverse effects, including neoplasms, hyperplasia and histiocytic cellular infiltration, were observed in all exposure groups.

A study of the effects of chromium(VI) in chickens (given in the form of 0.07424 mg/kg potassium dichromate from day 7 to day 35 post-hatch) showed reduced diversity in gut microbiota – stable healthy gut microbiota are needed for efficient digestion and nutrient absorption (Li et al. 2022). Butkauskas and Sruoga (2004) found that male Japanese quails fed 0.142 mg/kg of chromium in feed decreased the hatchability of their chicks, and early mortality of embryos increased as much as 2–3 times. After 32 weeks of feeding chicks chromium(VI) at 88.4 mg))/kg or 177 mg/kg, Asma et al. (1999) found the total body weight was significantly decreased in both the chromium-treated groups relative to the control. Additionally, egg laying was enhanced but hatchability was considerably decreased after chromium(VI) treatment. The eggshell thickness increased significantly (13%), and chromium was deposited in a dose-dependent manner in the liver and lungs, with some structural derangements in the liver also noted in the treated chicks.

Studies with rats and dogs showed that water containing 5–6 mg/L chromium(VI) did not cause tissue damage, whereas concentrations of 10 mg/L resulted in tissue accumulation of chromium, but no toxic effects were detected (NRCC 1976). Rats showed no obvious toxic effects at chromium concentrations (as potassium chromate) of 0.5 mg/L (Romoser et al. 1961) and 25 mg/L (MacKenzie et al. 1958) in their drinking water.

Derivation of guideline values

International guidelines for chromium vary by several orders of magnitude. The guideline of 1 mg/L is recommended in the United States for chromium (USEPA 1992) and in South Africa for chromium(VI) (DWAF 1996); it is also the maximum upper limit for livestock given by Beede (2012). However, the Canadian guideline (CCME 2005) and that recommended by FAO (Tanji & Kielen 2002) is significantly lower at 0.049 mg/L (see CCME chromium fact sheet). The upper limit recommended by NRC (2005) for cattle is 0.1 mg/L.

Chromium(III) is unlikely to be in drinking water because it is oxidised in air.

The limit for soluble chromium(III) in feed is assumed to be 100 mg/kg (dry matter) for all livestock, except poultry, which can tolerate up to 500 mg/kg (NRC 2005).

Based on the most conservative estimate of maximum dietary intake (100 mg/kg) (NRC 2005), the guideline values for 3 livestock types have been estimated for chromium(III) in Table 3. using Equation 3.2. A safety factor of 3 was assumed for possible long-term effects.

Table 3.12 Calculated guideline values for chromium(III) in livestock drinking water

Livestock	Maximum chromium(III) in feed (mg/kg)[a]	Safety factor[b]	Guideline value (mg/L)
Pigs	100	3	1.29
Cattle	100	3	1.57
Sheep	100	3	1.40

a Based on maximum tolerable dietary chromium(III) in NRC (2005).
b Safety factor of 3 was assumed for possible long-term effects.

The data in Table 3.12 is based on maximum feed of only chromium(III) (from NRC 2005); while the guideline values presented in Table 3.13 for chromium(VI) are based on values from the literature.

Table 3.13 Calculated guideline values for chromium(VI) in livestock drinking water

Livestock	LOAEL[a]/ LD50	Safety factor	Guideline value (mg/L)	Reference
Rat	0.2 mg/kg body weight	3[b]	0.89	Stout et al. (2009)
Poultry (quail)	50.1 mg/kg feed ~ converted to 2.68 mg/kg body weight[+]	30[c]	0.63	Butkauskas and Sruoga (2004)
Poultry	88.4 mg/kg feed ~ 4.74 mg/kg body weight	30[c]	1.12	Asma et al. (1999)
Rabbits	0.14 mg/kg body weight	30[c]	0.05	Abdel-Rahman et al. (2012)

a Any concentration tested that showed an effect was assumed the LOAEL (lowest observed adverse effect level), even in cases where a range of concentrations were not fed to a species. Feed LOAEL were converted to body weight limits using the standard values.
b Safety factor of 3 due to intra-species variation as it was assumed that long-term effects were accounted for by the length of the study.
c Safety factor of 30 due to possible long-term effects, tissue accumulation and intra-species variation.

3.3.7 Cobalt

Total cobalt concentrations <1 mg/L in livestock drinking water should not be harmful to animal health. If livestock diets are high in cobalt, the concentration in drinking water should be reduced.

Source
Cobalt occurs as various sulfide ores in nature and is generally associated with arsenic, iron, nickel, and copper.

Cobalt occurs in natural waters at concentrations <0.01 mg/L and, in most cases, <0.001 mg/L, but concentrations may be higher in wastewater (Galvin 1996, APHA, AWWA & WEF 1998).

Effects on animal health
Cobalt is an essential element in animal nutrition, and it is important in several enzyme systems, particularly as a component of vitamin B12.

Generally, cobalt has a low toxicity to animals; in ruminants, cobalt deficiency is more likely to occur (NRC 1980, 2005).

Underwood (1977) reported reduced appetite and some weight loss when cobalt was administered daily at concentrations of 1.1 mg/kg body weight to the diet of calves. According to CCREM (1987), drinking water for calves would have to contain at least 10 mg/L of cobalt before the symptoms observed by Underwood would be evident. NRC (1980) set the maximum tolerable limit for cobalt at 10 mg/kg diet; NRC (2005) increased this to 25 mg/kg for cattle, sheep and poultry and 100 mg/kg for pigs.

Derivation of guideline values
The ANZECC (1992) guideline of 1 mg/L for cobalt has been retained until more information becomes available from animal feeding trials. This value is consistent with guidelines developed for cobalt in Canada (CCME 2005) and South Africa (DWAF 1996).

3.3.8 Copper

Copper in livestock drinking water of the following concentrations should not be harmful to animal health:

- ***<0.5 mg/L for sheep***

- ***<1 mg/L for cattle***

- ***<5 mg/L for pigs and poultry.***

If livestock diets are high in copper, the concentration in drinking water should be reduced.

Source
Copper is widely distributed in rocks and soils as carbonate and sulfide minerals. Copper is a near noble metal, only dissolving in oxidising acids.

Copper is generally found in natural waters at concentrations <1 mg/L, often in association with organic compounds (Galvin 1996). However, concentrations in groundwater as high as 12 mg/L have been reported (Hart 1982). Copper concentrations in water supplies can be elevated as a result of copper-based algicide treatment or corrosion of copper and brass fittings in water with low pH (acidic).

Effects on animal health

Copper is an essential element in animal nutrition. Copper deficiency can result in morbidity and, in some cases, death (NAS 1977b).

Copper nutrition in animals is influenced by the dietary intake of iron, molybdenum and sulfur. Intake of iron, molybdenum and sulfur should also be considered in conjunction with copper. Cattle given water with 2.5–5 mg/L added were prevented from developing seasonal decline in plasma copper levels and showed no ill effects (Humphries et al. 1983).

Excessive intake of copper can lead to copper toxicosis in livestock (nearly always in sheep). Initially, copper accumulates in the liver of animals and may cause some reduction in growth. Chronic and acute effects such as liver damage and haemolytic jaundice can occur with extended exposure to high concentrations of copper (Blakley 2022a).

Toxic effects of copper depend on the type of livestock and the form of copper. For example, copper chloride is 2–4 times more toxic to sheep than copper sulfate (CCREM 1987). Demayo and Taylor (1981) suggested that to avoid toxicosis, the maximum copper concentration in the diet should not exceed 5–20 mg/kg for sheep, 100 mg/kg for cattle, 150–400 mg/kg for pigs and 250–500 mg/kg for chickens. NRC (2005) set maximum tolerable levels of copper in the diet as 15 mg/kg for sheep, 40 mg/kg for cattle, 100 mg/kg for pigs and 250 mg/kg for chickens.

Derivation of guideline values

The ANZECC (1992) guideline value of 0.5 mg/L of copper in sheep drinking water has been retained, which is consistent with guidelines in Canada (CCME 2005) and South Africa (DWAF 1996). The copper guideline values of 5 mg/L for pigs and poultry and of 1 mg/L for cattle are consistent with Canadian (CCME 2005) and South African (DWAF 1996) guidelines. Agriculture Victoria (2023) recommends a maximum level of 0.5 mg/L of copper for water in stock containment areas. In all cases, the guideline value should be reduced if livestock diets are high in copper.

3.3.9   Fluoride

Fluoride concentrations <2 mg/L in livestock drinking water should not be harmful to animal health. If livestock feed also contains fluoride, the guideline value should be reduced to 1.0 mg/L.

Source

Fluorine does not occur free in nature, but is the most reactive metalloid and binds, directly or indirectly, to form fluorides with all the elements except the inert gases. The occurrence of fluoride in Earth's crust is 0.027% and fluoride has been found to occur naturally in all soils.

Unpolluted surface waters generally contain low concentrations of fluoride, but concentrations in groundwater may be higher in some areas. Groundwater fluoride concentrations >2 mg/L have been reported at several locations in Queensland, mainly in the Great Artesian Basin, and in some cases show concentrations >10 mg/L (Gill 1986). Groundwater at Carnarvon, Western Australia, contains fluoride at concentrations up to 5 mg/L (Hart 1974).

The diet may be a source of excessive fluoride if vegetation is contaminated by aerial deposition in industrial areas (NAS 1971).

The risk of fluorosis in either sheep or cattle may be avoided through control measures. Control measures are less important in good seasons when stock receive most of their fluid requirements from pasture:

- If sufficient water of low fluoride concentration (e.g. surface water) is available, arrange paddock stocking so that young stock have access to only fluoride-free water for the first 3 years of life.

- Where only limited quantities of low-fluoride water are available, rotate stock from fluoride-enriched water for no more than 3 months to low-fluoride water for at least 3 months. These measures may reduce the risk of dental fluorosis in growing animals, but not necessarily longer-term skeletal fluorosis risk owing to accumulation.

- The fluoride concentration in water is rapidly increased by evaporation. This is particularly evident in flowing bores where the water is reticulated through shallow bore drains. As a temporary measure while paddocks are being arranged so that young stock may be kept on low-fluoride water, water young stock as near to the bore head as possible.

Effects on animal health

Cattle are the most sensitive livestock to fluoride, followed by sheep, horses, pigs, rats, guinea pigs and poultry (Van Paemel et al. 2010).

Fluoride accumulates in bones rather than in soft tissues, and excess uptake of fluoride can result in tooth damage to growing animals and bone lesions in older animals (Rose & Marier 1978, CPHA 1979). Chronic fluorosis is characterised by signs of malnutrition and skeletal and dental abnormalities (Blakley 2022b).

Moderate to severe dental disease caused by fluorosis can affect food consumption, cause pain and loss of function, and may lead to infection (Arundel et al. 1977, Leader-Williams 1980, Borland et al. 2012). In Queensland, livestock drinking water fluoride concentrations >2 mg/L have been observed to affect the teeth of young animals (VIRASC 1980). Moreover, Hibbs and Thilsted (1983) reported tooth erosion at 3.3 mg/L in drinking water.

Severe skeletal disease can cause pain and lameness, and can result in a reduction in general health, fitness, body condition and reproductive parameters, due to alterations in metabolism, gait and feeding (Roholm 1937, Shupe et al. 1992b, Weatherell & Weidmann 1959).

Experiments with laying hens showed a significant reduction in egg production for hens receiving 6 and 20 mg/L sodium fluoride (2.7 and 9 mg/L fluoride) in their drinking water, but that successful production could continue with concentrations up to 14 mg/L sodium fluoride (6.3 mg/L fluoride) (Coetzee et al. 1997).

Derivation of guideline values

The ANZECC (1992) guideline value of 2 mg/L for fluoride has been retained in the absence of new contradicting information. This value is consistent with guidelines for fluoride in Canada (CCME 2005) and South Africa, although the South African guidelines suggest that adverse effects are unlikely to occur in ruminants at concentrations <4 mg/L (DWAF 1996). Agriculture Victoria (2023) recommends a maximum level of 2 mg/L of fluoride for water in stock containment areas.

3.3.10 Iron

There is no guideline value for iron in livestock drinking water because it poses a very low risk to animal health.

Source

Iron is stable in dry air but readily oxidises in moist air, forming rust. The occurrence of iron in the Earth's crust is 4.7%. In water, iron can be present as dissolved ferric iron, Fe(III), as ferrous iron, Fe(II) or as suspended iron hydroxides.

Iron occurs naturally in water through dissolution of iron-bearing rock and minerals. It is present in water as soluble Fe^{2+} ions or the much less soluble Fe^{3+} form. In aerated surface water, iron concentrations are usually <1 mg/L. Groundwaters that are poorly oxygenated and rich in dissolved

carbon dioxide have been reported to have a total iron content of up to 100 mg/L (Galvin 1996, NHMRC & ARMCANZ 1996).

Water sources for livestock do not usually contain sufficient iron to cause health problems in livestock, but toxic effects have been reported when cows were grazed on pastures heavily irrigated with groundwater containing 17 mg/L of iron (Hart 1974).

Effects on animal health

Iron is an essential element in animal nutrition and has a low toxicity; it is only harmful to livestock if ingested in large amounts. Symptoms of iron toxicity include reduced feed intake and weight gain (Agriculture Victoria 2023). Excess intake of iron affects health through increasing reactive oxygen species (oxidative stress), which damages cell membranes and interrupts several biochemical reactions in the body. Oxidative stress in dairy cows has been related to increased incidences of mastitis, retained fetal membranes, and a general decrease in immune function (Linn 2008). Excessive iron intake may also reduce the absorption of other essential micronutrients, such as copper and zinc.

Coup and Campbell (1964) reported slight scouring and blackening of the faeces after administering a daily dose of 30 g of iron (as ferric hydroxide) to cattle. At a dose of 60 g/day, scouring and blackening were pronounced and associated with a decline in body weight, coat condition, and milk and fat yield. No adverse effects were reported from a dose of 15 g/day.

High levels of iron in drinking water may also reduce water intake because of effects on palatability.

Derivation of guideline values

There is no guideline value for iron because water sources for livestock do not usually contain sufficient iron to cause health problems in livestock. There is no guideline recommended for iron in livestock drinking water in Canada (CCME 2005). Similarly, Agriculture Victoria (2023) does not recommend a maximum level of iron for water in stock containment areas, but notes that it is of 'low toxicity'. A guideline value of 10 mg/L has been proposed in South Africa, although it was noted that adverse effects of excessive iron intake have not been well documented and that concentrations up to 50 mg/L may be tolerated (DWAF 1996). NRC (2005) set maximum tolerable concentrations of dietary iron at 500 mg/kg for cattle, 500 mg/kg for sheep, 500 mg/kg for poultry, and 3,000 mg/kg for pigs.

3.3.11 Lead

Lead concentrations >0.1 mg/L in livestock drinking water may be hazardous to animal health. However, lead is accumulative, and problems may begin at concentrations of 0.05 mg/L (Ayers & Westcot 1994).

Source

Lead is generally present in very low concentrations in natural waters. Lead chloride and bromide salts are slightly soluble (1%) in cold water, whereas carbonates and hydroxide salts are almost insoluble (Adriano 1986). Dissolved lead concentrations in unpolluted freshwater are generally <0.01 mg/L (Fergusson 1990, Galvin 1996).

Human outputs of lead to the environment outweigh natural sources – lead reaches the environment through precipitation, fallout of lead dust, street run-off and industrial and municipal wastewater discharges (USEPA 1976, Jaques 1985).

Effects on animal health

The toxicity of lead depends on the type and age of the animal, the form of lead, and the rate of lead ingestion (Hart 1982).

Young animals absorb lead more efficiently than older animals and show lower tolerance to lead. (Olkowski 2009). Symptoms of lead poisoning in mammals and birds include neurologic disturbances, gastrointestinal upset, haematologic abnormalities, immunosuppression, infertility and renal disease (Blakley 2022c). Reduced resistance to diseases has been reported following low-level intake of lead (Hemphill et al. 1971). Chronic effects such as anorexia and respiratory distress are associated with low-level poisoning.

Lead is accumulated in the skeleton to a critical maximum level, after which circulating concentrations increase until poisoning occurs (Hatch 1977, Jaworski 1979). Severe poisoning causes acute effects such as blindness (Agriculture Victoria 2023), frothing at the mouth, incoordination and convulsions (DWAF 1996).

Cattle, especially young calves, are susceptible to lead toxicity (Olkowski 2009). Hammond and Aronson (1964) suggested that daily ingestion of 6–7 mg/kg body weight of lead is the minimum dose that causes poisoning to cattle. Calves were killed by accidental exposure to an estimated dose of 5–8 mg/kg/day for 30 days (Osweiler & Ruhr 1978). Sheep deaths were reported following dietary exposure to 5.7 mg/kg/day (James et al. 1966). Horses have been reported to be more sensitive to lead poisoning than cattle and sheep (CCREM 1987, CCME 2005). In one case, chronic poisoning occurred after horses received drinking water and grass contaminated with lead at concentrations of 0.5–1 mg/L and 5–20 mg/kg (dry weight) respectively (Singer 1976). However, horses have also been reported as less sensitive to lead (DWAF 1996).

If livestock are raised in areas contaminated with lead, it can accumulate in soft tissues of animals to a degree which might exceed acceptable levels for human consumption (NRC 1980, 2005).

Derivation of guideline value

NRC (1980) set a maximum tolerable dietary concentration of 30 mg/kg of lead for all livestock diets; NRC (2005) increased this to 100 mg/kg for ruminants (cattle and sheep) and 10 mg/kg for nonruminants (horses, pigs and poultry), based on new data.

The ANZECC (1992) guideline value of 0.1 mg/L for lead has been retained in the absence of contradicting information. This value is consistent with lead guidelines in Canada (CCME 2005) and South Africa (DWAF 1996), although the South African guidelines suggest that for pigs, no adverse effects are likely to occur at lead concentrations up to 0.5 mg/L (DWAF 1996). Agriculture Victoria (2023) recommends a maximum level of 0.1 mg/L of lead for water in stock containment areas.

3.3.12 Manganese

Manganese concentrations <10 mg/L in livestock drinking water should not be harmful to animal health.

Source
Manganese occurs in water in several ionic states (Mn^{2+}, Mn^{4+} and Mn^{7+}), of which the divalent compounds are soluble. Manganese can be found in dissolved and colloidal forms, as well as complexed with organic matter. Manganese is a major constituent of soils and its solubility is controlled by pH and oxidation-reduction reactions, which control solubility and sorption reactions of manganese with soil.

Unpolluted surface water usually has low concentrations of manganese (i.e. 0.001–0.6 mg/L), as contact with air rapidly oxidises the divalent compounds, resulting in the precipitation of the insoluble Mn^{4+} compounds.

Higher concentrations of manganese may be found under anoxic conditions (which may occur in groundwater or the lower strata of deep dams and lakes), particularly if the water pH is low (acidic; Galvin 1996, NHMRC & ARMCANZ 1996).

Animal health
Manganese is an essential element in animal nutrition, but only about 3% of ingested manganese is absorbed. Manganese has low toxicity unless ingested in large amounts (NRC 1980, 2005). The issue of manganese in drinking water is usually associated with palatability.

Some toxicity studies have been completed with manganese in pig feed at significantly lower concentrations and noted that under manganese-deficient conditions, concentrations <500 mg/kg diet may cause toxicity effects (Miller et al. 2004).

Roy et al. (2015) noted histopathological changes in the liver with poultry birds when administered 100 mg/kg body weight. Liu et al. (2013) found that manganese concentrations of ≤1,800 mg/kg caused testicular damage in cocks.

Derivation of guideline values
NRC (2005) stated that the limit for cattle should be 0.05 mg/L in drinking water, as has Beede (2012). Similarly, Fairchild and Ritz (2009) quoted a target value of 0.05 mg/L, but stated that concentrations of up to 20 mg/L have been reported to not affect bird health. Canada has no guideline value for manganese in livestock drinking water (CCME 2005). South African guidelines (DWAF 1996) recommend an upper limit of 10 mg/L of manganese in livestock drinking water, and suggest the possibility of adverse chronic effects such as weight loss and anaemia at higher concentrations.

The literature on manganese toxicity and feed limits has been used to calculate guideline values using Equation 3.2; the results are presented in Table 3.14.

Table 3.14 Calculated guideline values for manganese in livestock drinking water

Livestock	Maximum manganese in feed (mg/kg)[a]	Safety factor[b]	Guideline value (mg/L)
Poultry	2,000	3	50.0
Horses	400	3	7.6
Pigs	1,000	3	12.9
Cattle	2,000	3	27.8
Sheep	2,000	3	27.8

a Maximum tolerable dietary manganese given in NRC (2005).
b Safety factor of 3 was assumed for possible long-term effects.

3.3.13 Mercury

Mercury concentrations >0.002 mg/L in livestock drinking water may be hazardous to animal health and may accumulate in edible animal tissue and pose a human health risk.

Source
Mercury occurs in 3 main categories: metallic mercury, which has a high vapour pressure and thus vaporises under atmospheric pressure; organic mercury, which consists of mercury covalently bound to carbon; and inorganic ions (mercury may exist as Hg^+ and Hg^{2+}, bivalent mercury readily forms complexes with organic ligands, and monovalent mercury binds less readily to organics and forms less water-soluble salts).

The concentration of mercury in unpolluted streams and groundwater is generally <0.001 mg/L (Fergusson 1990, Galvin 1996). Contamination through industrial emissions and spills can increase mercury concentrations. Mercury is also used in certain pesticide formulations.

Organic compounds of mercury, particularly methylmercury, are more bioavailable and more toxic than the inorganic salts, many of which are insoluble. However, inorganic salts of mercury in sediments can enter the food chain through biological conversion to organic forms (Hart 1982).

Animal health
Mercury is one of more toxic metals that may be present in the farm animal environment (Olkowski 2009). The toxicity of mercury depends on its chemical form, with alkylmercury compounds, particularly methylmercury, being the most toxic due to its greater absorption rate and increased retention in animals. Ingestion of feed is the predominant path of animal exposure to mercury. Symptoms of mercury poisoning in animals vary according to the form of mercury, the amount ingested, and the route of intake (Hart 1982).

Chronic mercury poisoning in animals results in loss of appetite, with consequent weight loss leading to possible hair loss, anal lesions and paralysis. Severe poisoning results in nervous system disorders (such as lack of coordination, tetanic spasms, and convulsions) and is usually fatal (Blakley 2022d). Ingestion of inorganic mercury results in the accumulation of mercury primarily in the brain, kidney and liver, whereas methylmercury is more evenly distributed through all tissues (NRCC 1979).

Signs of mercury poisoning were observed at 2 mg/kg in turkeys, 8 mg/kg in cattle and 10 mg/kg in sheep (Palmer et al. 1973). Cattle receiving 0.48 mg/kg of methylmercury compound per day accumulated 100 mg/kg in the kidney within 27 days; sheep accumulated 120–210 mg/kg under the same conditions (Palmer et al. 1973). NRC (1980, 2005) set a maximum tolerable limit on organic mercury in the diet at 2 mg/kg for ruminants and pigs.

Derivation of guideline values
In establishing guidelines for mercury in livestock drinking water, consideration should be given to the toxic effects of mercury on animals and its possible accumulation in animal tissues used for human consumption. Reeder et al. (1979) suggested that drinking water guidelines for mercury should be based on a maximum acceptable concentration of 0.5 mg/kg in edible animal tissue.

Using chickens as a model, Reeder et al. (1979) calculated the maximum allowable intake of mercury in livestock drinking water as 0.003 mg/L, assuming a maximum concentration of 0.2 mg/kg in edible animal tissue. Hart (1982) suggested a value of 0.002 mg/L as more appropriate under Australian conditions.

The ANZECC (1992) guideline value of 0.002 mg/L for mercury in livestock drinking water has been retained in the absence of new contradicting information. The mercury guideline value in Canada is 0.003 mg/L (CCME 2005) and in South Africa is 0.001 mg/L (DWAF 1996).

3.3.14 Molybdenum

Molybdenum concentrations <0.01 mg/L in livestock drinking water should not be harmful to animal health, depending on total dietary intake of molybdenum, copper, iron and sulfur. If molybdenum concentrations in drinking water are >0.01 mg/L, the animal diet should be investigated to ensure that copper concentrations are sufficient to account for the total dietary intake of molybdenum.

Source
Molybdenum commonly exists as an anion in waters and soils. The behaviour of molybdenum in soils is similar to other negatively charged elements, which tend to be very mobile.

Molybdenum is usually found at concentrations of ≤0.05 mg/L in natural waters (Galvin 1996). Higher concentrations are generally associated with human activities such as mining, industry fallout and chemical fertilisation. The predominant ion is molybdate, which is more soluble at higher pH (more alkaline; Cotton & Wilkinson 1972).

Livestock health effects are more likely to occur through foraging than through the intake of water. The concentrations of molybdenum in plants reflect the concentrations of the soils in which they are grown. High concentrations of molybdenum in plants may occur where soils are enriched with molybdenum (e.g. from fertilisers) but can also occur naturally, particularly when soils are of neutral to high pH, are very moist, and have a high organic content, such as peats and mucks (NRC 1980, 1988, 1996, Jones et al. 1994). Pastures with high molybdenum concentrations have been found on calcareous soils in southern Australia (McFarlane et al. 1990).

Animal health

Molybdenum is an essential element in animal nutrition. It is associated with various enzyme systems and is important during fetal development. There is little information on molybdenum requirements of domestic animals, but concentrations in the diet of <0.02 mg/kg and 0.01 mg/kg for chicks and sheep, respectively, have been suggested by Mills and Davis (1987) (cited by Jones et al. 1994).

Inorganic molybdenum combines with sulfide in the rumen to form thiomolybdates, which bind copper and interfere with its absorption. This increases the animal's requirement for, and tolerance of, copper. Molybdenum concentrations of 5–6 mg/kg in the diets of cattle have resulted in copper deficiency, depending on the level of copper in the diet and the period of exposure (NRC 1980, 1996, 2005). In a survey of copper deficiencies in herds in South Australia, McFarlane et al. (1990) observed that the risk of copper deficiency is associated with moderate concentrations of molybdenum, sulfur and iron in pasture, rather than low copper levels: copper from these pastures would rarely meet minimal cattle requirements when levels of molybdenum exceeded 2 mg/kg.

Molybdenosis ('peat scours' in New Zealand) in cattle is characterised by severe scouring and loss of condition, and secondary copper deficiency. The condition can be treated by adding sufficient copper to the diet. If dietary copper levels are low, molybdenum is toxic at lower concentrations (NRC 1980, 1988, 1996, Jones et al. 1994).

Ruminants are the most susceptible to excess molybdenum, with cattle more sensitive than sheep (NRC 1980, 2005, Jones et al. 1994). Effects of excessive molybdenum intake in ruminants (other than those attributed to copper deficiency) may include infertility, increased puberty age, testicular damage, and disorders of phosphorus metabolism that cause skeletal abnormalities and lameness (Blakley 2022e). Concentrations as low as 5 mg/kg of molybdenum in feed have been reported to cause infertility effects such as increased puberty age and reduced conception rate (Phillippo et al. 1987, cited by Jones et al. 1994 and NRC 1996).

In non-ruminants, the molybdenum–copper antagonism only occurs with lower gut sulfide generation associated with high sulfur intake (as inorganic sulfur or in high protein feed). Horses appear more resistant to molybdenosis than cattle (Olkowski 2009). Molybdenum seems to be rapidly absorbed and excreted by pigs, which makes them extremely tolerant of high levels of intake; pigs fed diets containing up to 1,000 mg/kg of molybdenum for 3 months have shown no ill effects. Poultry appears to be more sensitive to molybdenum; concentrations of 200 mg/kg in the diet have resulted in reduced growth (NRC 1980, 2005, Mills & Davis 1987, cited by Jones et al. 1994).

The type of diet may also influence animal tolerance of molybdenum. In dry forages, molybdenum may not be as available as it is in green feed, possibly due to the availability of soluble sulfur

containing proteins. Copper:molybdenum ratios of 2:1 and 4:1 in animal feed have been reported to prevent copper deficiency (NRC 1988, 1996).

Toxicity was not observed in cattle grazing at a reclaimed mine tailings site with molybdenum concentrations of 21–44 mg/kg in the forage. The absence of molybdenosis could be due to an interaction with high copper concentrations (and other metal ions) in the forage (Gardner et al. 2003).

Derivation of guideline values
There are a range of molybdenum concentrations quoted in the literature as livestock drinking water guidelines. Canada has a guideline value of 0.5 mg/L but states that it is more important to consider the molybdenum water content in the context of total dietary intake of molybdenum, copper and sulfur (CCME 2005). Raisbeck et al. (2008) noted that the problems associated with molybdenum, in many situations, can be dealt with by dietary management of copper and sulfur.

FAO (Tanji & Kielen 2002) quotes a limit of 0.5 mg/L, which is similar to the value of 0.3 mg/L noted by Raisbeck et al. (2008). In contrast, the South African guidelines note that a target value of 0.01 mg/L should be adopted to avoid possible adverse health issues and that concentrations greater than 0.02 mg/L should be avoided because acute and chronic adverse effects may occur. Similarly, Beede (2012) states an upper limit of 0.03 mg/L for livestock and maximum upper level of 0.06 mg/L. NRC (1980) set a maximum tolerable concentration of 10 mg/kg in the diets of cattle and sheep for short-term intake. NRC (2005) decreased this to 5 mg/kg for cattle, sheep and horses and increased it to 100 mg/kg for poultry and 150 mg/kg for pigs. Agriculture Victoria (2023) recommends a maximum level of 0.15 mg/L of molybdenum for water in stock containment areas.

The guideline values for molybdenum in livestock drinking water were calculated using Equation 3.2; the values are presented in Table 3.15.

Table 3.15 Calculated guideline values for molybdenum in livestock drinking water

Livestock	Maximum molybdenum in feed (mg/kg)[a]	Safety factor[b]	Guideline value (mg/L)
Poultry	100	10	0.038
Horses	5	10	0.029
Pigs	150	10	0.580
Cattle	5	10	0.024
Sheep	5	10	0.021

a Maximum tolerable dietary molybdenum given in NRC (2005).
b Safety factor of 10 was adopted due to possible long-term effects and tissue accumulation.

3.3.15 Nickel

Nickel concentrations <1 mg/L in livestock drinking water should not be harmful to animal health.

Source
Nickel is mainly present in igneous rocks and is ubiquitous in the environment (Scott-Fordsmand & Pedersen, 1995). Nickel concentrations in soils in Australia range from 5 mg/kg to 520 mg/kg with an average <100 mg/kg (CSIRO, unpublished). In New Zealand, the median ranges from 1.9 to 27.4 mg/kg and can range up to 154 mg/kg. Soils developed from serpentine rocks contain much higher nickel quantities (400–500 mg/kg).

Nickel usually enters natural waters through weathering of minerals and rocks. The concentration of nickel in natural waters is usually <0.01 mg/L, unless contaminated by industrial waste, fallout from burning fossil fuels or the corrosion of nickel-plated plumbing fittings (NHMRC & ARMCANZ 1996, Galvin 1996).

Effects on animal health
Nickel is an essential element in animal nutrition and is seldom toxic (NRCC 1981). Nickel concentrations of 0.05–0.08 mg/kg in the diet are regarded as essential (Hart 1982). Nickel deficiency can cause pigmentation changes and dermatitis of the shank skin in chickens. Effects of nickel deficiency on reproduction in pigs have been reported (Anke et al. 1974, Nielsen & Ollerich 1974).

Growth reduction in calves was induced by adding nickel salts to the diet at concentrations of 250 mg/kg (O'Dell et al. 1970). A concentration of 5 mg/L (as nickel acetate) in the drinking water of mice applied over a lifetime was not toxic (Schroeder et al. 1964), whereas nickel chloride at 5 mg/L in the drinking water of rats over 3 generations resulted in increased perinatal mortality and an increased number of runts (Schroeder & Mitchener 1971).

Derivation of guideline values
The ANZECC (1992) guideline value of 1 mg/L of nickel in livestock drinking water has been retained until more information becomes available. This value is consistent with nickel guidelines in Canada (CCME 2005) and South Africa (DWAF 1996).

3.3.16 Selenium

Selenium concentrations >0.02 mg/L in livestock drinking water may be hazardous to animal health.

Source
Selenium occurs in the environment in association with metal sulfides and is derived from igneous rocks (Ehrlich 1990). In surface water, selenium is generally present at concentrations <0.01 mg/L, although groundwater may contain up to 1 mg/L, usually in association with volcanic areas (Galvin 1996). Selenium can be released into the environment through the burning of coal and as a discharge from the processing of sulfide ores (NHMRC & ARMCANZ 1996).

Effects on animal health
Selenium is an essential element in animal nutrition. Diets containing less than 0.02–0.04 mg/kg of selenium can result in deficiency in cattle, sheep, pigs and poultry (Oldfield et al. 1974, Underwood 1977).

Selenium imbalances are common in livestock. Both acute and chronic selenium toxicosis occasionally result from supplement overdose; chronic selenosis can also occur in areas with high soil selenium bioavailability (Bischoff 2022).

At elevated concentrations, selenium is toxic to animals. The threshold concentration of dietary selenium required to induce toxicity is estimated to be 5 mg/kg (Horvath 1976). Poisoning of livestock has occurred following ingestion of forage grown in selenium-rich soil (Johnson 1976). The chronic symptoms of selenium poisoning (Alkali Disease) include loss of hair, lameness and decreased food intake, which may result in starvation. Acute selenium poisoning results in blindness and often paralysis, known as 'blind staggers' (Hart 1982). The symptoms of acute selenium poisoning include stumbling, difficulty breathing, diarrhoea and bloat, with death resulting from respiratory failure (NRC 1980, 2005).

In lactating animals, selenium in milk may lead to the formation of selenomethionine proteins. Milk from cows in areas where selenium poisoning occurred was reported to contain 0.3–1.2 mg/L of selenium; normal concentrations range from 0.003 mg/L to0.007 mg/L (Underwood 1971).

Derivation of guideline values

In the absence of new contradicting information, the existing guideline value of 0.02 mg/L (ANZECC 1992) for selenium in livestock drinking water has been retained. Guidelines in Canada (CCME 2005) and South Africa (DWAF 1996) recommend an upper limit of 0.05 mg/L; however, Olkowski (2009) notes that at this level water contribution to the total selenium intake can be substantial and total dietary selenium intake should be monitored.

3.3.17 Uranium

Uranium concentrations <0.2 mg/L in livestock drinking water should not be harmful to animal health.

Source

Uranium is a naturally radioactive element and is a chemically reactive cation forming compounds with anions such as fluoride, phosphorus and arsenic. Uranium may be present in the environment due to leaching from soils, rocks and natural deposits, release in mill tailings, combustion of coal and other fuels, and use of phosphate fertilisers (NHMRC & NRMMC 2011). Natural uranium consists almost entirely of the U-238 isotope.

Typical concentrations of uranium in surface soils range from 0.7–9 mg/kg, and as with most other cations, uranium binds strongly to negatively charged soil surfaces.

Uranium may be found in natural waters, particularly groundwaters, as a result of natural processes or mineral processing.

Effects on animal health

While uranium is usually considered in terms of its radioactive effects (see Radionucleotides), uranium is also a toxic chemical. Ingestion of high levels of uranium can cause kidney damage from its chemical properties much sooner than its radioactive properties would cause cancers of the bone or liver (CDC 2022). According to Garner (1963), the minimum concentration of uranium found to cause poisoning was 50 mg/day for sheep and 400 mg/day for cattle. Phosphorus supplements fed to dairy cattle may contribute 16 mg/day of uranium, depending on the source of phosphorus (Reid et al. 1977).

Derivation of guideline values

CCREM (1987, confirmed in CCME 2005) developed a guideline value of 0.2 mg/L of uranium in livestock drinking water by including a safety factor, estimating the allowable intake of uranium through water, and estimating the volume of water that animals drink. NRC (2005) estimated that the maximum tolerable intake for domestic animals is probably 100–400 mg/kg diet and noted that most diets probably do not exceed 3–4 mg/kg.

3.3.18 Vanadium

Vanadium concentrations >0.1 mg/L in livestock drinking water may be hazardous to animal health.

Source

Metallic vanadium does not occur in nature, vanadium being generally present as sulfide and calcium salts. Vanadium salts are soluble in water and do not normally adsorb onto clay particles.

Concentrations of vanadium in surface soils range from 5 to 250 mg/kg (Edwards et al. 1995, Olszowy et al. 1995). In Australia, the survey of Olszowy et al. (1995) found vanadium's median concentration was 12 mg/kg. Concentrations in uncontaminated surface waters are generally <0.0001 mg/L (DWAF 1996).

Vanadium compounds are used as catalysts in many industrial processes and livestock can ingest vanadium on contaminated land (Frank et al. 1996; Jewell et al. 2022).

Effects on animal health
Vanadium is toxic to animals at relatively low levels.

The average daily intake of vanadium in cattle grazing on a vanadium-contaminated field was estimated to be 72 mg/day/calf. Calves showed signs of stunted growth, pot belly, submandibular oedema, diarrhoea and some deaths (Gummow et al. 2006). Symptoms for Swedish cattle grazing on land contaminated with slag included lethargy, diarrhoea, incoordination, paralysis and abortions (Frank et al. 1996). Sheep fed vanadium compounds had reduced feed intake and diarrhoea at 400 mg/day, and one fed 550 mg died 3 days after dosing (Handsard et al. 1982).

For poultry, dietary concentrations of 30 mg/kg of vanadium induced toxicity effects including oxidative damage, renal and hepatic toxicity and lesions (Dent et al. 2012, Liu et al. 2012). According to van Zinderen Bakker and Javorski (1980), reduced growth rate resulted when chickens were given diets containing 13 mg/kg of vanadium.

Derivation of guideline values
The South African guidelines state that vanadium interacts with chromium and iron and that the concentrations of these elements should be considered when assessing vanadium toxicity (DWAF 1996). The South African guidelines recommend a target water concentration of <1 mg/L, with chronic and acute toxicity effects possible at concentrations >2 mg/L. Canada has a limit of 0.1 mg/L (CCME 2005), which is the same as that recommended by the United States (USDA 2009), FAO (Tanji & Kielen 2002), as well as that recommended by Beede (2012) and NRC (2005) for cattle, and van Heugten (2000) for pigs.

NRC (2005) recommends a vanadium concentration in feed of 25 mg/kg for poultry (or 5 mg/kg for laying hens), and 50 mg/kg for cattle and sheep. It assumes a value of 10 mg/kg for pigs and horses, but there are insufficient data available to set a precise value. These concentrations were used to calculate the guideline values in Table 3.16 using Equation 3.2.

Table 3.16 Calculated guideline values for vanadium in livestock drinking water

Livestock	Maximum vanadium in feed (mg/kg)[a]	Safety factor[b]	Calculated guideline value (mg/L)
Poultry	25	3	0.63
(Laying hens)	(5)	(3)	(0.13)
Horses	10	3	0.19
Pigs	10	3	0.13
Cattle	50	3	0.78
Sheep	50	3	0.70

a Maximum tolerable dietary vanadium from NRC (2005).
b Safety factor of 3 adopted for possible long-term effects.

A guideline value of 0.1 mg/L is recommended for vanadium in livestock drinking water, which is in line with the USA and Canada. However, each situation requires consideration of livestock type and dietary sources of vanadium.

3.3.19 Zinc

Zinc concentrations <20 mg/L in livestock drinking water should not be harmful to animal health.

Source

Zinc is a natural composite of Earth's crust, present in various minerals (e.g. sphalerite (ZnS), smithsonite ($ZnCO_3$) and hemimorphite ($Zn_4(OH)_2Si_2O_7H_2O$)) (Scott-Fordsmand & Pedersen 1995). Zinc sulfate, nitrate and halides (except fluorides) are readily soluble in water, while zinc carbonate, oxide, phosphate and silicate are sparingly soluble or insoluble in water (Weast 1982). In the presence of organic material, zinc has a high affinity for thiol and hydroxyl groups such as in proteins, enzymes and other essential compounds.

Concentrations of zinc rarely exceed 0.01 mg/L in natural waters (Galvin 1996). Higher concentrations in water can be associated with pollution from industrial wastes (Hart 1982) or corrosion of zinc-coated plumbing or galvanised iron water tanks, particularly at low pH (acidic; NHMRC & ARMCANZ 1996).

Effects on animal health

Zinc is an essential element in animal nutrition and is necessary for the function of various enzyme systems (Parisic & Vallee 1969). Zinc deficiency leads to growth retardation, disorders of bones and joints, skin diseases, and low fertility (Duffy et al. 2023). Diet requirements for zinc range from 50 mg/kg to 100 mg/kg (Underwood 1971).

Chronic overdosing of zinc in ruminants can damage the liver, pancreas and kidneys. Pregnant and young animals are at greatest risk (Benson 2022). Ruminants with acute zinc toxicosis can develop weight loss, diarrhoea, decreased appetite, decreased milk production, polyuria with secondary dehydration, and generalised listlessness (Benson 2022). High levels of zinc can also affect copper uptake.

Derivation of guideline values

The ANZECC (1992) guideline value of 20 mg/L of zinc in livestock drinking water (based on Hart 1982) has been retained. This value is consistent with the zinc guidelines in South Africa (DWAF 1996). A value of 50 mg/L has been set in Canada (CCME 2005).

According to Neathery and Miller (1977), the estimated maximum safe zinc concentrations in the diet are 500 mg/kg for calves; 600 mg/kg for sheep; 1,000 mg/kg for chicks, pigs and mature cattle; and 2,000 mg/kg for turkeys. NRC (1980, 2005) set maximum tolerable concentrations of zinc in the diet as 500 mg/kg for cattle, 300 mg/kg for sheep, and 1,000 mg/kg for pigs; poultry was reduced from 1,000 mg/kg in 1980 to 500 mg/kg in 2005.

3.4 Pesticides and other organic contaminants

In the absence of guidelines derived specifically for livestock, guidance around pesticides and other organic contaminants in livestock drinking water are based on the [Australian Drinking Water Guidelines](#) (NHMRC & ARMCANZ 2011).

These state:

'The Australian Pesticides and Veterinary Medicines Authority is responsible for assessing all pesticides prior to registration to allow sale and use in Australia. For registration, data required on the pesticide include information on the proposed use, the toxicity and the residues that might result from proper use. When the pesticide is registered, a safe level of exposure, conditions of use and

maximum levels of residues for water are determined. This mechanism allows the formulation of appropriate guideline values for pesticides in drinking water.

Pesticides should not be found in water supplies above safe levels and if they are, investigations should be undertaken to determine how they came to be there. These investigations should then be followed by corrective action aimed at the prevention of pesticide contamination of drinking water supplies.'

Guideline values for specific chemicals used in pesticides are provided in fact sheets attached to the Australian Drinking Water Guidelines.

For livestock drinking water, if a pesticide concentration is below the drinking water guidelines it is unlikely that there will be an effect on animal health. If the concentration is above guideline values, then further investigation of the effect on animal health and appropriate action is recommended.

Additional information on safe livestock guideline values for pesticides may be included in future editions of these guidelines.

Source
The use of pesticides to control insects, pathogens and weeds is important to the economic production of many agricultural commodities. Pesticides are also widely used for weed control along roads and waterways, and are sometimes applied in urban areas to control insects (e.g. mosquitoes).

Pesticides are mainly organic compounds, or in some cases organometallic compounds, and are categorised according to their intended use; for example, insecticides, herbicides, fungicides, or vertebrate poisons. Each pesticide category is often grouped into classes of chemically similar compounds; for example, the organochlorine and organophosphate insecticides, and the phenoxy herbicides (Schofield & Simpson 1996). Agricultural chemical products must be registered by the Australian Pesticides and Veterinary Medicines Authority before use in Australia. Information about registered products and active constituents can be found at PubCRIS or Infopest.

Pesticide residues can occur in both surface and groundwaters. In Australia, in a survey of surface water quality across 73 sites, pesticide residues were detected in 28% of the water samples (Scott et al., 2014).

Pesticide residues in surface waters may result from (Hunter 1992, CCREM 1987, Schofield & Simpson 1996):

- direct application (e.g. for weed control)
- accidental spillage
- inappropriate use or disposal of pesticides and their containers
- spray drift
- deep percolation
- surface run-off.

Movement of pesticide residues, which bind strongly to soil particles and are relatively insoluble in water, occurs mainly through soil erosion. Run-off waters may also contain other residues in dissolved form. Leaching of pesticide residues to groundwaters can occur depending on the chemical and physical properties of both the pesticide compound and the soil.

Residues of several pesticides, notably the herbicide atrazine, have been found in surveys of some Australian groundwaters, but generally at very low concentrations (Keating et al. 1996, Schofield & Simpson 1996).

Many factors influence the persistence of pesticide residues in aquatic environments, including processes such as decomposition by sunlight, chemical transformation and microbial decomposition. Residues of some persistent organochlorines (e.g. DDT, dieldrin) can still be found in the environment even though they were withdrawn from use or have had restricted use in Australian agriculture for decades (Schofield & Simpson 1996).

Effects on animal health

Pesticides encompass a broad range of natural and synthetic compounds of widely differing chemical composition; as a result the risks vary greatly and are influenced by factors such as toxicity to animals, solubility and stability.

Organophosphate and carbamate pesticides are the most likely to be toxic to livestock, depending on the concentration. They cause symptoms such as diarrhoea, salivation, excessive urination, and respiratory and muscle twitching and tremors followed by convulsions. These pesticides break down rapidly in the aquatic environment through microbial action and hydrolysis in alkaline waters (DWAF 1996).

Most commonly used herbicides are not highly toxic to mammals (CCREM 1987); however, some pesticides or their metabolites may accumulate in animal tissues or products meant for human consumption (DWAF 1996). The Codex Committee on Pesticide Residues develops and maintains acceptable pesticide MRLs for food commodities in international trade.

Derivation of guideline values

There is no information on guideline values for pesticides in livestock drinking water derived specifically for Australian and New Zealand. Adoption of the Australian Drinking Water Guidelines (NHMRC & NRMMC 2011) should provide a margin of safety for livestock and prevent accumulation of unacceptable pesticide residues in animal products.

Additional information can be obtained from guideline values for specific pesticides developed in Canada (CCME 2005), mainly using data obtained from animal toxicological studies:

- atrazine
- bromacil
- bromoxynil
- carbaryl
- captan
- chlorothalonil
- chlorpyrifos
- cyanazine
- deltamethrin
- dicamba
- diclofop-methyl
- dimethoate
- DIPA
- linuron
- MCPA
- metolachlor
- metribuzin
- simazine
- tebuthiuron
- trifluralin.

If the NHMRC & NRMMC (2011) values are greater than those endorsed in Canada (or NHMRC & NRMMC (2011) does not have a value for a particular pesticide), the Canadian water quality guidelines should be used in the absence of more contemporary recommended guideline values.

Monitoring and management

Livestock drinking water should be monitored and regularly assessed for contaminants of concern. Further information is available in the Australian and New Zealand Water Quality Management Framework, particularly the Monitoring section.

In particular, water should be tested if any adverse health or growth effects are noticed in livestock.

Actions to be taken will depend on the results of testing. If levels are increased but not yet unsafe, increased monitoring is recommended. If adverse health or growth effects are noticed, keep stock away from the water source.

3.5   Radionucleotides (radiological quality)

Guideline values for the radiological quality of livestock drinking water are given in Table 3.17.

Table 3.17 Guideline values for radionucleotides in livestock drinking water

Source	Guideline value (becquerel per litre – Bq/L)[a]
Radium 226	<5
Radium 228	<5
Uranium 238	<2.5
Gross alpha	<1
Gross beta (excluding k-40)	<5
Thorium 230/232/228	<10

a Change is based on the previous assumption that only 10% of radiation will enter the parts of the animal that might be used for human consumption.

Taking into account the recommended guideline value concentrations for specific radionucleotides, it is recommended that screening values should be established with a gross alpha level of 0.5 becquerel per litre (Bq/L) and a gross beta concentration of 0.5 Bq/L, after discounting the contribution due to potassium-40.

There will be certain circumstances when a dose may exceed the guidelines. For example, the annual dose rate for lactating dairy cows, which is drinking water contaminated with radium 228 at the guideline value (5 Bq/L), would be >100 mSv, because they consume a high volume of water (85 L/d). In such cases, the actual daily intake of water should replace the mean value used in estimating the dose before protective measures are proposed.

Source

Radioactive contaminants can originate from both natural and artificial sources and can potentially be found in surface water and groundwater.

It is important to determine the radiation dose for livestock associated with the presence of radioactive contaminants in different water sources:

* Groundwater is a major source of water for agriculture in Australia. The most significant radionuclides naturally occurring in groundwaters are those associated with the uranium and thorium series, because the parent nuclides were present during the formation of Earth (Kleinschmidt, 2011). More specifically, radium-226, radium-228 and uranium-238 are the natural radionuclides which are often detectable in groundwater supplies. Potassium-40 is a common radioactive constituent of groundwater. However, this radionuclide occurs in a fixed ratio to stable potassium and is not considered a health risk (UN, 1993).

- Surface water generally contains considerably lower concentrations of these radionuclides. Other long-lived natural radionuclides (e.g. thorium isotopes and lead-210) are normally not found in significant quantities in surface water or groundwater (UN, 1993).

When assessing the radiological quality of stock waters, consideration must also be given to the possibility of higher levels of radionuclides arising from activities such as processing of minerals containing uranium and thorium (e.g. from the processing of phosphate ores for fertiliser production, (Pearson et al. 2019)).

Levels of radionuclides in soils from nuclear fallout in the Australian environment are no longer significant, having decreased substantially since the tests of nuclear weapons in the 1950s and 1960s. They have still been detected in some Australian soils; however, their concentrations are well below the levels of natural radionuclides (M Cooper, unpublished). UNSCEAR (2000) estimated that the southern hemisphere received about one-third of global fallout from nuclear atmospheric tests. Nearly 60 years later at the time of the update of these guidelines, almost 2 half-lives of ^{137}Cs have passed (30.07-year half-life) and it is therefore difficult to detect this radionuclide in the soil. In the Sydney region, ratios of ^{240}Pu/^{239}Pu in creek sediments were found to be lower than the global average (estimated to be around 0.18) and similar to those reported for other locations away from nuclear testing sites (Smith et al. 2016).

Effects on animal health
It is not considered feasible that levels of radioactivity in livestock drinking water would be a direct threat to the health of the animals (UN 1993; International Atomic Energy Agency 1994).

The main risks to health due to radioactivity in water will arise from the transfer of radionuclides from water to animal products and their subsequent consumption by humans. Cancer is the potential health concern for humans associated with exposure to natural radionuclides.

However, the naturally occurring radionuclides representing the most significant radiological health risk, radium isotopes and uranium-238, are not taken up readily into animal tissues or organs. Moreover, these radionuclides do not concentrate in meat tissue or milk (International Atomic Energy Agency 1994; Brown & Simmonds 1995).

Derivation of guideline values
Minimising human exposure to radiation where possible should be a major consideration in establishing guidelines for radiological water quality. An ideal approach may be to maintain the same set of radiological guidelines for stock water as apply for drinking water quality in Australia and New Zealand. However, in most cases this would be impractical. Given that the main source of potential contamination will be naturally occurring radioactivity, it would be sensible to derive guideline values based upon the same dose limit (0.1 mSv) as applies to drinking water but to take into account the low transfer factors for such radionuclides into the human food chain via the animal pathway.

This review follows the methodology outlined in the *Australian Drinking Water Quality Guidelines* (NHMRC 2011) and WHO (2017), but using an annual committed effective dose of 1 mSv instead of 0.1 mSv to calculate guideline values for specific radionuclides in stock waters.

The guideline value (Bq/L) for radionuclides in drinking water are calculated using Equation 3.5.

Equation 3.5

Annual dose (mSv/year) = Dose per unit intake (mSv/Bq) x Annual water consumption (L) x Radionuclide concentration (Bq/L).

Where:

- The annual water consumption is estimated at 730 L/year (WHO, 2017), which is a daily intake of 2 L per adult person.

Only key natural radionuclides have been considered. It should be noted that the DGV for uranium-238 is based on chemical toxicity considerations rather than on radiological grounds. No guideline values are presented for other natural radionuclides, such as thorium isotopes, lead-210 or polonium-210, because they are rarely found in surface or groundwater in significant quantities.

Monitoring and management

To have a practical monitoring program, it would be appropriate to use gross radioactivity as a screening technique with a level established above which specific radionuclide analysis should be carried out.

In applying these guidelines, it should be noted that the gross alpha and beta recommendations are given to simplify screening measurements and monitoring procedures. Specific radionuclide analysis would only be appropriate if these values are exceeded.

Gross alpha radioactivity will indicate the presence of radium-226 and uranium isotopes. Potassium-40 will be the most likely contributor to gross beta radioactivity, along with radium-228. The contribution of potassium-40 to the gross beta activity should be determined before further assessment.

A water supply should not be considered to be unsafe for irrigation or stock water if specific radionuclide levels are exceeded. In such cases, further assessment of the supply should be conducted, including possible alternatives. If all or most other water quality parameters are acceptable, it may be possible to accept higher radionuclide concentrations without jeopardising health.

The values in Table 3.18 are based on the Australian Drinking Water Guidelines, Information Sheet 2.2 (NHMRC & ARMCANZ 2011).

Table 3.18 Operational response to different annual dose values of radionuclides

Annual dose (mSv)	Response
<10	1. Continue screening at normal frequency.
10–50	1. Consult with relevant authorities. 2. Review frequency of sampling. 3. Evaluate operational options for decreasing exposure.
>50–100	1. Consult with relevant authorities. 2. Assess protective measures in detail, including cost-effectiveness. 3. Implement appropriate protective measures based on cost–benefit evaluation.
>100	1. Water not suitable for livestock consumption 2. Consult with relevant authorities. 3. Implement protective measures immediately to decrease doses to below guideline value of 10 mSv.

4 Glossary

Term	Definition
acidity	Having the properties of an acid; a pH less than 7
active constituents	The component of a chemical product that is primarily responsible for the product's biological or other effects. A chemical product may contain more than one active constituent.
aerobic	The presence of gaseous or dissolved oxygen, the presence of or utilising oxygen
colony-forming unit (CFU)	An estimate of the number of the number of viable bacteria or the fungal cells in a sample
Food and Agriculture Organization (FAO)	The United Nations agency that leads international efforts to improve nutrition and food security
LD_{50}	A measure of the lethal dose of a toxin; the value of LD_{50} for a substance is the dose required to kill half the members of a tested population
lowest observed adverse effect level (LOAEL)	Greatest concentration or amount of a substance, found by experiment or observation, that causes no detectable adverse alteration of morphology, functional capacity, growth, development, or lifespan of the target organism under defined conditions of exposure (APVMA).
maximum contaminant level (MCL)	The greatest amount of a contaminant that can be present in water without causing a risk to its intended use
maximum residue limit (MRL)	The greatest amount of an agricultural or veterinary chemical residue that is legally allowed in a food product sold in Australia
monogastrics	Animals with 1 stomach (horses, pigs, chickens)
no observed effect level (NOEL)	Greatest concentration or amount of a substance, found by experiment or observation, that causes no alteration of morphology, functional capacity, growth, development, or lifespan of the target organism distinguishable from those observed in normal (control) organisms of the same species and strain under the same defined conditions of exposure (APVMA).
performance (in livestock)	A general measure of livestock health, growth, weight gain and reproduction
precautionary principle	An approach to decision-making that adopts conservative precautionary measures when scientific evidence about an environmental or human health hazard is uncertain
ruminants	Animals with complex 4-chambered stomachs that chew the cud (cattle, sheep, goats, deer). Alpacas and llamas are 'pseudo ruminants' – they have 3-chambered stomachs and chew the cud.

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