9.3 Livestock drinking water guidelines

9.3.1 Introduction

Livestock production in Australia and New Zealand relies on both surface water and groundwater supplies. Water quality in streams and dams (surface waters) is influenced by catchment geology, topography, soil type and climate. Groundwater, which is used as a source of drinking water for livestock over a large area of Australia (and in parts of New Zealand), may contain large quantities of dissolved salts, depending on the soil and parent rock of the surrounding area and many other factors including rainfall, evaporation, vegetation and topography. The quality of both groundwaters and surface waters may be affected by catchment land use practices, including agriculture, mining and other industries, with the potential for increased concentrations of salt, nutrients and other contaminants, such as pesticide residues and heavy metals.

Daily water intake varies widely among different forms of livestock and is also influenced by factors such as climate and the type of feed being consumed. Average and peak daily water requirements for a range of livestock are given in table 9.3.1.

Table 9.3.1 Stock water requirements[a]

Type of livestock		Average daily consumption	Peak daily consumption
Sheep		(litres/head)	(litres/head)
	Nursing ewes on dry feed	9	11.5
	Mature sheep on dry pastures	7	8.5
	Mature sheep on green pastures	3.5	4.5
	Fattening lambs on dry pasture	2.2	3
	Fattening lambs on green pasture	1.1	
Cattle			
	Dairy cows in milk	70	85
	Dairy cows, dry	45	60
	Beef cattle	45	60
	Calves	22	30
Horses			
	Working	55	70
	Grazing	35	45
Pigs			
	Brood sows	22	30
	Mature pigs	11	15
Poultry		(litres/100 birds)	(litres/100 birds)
	Laying hens	32	40
	Non-laying hens	18	23
	Turkeys	55	70

a From Burton (1965)

9.3.2 Derivation and use of guidelines

Information used to determine the trigger values was sourced from the current literature and evaluated for relevance, with preference given to data from Australia and New Zealand. Details of the databases searched are provided in Section 9.2. Material provided by the public was also considered. Much of the information found in the literature was based on field observations rather than rigorous experimentation. In several cases it was possible to calculate trigger values using data on chronic and toxic effect levels on animals, taking into consideration animal weights, percentage intake from water, and safety factors for data not specific to the species. Derivation of most trigger values for livestock drinking water requires further validation and they should be considered interim at this stage. The particular methodologies used to develop specific trigger values are discussed further in relevant Sections.

Consistent with guidelines derived for other environmental values, these guidelines are trigger values. Below the trigger value there should be little risk of adverse effects on animal health. Above the trigger value, investigations are recommended (e.g. of other factors such as age, condition, other dietary sources) to further evaluate the situation.

9.3.3 Biological parameters

9.3.3.1 Cyanobacteria (blue-green algae)

> ***Algal blooms should be treated as possibly toxic and the water source should be withdrawn from stock until the algae are identified and the level of toxin determined.***
>
> ***An increasing risk to livestock health is likely when cell counts of* Microcystis *exceed 11 500 cells/mL and/or concentrations of microcystins exceed 2.3 µg/L expressed as microcystin-LR toxicity equivalents. There are insufficient data available to derive trigger values for other species of cyanobacteria.***

Source

Cyanobacteria (often called blue-green algae because they are similar to algae in habitat, morphology and photosynthetic activity) are a component of the natural plankton population in healthy and balanced surface water supplies. They 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 toxic cyanobacteria associated with known animal poisoning incidents are *Microcystis* (colonial); and *Anabaena* and *Nodularia* (filamentous) (Steffensen et al. 1998). The genus *Cylindrospermopsis* has been identified in surface waters, mainly in tropical and subtropical areas (Queensland Water Quality Task Force 1992, Jones et al. 1993, Jones 1994). Cyanobacteria only become a potential hazard when they are present in large numbers (blooms). Blooms typically occur on warm days with light to calm winds (summer to autumn) in waters of neutral to alkaline pH containing elevated levels of inorganic phosphorus and nitrogen, although blooms at other times are possible (Carmichael 1994). There may be often more than one species of cyanobacteria associated with a bloom (Ressom et al. 1994).

Animal health

The toxins associated with cyanobacteria are mostly intracellular in healthy blooms and only affect stock following direct ingestion of cells (either in the water or as dried mats left on the shore), or from drinking water where the death of cells has caused a considerable release of toxins into the water supply. In the latter situation it may take weeks for toxins to be degraded by naturally occurring bacteria (Carmichael 1994, Jones 1994).

Not all blooms of cyanobacteria appear to be hazardous to animals for the following reasons (Carmichael & Falconer 1993):

- only low concentrations of toxins may be associated with the bloom;

- stock are not equally susceptible to algal intoxication — species, age and sex affect susceptibility;
- the amount of toxin consumed may be small and/or countered by the amount of other food in the animal's gut.

Worldwide, the most common cyanobacterial toxin is microcystin, a hepatotoxin which is produced predominantly by the genus *Microcystis,* and occasionally by species of *Anabaena*, although this appears to be rare in Australia. There may be some differences between animal species in the symptoms of this type of poisoning, but typically they include a display of weakness, lethargy, anorexia, paleness, sometimes mental derangement, and often accompanied by diarrhoea. In serious cases animals suffer general distress, muscle tremors and coma which is followed by death within a few hours to a few days. Animals, particularly cattle, which survive hepatotoxicosis may suffer from photosensitisation resulting in cows refusing to suckle their young (Carmichael & Falconer 1993). *Nodularia spumigena,* which produces another hepatotoxin, nodularin, was the first well-documented case in the world of a cyanobacterial outbreak, at Lake Alexandrina, South Australia in 1878 (Francis 1878). Domestic animals in Australia have been affected by exposure to nodularin (Steffensen et al. 1998).

The neurotoxins produced by *Anabaena circinalis* are a group of closely related alkaloids known as saxitoxins. When ingested by animals, these toxins restrict message transmission between neurones 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 *A. circinalis* 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 will be more obvious than the effects of hepatotoxins, in cases where both are present (Carmichael & Falconer 1993).

Cylindrospermopsin is a cytotoxic alkaloid associated with the nitrogen fixing *Cylindrospermopsis raciborskii*. 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. Falconer et al. (1994) in experiments with bloom material of *Microcystis aeruginosa* showed there was no adverse effect on the livers of pigs supplied with 280 µg toxins/kg/day via drinking water over a period of 44 days. Long-term effects of ingestion of lower levels of toxins are not well understood.

While the risk of possible accumulation of toxins in animal products for human consumption is not fully known, a study of dairy cattle ingesting up to 15 mg of Microcystin-LR over a period of three weeks showed no transmission of toxin into the milk (G Jones, pers comm).

Derivation of trigger value

Establishing trigger values based on health considerations of animals is difficult for the following reasons:

- 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); and
- insufficient toxicological data are available for all toxins.

To derive reliable trigger values, accurate and accessible methods for determination of toxins in water need to be further developed, and data provided on the acute and chronic effects of these toxins on domestic animals.

Microcystin

The following calculations and assumptions were used to derive a trigger value for microcystin-LR toxicity equivalents. 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 Organisation (Falconer et al. 1999). The example given is for pigs; data for other livestock are provided in table 9.3.2.

For pigs:

$$\text{trigger value} = \frac{\text{LOAEL} \times \text{animal weight}}{\text{max daily water intake} \times \text{safety factor}} = \frac{100\,\mu\text{g/kg/day x } 110\text{kg}}{15\text{L/day} \times 45} = 16.3\mu\text{g/L} \qquad (9.47)$$

where:

- 100 µg microcystin-LR toxicity equivalents/kg bw/day 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 NOEL (No Observed Effect Level) from the LOEAL of the pig study.

Table 9.3.2 Summary of calculations for microcystin-LR equivalent levels and cell numbers of *Microcystis aeruginosa* used to develop a guideline for a range of livestock

Animal	**Body weight**	**Peak water intake**	**Safety factor**					**Toxin level calc.**	**Equivalent cell number**[a]
	(kg)	**(L/day)**	**Less than lifetime**	**Inter-species variation**	**Intra-species variation**	**LOAEL to NOEL**	**Total**	**(µg/L)**	**(cells/mL)**
Cattle	800	85	3	5	3	5	225	4.2	21000
Sheep	100	11.5	3	5	3	5	225	3.9	19500
Pigs	110	15	3	1	3	5	45	16.3	81500
Chickens[b]	2.8	0.4	3	5	3	5	225	3.1	15500
Horses	600	70	5[c]	5	3	5	375	2.3	11500

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 have a very similar body weight/water intake ratio.

c Horses generally live longer than other livestock

Using the above approach, estimated trigger values for microcystin-LR toxicity equivalents for various types of livestock range from 2.3 to 16.3 µg/L, equivalent to 11 500 to 81 500 cells/mL of *Microcystis aeruginosa* (table 9.3.2). Taking the most sensitive animals (horses), the value of 11 500 cells/mL can be used as a trigger value, below which little or no risk to stock should occur.

Other cyanotoxins

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

Diagnostic procedure

The presence of an algal bloom does not necessarily mean that animals will be poisoned, so the following steps should be taken to assess the risk from such a bloom (after Carmichael & Falconer 1993).

1. Establish that animals are drinking the water or eating algal mats from the area where there is a substantial bloom.
2. Indentify the algae associated with the bloom to determine whether cyanobacteria are present in numbers large enough to constitute a risk.
3. If necessary, chemically analyse a sample of the bloom to identify and quantify toxins present.

Since all blooms of cyanobacteria have the potential to be toxic and all livestock are susceptible, it is prudent to consider all scums toxic until proven safe, as described above. In the interim, stock should be withdrawn from the water supply and an alternative source used. Where an alternative source is not available and the bloom is localised, it may be possible to allow stock to drink from an area on the upwind side of the bloom. In the long term, prevention of blooms is by far the best strategy and water supplies should be managed so that nutrient inputs are minimal.

9.3.3.2 Pathogens and parasites

> ***Drinking water for livestock should contain less than 100 thermotolerant coliforms/100 mL (median value).***

Source

A large variety of microbial pathogens can be transmitted to stock from drinking water supplies contaminated by animals and their faeces. The risk of contamination is greatest in surface waters (dams, watercourses, etc) which are directly accessible by stock or which receive runoff or drainage from intensive livestock operations or human wastes. 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.

Management of water supplies to minimise contamination is the best strategy for protecting livestock from water-borne microbial pathogens. Effective measures include preventing direct access by stock to watercourses and minimising drainage of waters containing animal wastes to streams and groundwaters.

Animal health

Infections in livestock often result in reduced growth and morbidity and possibly mortality (Smith et al. 1974).

The bacteria of most concern in water supplies with unacceptably high bacterial counts are the enteric bacteria, *Escherichia coli* and *Salmonella* and to a lesser extent *Campylobacter jejuni* and *C coli, Yersinia enterocolitica* and *Y pseudotuberculosis.* Other bacteria known to affect stock and which may be transmitted through water supplies include *Leptospira* (leptospirosis), *Burkholderia (Pseudomonas) pseudomallei* (melioidosis), *Clostridium botulinum* (botulism), Mycobacteria (pulmonary disease), *Pseudomonas* (mastitis) and Cyanobacteria (blue-green algal toxicosis, see Section 9.3.3.1).

A number of serious pathogenic conditions in livestock can be caused by viruses. Water supplies have been implicated in transmitting Newcastle disease and infectious bursitis in poultry (CCREM 1987).

Well-managed livestock usually have a relatively low incidence of parasitic infections. Most infections do not cause mortality directly, but reductions in growth rates and vitality occur and susceptibility to fatal infectious disease organisms increases (CCREM 1987). A number of stock parasites spend part of their life-cycles in water, and faecal contamination of water is the usual means of introduction. One parasitic disease of concern in Australia is cysticercosis in cattle (beef measles) caused by the tapeworm *Taenia saginata* (Arundel 1972).

Experiments with lambs have shown that the minimum infectious dose of the protozoan *Cryptosporidium parvum* may be as little as one oocyst and that the infection may be water-borne (Blewett et al. 1993). *Giardia* is another protozoan which can be transmitted in water. Weight loss in stock has been reported from infection with *Giardia* (Olson et al. 1995).

Water-borne pathogens not only affect stock health, but may also impact on human health. It is reasonable to assume that a contaminated water supply introducing high numbers of organisms into a group of animals may create a ‘multiplier’ effect through the food chain. High numbers of pathogens (e.g. the enterohaemmorhagic *E. coli*) in the herd could then lead to high numbers of organisms on meat, with increased risk of infections in human consumers.

Derivation of trigger value

Expanding interest worldwide in the use of reclaimed wastewaters for agricultural purposes has generated much of the recent activity in developing guidelines for their safe use for this and other purposes. Although the present guidelines concern natural waters rather than reclaimed waters, the underlying issues regarding risks to human and animal health are the same.

In Australia and New Zealand, the management and use of reclaimed water from sewerage systems forms an important component of the National Water Quality Management Strategy (NWQMS). Guidelines for pathogen levels in stock drinking water have been proposed in the NWQMS document, *Guidelines for sewerage systems — use of reclaimed water* (ARMCANZ, ANZECC & NHMRC 2000). These guidelines have been adopted for use in the present water quality guidelines for primary industries.

It is generally not feasible nor warranted to test livestock drinking water for the presence of the wide range of water-borne microbial pathogens that may affect stock health. In practice, water supplies are more commonly tested for the presence of thermotolerant coliforms (also known as faecal coliforms), to give an indication of faecal contamination and thus the possible presence of microbial pathogens. However, note that in tropical and sub-tropical areas thermotolerant coliforms may on some occasions include microorganisms of environmental rather than faecal origins (NHMRC & ARMCANZ 1996). Moreover, the test does not specifically indicate whether pathogenic organisms are present or not. Testing for specific organisms may be necessary in these situations if animal health is affected.

The NWQMS guidelines for pathogens in stock drinking water (ARMCANZ, ANZECC & NHMRC 2000) were proposed after consideration of the methodologies and information used in developing guidelines proposed by the World Health Organization (WHO 1989) and the United States Environmental Protection Agency (USEPA 1992), together with local considerations. This is consistent with WHO recommendations that the WHO (1989) guidelines be adapted according to local conditions and socio-economic factors (Hespanhol & Prost 1994). The ARMCANZ, ANZECC & NHMRC (2000) guidelines are based on:

- the best available scientific evidence;
- worldwide practice in reclaimed water use;
- a consensus of local practice demonstrated to be safe.

It is recommended that a median value of thermotolerant coliforms is used, based on a number of readings generated over time from a regular monitoring program. Investigations of likely causes are warranted when 20% of results exceed four times the median guideline level (ARMCANZ, ANZECC & NHMRC 2000).

9.3.4 Major ions of concern for livestock drinking water quality

9.3.4.1 Calcium

> ***Stock should tolerate concentrations of calcium in water up to 1000 mg/L, if calcium is the dominant cation and 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 drinking water may be less.***

Source

Calcium is found in natural waters over a wide range of concentrations. The level of calcium in water is related closely to the geology of the source areas, the calcium being derived by weathering processes from minerals such as gypsum, limestone and dolomite. Calcium contributes to the hardness of the water, which may cause scaling problems in pipes, troughs and fittings (see Section 9.2.9.3).

Animal health

Calcium is an essential element in the animal diet. However, high calcium concentrations may cause phosphorus deficiency by interfering with phosphorus absorption in the gastrointestinal tract and calcious formation in the body (Mulhearn 1964). Long-term intake by sheep of water containing around 1100 mg/L calcium was found to have no adverse effect on health and wool production, although the calcium concentration of plasma increased, while the sodium concentration decreased (Peirce 1960).

Derivation of trigger value

The ANZECC (1992) guideline for calcium has been retained in the absence of any new contradictory information. The trigger value of 1000 mg/L is consistent with guidelines developed in both Canada (CCREM 1987) and South Africa (DWAF 1996b).

9.3.4.2 Magnesium

> ***Insufficient information is available to set trigger values for magnesium in livestock drinking water.***

Source

The concentration of magnesium in natural waters varies considerably, with concentrations in natural freshwaters ranging from <1 mg/L to >1000 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 troughs and fittings (see Section 9.2.9.3).

Animal health

Recent work by CSIRO in Queensland suggests that Brahman steers can tolerate magnesium concentrations in drinking water up to 2000 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 *per se* or whether they were confounded by other issues such as the overall salinity of the water or the presence of other specific ions (e.g. sulfate) known to have adverse effects.

High magnesium concentrations in water are generally associated with high concentrations of total dissolved salts (TDS), hence many problems attributed to magnesium may well be due to the high TDS levels. Flinn (1980) showed that concentrations of 400–600 mg/L magnesium were typically found in water containing 8000–12 000 mg/L TDS which is at the upper limit of tolerance by stock. The findings of Saul and Flinn (1985) would also seem to support this position.

Derivation of trigger value

Present information is inconclusive regarding the effects of magnesium levels in drinking water on animal health. No trigger value is recommended until further information from animal feeding trials becomes available.

The ANZECC (1992) guidelines (based on Flinn 1984) gave an upper limit for magnesium for all forms of livestock of 600 mg/L but this is not now supported, for the reasons given above. Present Canadian Water Quality Guidelines (CCREM 1987) do not include a guideline for magnesium in livestock drinking water; while in South Africa, an upper limit of 1000 mg/L magnesium is proposed, with some adverse effects considered likely to occur at magnesium concentrations between 500 and 1000 mg/L (DWAF 1996b).

9.3.4.3 Nitrate and nitrite

> ***Nitrate concentrations less than 400 mg/L in livestock drinking water should not be harmful to animal health. Stock may tolerate higher nitrate concentrations in drinking water provided nitrate concentrations in feed are not high. Water containing more than 1500 mg/L nitrate is likely to be toxic to animals and should be avoided.***
>
> ***Concentrations of nitrite exceeding 30 mg/L may be hazardous to animal health.***

Source

Nitrate and nitrite are oxidised forms of nitrogen, both of which can occur naturally in waters, although nitrate generally predominates. Nitrate is usually present in unpolluted streams at concentrations below 1 mg/L (Meybeck 1982). Higher concentrations are often associated with over-use of nitrogen fertilisers and manures; intensive livestock operations; and/or leakage from septic systems and municipal wastes. Elevated nitrite concentrations typically are found only under anoxic conditions, for example where waters are polluted by organic wastes.

Groundwaters may contain elevated nitrate concentrations due to natural processes (Lawrence 1983) but more typically, high nitrate concentrations in groundwaters 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).

Overfertilisation of 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. Animals are likely to be at higher risk of nitrate/nitrite poisoning through consumption of pastures, forages and feeds containing high levels of nitrate than from their water supplies.

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

$$1\text{mg/L } NO_3\text{–N} = 4.43 \text{ mg/L } NO_3 \qquad (9.48)$$

$$1\text{mg/L } NO_2\text{–N} = 3.29 \text{ mg/L } NO_2 \qquad (9.49)$$

Note that guideline values presented here are for nitrate and nitrite.

Animal health

Both nitrate and nitrite can cause toxicity, with nitrite being 10–15 times more toxic than nitrate (Case 1963). To cause toxicity, nitrate must first be 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.

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 show an increased rate of nitrate/nitrite reduction. Nitrate toxicity is also dependent on the rate of consumption, with slow intake and a balanced ration reducing toxicity (Crowley 1985).

Winks (1963) reported death of calves and cattle in Queensland from drinking water containing 2200 mg/L nitrate. He suggested a toxic nitrate concentration for cattle as somewhere between 300 mg/L and 2200 mg/L. Seerly 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 less than 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 around 1300 mg/L nitrate. Sorensen et al. (1994) found no effect on early weaned piglets and growing pigs from water containing up to 2000 mg/L nitrate or up to 17 mg/L nitrite. In experiments carried out in Queensland, pigs raised from 20 to 80 kg showed no decrease in performance and no adverse effects on health, 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 US showed no association between animal health or performance and drinking water containing up to 460 mg/L nitrate (Bruning-Fann et al. 1996). 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).

Derivation of trigger values

As ingestion of nitrite leads to a more rapid onset of toxic effects than nitrate, the guideline value for nitrite must be correspondingly lower than that for nitrate. The total dietary intake of nitrate by livestock needs to be considered when interpreting the trigger values. High nitrate concentrations in the water supply may indicate that nitrate levels in locally grown feed may also be elevated.

Trigger values of 400 mg/L nitrate and 30 mg/L nitrite are recommended for livestock drinking water. Depending on the nitrate content of feed, the type of livestock and other factors such as animal age and condition, concentrations up to 1500 mg/L nitrate may tolerated, at least for short-term exposure.

The recommended trigger values are consistent with present Canadian guidelines for livestock drinking water (100 mg/L nitrate–N; 10 mg/L nitrite–N) (CCREM 1987). In South Africa, trigger values range from 100 to 400 mg/L nitrate, depending on the type of livestock, animal condition and period of exposure (DWAF 1996b).

9.3.4.4 Sulfate

> ***No adverse effects to stock are expected if the concentration of sulfate in drinking water does not exceed 1000 mg/L. Adverse effects may occur at sulfate concentrations between 1000 and 2000 mg/L, especially in 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. Levels of sulfate greater than 2000 mg/L may cause chronic or acute health problems in stock.***

Source

Sulfate is found in most natural waters 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 groundwaters. Mine waste waters, tannery wastes and other industrial discharges often contain high concentrations of sulfate, while the use of alum as a flocculant may increase the levels of sulfate in stock drinking water.

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

Animal health

Sulfate is an essential element for animal nutrition. Excessive concentrations of sulfate in water typically cause diarrhoea in stock. Animals generally avoid water containing high sulfate concentrations in favour of water containing lower concentrations, where available (Weeth & Capps 1972).

Sulfate can cause diarrhoea in young animals at concentrations of 1000 mg/L (Church 1979). Higher concentrations of sulfate may be tolerated, depending on the species of livestock, age, and the principal cations associated with the sulfate ion, but loss of production may be expected (CCREM 1987). Weanling pigs showed no significant effect on performance from drinking water containing up to 2400 mg/L sulfate for 20 days (although scouring was reported), but performance was reduced at 4880 mg/L sulfate (McLeese et al. 1992). An improvement was reported in productivity and health of dairy cattle when their source of drinking water was changed from deep-well water containing 1500–2500 mg/L sulfate to surface water containing less than 1000 mg/L sulfate (CCREM 1987). Hereford cattle showed decreased water and food consumption, weight loss and diuresis when consuming water containing 3380 mg/L sulfate (Weeth & Hunter 1971).

Brahman steers fed diluted coal mine pit water containing approximately 2000 mg/L 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 2000 mg/L sulfate, but water and dry matter intakes were reduced when animals were exposed to drinking water containing 4000 mg/L (Harper et al. 1997). However, liveweight gains for lactating cows and their calves were found to be significantly reduced by drinking water containing ≥1300 mg/L sulfate, but not at 630 mg/L (Harper et al. 2000).

Very high concentrations of sulfate in drinking water (7200 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 trigger value

The trigger value for the concentration of sulfate in the drinking water of livestock has been adopted after consideration of reported experimental findings from trials feeding water to animals. The guideline is consistent with values recommended for sulfate is livestock drinking water in Canada (CCREM 1987) and South Africa (DWAF 1996b).

Interactions such as those with dietary copper and molybdenum (see Section 9.3.5.14) should be taken into account when deciding the suitability for stock of water containing high sulfate concentrations.

9.3.4.5 Total dissolved solids (salinity)

> ***Recommended concentrations of total dissolved solids in drinking water for livestock are given in table 9.3.3.***

Table 9.3.3 Tolerances of livestock to total dissolved solids (salinity) in drinking water[a]

Livestock	**Total Dissolved Solids (mg/L)**		
	No adverse effects on animals expected	Animals may have initial reluctance to drink or there may be some scouring, but stock should adapt without loss of production	Loss of production and a decline in animal condition and health would be expected. Stock may tolerate these levels for short periods if introduced gradually
Beef cattle	0–4000	4000–5000	5000–10000
Dairy cattle	0–2400	2400–4000	4000–7000
Sheep	0–4000	4000–10000	10000–13000[b]
Horses	0–4000	4000–6000	6000–7000
Pigs	0–4000	4000–6000	6000–8000
Poultry	0–2000	2000–3000	3000–4000

a Adapted from ANZECC (1992); b Sheep on lush green feed may tolerate up to 13000 mg/L TDS without loss of condition or production.

Source

Total dissolved solids (TDS) is a measure of all inorganic salts dissolved in water and is a guide to water quality. The measurement also includes other dissolved substances such as organic compounds, when present. The concentration of TDS in natural waters ranges widely, from <1 mg/L in rainwater to about 35 000 mg/L in seawater and higher in brines and some natural waters. 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, sulphate 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 by both natural weathering processes and human activities, such as discharges of domestic and industrial effluents and runoff from urban and rural areas. Water supplies in dams, lakes and water troughs can increase in TDS concentrations due to evaporation, particularly if they are not flushed out regularly.

Animal health

Highly mineralised waters can cause physiological upset and sometimes death in terrestrial animals, including humans. Animals under physiological stress, for example due to pregnancy, lactation or rapid growth, are particularly susceptible to mineral imbalances. Livestock generally find water of high salinity unpalatable. Water of marginal quality can cause gastrointestinal symptoms and a reduction in weight gain and milk or egg production. However, livestock can acclimatise physiologically to some extent to water of higher salinity when the level is adjusted over several weeks.

In dairy cattle, a reduction in milk production in cows and decreased liveweight gain have been reported at TDS levels of 4360 mg/L (Challis et al. 1987); 3574 mg/L (Solomon et al. 1995) and 2696 mg/L (Jaster et al. 1978). Saul and Flinn (1985) reported losses in animal production when Hereford heifers were introduced to water containing TDS levels of 5000–11 000 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 showed increased diarrhoea, heavier mortality and decreased body weight gains at 13 000 mg/L TDS; and reduced body weight gains and wool production at 10 000 mg/L TDS (Peirce 1968b).

The incidence of egg shell defects (thin and cracked shells) in chickens was shown to be significantly increased by an increased intake of mineral salts (Balnave & Scott 1986). Municipal water supplemented with 250 mg/L sodium chloride (NaCl) increased shell defects two fold, while 2000 mg NaCl/L added to drinking water produced up to 50% of all eggs with defects (Balnave & Yoselwitz 1987, Brackpool et al. 1996). The adverse effect of drinking the saline water even for short periods of time during early lay was not overcome when the water supply was replaced with lower salinity water (Balnave & Zhang 1998). Equivalent levels of sodium chloride in feed did not adversely affect egg shell quality (Yoselwitz & Balnave 1989).

While increased water consumption and some initial diarrhoea are common observations when pigs are introduced to water containing >4000 mg/L TDS, concentrations as high as 6000 mg/L TDS are unlikely to adversely effect pigs that have become accustomed to the water (Robards & Radcliffe 1987, Williams 1990). In experiments carried out in Queensland, pigs raised from 20 to 80 kg showed no decrease in performance and no adverse effects on health, when given water containing up to 8000 mg/L TDS, although water consumption did increase with increasing salinity, particularly in summer months (McIntosh 1982).

Derivation of trigger values

Salinity (TDS) is used throughout Australia as a convenient guide to the suitability of water for livestock watering. However, if a water has purgative or toxic effects, especially if the

TDS is above 2400 mg/L, the water should be analysed to determine the concentrations of specific ions.

Table 9.3.3 summarises the salinity tolerances of livestock (from ANZECC 1992), taking into consideration the information supplied above. The guidelines are broadly consistent with those recommended in Canada (CCREM 1987) and South Africa (DWAF 1996b), although there are some differences in TDS concentration ranges proposed for different types of livestock. In Canada, the maximum TDS level that is recommended as safe for livestock consumption is 10 000 mg/L (CCREM 1987).

In natural waters, the electrical conductivity (EC, in dS/m) is directly proportional to TDS (mg/L) by a factor ranging from 550 to 900, depending on the types of dissolved salts present in the water. Typical conversion factors used in Australia include 640 (Gill 1986) and 670 (Rayment & Higginson 1992). For convenience, TDS is often estimated from EC. The following are some useful conversions:

$$1 \text{ dS/m} = 1000 \ \mu\text{S/cm} \tag{9.50}$$

$$\text{EC (dS/m)} \times 670 = \text{TDS (mg/L)} \tag{9.51}$$

$$\text{EC } (\mu\text{S/cm}) \times 0.67 = \text{TDS (mg/L)} \tag{9.52}$$

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

9.3.5 Heavy metals and metalloids

9.3.5.1 Aluminium

> ***Where aluminium concentrations in water exceed 5 mg/L, stock intake of phosphorus in the diet should be investigated. Animals, particularly ruminants, may tolerate much higher levels of aluminium as long as there is sufficient phosphorus in the diet to compensate for the effects of aluminium.***

Source

Aluminium is usually present in natural waters in concentrations below 1 mg/L, except in areas with low soil pH, where the aluminium content may be as high as 10 mg/L, due to the increased solubility of soil aluminium oxides and clay minerals (Galvin 1996). The use of alum and other aluminium based flocculants may also be responsible for increased concentrations of aluminium in water supplies.

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 symptoms of phosphorus deficiency (NRC 1980). Symptoms include reduced growth and disturbances in carbohydrate metabolism. Ruminants may be less susceptible than monogastrics, since organic anions in the rumen may complex the aluminium and prevent it precipitating with phosphate (Thompson et al. 1959, cited by NRC 1980).

No adverse effects were observed when aluminium sulfate was fed to sheep and cows at concentrations of 1215 mg Al/kg (Bailey 1977), or when aluminium chloride was added to feed for steers at concentrations of 1200 mg Al/kg (Valdivia et al. 1978). Based on these results the

NRC (1980) set a maximum tolerable level of aluminium in the diet of cattle and sheep of 1000 mg/kg. Chicks and turkeys showed no effects when fed 486 mg Al/kg, but there is no information on the tolerance of pigs to aluminium (Cakir et al. 1978, cited by NRC 1980).

Derivation of trigger value

The ANZECC (1992) trigger value of 5 mg/L has been retained and is supported by calculation of a theoretical trigger value based on a toxicological approach using data from the literature and assumptions as detailed below.

For cattle:

$$\text{trigger value} = \frac{\text{NOEL x daily feed intake x proportion from water}}{\text{max daily water intake x safety factor}} = \frac{\text{1200mg/kg/day x 20kg x 0.2}}{\text{15 L/day x 10}} = 5.6\ \text{mg/L} \qquad (9.53)$$

where:

1200 mg/kg is the level in the diet for cattle fed over 84 days used as the no observed effect level (NOEL) (Valdivia et al. 1978);

20 kg/day is an estimate of the average food consumption of cattle at this weight assuming they consume about 2.5% their bodyweight in feed;

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

85 L/day is the peak consumption of water for cattle;

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

Based on the above approach, estimated trigger values for various types of livestock range from 3.6 to 5.6 mg Al/L (table 9.3.4), consistent with a trigger value of 5 mg/L for all livestock. The guideline is also consistent with present Canadian (CCREM 1987) and South African (DWAF 1996b) guidelines for aluminium in livestock drinking water of 5 mg/L, with both the Canadian and South African guidelines indicating that much higher levels of aluminium may be tolerated in many instances.

Table 9.3.4 Summary of calculations used to develop a trigger value for aluminium in drinking water for a range of livestock

Animal	Quantity of element[a] (mg/kg)	Daily feed intake (kg/day)	Peak water intake (L/day)	Safety factor[b]	Calculated value (mg/L)
Cattle	1200	20	85	10	5.6
Sheep	1215	2.4	11.5	10	5.1
Chickens[c]	486	0.15	0.4	10	3.6

[a] From summary of toxic responses of animals to levels of aluminium given in feed in NRC (1980).

[b] Safety factor for possible long-term effects and tissue accumulation.

[c] All poultry have a very similar body weight/water intake ratio, hence these values can be taken to represent all poultry.

9.3.5.2 Arsenic

> ***A concentration of total arsenic in drinking water for livestock exceeding 0.5 mg/L may be hazardous to stock health. If arsenic is not provided as a food additive and natural levels of arsenic in the diet are low, a level of 5 mg/L in drinking water may be tolerated.***

Source

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 mining or industrial activities (Fergusson 1990, Galvin 1996).

Arsenic is used in a number of industrial processes. It is no longer used as an insecticide in sheep dips but organic forms of arsenic are included in certain herbicide formulations (Hamilton & Haydon 1996). Organic arsenic compounds are sometimes used as feed additives to enhance growth in pigs and poultry (Gough et al. 1979).

Animal health

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 hazardous than the pentavalent form (arsenate). NRC (1980) suggested a maximum tolerable dietary level for livestock of 50 mg/kg in feed for inorganic forms and 100 mg/kg for organic forms of arsenic.

Acute effects such as diarrhoea, loss of coordination and anaemia are symptoms of arsenic intoxication. Non-ruminants (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).

Derivation of trigger value

The ANZECC (1992) guideline of 0.5 mg As/L has been retained in the absence of any new contradictory information and is consistent with the present Canadian guideline for arsenic in livestock drinking water (CCREM 1987). Recent South African guidelines suggest that arsenic concentrations less than 1.0 mg/L are unlikely to cause adverse effects on animal health, but long-term exposure to concentrations >1.5 mg As/L may be harmful to sensitive species such as pigs and poultry (DWAF 1996b).

9.3.5.3 Beryllium

> ***There are insufficient data to set trigger values for animal consumption of beryllium in livestock drinking water.***

Source

Beryllium may be present in water supplies through the weathering of rocks containing feldspars or it may be deposited from the atmosphere, predominantly as a result of burning fossil fuels. The concentration of beryllium in freshwaters is usually <1 µg/L (Galvin 1996).

Animal health

Beryllium is generally poorly absorbed from the gastrointestinal tract, and toxicity due to ingestion is low (WHO 1984). Mice and rats fed over their life-span with a concentration of 0.43 mg Be/L as beryllium sulfate showed no affect in growth and longevity, but some leukemias and tumours were observed (Schroeder & Mitchener 1975 a,b). In another study, rats fed with beryllium in the diet at levels of 5 mg/kg, 50 mg/kg and 500 mg/kg of feed, showed no evidence of carcinogenic response related to beryllium (WHO 1984).

In a review of the limited amount of toxicity data available for animals, IPCS (1990) indicated that ingestion of beryllium in the water supply for long periods of time caused no ill effects.

Derivation of trigger value

The data presently available are insufficient and inconclusive. Derivation of a trigger value should be deferred until more data become available.

9.3.5.4 Boron

> ***If the concentration of boron in water exceeds 5 mg/L, the total boron content of the livestock diet should be investigated. Higher concentrations in water may be tolerated for short periods of time.***

Source

Boron concentrations in unpolluted waters are generally <0.1 mg/L (Galvin 1996). Boron concentrations in groundwater may be higher, although 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 via the 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) suggested a maximum tolerable level of 150 mg B/kg (as borax) in the diet of cattle, and presumed that this value should be reasonable for other species of livestock.

Derivation of trigger value

The following calculations and assumptions, 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 to 11.3 mg B/L (table 9.3.5).

Table 9.3.5 Summary of calculations used to develop a guideline for boron in livestock drinking water

Animal	Body weight (kg)	Peak water intake (L/day)	Peak food intake (kg/day)	Calculated value (mg/L)
Cattle	150	85	20	7
Pigs	110	15	2.9	5.8
Sheep	100	11.5	2.4	6.2
Chickens[a]	2.8	0.4	0.15	11.3
Horses	600	70	20	8.6

a All poultry have a very similar body weight/water intake ratio; hence these values can be taken to represent all poultry

For cattle:

$$\text{trigger value} = \frac{\text{MTDL x daily feed intake x proportion from water}}{\text{max daily water intake}} = \frac{\text{150mg/kg/day x 20kg x 0.2}}{\text{85L/day}} = 7\ \text{mg/L} \qquad (9.54)$$

where:

MTDL is the suggested maximum total dietary level of 150 mg/kg B in the animal diet (NRC 1980);

20 kg/day is an estimate of the average food consumption of cattle at this weight assuming they consume about 2.5% their bodyweight 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.

Note that a safety factor for possible long-term effects was not included in the calculations because it is considered that there is little likelihood of there being long-term effects due to boron ingestion (NRC 1980).

A value of 5 mg/L has been proposed for livestock use in both Canada (CCREM 1987) and South Africa (DWAF 1996b) and although somewhat contrary to evidence in Green and Weeth (1977), the values calculated here tend to support this value. It is likely, however, that stock would tolerate much higher levels if the feed concentration of boron was low or for short periods of time (NRC 1980).

9.3.5.5 Cadmium

A concentration of total cadmium greater than 0.01 mg/L in drinking water for livestock may be hazardous to animal health.

Source

Cadmium concentrations in surface waters are usually extremely low (<0.001 mg/L). In unpolluted streams the cadmium occurs predominantly in association with suspended particulate matter, rather than in the dissolved state. Concentrations of cadmium in groundwaters may be slightly higher in some areas (Fergusson 1990). The solubility of cadmium in water increases with decreasing pH. Industrial waste waters, metallurgical industries and fertilisers which contain cadmium as an impurity can be sources of cadmium released into the environment. Corrosion of galvanised tanks and pipes and solders can contaminate water supplies with cadmium.

Animal health

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).

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) suggested a concentration of 0.5 mg/kg as the maximum tolerable dietary intake.

Anaemia, abortions, stillbirth and reduced growth were observed in animals given cadmium in doses of 1–160 mg/kg bodyweight (Powell et al. 1964, Miller et al. 1967, Doyle et al. 1974, Supplee 1961). Due to the accumulation of cadmium in the liver and kidneys of livestock, and the possible consumption of these organs by humans, toxic levels of cadmium can be passed directly to the consumer.

Derivation of trigger value

The ANZECC (1992) guideline for cadmium (based on Hart 1982) has been retained until more information becomes available from animal feeding trials. The guideline value of

0.01 mg/L is consistent with guidelines developed for cadmium in South Africa (DWAF 1996b); a value of 0.08 mg/L has been proposed in Canada (CCME 1996).

9.3.5.6 Chromium

> ***Levels of total chromium exceeding 1 mg/L in the drinking water of livestock may be hazardous to animal health.***

Source

Chromium occurs in the environment in two forms; as trivalent chromium, chromium (III), and hexavalent chromium, chromium (VI). Total chromium concentrations in natural unpolluted waters are generally very low (<0.025 mg/L, Galvin 1996). Chromium may enter water supplies through the waste discharge of a range of industrial processes in which it is used.

Animal health

Trivalent chromium is an essential element in the diet of mammals, being required for carbohydrate and lipid metabolism. Salts of chromium (III) are poorly absorbed by the gastrointestinal tract, whereas the absorption rate of chromium (VI) is much higher. Chromium (VI) is much more toxic to animals than chromium (III) (WHO 1984, NRC 1980, CCREM 1987).

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 at 25 mg/L (MacKenzie et al. 1958) in their drinking water.

Derivation of trigger value

The ANZECC (1992) guideline for chromium has been retained until more information becomes available from animal feeding trials. The trigger value of 1 mg/L is consistent with guidelines developed for chromium in Canada (CCREM 1987); while in South Africa a guideline value of 1 mg/L chromium (VI) has been proposed (DWAF 1996b).

9.3.5.7 Cobalt

> ***Levels of total cobalt in drinking water for livestock exceeding 1 mg/L may be hazardous to animal health, particularly if cobalt supplements are being used.***

Source

Cobalt normally occurs in natural waters at levels well below 0.01 mg/L and in most cases below 0.001 mg/L, but may be higher in some wastewaters (Galvin 1996, APHA, AWWA & WEF 1998).

Animal health

Cobalt is an essential element in the diet of animals, and is important in several enzyme systems, particularly as a component of vitamin B12. Generally cobalt has a low toxicity to animals and in ruminants, cobalt deficiency, in practice, is more likely to occur (NRC 1980).

Underwood (1977) reported reduced appetite and some weight loss when cobalt was administered daily at concentrations of 1.1 mg/kg bodyweight to the diet of calves. According to CCREM (1987), drinking water for calves would have to contain at least 10 mg/L cobalt before the symptoms observed by Underwood would be evident. Pigs, cattle and poultry may tolerate cobalt at concentrations of 10 mg/kg in their diet, which is about 100 times normal requirements (NRC 1980).

Derivation of trigger value

The ANZECC (1992) guideline for cobalt has been retained until more information becomes available from animal feeding trials. The guideline value of 1 mg/L is consistent with guidelines developed for cobalt in Canada (CCREM 1987) and South Africa (DWAF 1996b).

9.3.5.8 Copper

> ***Concentrations of total copper in drinking water for livestock exceeding 0.5 mg/L may be hazardous to the health of sheep. Adverse effects may be experienced in cattle at concentrations above 1 mg/L copper, and in pigs and poultry concentrations exceeding 5 mg/L. If animal diets are high in copper, the levels in drinking water should be revised downwards. Animal intake of sulfur and molybdenum should also be considered in conjunction with copper.***

Source

Copper is generally found in natural waters at concentrations much less than 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 waters of low pH.

Animal health

Copper is an essential element in the animal diet. Copper nutrition in animals is influenced by the dietary intake of molybdenum, iron and sulfur (see Section 9.3.5.14 for molybdenum). Copper deficiency can result in morbidity and, in some cases, death (NAS 1977b). Cattle given water with 2.5–5 mg Cu/L added were prevented from developing seasonal decline in plasma copper levels and showed no ill effects (Humphries et al. 1983). Copper nutrition in animals is influenced by the dietary intake of molybdenum, iron and sulfur (see Section 9.3.5.14 on molybdenum).

Excessive intake of copper can lead to copper toxicosis in livestock, which generally would be expected to relate to a high intake from feed rather than from water. 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 levels of copper. The tendency of copper to accumulate in the liver has potential implications for the health of consumers.

Toxic effects of copper depend largely on the type of livestock, but also on the form of copper. For example, copper chloride is two to four times more toxic to sheep than is copper sulfate (CCREM 1987). Sheep are particularly sensitive to copper. Demayo and Taylor (1981), who reviewed maximum levels of dietary copper intake by livestock, 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.

Derivation of trigger value

The ANZECC (1992) guideline for sheep has been retained at 0.5 mg Cu/L, which is consistent with present guidelines proposed for use in Canada (CCREM 1987) and South Africa (DWAF 1996b). Trigger values for pigs and poultry of 5 mg Cu/L, and for cattle 1 mg Cu/L, are consistent with current Canadian (CCREM 1987) and South African (DWAF 1996b) guidelines and take into account the relatively greater susceptibility of cattle to copper toxicity. In all cases the trigger values should be revised downwards if the total intake of copper by stock is high.

Further information is needed from animal feeding trials before more definitive guidelines for copper in livestock drinking water can be set.

9.3.5.9 Fluoride

> ***Fluoride concentrations greater than 2 mg/L in drinking water for livestock may be hazardous to animal health. If livestock feed contains fluoride, the trigger value should be reduced to 1.0 mg/L.***

Source

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

Animal health

Fluoride accumulates in bones rather than in soft tissue and excess uptake of fluoride can result in tooth damage to growing animals and bone lesions in older animals (Rose & Marier 1978, CPHA 1979). In Queensland, fluoride in drinking water for livestock at concentrations greater than 2 mg/L has been observed to affect the teeth of young animals (VIRASC 1980).

The diet may be another source of excessive ingestion of fluoride if the vegetation is contaminated by aerial deposition in industrial areas (NAS 1971), but no toxic effects were reported from dietary concentrations of 30–50 mg/kg for cattle, 70–100 mg/kg for sheep and pigs and 150–400 mg/kg for poultry. Van Hensburn and de Vos (1966) showed that levels of fluoride >5 mg/L in drinking water adversely affected breeding efficiency in cattle. Moreover, Hibbs and Thilsted (1983) reported erosion of teeth at concentrations of 3.3 mg/L. 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).

The risk of fluorosis in either sheep or cattle may be avoided if sufficient water of low fluoride concentration (e.g. surface water) is available and paddocks arranged so that young stock have access only to fluoride-free water for the first three years of life. Where only limited quantities of low-fluoride water are available, the damage from fluorosis will be minimal if young stock are exposed to fluoride-enriched water for no more than three months at a time and then kept for at least three months on low-fluoride water. Control measures are less important in good seasons when stock receive the bulk of their fluid requirements from pasture.

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, it is important that the young stock should be watered as near to the bore head as possible.

Derivation of trigger value

The ANZECC (1992) guideline for fluoride has been retained in the absence of any new contradictory information. The trigger value of 2 mg/L is consistent with guidelines developed for fluoride in Canada (CCREM 1987) and South Africa, although the South African guidelines suggest that adverse effects are unlikely to occur in ruminants at concentrations less than 4 mg F/L (DWAF 1996b).

9.3.5.10 Iron

> ***No guideline has been established for iron in drinking water for livestock as it poses a very low health risk to animals.***

Source

Iron occurs naturally in water through dissolution of iron-bearing rock and minerals. It is present in waters as soluble Fe^{2+} ions or in the much less soluble Fe^{3+} form. In aerated surface waters iron concentration is usually <1 mg/L. Groundwaters rich in dissolved carbon dioxide and poorly oxygenated have been reported to have a total iron content of up to 100 mg/L (Galvin 1996, NHMRC & ARMCANZ 1996).

Animal health

Iron is essential to animal life and has a low toxicity, being harmful to livestock only if ingested in large amounts. Coup and Campbell (1964) reported slight scouring and blackening of the faeces after administering a daily dose of 30 g iron as ferric hydroxide. At a dosage of 60 g/day, scouring and blackening were pronounced and associated with a decline in bodyweight, reduced milk and fat yield and a general worsening in the condition of the coat. No adverse effects were reported from a dosage of 15 g iron/day.

Iron-contaminated water does not contain enough iron to cause the abovementioned problems, but toxic effects have been reported when cows were grazed on pastures heavily irrigated with groundwater containing 17 mg Fe/L (Hart 1974).

Derivation of trigger value

No trigger value for iron is recommended since water sources generally do not usually contain enough iron to cause health problems in livestock. There is no guideline recommended for iron in livestock drinking water in Canada (CCREM 1987). A guideline value of 10 mg/L has been tentatively proposed in South Africa, although it was noted that adverse effects of excessive iron intake have not yet been well documented in that country and concentrations up to 50 mg Fe/L may be tolerated in many situations (DWAF 1996b).

9.3.5.11 Lead

> ***Concentrations of total lead in drinking water for livestock exceeding 0.1 mg/L may be hazardous to animal health.***

Source

Dissolved lead concentrations in unpolluted freshwaters are generally <0.01 mg/L (Fergusson 1990, Galvin 1996), and over 90% of lead transported by unpolluted streams is associated with suspended particulate matter (Salomons & Förstner 1984).

Animal health

The toxicity of lead depends on the type of animal (including its age), the form of lead and the rate of lead ingestion (Hart 1982). Lead is accumulated in the skeleton to a critical maximum level, after which circulating concentrations increase until poisoning occurs (Hatch 1977, Jaworski 1979). Chronic effects such as anorexia and respiratory distress are associated with low level poisoning. Severe poisoning causes acute effects such as frothing at the mouth, uncoordination and convulsions (DWAF 1996b).

Hammond and Aronson (1964) suggested that daily ingestion of 6–7 mg Pb/kg bodyweight is the minimum dose that causes poisoning to cattle. Calves were killed by accidental exposure to an estimated dose of 5–8 mg Pb/kg/d for 30 days (Osweiler & Ruhr 1978). Sheep deaths were reported following dietary exposure to 5.7 mg Pb/kg bodyweight/day (James et al. 1966). Horses have been reported to be both more sensitive to lead poisoning than cattle and sheep (CCREM 1987) and less sensitive (DWAF 1996b). 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). Reduced resistance to diseases has been reported following low-level intake of lead (Hemphill et al. 1971).

A maximum tolerable dietary level of lead for all animals of 30 mg/kg was suggested by NRC (1980) in a summary of available toxicological data. At high dosage rates lead can accumulate in soft tissues of animals to a degree which might exceed acceptable levels for human consumption if livestock are raised in areas contaminated with Pb (NRC 1980).

Derivation of trigger value

The ANZECC (1992) guideline for lead has been retained in the absence of any new contradictory information. The trigger value of 0.1 mg/L is consistent with guidelines developed for lead in Canada (CCREM 1987) and South Africa, although the latter guidelines suggest that for pigs, no adverse effects are likely to occur at concentrations up to 0.5 mg Pb/L (DWAF 1996b).

9.3.5.12 Manganese

No guideline has been established for manganese in drinking water for livestock.

Source

Manganese occurs in water in several ionic states; Mn^{2+}, Mn^{4+} and Mn^{7+}, of which the divalent compounds are soluble. Unpolluted surface waters usually have low concentrations of manganese (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. Similarly to iron, manganese can be found in dissolved and colloidal forms, as well as complexed with organic matter.

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 pH of the water is low (Galvin 1996, NHMRC & ARMCANZ 1996).

Animal health

Manganese is an essential element for animal nutrition, but only about 3% of ingested manganese is absorbed. Manganese has low toxicity unless ingested in large amounts (NRC 1980).

Derivation of trigger value

No trigger value for manganese is proposed as there is little information to indicate that manganese concentrations high enough to cause any adverse health effects are likely to be found in waters used for livestock drinking purposes. This is consistent with present Canadian guidelines (CCREM 1987). Recent South African guidelines (DWAF 1996b) recommend an upper limit of 10 mg Mn/L in livestock drinking water, and suggest the possibility of adverse chronic effects such as weight loss and anaemia at higher concentrations.

9.3.5.13 Mercury

> ***Levels of total mercury exceeding 0.002 mg/L in drinking water for livestock may accumulate in edible animal tissue to a level which may pose a human health risk.***

Source

The concentration of mercury found in unpolluted streams and groundwaters is generally well below 0.001 mg/L (Fergusson 1990, Galvin 1996). Contamination through industrial emissions and spills can elevate mercury levels. 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

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 the body of animals. Ingestion of feed is the predominant path of animal exposure to mercury. Symptoms of mercury poisoning in animals vary with the chemical form of mercury, amount ingested and route of intake (Hart 1982).

Signs of mercury poisoning were observed at 2 mg/kg in turkey, 8 mg/kg in cattle and 10 mg/kg in sheep (Palmer et al. 1973). Cattle receiving only 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).

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, convulsions) and is usually fatal.

Ingestion of inorganic mercury by animals results in the accumulation of mercury primarily in the kidney and liver, whereas methylmercury is more evenly distributed through all tissues (NRCC 1979).

Derivation of trigger value

In establishing guidelines for mercury in drinking water for livestock, consideration must be given to both 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 level of 0.5 mg/kg in edible animal tissue.

Using chicken as a model, Reeder et al. (1979) calculated the maximum allowable intake of mercury in drinking water for stock 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 for mercury of 0.002 mg/L has been retained in the absence of any new contradictory information. The guideline value developed for mercury in Canada is 0.003 mg/L (CCREM 1987) and in South Africa, 0.001 mg/L (DWAF 1996b).

9.3.5.14 Molybdenum

> ***Concentrations of molybdenum in livestock drinking water greater than 0.15 mg/L may cause health problems to stock, depending on total dietary intakes of molybdenum, copper, iron and sulfur. At molybdenum concentrations greater than 0.15 mg/L, the animal diet should be investigated to ensure that copper levels are sufficient to account for the total dietary intake of molybdenum.***

Source

Molybdenum is usually found at concentrations of 0.05 mg/L or less 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 (Cotton & Wilkinson 1972).

Health effects on stock are more likely to occur through the ingestion of forages which can accumulate and hence concentrate molybdenum, than through the intake of water. The level of molybdenum in plants reflects the level in 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 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 containing high molybdenum levels 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 seems to be of most importance during early foetal development. There is little information on molybdenum requirements of domestic animals but levels in the diet of <0.02 mg/kg for chicks and around 0.01 mg/kg for sheep have been suggested by Mills and Davis (1987) (cited by Jones et al. 1994).

Ruminants are most susceptible to elevated levels of molybdenum with cattle more sensitive than sheep (NRC 1980, Jones et al. 1994). Molybdenosis (‘teart’ disease or ‘peat scours’ in New Zealand) in cattle is characterised by severe scouring and loss of condition, and secondary copper deficiency. 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 copper and raises its tolerance level to copper. The condition can be treated by adding sufficient copper to the diet. Low dietary copper levels will result in a lesser amount of molybdenum being toxic (NRC 1980, 1988, 1996, Jones et al. 1994).

Other effects of excessive molybdenum intake in ruminants other than those attributed to copper deficiency have been suggested, such as infertility, increased age at puberty, testicular damage and disorders of phosphorus metabolism that produce skeletal abnormalities and cause lameness. Concentrations as low as 5 mg Mo/kg feed have been reported to cause infertility effects such as increased age at puberty and reduced conception rate (Phillipo et al. 1987, cited by Jones et al. 1994 and NRC 1996).

Levels of 5–6 mg Mo/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). The National Research Council (1980) has estimated a maximum tolerable level of 10 mg/kg in the diet of cattle and sheep for short-term intake. 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; and that copper from these pastures would rarely meet the requirements of cattle when there are levels of molybdenum >2 mg/kg.

In non-ruminant species the Mo-Cu antagonism only occurs with lower gut sulfide generation associated with high sulfur intake (as inorganic sulfur or in high protein feed). 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 1000 mg Mo/kg for three months have shown no ill effects. Poultry appear to be more sensitive to molybdenum and levels in the diet of 200 mg/kg have resulted in reduced growth (NRC 1980, 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. Ratios of copper:molybdenum in animal feeds of 2:1 and 4:1 have been reported to prevent copper deficiency (NRC 1988, 1996).

Derivation of trigger value

The following calculations and assumptions, based on the principles adopted by the World Health Organization (Albanus et al. 1989, cited by Hamilton & Haydon 1996) were used to derive a trigger value. Based on this approach, a trigger value of 0.15 mg/L was derived for molybdenum in drinking water for both cattle and sheep (table 9.3.6).

Table 9.3.6 Summary of calculations used to develop a trigger value for molybdenum in livestock drinking water

Animal	Quantity of element (mg/kg)	Daily feed intake (kg/day)	Peak water intake (L/day)	Safety factor[a]	Calculated value (mg/L)
Cattle	10	20	85	3	0.15
Sheep	10	2.4	11.5	3	0.15

[a] For possible long-term effects

For cattle:

$$\text{trigger value} = \frac{\text{MTDL x daily feed intake x proportion from water}}{\text{max daily water intake x safety factor}} = \frac{\text{10 mg/kg/day x 20 kg 0.2}}{\text{85 L/day x 3}} = 0.15\,\text{mg/L} \qquad (9.55)$$

where:

MTDL is the suggested short-term maximum total dietary level of molybdenum in feed of 10 mg/kg (NRC 1980);

20 kg/day is an estimate of the average food consumption by cattle at this weight assuming consumption of about 2.5% of bodyweight in feed;

0.2 is the proportion of molybdenum attributed to water intake;

85 L/day is the peak rate of water consumption by cattle; and

3 is the safety factor for possible long-term effects.

As cattle and sheep (ruminants) appear to be most sensitive to molybdenum this value can be used as a guide for other livestock. However, the levels of copper, iron and sulfur in the diet and the type of pasture may greatly influence animal tolerance of molybdenum. Animals may tolerate concentrations of molybdenum in water considerably higher than the guideline value provided dietary levels of copper are adequate to compensate for the high level of Mo.

The guideline recommended in South Africa for molybdenum in livestock drinking water is 0.01 mg/L, with concentrations <0.02 mg/L considered likely to be tolerated provided copper and sulfur intakes are adequate (DWAF 1996b). Canadian guidelines recommend an upper limit of 0.5 mg Mo/L in livestock drinking water (CCREM 1987).

9.3.5.15 Nickel

Concentrations of total nickel in livestock drinking water greater than 1 mg/L may have adverse effects on animal health.

Source

The concentration of nickel in natural waters is usually below 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).

Animal health

Nickel is an essential element in animal nutrition and is considered to have low toxicity (NRCC 1981). Nickel levels 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 (Nielsen & Ollerich 1974, Anke et al. 1974).

Growth reduction in calves was induced by adding nickel salts to the diet at concentrations of 250 mg Ni/kg (O’Dell et al. 1970). A concentration of 5 mg Ni/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 Ni/L in the drinking water of rats through three generations resulted in increased peri-natal mortality and an increased number of runts (Schroeder & Mitchener 1971).

Derivation of trigger value

The ANZECC (1992) guideline for nickel has been retained until more information becomes available. The trigger value of 1 mg/L is consistent with guidelines developed for nickel in Canada (CCREM 1987) and South Africa (DWAF 1996b).

9.3.5.16 Selenium

Concentrations of total selenium in drinking water for livestock exceeding 0.02 mg/L may be hazardous to stock health.

Source

Selenium occurs in the environment in association with metal sulfides and is derived from igneous rocks (Ehrlich 1990). In surface waters selenium is generally present at concentrations below 0.01 mg/L, although groundwaters have been reported to contain up to 1 mg Se/L, usually in association with areas of volcanic activity (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).

Animal health

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

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

In lactating animals, an additional problem is the transmission of selenium to the milk, forming selenomethionine proteins. Milk from cows in areas where selenium poisoning occurred was reported to have contained 0.3–1.2 mg Se/L; normal concentrations range from 0.003–0.007 mg/L (Underwood 1971).

Derivation of trigger value

In the absence of any new contradictory information the existing guideline (ANZECC 1992) has been is retained. Recent guidelines developed in Canada (CCREM 1987) and South Africa (DWAF 1996b) recommend an upper limit of 0.05 mg/L.

9.3.5.17 Uranium

> ***Concentrations of uranium less than 0.2 mg/L in livestock drinking water are unlikely to be harmful to animal health.***

Source

Uranium may be found in natural waters, particularly groundwaters and may be the result of natural processes or may arise from mineral processing.

Animal health

According to Garner (1963), the minimum concentration of uranium found to cause poisoning was 50 mg/d for sheep and 400 mg/d for cattle. Phosphorus supplements fed to dairy cattle may contribute 16 mg/d uranium, depending on the source of phosphorus (Reid et al. 1977).

Derivation of trigger value

CCREM (1987) developed a guideline value of 0.2 mg U/L in livestock drinking water by the inclusion of a safety factor, estimation of allowable intake of urganium through water and the volume of water animals drink based on the above level for cattle. A concentration of 0.2 mg U/L in stock drinking water is recommended as an interim trigger value until further information from animal feeding trials becomes available. For information on radiological quality concerning uranium (and other radionuclides) see Section 9.2.8.

9.3.5.18 Vanadium

> ***Insufficient information is available to set a trigger value for vanadium in livestock drinking water.***

Source

Vanadium salts are soluble in water and do not normally adsorb onto clay particles. Vanadium compounds are used as catalysts in many industrial processes. The concentration of vanadium in natural waters is usually less than 0.001 mg/L (DWAF 1996b).

Animal health

Some experiences with rats and chicks suggest that vanadium is required for lipid, tooth and bone metabolism (Hopkins & Mohr 1971). Concentrations of 2 mg V/L (as NH_4VO_3) in drinking water improved the development of growing chicks. According to Van Zinderen Bakker and Javorski (1980), reduced growth rate resulted when chickens and rats were given diets containing 13 mg V/kg and 25 mg V/kg respectively.

Derivation of trigger value

Present information is inconclusive regarding the effects of vanadium levels in drinking water on animal health. No guideline is recommended until further information from animal feeding trials becomes available.

The ANZECC (1992) guidelines gave an upper limit for vanadium for all forms of livestock of 0.1 mg/L but this seems contradictory to some of the evidence given above. Present Canadian Water Quality Guidelines (CCREM 1987) give the same guideline value for vanadium in livestock drinking water; while in South Africa, an upper limit of 1 mg V/L is proposed, with some adverse effects considered likely to occur at higher concentrations (DWAF 1996b).

9.3.5.19 Zinc

> ***Total zinc concentrations in livestock drinking water less than 20 mg/L are unlikely to pose a threat to animal health.***

Source

Concentrations of zinc rarely exceed 0.01 mg/L in natural waters (Galvin 1996). Higher concentrations in waters 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 (NHMRC & ARMCANZ 1996).

Animal health

Zinc is an essential element in the animal diet 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 (Farnsworth & Kline 1973). Requirements for zinc range from 50 mg/kg to 100 mg/kg in the diet (Underwood 1971). According to Neathery and Miller (1977), the estimated maximum safe levels of zinc, expressed as concentrations in the diet, are 500 mg/kg for calves, 600 mg/kg for sheep, 1000 mg/kg for chicks, pigs and mature cattle, and 2000 mg/kg for turkeys. NRC (1980) proposed maximum tolerable levels of zinc of 500 mg/kg for cattle, 300 mg/kg for sheep and 1000 mg/kg for pigs and poultry.

Derivation of trigger value

The ANZECC (1992) guideline for zinc (based on Hart 1982) has been retained until more information becomes available from animal feeding trials. The trigger value of 20 mg/L is consistent with guidelines developed for zinc in South Africa (DWAF 1996b); a value of 50 mg/L has been proposed in Canada (CCREM 1987).

9.3.6 Pesticides

> ***In the absence of adequate information derived specifically for livestock under Australian and New Zealand conditions, it is recommended that the guidelines set for raw water for drinking water supply be adopted.***

Source

The use of pesticides to control insects, pathogens and weeds is an integral part of the economic production of many agricultural commodities. Pesticides are also widely used for weed control along roads, waterways, etc and are sometimes applied in urban areas to control insects such as mosquitoes.

Pesticides are mainly organic compounds, or in some cases organo-metallic compounds, and are categorised according to their intended use: as insecticides (controlling insect pests), herbicides (controlling weeds), fungicides (control of fungal pests) and veterinary medicines (for animal health). Each category of pesticide is often grouped into classes of chemically similar compounds; for example, the organochlorine and organophosphate insecticides, and the phenoxy herbicides (Schofield & Simpson 1996). Pesticides encompass a broad range of natural and synthetic compounds of widely differing chemical composition. All are carefully screened for health and environmental effects prior to registration for use.

Pesticide residues can sometimes be found in surface waters, as a result of: direct application (e.g. for weed control); careless use or disposal of pesticides and their containers; aerial drift and wind erosion; and transport in runoff waters (Hunter 1992, CCREM 1987, Schofield & Simpson 1996). Movement of pesticide residues which bind strongly to soil particles and are relatively insoluble in water occurs mainly through soil erosion processes. Runoff waters may also contain other residues in dissolved form. Leaching of pesticide residues to groundwaters can occur and is dependent 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, such as DDT and dieldrin, can still be found in the environment although they were withdrawn from use or have had restricted use in Australian agriculture for decades (Schofield & Simpson 1996).

Animal health

The organophosphate and carbamate pesticides are relatively toxic to livestock causing symptoms such as diarrhoea, salivation, excessive urination and respiratory and muscle malfunction. These pesticides break down quite rapidly in the aquatic environment through microbial action (DWAF 1996b).

Most commonly used herbicides are considered not to be highly toxic to mammals (CCREM 1987). Of primary concern is that some pesticides or their metabolites may accumulate in animal tissues or products meant for human consumption at levels which may affect the saleability of these products (DWAF 1996b).

Derivation of guidelines

Information is not yet available on guidelines for pesticide residues in drinking water derived specifically for livestock under Australian and New Zealand conditions. Adoption of the Australian Drinking Water Guidelines (NHMRC & ARMCANZ 1996) 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 certain pesticides developed in Canada (CCREM 1987), mainly using data obtained from animal toxicological studies (summarised in table 9.3.7).

Table 9.3.7 Canadian water quality guidelines for pesticides in livestock drinking water[a]

Pesticide	Guideline value µg/L
Insecticides	
Aldicarb	11[b]
Carbofuran	45
Dimethoate	3[b]
Herbicides	
Bromoxynil	11[b]
Cyanazine	10[b]
Dicamba	122
Diclofop-methyl	9
Dinoseb	150
Glyphosate	280
Simazine	10[b]
Tebuthiuron	130[b]
Triallate	230
Trifluralin	45[b]
Fungicides	
Chlorothalonil	170[b]

[a] From CCREM (1987)

[b] Toxicological data available only sufficient to produce an interim guideline value

9.3.7 Radiological quality

Please refer to Section 9.2.8. The same trigger values and discussion apply to radiological quality for both irrigation and livestock drinking water uses.

9.3.8 Future information needs for livestock drinking water

In this review we have updated the information that was previously used in determining the guidelines for livestock drinking water (ANZECC 1992). With several notable exceptions, few examples of new studies were found, with most information coming from the 1960s and 1970s.

Two differing approaches have been used in developing guidelines in other countries. A toxicological approach as proposed by the Canadian Council of Ministries of the Environment (CCME 1993) is based on the following principles:

- the method of developing guideline values is transparent and consistent;
- selection criteria and appraisal protocols ensure only valid sound scientific data are used;
- data can be obtained through feeding trials with animals.

Some disadvantages of this approach include:

- the need to make many assumptions on, for example, the value of a ‘safety factor’ for inter- and intra-species differences, long-term effects, and the contribution of water consumption to total intake of a chemical;
- no account is taken for the risk of animals consuming the contaminants;
- differing climatic conditions, feed types, animal ages and condition are not usually addressed;
- interactions with other elements in the metabolism of animals are not considered;
- users of the guidelines have to interpret the suitability of the water in specific cases.

An alternative is a more ‘holistic’ approach, as taken by the Department of Water Affairs and Forestry (DWAF 1996b) in developing the South African guidelines. This approach includes the use of in situ observations and studies to identify the level of a constituent at which no adverse effect would be expected, taking into consideration the major synergistic and antagonistic factors affecting the onset of adverse effects. Guidelines are given in the context of a risk-based approach, with an indication given of contaminant levels that might be tolerated for short periods of exposure, or following adaptation to the water source. Where possible, differences among animal species and stages of life are considered.

9.3.8.1 Biological parameters

Detection of pathogens in water supplies is time consuming and expensive. Currently, it is common practice to monitor and control microbiological water quality on the basis of concentration of indicator organisms. The presence of indicator organisms does not always mean that pathogens are present and conversely a lack of these indicators does not mean the water is free of other pathogens. A single bacterial indicator may not be suited to all situations and a combination of organisms may be required to assess the levels of viruses and parasites. The lack of data available on pathogens in livestock water supplies, while making the development of accurate guideline values difficult, may in fact reflect the extent of the problem.

A study being set up in New Zealand by the Ministry for the Environment, Ministry of Agriculture and Ministry of Health has proposed a procedure for developing a risk model from information gained from a pathogen characterisation study at different sites around New Zealand and then refined with data from epidemiological studies on animal health. Although the use of indicator organisms may still be necessary, the risk model may allow for a ‘best’ choice of an indicator for different situations and sites. The outcome from this study will act as a model for developing guidelines for freshwater usage.

Work is currently being undertaken into developing guidelines for cyanobacteria and cyanobacterial toxins. A working group set up by ARMCANZ and the NHMRC as part of the National Algal Management Strategy is examining the issues for developing guidelines for, for example, drinking water, recreation, livestock and irrigation use.

9.3.8.2 Pesticides

Emerging issues for agriculture concerning pesticide residues in irrigation waters and drinking water for livestock are not adequately covered in the present guidelines. Accumulation of pesticide residues at detectable levels in plant and animal tissues has implications for animal and human health, as well as potentially serious consequences for Australian and New Zealand agriculture. There are implications for our domestic and export meat and grain trades, in particular. The present guidelines have not been scientifically derived from first principles. Livestock guidelines are based on those for human drinking water, which may well be inappropriate and/or unnecessarily restrictive of farmers' options in providing water for their stock.

Development of guidelines for livestock should be based on estimates of permissible intakes for each pesticide, which can be derived from animal metabolism and animal feeding studies. Each pesticide residue would need to be considered individually, since pesticides cover a very diverse group of compounds with widely differing properties. Each trigger value will need to be derived from an evaluation that takes into account the numerous factors affecting the nature of the residue and likely levels in animal tissues. A comprehensive search of the literature for basic data for deriving each guideline level would be required. Issues include pesticide chemistry, environmental fate of pesticides, daily water intake by animals, likely additional intake of pesticides in food, animal liveweight gains, pesticide metabolism and accumulation in animal tissues. Priority should be given to developing guidelines for residues of those pesticides commonly employed in Australian and New Zealand agriculture that are likely to be found in surface waters and groundwaters used for stock watering.

A risk-based approach is recommended, with the following principles applied in the development of guidelines:

- guidelines must be based on scientific data and information;
- derivation of the guidelines should be fully documented and transparent, with all sources, deductions, extrapolations and conclusions fully explained; and
- studies producing the primary data must be subject to critical review (validity of methods, conclusions, etc).