4 Primary industries

4.1 Introduction

Both the quality and the quantity of water resources are critical issues for agriculture and aquaculture in Australia and New Zealand. Water quality is also of major importance for the protection of human consumers of food products. Growth of these major primary industries, together with expanding urbanisation and other industrial development, has increased the demand for good quality water but at the same time exerted escalating pressures on the quality of the water resources that are available. Therefore, to assess water quality for primary industries, not only must productivity issues be considered but also the possible adverse effects of these enterprises on downstream water quality and activities.

In recent years it has been recognised that pollution-related issues should be addressed by approaching the conservation, management and use of water resources in a holistic manner, according to the principles of integrated catchment management. Key strategies for achieving ecologically sustainable development include the involvement of stakeholders in decision-making processes and the development and adoption by industry of best management practice guidelines.

This is the first occasion on which water quality guidelines have been provided for aquaculture industries in Australia and New Zealand. Most of the guidelines presented for aquaculture should be used with some caution because few are based on a critical assessment of a wide data set.[a] This chapter also discusses issues concerning water quality guidelines for the protection of human consumers of aquatic foods. Recreational and commercial fisheries are based on wild populations of fish, crustacea and shellfish species, which are supported by natural habitats and food webs. Accordingly, for the protection of wild animal stocks, the reader is referred to the water quality guidelines for the protection and maintenance of aquatic ecosystems (Chapter 3).

a See Sections 4.4 and 9.4.4

Irrigation and livestock watering are the major agricultural uses of water. Minor amounts are used for other production purposes, such as the mixing of pesticide, fertiliser and veterinary formulations, and livestock dietary supplements. In Australia particularly, both the irrigation and livestock industries rely heavily on the use of groundwater, as well as surface water resources. Groundwater is also an important source of stock water in parts of New Zealand. Thus the guidelines provided for these industries are applicable (where appropriate) to both surface and groundwater quality.

Guidelines for general on-farm water use are included with the irrigation guidelines and cover topics such as corrosion and fouling of pipes and fittings. Certain issues concerning water quality for use by agriculture are also discussed in other documents published in conjunction with the National Water Quality Management Strategy; for example, the *Guidelines for Sewerage Systems — Use of Reclaimed Water* (ARMCANZ, ANZECC & NHMRC 2000). Note, however, that occasional discrepancies may occur in the information provided by different NWQMS documents; for example, when revision of the documents is out of step. All the guideline documents are based on the best scientific information available at the time of publication.

For information on the quality of farmstead water supplies for domestic use in Australia, the reader is referred to Chapter 6 of these Guidelines and Section 7.7 of the *Australian Drinking Water Guidelines* (NHMRC & ARMCANZ 1996). Readers in New Zealand are referred to the *Drinking-water Standards for New Zealand* (New Zealand Ministry of Health 1995a) and the *Guidelines for Drinking-water Quality Management* (New Zealand Ministry of Health 1995b). Issues such as water quality for washing of farm produce or for dairy water supplies are outside the scope of the present guidelines and the reader is referred to local health and hygiene regulations and the proposed food safety standards of the Australian and New Zealand Food Authority.

An important first step in using these guidelines is to consider the management framework for their application. This includes defining the primary management aims, determining appropriate trigger values, defining water quality objectives, and establishing a monitoring and assessment program to address these objectives.[a]

a See Section 2.1

The type of monitoring and assessment program required will be specific to each situation, but there are several broad principles or procedures that are common to all programs. For details see Chapter 7, particularly noting figure 7.1 which gives a generic flow chart of the procedural framework for monitoring and assessment, and Section 7.4 which discusses specific issues for physical and chemical indicators.

4.2 Water quality for irrigation and general water use

Agricultural practice in Australia and New Zealand is often dependent on irrigation, because of climatic constraints on crop demand. In Australia particularly, agriculture is predominantly based in areas of limited rainfall, and there is heavy reliance on the use of surface and groundwaters for irrigation of crops and pastures. Approximately 70% (nearly 12 000 giga-litres) of Australia's developed water is used for irrigation, 21% for urban or industrial purposes and 9% for rural water supply (DEST State of the Environment Advisory Council 1996). Irrigated agriculture contributes very significantly to the Australian economy, with an annual production value of commodities such as cotton, rice, cereals, sugar, horticulture and irrigated fodder, of over $7 billion (Cape 1997).

In New Zealand irrigation is playing an increasingly important role in agricultural production. The area of irrigated land is doubling approximately every 10 years. Around 80% of allocated water in New Zealand is used for irrigation, with the remaining 20% for urban and industrial uses. Irrigated agriculture makes a significant contribution to the New Zealand economy, with irrigation being worth an extra $800 million 'at the farm gate' and possibly three times this in export earnings.

a See Section 4.2.1

An important goal of these Water Quality Guidelines is to maintain the productivity of irrigated agricultural land and associated water resources, in accordance with the principles of ecologically sustainable development and integrated catchment management.[a] This should be a key consideration in any irrigation strategy, alongside maximum yield and economic viability.

4.2.1 Philosophy

In developing the guidelines, emphasis has been placed on sustainability in agricultural practice (DEST State of the Environment Advisory Council 1996), which aims to ensure that:

- the supply of necessary inputs is sustainable;
- the quality of natural resources is not degraded;
- the environment is not irreversibly harmed;
- the welfare and options of future generations are not jeopardised by the production and consumption activities of the present generation; and
- yields and produce quality are maintained and improved.

In terms of water quality, the focus for sustainable farming systems is on adopting management practices that maintain productivity and minimise the off-farm movement or leaching of potential aquatic contaminants. Key issues include soil erosion, landscape salinity, fertiliser and pesticide management, livestock access to streams, and safe disposal of effluent from intensive animal industries (Hunter et al. 1996).

4.2.2 Scope

Soil, plant and water resource issues that have been taken into account in developing the water quality guidelines for irrigation use are summarised in table 4.2.1. Factors affecting irrigation water quality concern physical, chemical and biological characteristics that may affect the soil environment and crop growth.

Table 4.2.1 Key issues concerning irrigation water quality effects on soil, plants and water resources

	Key issues
Soil	Root zone salinity Soil structural stability Build-up of contaminants in soil Release of contaminants from soil to crops & pastures
Plants	Yield Salt tolerance Specific ion tolerance Foliar injury Uptake of toxicants in produce for human consumption Contamination by pathogens
Water resources	Deep drainage & leaching below root zone Movement of salts, nutrients & contaminants to groundwaters & surface waters
Important associated factors	Quantity and seasonality of rainfall Soil properties Crop and pasture species and management options Land type Groundwater depth and quality

Guidelines are also included for general on-farm water use dealing with the corrosion and fouling potential of waters. These characteristics are important for the maintenance of farm equipment (pumps, pipes, etc.). The guidelines may also be applied more widely where corrosion and fouling are of concern.

Specific irrigation water quality guidelines for intensive horticultural activities (e.g. hydroponics and glass-house growing) are not included in this document.

Guidelines for irrigation water quality are given here for biological parameters, salinity and sodicity, inorganic contaminants (i.e. specific ions, including heavy metals and nutrients), organic contaminants (i.e. pesticides) and radiological characteristics. The guidelines are trigger values below which there should be minimal risk of adverse effects. Further investigation is recommended if a trigger value is exceeded, to determine the level of risk.

A more detailed discussion of all water quality parameters included in the guidelines is given in Volume 3, Section 9.2.

4.2.3 Biological parameters

4.2.3.1 Algae

> ***No trigger value for algae in irrigation waters is recommended; however, excessive algal growth may indicate nutrient pollution of the water supply.***

Algae are commonly found in most water sources and do not generally cause problems in irrigation waters unless there is excessive growth due to factors such as suitable flow regime, temperature, abundant nutrients and adequate sunlight. The main problem associated with excessive algal growth in irrigation waters is the blockage of distribution and irrigation equipment. This can result in reduced or uneven flow throughout the irrigation system which may reduce crop yield and increase overall maintenance costs.

4.2.3.2 Cyanobacteria (blue-green algae)

No trigger values for cyanobacteria in irrigation waters are recommended at this time.

Cyanobacteria (blue-green algae) form part of the natural microbial population in most waterbodies. Under certain natural or human-induced circumstances, toxic blooms can occur and these may adversely affect the suitability of waters for irrigation, particularly because toxin residues can potentially accumulate on produce for human or animal consumption. If an algal bloom occurs, it is recommended that an alternative source of irrigation water be used, and that the water be tested for microbial composition and (if necessary) toxicity. There is presently insufficient information available for use in deriving trigger values for cyanobacteria in irrigation water.

4.2.3.3 Human and animal pathogens

Trigger values for thermotolerant coliforms in irrigation waters are provided in table 4.2.2.

Table 4.2.2 Trigger values for thermotolerant coliforms in irrigation waters used for food and non-food crops[a]

Intended use	Level of thermotolerant coliforms[b]
Raw human food crops in direct contact with irrigation water (e.g. via sprays, irrigation of salad vegetables)	<10 cfu[c] / 100 mL
Raw human food crops not in direct contact with irrigation water (edible product separated from contact with water, e.g. by peel, use of trickle irrigation); or crops sold to consumers cooked or processed	<1000 cfu / 100 mL
Pasture and fodder for dairy animals (without withholding period)	<100 cfu / 100 mL
Pasture and fodder for dairy animals (with withholding period of 5 days)	<1000 cfu / 100 mL
Pasture and fodder (for grazing animals except pigs and dairy animals, i.e. cattle, sheep and goats)	<1000 cfu / 100 mL
Silviculture, turf, cotton, etc. (restricted public access)	<10 000 cfu / 100 mL

a Adapted from ARMCANZ, ANZECC & NHMRC (1999)

b Median values (refer to text)

c cfu = colony forming units

It is generally not feasible nor warranted to test irrigation water for the presence of the wide range of water-borne microbial pathogens that may affect human and animal health. The guidelines recommended here are based on the practicable testing of irrigation waters for the presence of thermotolerant coliforms (also known as faecal coliforms), which gives an indication of faecal contamination and thus the possible presence of microbial pathogens (NHMRC & ARMCANZ 1996). However, the test does not specifically indicate whether pathogenic organisms are present.

It is recommended that a median value of thermotolerant coliforms be 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 value (ARMCANZ, ANZECC & NHMRC 2000).

a See also Section 9.2.2.3

For helminths, a trigger value of ≤1 helminth egg per litre is proposed for the protection of crop consumers in areas where helminth infections are known to be endemic. A lower value of 0.5 eggs per litre may be required to protect farm workers and their families in situations of direct exposure to the water (ARMCANZ, ANZECC & NHMRC 2000). Insufficient information is available for use in setting guidelines for protozoa and viruses in irrigation water.[a]

4.2.3.4 Plant pathogens

> ***No trigger values for plant pathogens in irrigation waters are recommended at this time. As a general precaution, disinfestation treatment is advisable for water that contains plant pathogens and is to be used for irrigating potentially susceptible plants.***

Agricultural crops and pastures can be affected by various plant pathogens transmitted through a number of different pathways including irrigation water, although it is believed that the risk from pathogens in irrigation water is low under most circumstances. However, plant pathogens in irrigation water used for intensive agricultural and horticultural industries (particularly where wastewaters are reused) can potentially lead to crop damage and economic loss.

A great deal of work needs to be done before guidelines can be developed, particularly regarding the efficacy of water-borne plant pathogens on a wide range of crops.

4.2.4 Irrigation salinity and sodicity

4.2.4.1 Salinity and sodicity

> ***To assess the salinity and sodicity of water for irrigation use, a number of interactive factors must be considered. As outlined in this section, these include irrigation water quality, soil properties, plant salt tolerance, climate, landscape (including geological and hydrological features), and water and soil management.***

Salinity is the presence of soluble salts in or on soils, or in waters. High salinity levels in soils may result in reduced plant productivity or, in extreme cases, the elimination of crops and native vegetation. Salinity related issues are of concern in many parts of Australia but salinisation is currently considered to be only of minor importance in New Zealand.

Sodicity is the presence of a high proportion of sodium (Na^+) ions relative to calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions in soil or water. Sodicity degrades soil structure by breaking down clay aggregates, which makes the soil more erodible and less permeable to water, and reduces plant growth.

The effects of salinity and sodicity in irrigation waters are very situation-specific, making it inappropriate to set water quality trigger values for general application. Factors which need to be considered include: the type of crop being cultivated and its salt tolerance, the characteristics of the soil under irrigation, soil management and water management practices, climate and rainfall (figure 4.2.1).

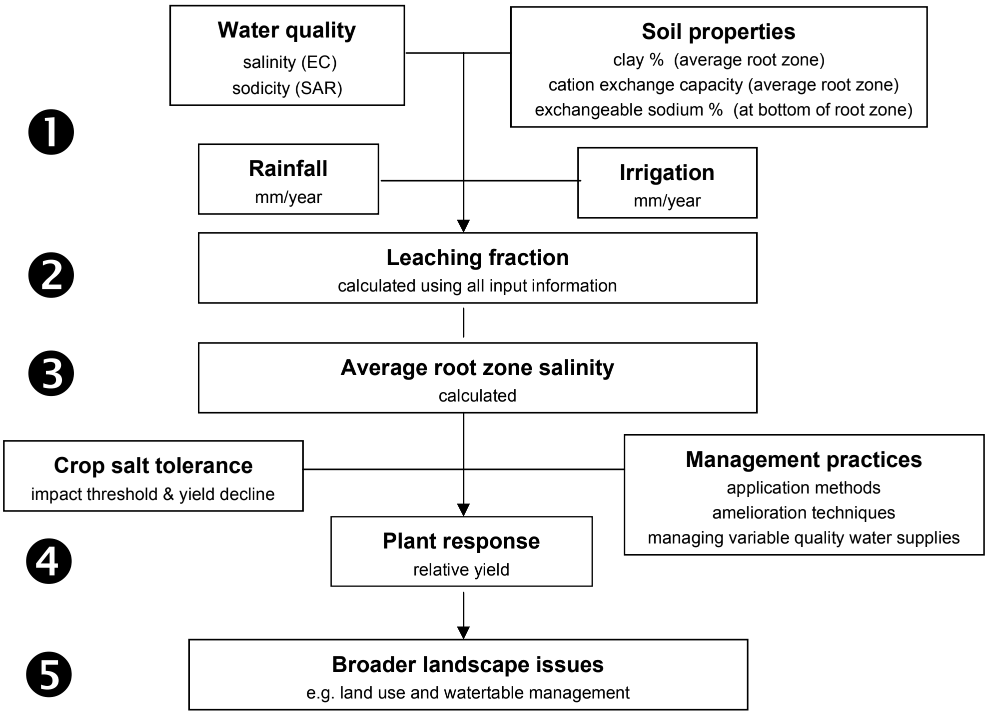

Figure 4.2.1 Flow diagram for evaluating salinity and sodicity impacts of irrigation water

a See details in Section 9.2.3

There are five key steps to determining the suitability of irrigation water with respect to salinity and sodicity (figure 4.2.1).[a]

Step 1. Identify the soil properties, water quality, climate (rainfall) and management (irrigation application rates) practices for the site in question.

Step 2. Estimate the leaching fraction under the proposed irrigation regime using approaches outlined in this section.

Step 3. Estimate the new average root zone salinity as outlined in this section. Average root zone salinity is considered the key limitation to plant growth in response to salinity and sodicity levels in irrigation water. However, poor soil structure can also reduce plant yields by limiting aeration, water infiltration and root growth. The likelihood of soil structural problems induced by irrigation can be predicted from trigger values derived in this section.

Step 4. Estimate relative plant yield (although note that the impact of salinity and sodicity can be modified by management practices as discussed later in this section).

Step 5. Consider salinity and sodicity problems within the framework of broader catchment issues such as regional watertables, groundwater pollution and surface water quality. Watertable salinity develops in response to excess water and salts accumulating in sensitive parts of the landscape. Excess water can percolate to groundwaters as a result of changing climatic patterns (e.g. frequency and duration of rainfall events), land use or land management (including irrigation). Before an irrigation scheme is developed, the planning process should include investigation of the regional hydrogeology to avoid development of watertable salinity. The guidelines given here concentrate on localised effects of irrigation, but broader salinity issues should not be ignored.

Software *SALF PREDICT* is now available. It estimates the parameters necessary for a detailed assessment of irrigation water quality in relation to soil properties, rainfall, water quality and plant salt tolerance. The software is based on summer rainfall areas and should be used with some caution in winter rainfall areas. It incorporates many of the detailed algorithms presented in Volume 3, Section 9.2.3. The software is provided on the CD ROM provided with these Guidelines and is also available from the Queensland Department of Natural Resources.

A simple initial assessment can be made by measuring the electrical conductivity (EC_i) and concentrations of sodium (Na^+), calcium (Ca^{2+}) and magnesium (Mg^{2+}) in irrigation water. Note that EC is expressed in units of dS/m throughout Section 4.2.4 (1 dS/m = 1000 µS/cm).

Determining the suitability of irrigation water salinity for a crop

Calculate the average root zone salinity (EC_{se}) from EC_i and the average root zone leaching fraction (LF), to see if a crop is likely to be affected by the irrigation water salinity. First, estimate the LF of the soil being irrigated (i.e. the proportion of applied water that leaches below the root zone). Approximate average LF values for four broad soil types are listed in table 4.2.3. Then calculate EC_{se} using the following equation:

$$EC_{se} = \frac{EC_i}{2.2 \mathrm{x} LF} \tag{4.1}$$

where:
EC_{se} = average root zone salinity in dS/m
EC_i = electrical conductivity of irrigation water in dS/m
LF = average leaching fraction.

Table 4.2.3 Soil type and average root zone leaching fraction[a]

Soil type	Average root zone LF
Sand	0.6
Loam	0.33
Light clay	0.33
Heavy clay	0.2

a From DNR (1997a), adapted from DNR (1997b)

Then use the EC_{se} value to assess the general level of crop tolerance to the irrigation water salinity by comparing it with the values in table 4.2.4. Alternatively, compare the EC_{se} with the relative salt tolerances of specific crop and pasture species provided here in table 4.2.5 and in Volume 3, Section 9.2.3, table 9.2.10.

Table 4.2.4 Soil and water salinity criteria based on plant salt tolerance groupings[a]

Plant salt tolerance groupings	Water or soil salinity rating	Average root zone salinity, EC_{se} (dS/m)[b]
Sensitive crops	Very low	<0.95
Moderately sensitive crops	Low	0.95–1.9
Moderately tolerant crops	Medium	1.9–4.5
Tolerant crops	High	4.5–7.7
Very tolerant crops	Very high	7.7–12.2
Generally too saline	Extreme	>12.2

a Adapted from DNR (1997b)

b 1 dS/m = 1000 µS/cm

a See also Section 9.2.3

A list of the relative salt tolerances of a limited selection of common field crop, pasture and horticulture species is provided in table 4.2.5. Information in this table is derived from data currently available in the literature, but preference should be given to locally derived data where available. This gives approximate values of average root zone salinities at the threshold level (the level causing yield reduction). It also shows electrical conductivity of irrigation water at the threshold level for a range of soil types, but it is meant as a general guide only.[a]

If at all uncertain about salt tolerance or the effect of irrigation water quality on soil structure, submit a soil sample for analysis and seek expert advice.

Determining the risk of soil structure degradation caused by irrigation water quality

Calculate the sodium adsorption ratio (SAR) and use it (with EC_i) to predict soil structure stability in relation to irrigation water. The SAR value measures the relative concentration of sodium (Na^+) to calcium (Ca^{2+}) and magnesium (Mg^{2+}) and can be calculated from the following equation:

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} \tag{4.2}$$

Where Na^+, Ca^{2+} and Mg^{2+} are expressed in $mmole_c/L$ (where subscript c indicates change).

Evaluate the quality of the irrigation water by superimposing its EC_i and SAR values on figure 4.2.2, to see if it will affect soil structure (through clay aggregate breakdown). Water quality that falls to the right of the dashed line is unlikely to cause soil structural problems. Water quality that falls to the left of the solid line is likely to induce degradation of soil structure; corrective management will be required (e.g. application of lime or gypsum). Water that falls between the lines is of marginal quality and should be treated with caution.

Table 4.2.5 Tolerance of plants to salinity in irrigation water[a]

Common name	Scientific name	Average root zone salinity threshold (EC_{se}) (dS/m)[b]	EC_i threshold for crops growing in		
			sand	loam	clay
Field Crops					
Barley, grain	*Hordeum vulgare*	8	12.6	7.2	4.2
Cotton	*Gossypium hirsutum*	7.7	12.1	6.9	4.0
Beet, sugar	*Beta vulgaris*	7	11.0	6.3	3.7
Sorghum	*Sorghum bicolor*	6.8	9.4	5.3	3.1
Wheat	*Triticum aestivum*	6	9.4	5.3	3.1
Sunflower	*Helianthus annuus*	5.5	7.5	4.3	2.5
Oats	*Avena sativa*	5	7.0	4.0	2.3
Soybean	*Glycine max*	5	7.0	4.0	2.3
Peanut	*Arachis hypogala*	3.2	4.4	2.5	1.5
Rice, paddy	*Oryza sativa*	3	4.8	2.7	1.6
Corn, grain, sweet	*Zea mays*	1.7	3.2	1.8	1.1
Sugarcane	*Saccharum officinarum*	1.7	4.3	2.5	1.4
Fruits					
Olive	*Olea europaea*	4	5.1	2.9	1.7
Macadamia seedling		3.6	4.6	2.6	1.5
Peach	*Prunus persica*	3.2	4.7	2.7	1.6
Rockmelon	*Cucumis melo*	2.2	4.6	2.6	1.5
Grapefruit	*Citrus paradisi*	1.8	3.0	1.7	1.0
Orange	*Citrus sinensis*	1.7	2.9	1.7	1.0
Grape	*Vitis* spp.	1.5	3.3	1.9	1.1
Avocado	*Persea americana*	1.3	2.3	1.3	0.8
Apple	*Malus sylvestris*	1	2.0	1.2	0.7
Pastures					
Wheatgrass, tall	*Agropyron elongatum*	7.5	12.5	7.2	4.2
Rhodes grass, Pioneer	*Chloris gayana*	7	12.8	7.3	4.2
Couch grass	*Cynodon dactylon*	6.9	10.8	6.1	3.6
Buffel grass, Gayndah	*Cenchrus ciliaris var Gayndah*	5.5	8.2	4.7	2.7
Phalaris	*Phalaris tuberosa (aquatica)*	4.2	5.3	3.0	1.8
Fescue	*Festuca clatior*	3.9	7.3	4.2	2.4
Green panic, Petri	*Panicum maximum*	3	5.6	3.2	1.8
Townsville stylo	*Stylosanthes humilis*	2.4	3.7	2.1	1.2
Clover, Berseem Clover	*Trifolium alexandrinum*	2	3.8	2.2	1.3
Lucerne, Hunter River	*Medicago sativa*	2	4.7	2.7	1.6
Clover, strawberry (Palestine)	*Trifolium fragiferum*	1.6	3.3	1.9	1.1
Snail medic	*Medicago scutellata*	1.5	2.9	1.7	1.0
Clover, white (New Zealand)	*Trifolium repens*	1	2.5	1.4	0.8
Vegetables					
Zucchini	*Cucurbita pepo melopepo*	4.7	7.3	4.2	2.4
Beet, garden	*Beta vulgaris*	4	6.5	3.7	2.1
Broccoli	*Brassica oleracea*	2.8	4.9	2.8	1.6
Cucumber	*Cucumis sativus*	2.5	4.2	2.4	1.4
Pea	*Pisum sativum* L.	2.5	3.2	1.8	1.1
Tomato	*Lycopersicon esculentum*	2.3	3.5	2.0	1.2
Potato	*Solanum tuberosum*	1.7	3.2	1.8	1.1
Pepper	*Capsicum annum*	1.5	2.8	1.6	0.9
Lettuce	*Lactuca sativa*	1.3	2.7	1.5	0.9
Onion	*Allium cepa*	1.2	2.3	1.3	0.8
Eggplant	*Solanum melongena*	1.1	3.2	1.8	1.1
Bean	*Phaseolus vulgaris*	1	1.9	1.1	0.6
Carrot	*Daucus carota*	1	2.2	1.2	0.7

a From DNR (1997a), adapted from DNR (1997b); b 1 dS/m = 1000 µS/cm

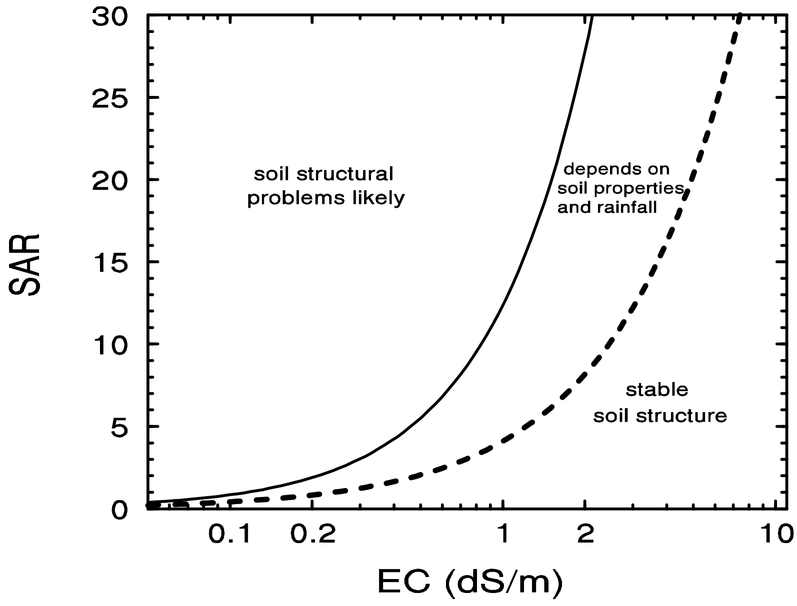

Figure 4.2.2 Relationship between SAR and EC of irrigation water for prediction of soil structural stability (from DNR 1997a, adapted from DNR 1997b; note that 1 dS/m = 1000 µS/cm)

4.2.5 Major ions of concern for irrigation water quality

4.2.5.1 Bicarbonate

No trigger value is recommended for bicarbonate in irrigation waters.

Elevated levels of bicarbonate in irrigation waters can adversely affect irrigation equipment, soil structure and crop foliage. These problems occur when the bicarbonate (or carbonate) in solution with calcium is sufficient to exceed the solubility of calcium carbonate. The precipitation of calcium carbonate can lead to white scale formation on leaves and fruit and may clog irrigation equipment.

The same process can give rise to precipitates of calcium carbonate in soil. This will effectively increase the sodium adsorption ratio (SAR) or exchangeable sodium percentage (ESP) and may lead to soil structural problems. An overview of the effect of irrigation with waters of high SAR is given in Volume 3, Section 9.2.3.

4.2.5.2 Chloride

Issues concerning chloride in irrigation waters relate to the risk of: (1) foliar injury to crops; and (2) increased uptake by plants of cadmium from soil. These are discussed more fully in Volume 3, Section 9.2.4.2.

1 Foliar injury

Trigger values for prevention of foliar injury due to chloride in irrigation water from sprinkler application are provided in table 4.2.6.

Chloride in irrigation water can also reduce the quality of tobacco leaf. Chloride concentrations >40 mg/L are considered unsuitable for irrigation of tobacco and some reduction in quality may occur with concentrations in the range 25–40 mg/L (Gill 1986).

Table 4.2.6 Chloride concentrations (mg/L) causing foliar injury in crops of varying sensitivity[a]

Sensitive <175	Moderately sensitive 175–350	Moderately tolerant 350–700	Tolerant >700
Almond	Pepper	Barley	Cauliflower
Apricot	Potato	Maize	Cotton
Citrus	Tomato	Cucumber	Sugar beet
Plum		Lucerne	Sunflower
Grape		Safflower	
		Sorghum	

[a] After Maas (1990)

2 Interaction between chloride in irrigation water and cadmium in soil

Trigger values for assessing chloride levels in irrigation water with respect to increased cadmium uptake by crops are provided in table 4.2.7.

Table 4.2.7 Risks of increasing cadmium concentrations in crops due to chloride in irrigation waters[a]

Irrigation water chloride concentration (mg/L)	Risk of increasing crop cadmium concentrations
0–350	Low
350–750	Medium
>750	High

[a] McLaughlin et al. (1999)

If high chloride concentrations are present in irrigation water, it is recommended that produce is tested for cadmium concentration in the edible portions (e.g. tubers for potatoes, leaves for leafy vegetables, grain for cereals, etc.).

4.2.5.3 Sodium

Trigger values for prevention of foliar injury due to sodium in irrigation water from sprinkler application are provided in table 4.2.8. Trigger values for specific toxicity effects are provided in table 4.2.9.

Table 4.2.8 Sodium concentration (mg/L) causing foliar injury in crops of varying sensitivity[a]

Sensitive <115	**Moderately sensitive 115–230**	**Moderately tolerant 230–460**	**Tolerant >460**
Almond	Pepper	Barley	Cauliflower
Apricot	Potato	Maize	Cotton
Citrus	Tomato	Cucumber	Sugar beet
Plum		Lucerne	Sunflower
Grape		Safflower	
		Sesame	
		Sorghum	

[a] After Maas (1990)

Table 4.2.9 Effect of sodium expressed as sodium adsorption ratio (SAR) on crop yield and quality under non-saline conditions[a]

Tolerance to SAR and range at which affected	Crop	Growth response under field conditions
Extremely sensitive SAR = 2–8	Avocado Deciduous fruits Nuts Citrus	Leaf tip burn, leaf scorch
Sensitive SAR = 8–18	Beans	Stunted growth
Medium SAR = 18–46	Clover Oats Tall fescue Rice Dallis grass	Stunted growth, possible sodium toxicity, possible calcium or magnesium deficiency
High SAR = 46–102	Wheat Cotton Lucerne Barley Beets Rhodes grass	Stunted growth

a After Pearson (1960); SAR = Sodium Adsorption Ratio (see Section 4.2.4.1)

4.2.6 Heavy metals and metalloids

Long-term trigger values (LTV) and short-term trigger values (STV) for heavy metals and metalloids in irrigation water are presented in table 4.2.10. Concentrations in irrigation water should be less than the recommended trigger values.

Table 4.2.10 Agricultural irrigation water long-term trigger value (LTV), short-term trigger value (STV) and soil cumulative contaminant loading limit (CCL) triggers for heavy metals and metalloids[a]

Element	Suggested soil CCL[b] (kg/ha)	LTV in irrigation water (long-term use — up to 100 yrs) (mg/L)	STV in irrigation water (short-term use — up to 20 yrs) (mg/L)
Aluminium	ND	5	20
Arsenic	20	0.1	2.0
Beryllium	ND	0.1	0.5
Boron	ND	0.5	Refer to table 9.2.18 (Volume 3)
Cadmium	2	0.01	0.05
Chromium	ND	0.1	1
Cobalt	ND	0.05	0.1
Copper	140	0.2	5
Fluoride	ND	1	2
Iron	ND	0.2	10
Lead	260	2	5
Lithium	ND	2.5 (0.075 Citrus crops)	2.5 (0.075 Citrus crops)
Manganese	ND	0.2	10
Mercury	2	0.002	0.002
Molybdenum	ND	0.01	0.05
Nickel	85	0.2	2
Selenium	10	0.02	0.05
Uranium	ND	0.01	0.1
Vanadium	ND	0.1	0.5
Zinc	300	2	5

a Trigger values should only be used in conjunction with information on each individual element and the potential for off-site transport of contaminants (Volume 3, Section 9.2.5)

b ND = Not determined; insufficient background data to calculate CCL

The *long-term trigger value* (LTV) is the maximum concentration (mg/L) of contaminant in the irrigation water which can be tolerated assuming 100 years of irrigation, based on the irrigation loading assumptions described in Volume 3, Section 9.2.5.

The *short-term trigger value* (STV) is the maximum concentration (mg/L) of contaminant in the irrigation water which can be tolerated for a shorter period of time (20 years) assuming the same maximum annual irrigation loading to soil as for LTV.

The LTV and STV values have been developed: (1) to minimise the build-up of contaminants in surface soils during the period of irrigation; and (2) to prevent the direct toxicity of contaminants in irrigation waters to standing crops. Where LTV and STV have been set at the same value, the primary concern is the direct toxicity of irrigation water to the standing crop (e.g. for lithium and citrus crops), rather than a risk of contaminant accumulation in soils and plant uptake.

The trigger value for contaminant concentration in soil is defined as the *cumulative contaminant loading limit* (CCL). The CCL is the maximum contaminant loading in soil defined in gravimetric units (kg/ha) and indicates the cumulative amount of contaminant added, above which site-specific risk assessment is recommended if irrigation and contaminant addition is continued.

Once the CCL has been reached, it is recommended that a soil sampling and analysis program be initiated on the irrigated area, and an environmental impact assessment of continued contaminant addition be prepared. As background concentrations of contaminants in soil may vary with soil type, and contaminant behaviour is dependent on soil texture, pH, salinity, etc., it should be noted that CCLs may be overly protective in some situations and less protective in others. The CCL is designed for use in soils with no known history of contamination from other sources. When it is suspected that the soil is contaminated before commencement of irrigation, background levels of contaminants in the soil should be determined and the CCL adjusted accordingly.

The trigger values assume that irrigation water is applied to soils and that soils may reduce contaminant bioavailability by binding contaminants and reducing concentrations in solution. They may not be suitable for plants grown in soil-less media (hydroponics or similar methods). The trigger values should only be used in conjunction with the discussion in Volume 3 on each individual element and the potential for off-site transport of contaminants.[a] The assumptions underlying these trigger values are recognised internationally as a basis for developing irrigation water quality guidelines.

[a] See Section 9.2.5 for full details of methods used

4.2.7 Nitrogen and phosphorus

Long-term trigger values (LTV) and short-term trigger values (STV) for nitrogen and phosphorus in irrigation water are presented in table 4.2.11. They are based on maintaining crop yield, preventing bioclogging of irrigation equipment and minimising off-site impacts. Concentrations in irrigation water should be less than the recommended trigger values.

Table 4.2.11 Agricultural irrigation water long-term trigger value (LTV) and short-term trigger value (STV) guidelines for nitrogen and phosphorus

Element	LTV in irrigation water (long-term — up to 100 yrs) (mg/L)	STV in irrigation water (short-term — up to 20 yrs) (mg/L)
Nitrogen	5	25–125 [a]
Phosphorus	0.05 (To minimise bioclogging of irrigation equipment only)	0.8–12 [a]

a Requires site-specific assessment (see Section 9.2.6)

The concepts of long-term trigger value (LTV) and short-term trigger value (STV) developed for metals and metalloids have also been used to develop guidelines for phosphorus (P) and nitrogen (N).

Excess quantities of N can lead to leaching of N into groundwater and surface water, over-stimulation of plant growth (decreasing yields) and stimulation of algal growth in surface water. The LTV for nitrogen has been set at a concentration low enough to ensure no decreases in crop yields or quality occur. The STV range for nitrogen has been set to minimise the risk of contaminating groundwater and surface water and requires site-specific information[a] which considers the crop that is being grown, environmentally significant concentrations, and gaseous losses.

a See Section 9.2.6

Phosphorus is often the nutrient that stimulates rapid growth of many microorganisms (i.e. algal blooms). The LTV for P has been set to prevent algal growth in irrigation water. The STV range for P has been set as an interim range due to the limited data currently available. Calculation of the interim range considers the fertiliser value of phosphorus in water, the phosphorus removed from irrigation sites through harvest, fertiliser inputs, and phosphorus sorption/retention capacities of soils.[b]

b An interim method of calculating a site-specific STV is outlined in Section 9.2.6

The trigger values provided in table 4.2.11 should only be used in conjunction with the discussion contained in Volume 3, Section 9.2.6.

4.2.8 Pesticides

> ***Trigger values for pesticides in irrigation water are listed in table 4.2.12. They consider likely adverse effects of herbicides on crop growth but do not consider potential impacts on aquatic ecosystems. They are based on relatively limited information and include only a subset of herbicides (and no other pesticides) that might be found in irrigation waters.***

4.2.9 Radiological quality of irrigation water

> ***Trigger values for the radiological quality of agricultural waters are given in table 4.2.13.***

Radioactive contaminants can originate from both natural and artificial sources and can potentially be found in surface waters and groundwaters. The main risks to human health due to radioactivity in irrigation water arise from the transfer of radionuclides to crop and animal products for human consumption. Cancer is a potential health hazard for humans associated with exposure to radionuclides in irrigation water.

Table 4.2.12 Interim trigger value concentrations for a range of herbicides registered in Australia for use in or near waters[a]

Herbicide	Residue limits in irrigation water (mg/L)[b]	Hazard to crops from residue in water[c]	Crop injury threshold in irrigation water (mg/L)
Acrolein	0.1	+	Flood or furrow: beans 60, corn 60, cotton 80, soybeans 20, sugar-beets 60. Sprinkler: corn 60, soybeans 15, sugar-beets 15
AF 100		+	Beets (rutabaga) 3.5, corn 3.5
Amitrol	0.002	++	Lucerne 1600, beans 1200, carrots 1600, corn 3000, cotton 1600, grains sorghum 800
Aromatic solvents (Xylene)		+	Oats 2400, potatoes 1300, wheat 1200
Asulam		++	
Atrazine		++	
Bromazil		+++	
Chlorthiamid		++	
Copper sulfate		+	Apparently above concentrations used for weed control
2,4-D		++	Field beans 3.5–10, grapes 0.7–1.5, sugar-beets 1.0–10
Dicamba		++	Cotton 0.18
Dichlobenil		++	Lucerne 10, corn 10, soybeans 1.0, sugar-beets 1.0–10, corn 125, beans 5
Diquat		+	
Diuron	0.002	+++	
2,2-DPA (Dalapon)	0.004	++	Beets 7.0, corn 0.35
Fosamine		+++	
Fluometuron		++	Sugar-beets, alfalfa, tomatoes, squash 2.2
Glyphosate		+	
Hexazinone		+++	
Karbutilate		+++	
Molinate		++	
Paraquat		+	Corn 10, field beans 0.1, sugar-beets 1.0
Picloram		+++	
Propanil		++	Alfalfa 0.15, brome grass (eradicated) 0.15
Simazine		++	
2,4,5-T		++	Potatoes, alfalfa, garden peas, corn, sugar-beets, wheat, peaches, grapes, apples, tomatoes 0.5
TCA (Trichloroacetic acid)		+++	
Terbutryne		++	
Triclopyr		++	

[a] From ANZECC (1992). These should be regarded as interim trigger values only.

[b] Guidelines have not been set for herbicides where specific residue limits are not provided, except for a general limit of 0.01 mg/L for all herbicides in NSW.

[c] Hazard from residue at maximum concentration likely to be found in irrigation water: + = low, ++ = moderate, +++ = high

Table 4.2.13 Trigger values for radioactive contaminants for irrigation water

Radionuclide	Trigger concentration
Radium 226	5 Bq/L
Radium 228	2 Bq/L
Uranium 238	0.2 Bq/L
Gross alpha	0.5 Bq/L
Gross beta (excluding K-40)	0.5 Bq/L

4.2.10 General water uses

4.2.10.1 pH

To limit corrosion and fouling of pumping, irrigation and stock watering systems, pH should be maintained between 6 and 8.5 for groundwater systems and between 6 and 9 for surface water systems.

The pH of water is a measure of its acidity or alkalinity. Generally, pH itself is not a water quality issue of concern, but it can indicate the presence of a number of related problems. The greatest hazard with high or low pH is the potential for deterioration as a result of corrosion or fouling. Values between 4 and 6 should be regarded with caution and a pH >6 should be maintained to reduce the potential for corrosion. The upper pH limit for groundwaters should be slightly lower than for surface waters because of the increased potential for encrustation and fouling. Soil and animal health will not generally be affected by water with pH in the range of 4–9.

4.2.10.2 Corrosion

Trigger values for assessing the corrosiveness of water are given in table 4.2.14.

Table 4.2.14 Corrosion potential of waters on metal surfaces as indicated by pH, hardness, Langelier index, Ryznar index and the log of chloride:carbonate ratio

Parameter[a]	Value	Comments
pH	<5 5 to 6 >6	High corrosion potential Likelihood of corrosion Limited corrosion potential
Hardness	<60 mg/L CaCO3	Increased corrosion potential
Langelier Index	<-0.5 -0.5 to 0.5	Increased corrosion potential Limited corrosion potential
Ryznar Index	<6 >7	Limited corrosion potential Increased corrosion potential
Log of chloride to carbonate ratio	>2	Increased corrosion potential

[a] For further information on these parameters refer to Volume 3, Section 9.2.9.1

Corrosion of pumping, irrigation and stock watering equipment is a common problem in many agricultural areas of Australia, particularly where groundwater sources are used. It often results in the deterioration of well and pumping equipment, pipelines, channels, sprinkler devices and storage tanks, leading to decreased or uneven water distribution. Corrosion can be caused by chemical, physical or microbiological processes acting on metal surfaces in contact with water. Plastics and concrete may also deteriorate, through processes similar to corrosion, if elevated levels of certain constituents are present.

4.2.10.3 Fouling

Trigger values for assessing the fouling potential of water are given in table 4.2.15.

Table 4.2.15 Fouling potential of waters as indicated by pH, hardness, Langelier index, Ryznar index and the log of chloride:carbonate ratio

Parameter[a]	**Value**	**Comments**
pH	<7	Limited fouling potential
	7 to 8.5	Moderate fouling potential (groundwater)[b]
	>8.5	Increased fouling potential (groundwater)[c]
Hardness	>350 mg/L CaCO3	Increased fouling potential
Langelier Index	>0.5	Increased fouling potential
	-0.5 to 0.5	Limited fouling potential
Ryznar Index	<6	Increased fouling potential
	>7	Limited fouling potential
Log of chloride to carbonate ratio	<2	Increased fouling potential

a For further information on these parameters refer to Volume 3, Section 9.2.9.1
b For surface waters, pH range 7 to 9
c For surface waters, pH >9

Fouling of agricultural water systems can lead to decreased water quality and yield as a result of clogging, encrustation and scaling. All parts of the system can be affected including wells, pumping equipment, pipes and sprinklers. The main causes of fouling in agricultural water systems can be attributed to physical, chemical and biological properties of the water.

4.2.10.4 Agricultural chemical preparation

Insufficient information is available to set trigger values for water used to prepare agricultural chemicals.

Water is the most common additive and diluent used in the preparation of agricultural chemicals (e.g. pesticides, stock dips and fertilisers) for on-farm use. Although some agricultural chemicals can withstand a range of water qualities before performance is substantially affected, it is recommended that good quality water be used to ensure the desired result.

To check that a particular water is suitable for use with an agricultural chemical, it is best to make up and test a trial solution first. Specific details on water quality requirements should be noted from the product label or by contacting the manufacturer.

4.3 Livestock drinking water quality

Good water quality is essential for successful livestock production. Poor quality water may reduce animal production and impair fertility. In extreme cases, stock may die. Contaminants in drinking water can produce residues in animal products (e.g. meat, milk and eggs), adversely affecting their saleability and/or creating human health risks. Animal industries themselves may impair water quality downstream (e.g. through faecal contamination), highlighting the need for an integrated approach to land and water management in rural catchments.

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 Volume 3, Section 9.3.1.

4.3.1 Derivation and use of guidelines

Many factors influence the suitability of waters for livestock watering. Requirements may differ between animal species (generally tolerances decrease in the order sheep, cattle, horses, pigs, poultry), and between different stages of growth and animal condition, and between monogastric and ruminant animals. Moreover, stock accustomed to good quality water can initially suffer ill effects or refuse to drink water of poorer quality, but may adjust if introduced gradually.

A review of the scientific literature reveals that most trigger values tend to be based on field observations rather than rigorous experimentation, although there are notable exceptions. In the present guidelines, several new trigger values have been calculated using data on chronic and toxic effect levels on animals. Since derivation of most trigger values for livestock drinking water needs further validation, they should be considered interim guidelines at this stage. Further details on the derivation of each trigger value and a more detailed discussion of all water quality parameters included in the guidelines are given in Volume 3, Section 9.3.

The scope of the guidelines for livestock drinking water includes biological, chemical and radiological characteristics that may affect animal health. The guidelines are trigger values below which there should be minimal risk to animal health. If the water quality exceeds a trigger value, it is advisable to investigate further to determine the level of risk.

4.3.2 Biological parameters

4.3.2.1 Cyanobacteria (blue-green algae)

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.

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.[a]

a See also Section 9.3.3.1

4.3.2.2 Pathogens and parasites

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

It is generally not feasible nor warranted to test livestock drinking water for the presence of the wide range of water-borne microbial pathogens (bacteria, viruses and protozoa) and parasites 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 (NHMRC & ARMCANZ 1996). However, 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.

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 trigger value (ARMCANZ, ANZECC & NHMRC 1999).[b]

b Section 9.3.3.2

4.3.3 Major ions of concern for livestock drinking water quality

Many inorganic salts are essential nutrients for animal health, but elevated concentrations of certain compounds may cause chronic or toxic effects in livestock. Unless otherwise stated, the trigger values relate to the total concentration of the constituent, irrespective of whether it is dissolved, complexed with an organic compound, or bound to suspended solids.[c]

c Section 9.3.4

4.3.3.1 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.***

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.

4.3.3.2 Magnesium

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

a See Section 9.3.4.2

Magnesium is an essential element for animal nutrition. In high doses magnesium can cause scouring and diarrhoea, lethargy, lameness, decreased feed intake and decreased performance. Drinking water containing magnesium at concentrations up to 2000 mg/L has been found to have no adverse effects on cattle.[a]

4.3.3.3 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.

Both nitrate and nitrite can cause toxicity to animals, with nitrite being far more toxic than nitrate. Symptoms of acute poisoning include increased urination, restlessness and cyanosis, leading to vomiting, convulsions and death.

Confusion can arise concerning trigger values for nitrate and nitrite because concentrations are sometimes reported on the basis of their respective nitrogen (N) contents, i.e. as nitrate-N and nitrite-N. Note that trigger values in the present guidelines are expressed as nitrate and nitrite. The conversions are as follows:

$$1 \text{ mg/L nitrate-N} = 4.43 \text{ mg/L nitrate,} \tag{4.3}$$

$$1 \text{ mg/L nitrite-N} = 3.29 \text{ mg/L nitrite.} \tag{4.4}$$

4.3.3.4 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.

Sulfur is essential for animal nutrition. Excessive concentrations of sulfate in water typically cause diarrhoea in stock, but animals generally avoid water containing high sulfate concentrations.

4.3.3.5 Total dissolved solids (salinity)

Recommended concentrations of total dissolved solids in drinking water for livestock are given in table 4.3.1.

Table 4.3.1 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	5000–10 000
Dairy cattle	0–2500	2500–4000	4000–7000
Sheep	0–5000	5000–10 000	10 000–13 000[b]
Horses	0–4000	4000–6000	6000–7000
Pigs	0–4000	4000–6000	6000–8000
Poultry	0–2000	2000–3000	3000–4000

a From ANZECC (1992), adapted to incorporate more recent information

b Sheep on lush green feed may tolerate up to 13 000 mg/L TDS without loss of condition or production

Total dissolved solids (TDS) is a measure of all inorganic salts dissolved in water and is a guide to water quality. For convenience, TDS is often estimated from electrical conductivity (EC). An approximate conversion of EC to TDS is:

$$\text{EC (dS/m)} \times 670 = \text{TDS (mg/L) or,} \qquad (4.5)$$

$$\text{EC } (\mu\text{S/cm}) \times 0.67 = \text{TDS (mg/L)} \qquad (4.6)$$

Salinity is used as a convenient guide to the suitability of water for livestock watering. If a water has purgative or toxic effects, especially if the TDS concentration is above 2400 mg/L, the water should be analysed to determine the concentrations of specific ions.

4.3.4 Heavy metals and metalloids

a See also Section 9.3.5

Many metal elements are essential nutrients for animal health, but elevated concentrations of certain compounds may cause chronic or toxic effects in livestock. Stock can tolerate many metal elements in drinking water if they are not ingesting them in quantity in the diet, because accumulation in the body depends on the amount ingested from both food and water sources. The trigger values in table 4.3.2 are the metal concentrations below which there is a minimal risk of toxic effects. If these values are exceeded the situation should be investigated further. In some cases higher concentrations may be tolerated, depending on factors such as total dietary exposure to the metal or levels of other compensating elements.[a] Unless otherwise stated, the trigger values relate to the total concentration of the constituent, irrespective of whether it is dissolved, complexed with an organic compound, or bound to suspended solids.

Table 4.3.2 Recommended water quality trigger values (low risk) for heavy metals and metalloids in livestock drinking water [a]

Metal or metalloid	Trigger value (low risk)[a,b] (mg/L)
Aluminium	5
Arsenic	0.5 up to 5[c]
Beryllium	ND
Boron	5
Cadmium	0.01
Chromium	1
Cobalt	1
Copper	0.4 (sheep) 1 (cattle) 5 (pigs) 5 (poultry)
Fluoride	2
Iron	not sufficiently toxic
Lead	0.1
Manganese	not sufficiently toxic
Mercury	0.002
Molybdenum	0.15
Nickel	1
Selenium	0.02
Uranium	0.2
Vanadium	ND
Zinc	20

a Higher concentrations may be tolerated in some situations (details provided in Volume 3, Section 9.3.5)

b ND = not determined, insufficient background data to calculate

c May be tolerated if not provided as a food additive and natural levels in the diet are low

4.3.5 Pesticides and other organic contaminants

In the absence of adequate information derived specifically for livestock under Australian and New Zealand conditions, it is recommended that the drinking water guidelines for human health be adopted.

A major concern in rural environments is the potential for pesticide residues to contaminate water supplies by spray drift, deep percolation, surface runoff, accidental spillage, or by direct application to water supplies for controlling aquatic weeds. In the absence of guidelines derived specifically for livestock, the reader is referred to the *Australian Drinking Water Guidelines* (NHMRC & ARMCANZ 1996). Readers in New Zealand are referred to the *Drinking-water Standards for New Zealand* (New Zealand Ministry of Health 1995a) and the *Guidelines for Drinking-water Quality Management for New Zealand* (New Zealand Ministry of Health 1995b).

4.3.6 Radiological quality of livestock drinking water

Trigger values for the radiological quality of livestock drinking water are given in table 4.3.3.

Table 4.3.3 Trigger values for radioactive contaminants in livestock drinking water

Radionuclide	Trigger value
Radium 226	5 Bq/L
Radium 228	2 Bq/L
Uranium 238	0.2 Bq/L
Gross alpha	0.5 Bq/L
Gross beta (excluding K-40)	0.5 Bq/L

Radioactive contaminants can originate from both natural and artificial sources and can potentially be found in surface waters and groundwaters. For livestock, the main water-related risks due to radioactivity arise from the transfer of radionuclides from irrigation or stock drinking water to animals and animal products for human consumption. Cancer is a potential health hazard for humans associated with exposure to radionuclides.

4.4 Aquaculture and human consumption of aquatic foods

4.4.1 Background

Aquaculture involves the production of food for human consumption, fry for recreational fishing and natural fisheries, ornamental fish and plants for the aquarium trade, raw materials for energy and biochemicals, and a number of items for the fashion industry. With wild fisheries approaching maximum sustainable levels and many already being over exploited, aquaculture is increasingly important worldwide as a source of aquatic food and other products.

During 1997–98, almost 31 000 tonnes of product and around 9.3 million juveniles (mostly finfish fry and ornamental fish) were produced in Australia at an estimated farm gate value in excess of $517.4 million (O'Sullivan & Roberts 1999). This represents approximately 25% of total aquatic food production in Australia. The pearl oyster, southern bluefin tuna, salmonid, edible oyster and prawn industries represent the major commercial aquaculture sectors economically, totalling more than 90% of overall aquaculture production.

The main culture species in New Zealand are green shell mussels, Pacific salmon and Pacific oysters. According to the New Zealand Fishing Industry (Treyton Maldoc, pers. com. 1999), annual production of these species totalled almost 50 000 tonnes, with an estimated value of around $160 million. Aquaculture now contributes over 13% of all New Zealand aquatic food exports.

Within the growing aquaculture industry, it is well accepted that satisfactory water quality is needed for maintaining viable aquaculture operations. Poor water quality can result in loss of production of culture species, and can also reduce the quality of the end product. Production is reduced when influent water contains enough contaminants to impair development, growth or reproduction, with the ultimate result being death. Quality is reduced when low levels of a contaminant cause no obvious adverse effects but gradually accumulate in the culture species to the point where it poses a potential health risk to human consumers. Thus, both these issues needed to be considered if useful and usable guidelines are to be provided for the aquaculture industry.

This section provides water quality guidelines for influent (i.e. water that is entering the aquaculture operation) or source water quality, and it also addresses the safety of aquatic foods for human consumers, whether the foods be produced by aquaculture, or commercial, or recreational or indigenous fishing. It is the first set of joint guidelines to have been provided for the protection of aquaculture in Australia and New Zealand. Note that these guidelines for protecting the health of commercial fish species[a] do not apply to recreational and commercial fisheries based upon wild populations of aquatic organisms. Wild fish stocks are dependent on healthy ecosystems to support them thoughout their life cycle (e.g. for feeding, breeding, habitat). Hence, for the protection of wild fish stocks it is best to apply the water quality guidelines for managing aquatic ecosystems.[b]

a See Section 4.4.4

b Chapter 3

4.4.2 Philosophy

In developing these guidelines, the objective was to provide information and guidance that would:

- promote the quality of water necessary for use by the aquaculture industry; and
- protect human consumers of harvested aquatic food species.

4.4.2.1 Protection of cultured fish, molluscs and crustaceans

The guidelines for protecting aquaculture species have been developed to assist water managers to maintain an appropriate level of water quality for existing and future aquaculture activities. The water quality guidelines will provide a basis for aquaculture management decisions, such as:

- environmental planning and management,
- environmental assessment and monitoring requirements,
- appropriate environmental zoning and legislation,
- appropriate species and suitable site selection,
- site capacity,
- farm design criteria,
- stocking densities and feeding regimes,
- production schedules.

4.4.2.2 Protection of human consumers of aquatic foods

Standards for the protection of human consumers of aquatic foods are of paramount importance to the viability of the aquaculture industry. To maintain demand, the aquaculture and fishing industries must ensure the highest quality of their products, both from a visual and, more importantly, from a human health perspective. Under a treaty between Australia and New Zealand (ANZFA 1996), the Australia New Zealand Food Authority (ANZFA) develops and administers uniform (statutory) standards for chemical contamination in foods (including aquatic foods) that are likely to affect human health. Unlike the water quality guidelines, the ANZFA food standards are enforceable through legislation. Guidelines are also provided in this section against biological contaminants and against the tainting of aquatic animal flesh.

4.4.3 Scope

As the aquaculture guidelines for Australia and New Zealand are a new development, they have drawn extensively on recent overseas guidelines for aquaculture as well as on the personal experiences of a number of local industry specialists. The guidelines address the following issues:

- protection of the health of culture species from water-borne contaminants (chemicals, elements, microorganisms, toxins, etc.) during the growing period (pre-harvest), but not during post-harvest processes (e.g. slaughter, processing, transport, marketing);
- the effects of water quality on adult forms of cultured species, recognising that larval and juvenile stages may have lower tolerance levels than the adult stages;
- the protection of human consumers of harvested aquatic food species from the toxic effects of chemical and biological contaminants and from tainted flesh.

The guidelines do not address effluent water quality from aquaculture activities; however, aquaculturists need to manage their operations with downstream water quality in mind. Effluent water quality is regulated by state and federal government legislation and regulations in Australia, and through the Resource Management Act and Industry Agreed Implementation Standards in New Zealand. In addition, as stated above, the guidelines in Section 4.4.4 are only concerned with the protection of cultured, not wild species.

Given the limited information on contaminant accumulation in aquaculture species, it has not been possible to provide water quality guidelines that will guarantee that the Australian and New Zealand food standards will be achieved. Therefore, the guidelines for the protection of human consumers of aquatic foods are intended to be used in conjunction with the *Food Standards Code* (ANZFA 1996, and updates) to protect the health of human consumers of aquatic foods from the aquaculture industry. These standards are continually under review and can be examined on the appropriate web sites (for Australia: www.anzfa.gov.au; for New Zealand: www.anzfa.govt.nz).

Precautionary comments and discussion on the limitations of the guidelines are provided below in Section 4.4.6.[a]

a See Section 9.4.1 for more detail

4.4.4 Water quality guidelines for the protection of cultured fish, molluscs and crustaceans

4.4.4.1 Overview of approach

There are many aquaculture species in Australia and New Zealand and information is generally lacking on most of them, so all finfish, mollusc and crustacean species were divided into eight indicative groups. Then toxicity and tolerance data were reviewed for one or two representative species within those groups, with the species being chosen according to the level of production and availability of scientific data. Where discrepancies in the data were identified, the more conservative data were generally used. The species groups and representative species are summarised in table 4.4.1.

Justification for selecting the representative species is provided in Section 9.4.1.4 (Volume 3). As indicated in table 4.4.1, a range of aquatic plants, reptiles and invertebrates that are cultured were not included in the list of representative species. In 1997/98 the production of these species contributed less than 1.5% of the total value of aquaculture production in Australia (O'Sullivan & Roberts 1999), with the amount of relevant literature or information about them being correspondingly small.

Guideline values were determined in several ways, depending on the quantity and quality of information. Where they were available, appropriate guidelines for the protection of aquaculture from other countries (e.g. DWAF 1996, Zweig et al. 1999) were applied. In some cases, guideline values were based on acceptable risks, according to the value judgements or professional judgements of local aquaculture specialists. When neither of the above approaches could be used, the water quality requirements for the eight indicative species groups were reviewed to determine a guideline value.[b] Discussion of the confidence levels for these guidelines is provided in Section 9.4.1.5 (Volume 3).

b Sections 9.4.1.4, 9.4.1.5

Table 4.4.1 Representative aquaculture species, occurrence and culture status

Species group	Representative species[1]	Occurrence	Aquaculture status[2]
Freshwater fish	rainbow trout	Australia/New Zealand	commercial/none
	silver perch	Australia	commercial
Marine fish	snapper	Australia/New Zealand	commercial/commercial
	flounder/whiting	Australia/Australia	experimental/experimental
Brackish water or euryhaline fish	barramundi	Australia	commercial
	black bream	Australia	experimental
Freshwater crustaceans	marron	Australia	commercial
	yabbies	Australia	commercial
	red claw	Australia	commercial
	freshwater shrimp	Australia/New Zealand	experimental/commercial
Marine crustaceans	black tiger prawns	Australia	commercial
	kuruma prawns	Australia	commercial
Edible bivalves	Sydney rock oysters	Australia	commercial
	Pacific oysters	Australia/New Zealand	commercial/commercial
	blue mussels	Australia/New Zealand	commercial/none
	green shell mussels	New Zealand	commercial
Pearl oysters	golden lip	Australia	commercial
Gastropod/molluscs	abalone/paua	Australia/New Zealand	commercial/commercial
	trochus	Australia	experimental

[1] The groups of aquaculture species not included in this list are: seaweeds and aquatic plants; crocodiles; a range of live feed and microalgal species; sea cucumbers (beche-de-mer), sponges and other invertebrates.

[2] commercial = products offered for sale; experimental = production but no sales; none = species occurs but no culture is undertaken

The guidelines are provided in the following four categories:

- physico-chemical stressors,
- inorganic toxicants,
- organic toxicants,
- pathogens and biological contaminants.

General guideline values for the aquaculture of freshwater and saltwater (brackish and marine water) are recommended. In addition, specific guideline values are provided for species groups for which information is available on their water quality requirements. Information sources used to derive the water quality guidelines for protection of aquaculture species are listed in Section 9.4.1.4 (Volume 3).

4.4.4.2 Using the guidelines

The water quality guidelines can be used with reasonable confidence to assess ambient water quality for aquacultural uses. Where specific water quality guidelines cannot be given for the protection of aquaculture species, use the guidelines for the protection of aquatic ecosystems.[a]

a See Chapter 3

Many different aquaculture production systems and species are used in Australia and New Zealand across a wide range of environmental conditions, so it should not be assumed that one set of specific values will apply equally in all situations. Local, site-specific information will be needed to supplement the broad information provided in this chapter. This might include information on specific culture species, or local water quality variables that could affect the bioavailability and toxicity of metals (e.g. hardness, dissolved organic matter, pH, temperature).

Details of factors that could affect toxicant bioavailability are provided in Section 8.3.5 (Volume 2).

a See Section 3.4.3, Vol. 1; Section 8.3.6, Volume 2

Figure 4.4.1 is a decision tree for determining water quality guidelines for the protection of aquaculture species; it includes a number of factors that might modify the guideline values. Specialist assistance may be required to complete the steps which involve chemical speciation/complexation, and likewise to conduct toxicity tests should they become necessary.[a]

Note that a user can make a decision on the risk-based framework and leave the process at any level. However, the further through the process one moves, the greater the confidence in the level of risk. A worked example of the use of the decision tree for an aquaculturist planning to culture prawns is provided in Section 9.4.2 (Volume 3).

If ambient water quality exceeds the guideline value for any parameter then there could be a significant risk of an impact on aquacultural activities, and further investigations should be undertaken, in accordance with the decision framework in figure 4.4.1. If ambient water quality remains below the guideline values, risk can be deemed to be low. However, this cannot be taken as a guarantee that problems will not occur in the future.

It is unrealistic to expect an aquaculture operation to measure all of the water quality parameters. However, knowledge of activities upstream of the operation that may be contributing to contaminants in the influent water should serve to identify which of the parameters might be of particular concern.

4.4.4.3 The guideline values

Tables 4.4.2 and 4.4.3 provide the recommended water quality guideline values for physico-chemical parameters and toxicants, respectively, to be applied for use in general freshwater and saltwater (brackish and marine water) aquaculture. Where guideline values are available for some or all of the species groups outlined in table 4.4.1, they have been incorporated in Section 9.4.2 (Volume 3), and can be used where guidance is sought for a particular species group. A short summary for each category (i.e. physico-chemical, inorganic, etc.) is also provided after the tables. Section 9.4.2 (Volume 3) also contains further background information on each water quality parameter, including a description of how the recommended guideline value was determined.

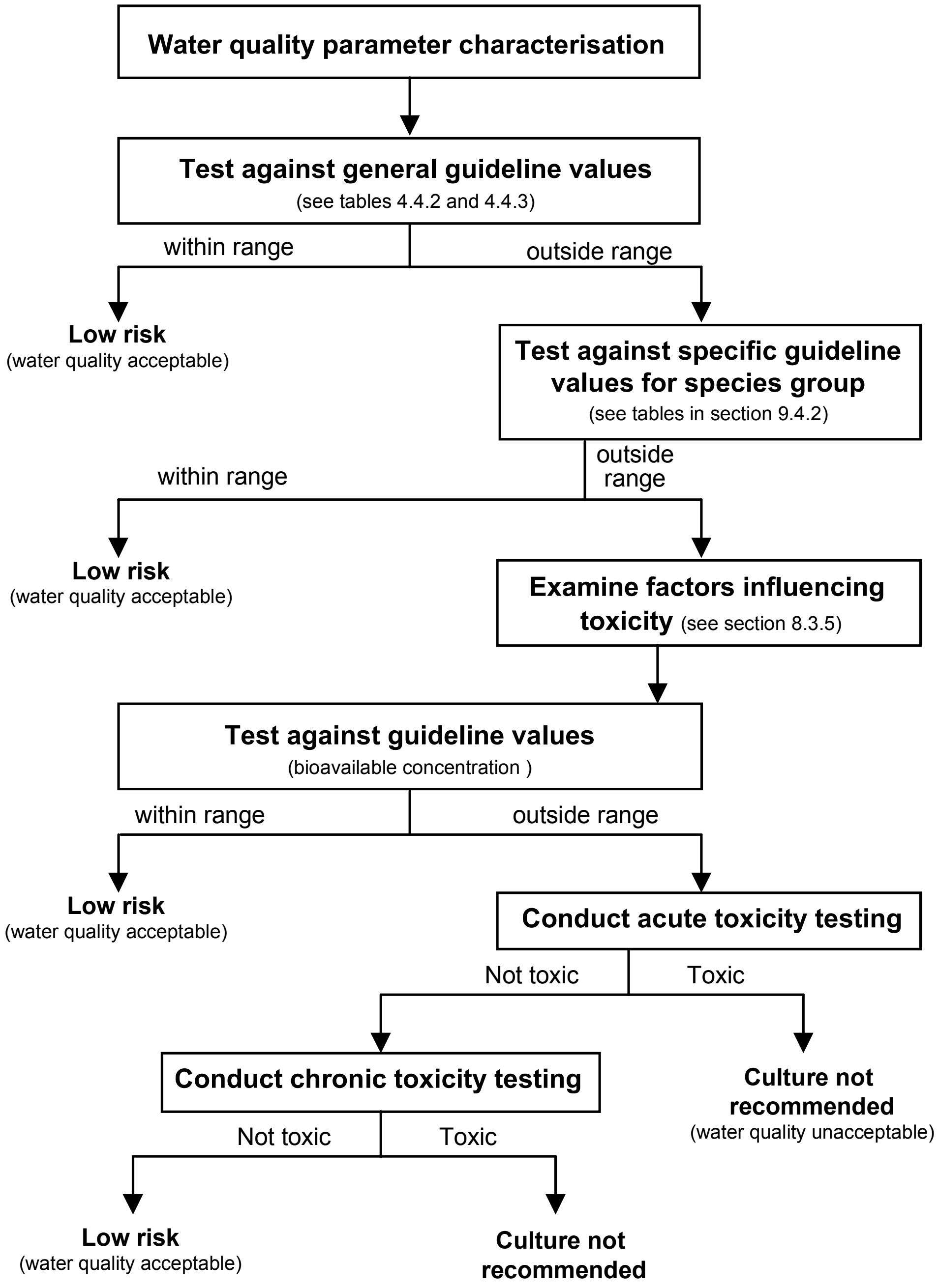

Figure 4.4.1 Decision tree for determining if water quality is acceptable for the protection of aquaculture species

Table 4.4.2 Physico-chemical stressor guidelines for the protection of aquaculture species

Measured parameter	**Recommended guideline (mg/L)**	
	Freshwater production	**Saltwater production**
Alkalinity	≥20[5]	>20[3]
Biochemical oxygen demand (BOD_5)	<15[1]	ND
Chemical oxygen demand (COD)	<40[1]	ND
Carbon dioxide	<10	<15
Colour and appearance of water	30–40[2] (Pt-Co units)	30–40[2] (Pt-Co units)
Dissolved oxygen	>5[3]	>5[3]
Gas supersaturation	<100%[6]	<100%[6]
Hardness ($CaCO_3$)	20–100[5]	NC[6]
pH	5.0–9.0	6.0-9.0
Salinity (total dissolved solids)	<3000[6]	33 000–37 000[6] (3000–35 000 Brackish)[6]
Suspended solids	<40	<10 (<75 Brackish)
Temperature	<2.0°C change over 1 hour[4]	<2.0°C change over 1 hour[4]

[1] Schlotfeldt & Alderman (1995)

[2] O'Connor pers. comm.

[3] Meade (1989)

[4] ANZECC (1992)

[5] DWAF (1996)

[6] Lawson (1995)

Others are based on professional judgements of the project team.

Table 4.4.3 Toxicant guidelines for the protection of aquaculture species

Measured parameter	**Guideline (µg/L)**	
	Freshwater production	**Saltwater production**
INORGANIC TOXICANTS (HEAVY METALS AND OTHERS)		
Aluminium	<30 (pH >6.5)[1] <10 (pH <6.5)	<10[1]
Ammonia (un-ionised)	<20 (pH >8.0) coldwater[2] <30 warmwater[2]	<100
Arsenic	<50[1,2]	<30[1,2]
Cadmium (varies with hardness)	<0.2–1.8[2]	<0.5–5[1]
Chlorine	<3[1]	<3[1]
Chromium	<20[2]	<20
Copper (varies with hardness)	<5[2]	<5[3]
Cyanide	<5[1]	<5[1]
Fluorides	<20[4]	ND
Hydrogen sulfide	<1[2]	<2
Iron	<10[1]	<10[1]
Lead (varies with hardness)	<1–7[4]	<1–7[4]
Magnesium	<15 000[1]	ND
Manganese	<10[1,5]	<10[1,5]
Mercury	<1	<1
Nickel	<100[1]	<100[1]
Nitrate (NO_3^-)	<50 000[6]	<100 000[3,7]
Nitrite (NO_2)	<100[1,7]	<100[1,7]
Phosphates	<100[2]	<50
Selenium	<10[1]	<10[1]
Silver	<3[1]	<3[1]
Tributyltin (TBT)	<0.026[1]	<0.01[1]
Total available nitrogen (TAN)	<1000[1]	<1000[1]
Vanadium	<100[1]	<100[1]
Zinc	<5[1]	<5[1]
ORGANIC TOXICANTS (NON-PESTICIDES)		
Detergents and surfactants	<0.1[8]	ND
Methane	<65 000[9,10]	<65 000[9,10]
Oils and greases (including petrochemicals)	<300[6]	ND
Phenols and chlorinated phenols	<0.6–1.7[6]	ND
Polychlorinated biphenyls (PCBs)	<2[1]	<2[1]
PESTICIDES		
2,4-dichlorophenol	<4.0[2]	ND
Aldrin	<0.01[2,3,8]	ND
Azinphos-methyl	<0.01[2]	ND
Chlordane	<0.01[11]	0.004[11]
Chlorpyrifos	<0.001[2]	ND
DDT (including DDD & DDE)	<0.0015[2]	ND
Demton	<0.01[11]	ND
Dieldrin	<0.005[2]	ND
Endosulfan	<0.003[2,11]	0.001[11]
Endrin	<0.002[2]	ND
Gunthion (see also Azinphos-methyl)	<0.01[11]	ND
Hexachlorobenzole	<0.00001[6]	ND
Heptachlor	<0.005[2]	ND
Lindane	<0.01[11]	0.004[11]
Malathion	<0.1[5,11]	ND
Methoxychlor	<0.03[11]	ND
Mirex	<0.001[2,11]	ND
Paraquat	ND	<0.01
Parathion	<0.04[11]	ND
Toxaphene	<0.002[2]	ND

ND: Not determined — insufficient information; NC: Not of concern; 1. Meade (1989); 2. DWAF (1996); 3. Pillay (1990); 4. Tebbutt (1972); 5. Zweig et al. (1999); 6. Schlotfeldt & Alderman (1995); 7. Coche (1981); 8. Langdon (1988); 9. McKee & Wolf (1963); 10. Boyd (1990); 11. Lannan et al. (1986). Others are based on professional judgements of the project team.

1 Physico-chemical stressors

a See also Section 9.4.2.1

A number of naturally-occurring physico-chemical stressors can cause adverse effects on aquaculture operations when influent water values are too high and/or too low. These guidelines address 11 physico-chemical stressors that are considered of importance to aquaculture operations. Many of these should also be regularly monitored in the culture system to ensure that the aquatic organisms are being held in conditions conducive to survival and growth. Some of the major stressors are summarised below.[a]

Dissolved oxygen (DO) is a basic requirement for aquaculture species (Zweig et al. 1999). The amount of oxygen required by aquatic animals is quite variable and depends on species, size, activity, water temperature, condition, and the DO concentration itself (Boyd 1990). Thus, some species are more sensitive to low levels of oxygen than others. Daily fluctuations of DO in impounded waters are much higher than those in the open sea or running waters, with low levels often occurring at dawn, and high levels in the late afternoon (Boyd 1990). The most common cause of low DO levels in an aquaculture operation is contamination by biodegradable organic substances resulting in a high BOD; the problem is further exacerbated at higher temperatures.

Water hardness, a total measure of the major cations (predominantly calcium and magnesium), is an important parameter in freshwaters, mostly because it can have a major effect on the toxicity of metals. In addition, some aquaculture species have specific calcium requirements for bone or exoskeleton formation, and calcium is also necessary for proper osmoregulation. Water hardness (measured as mg $CaCO_3$/L) can range from <1 (very soft) to >400 mg/L (very hard).

The pH of influent water refers to the $\log_{10}$ of the hydrogen ion concentration, or, more simply, how acidic or basic the water is. The pH is interdependent with a number of other water quality parameters including carbon dioxide, alkalinity and hardness. It is known to influence the toxicity of hydrogen sulfide, cyanides, heavy metals, and ammonia (Klontz 1993), and it can also be toxic in its own right. The pH levels in natural waters vary enormously and the aquaculturist should ensure that culture species are adapted to living in the conditions existing in the aquaculture operation.

Salinity is an important limiting factor in the distribution of many aquatic animals, and therefore it is an important parameter for aquaculture. In addition, salinity requirements can vary for particular species depending on their life cycle stage. Outside their natural salinity ranges, aquatic animals must expend considerable energy on osmoregulation at the expense of other processes such as growth. Salinity ranges are 0.05–1.0 gL^{-1} for freshwaters, 0.5–>30 gL^{-1} for estuarine waters, 30–40 gL^{-1} for marine waters, and can exceed 40 gL^{-1} for hypersaline/brackish waters.

Suspended solids and turbidity can have major effects on aquaculture operations. Suspended solids include phytoplankton, zooplankton and bacterial blooms, suspended organic and humic acids, and suspended silt and clay particles. All these components contribute to some extent to increased turbidity. In some instances this is advantageous, because it inhibits the growth of nuisance algae and macrophytes. However, suspended solids can cause gill irritations and tissue damage to aquatic animals, while they can also shield food organisms and clog filters (Zweig et al. 1999). Smothering effects caused by suspended solids settling on sessile aquaculture species (e.g. mussels, oysters) can also present problems (Duchrow & Everhart 1971).

In summary, it should be highlighted that physico-chemical parameters vary widely in natural waters, and aquatic organisms have a wide range of tolerances and adaptive capacities. Thus, it is extremely difficult to recommend broadly applicable guidelines.

2 *Inorganic toxicants (heavy metals and others)*

A wide range of inorganic toxicants, particularly heavy metals, can be a problem in freshwater, brackish water and inshore marine aquaculture, especially in areas of human habitation that may be polluted. Trace quantities of metals are present in natural waters; however, their concentrations are generally greater in the vicinity of industrial processes (ore mining and processing, smelting plants, rolling sheet metal mills, textile and leather industries) and exhaust gases of motor vehicles and burning of other fossil fuels. These guidelines provide information on 27 inorganic toxicants. Those of greatest concern to fisheries (including aquaculture) include aluminium, arsenic, cadmium, chromium, copper, iron, lead, mercury, nickel and zinc (Svobodova et al. 1993). Other inorganic toxicants include ammonia, chlorine, cyanide, fluoride, hydrogen sulfide, nitrite, nitrate and phosphates. As mentioned above, the levels of calcium and magnesium are also important because they influence the hardness of the waters.[a]

a See Section 9.4.2.1/7

Speciation of metals is important in determining toxicity to aquatic organisms because it influences metal bioavailability. Water quality guidelines for metals in aquatic ecosystems have typically been based on total concentrations; yet it is now well established that the chemical form or speciation of metals critically influences their bioavailability (i.e. their ability to penetrate a biological cell membrane) and toxicity to aquatic organisms.[b]

b Sections 8.3.5.16 and 9.4.2.2

Most studies of the toxicity of heavy metals to fish and other aquatic organisms have shown that the free (hydrated) metal ion is the most toxic form, and that toxicity is related to the activity of the free (dissolved) metal ion (e.g. Cu^{2+} or Zn^{2+}) rather than to total metal concentration (including adsorbed, chelated or complexed forms) (Florence & Batley 1988, Boyd 1989). Heavy metal toxicity also can be affected by pH, hardness, alkalinity, dissolved oxygen, temperature and turbidity (SECL 1983). In pond water, heavy metals can be adsorbed onto clay particles and chelated by organic matter so that they remain in solution but may not have an adverse effect on fish or crustaceans (Boyd 1990). Duration of exposure, interaction with other toxic agents and species can affect the biological response to these toxic metals significantly (e.g. mercury and methane give rise to methyl mercury).

Guidelines based on total concentrations may be over-protective, since only a fraction of the total concentration will generally be bioavailable, especially in samples containing appreciable concentrations of particulate matter. Thus, it is important to measure the bioavailable metal fraction.[c] Importantly, Svobodova et al. (1993) noted that the toxic action of metals is particularly pronounced in the early stages of development of the fish.

c Section 8.3.5

3 *Organic toxicants*

Organic toxicants can present a problem to all types of aquaculture operations. The types of organic chemicals considered in these guidelines are detergents and surfactants, hydrocarbons derived from human activities (namely petroleum hydrocarbons), a large number of pesticides, phenolic compounds, and polychlorinated biphenyls. Most of these originate from domestic, agricultural or industrial activities, and some are also used by aquaculture operations.

No data were available to provide guidelines for antibiotics and antimicrobials, but it is best to take due care when using such chemicals in aquaculture operations.

Detergents and surfactants are widely used in domestic and industrial operations, and can often be detected in natural waters receiving domestic and industrial effluent (Svobodova et al. 1993), while on-farm activities may also be major sources of such chemicals. There is limited toxicity information for detergents and surfactants, although a general guideline value was derived for freshwaters.

Petroleum hydrocarbons are among the most widely processed and distributed chemical products in the world (Zweig et al. 1999). Although high levels of petroleum hydrocarbons can result in mortalities and major losses of production, the major concern to the aquaculture industry is the tainting of culture animals with off-flavours (Zweig et al. 1999[a]). Given the large number of petroleum-derived hydrocarbons and their wide ranges of toxicities, it is difficult to derive meaningful guidelines (SECL 1983), although some general guidelines have been recommended.

a Also see Section 4.4.5.3/3 below

The pesticides represent a large and complex group of organic toxicants because they incorporate insecticides, acaricides, herbicides, algicides and fungicides. In addition, the behaviour (e.g. persistence, partitioning) and toxicity of pesticides varies greatly, making it difficult to generalise about risks. Pesticides generally enter water from sources in the primary industry sector, including aquaculture, but primarily agriculture. Table 4.4.2 presents guideline values only for those pesticides for which a general freshwater or saltwater value can be recommended. A more comprehensive list of pesticide guideline values for specific species groups is provided in Section 9.4.2.3/4 (Volume 3). Given the limited information on the effects of pesticides on culture species, it is also worthwhile consulting the guidelines for aquatic ecosystem protection.[b]

b Chapter 3, Volume 1

Other organic compounds of concern include phenols and polychlorinated biphenyls (PCBs). Phenolic compounds originate from the distillation of fossil fuels, the degradation of pesticides, natural (SECL 1983) and other sources. They can result in effects ranging from toxicity to the tainting of flesh. Guideline values are recommended for freshwater and saltwater, while some guideline values for specific phenols are recommended for freshwater fish culture. The PCBs are extremely persistent lipid soluble chemicals that are of great environmental concern (Svobodova et al. 1993). It is extremely difficult to recommend guidelines for PCBs because of their large number and the wide spectrum of toxicity they exhibit. However, general guideline values are recommended for freshwater and saltwater.

4 Pathogens and biological contaminants

Pathogens and biological contaminants also need to be considered for aquaculture operations, and include algal blooms and algal toxins, bacteria, viruses and parasites. As noted by Zweig et al. (1999), high concentrations of pathogenic organisms are commonly found in waters polluted by human sewage and animal wastes. No guidelines are provided for pathogens and biological contaminants because their effects can vary considerably between the type of contaminant or species of pathogen, and the culture species. Nevertheless, Section 9.4.2.4

(Volume 3) provides useful background information and some guidance on how to manage for them. Brief summary information is provided below.

Algal blooms arise from a series of processes but commonly from eutrophication (addition of excess nutrients). Direct and indirect results of algal blooms include increased pH, depleted oxygen (anoxia), the production and release of algal toxins, and gill obstruction and irritation in fish. Algal toxins can also accumulate in culture species, resulting in potential risks to human consumers.[a]

[a] See Section 4.4.5.3/2

It has been suggested that culture organism mortality due to disease poses a more direct threat to the aquaculture industry than pollutants (Handlinger 1996). Aquaculture source waters contain a certain number of bacteria, viruses, fungi, parasites and other organisms, which, given certain environmental conditions, can contribute to impaired health of the culture species. Thus, the maintenance of optimal water quality appears to be the best defence against infections by these organisms (DWAF 1996). Some equipment that reduces the amount of incoming potential pathogens includes inflow filters that retain particles (to which most of the bacteria will be attached) and ultra-violet (UV) sterilisers. Reducing the level of infectious organisms contributes to better culture health, reduced need to treat animals with chemicals and drugs, and lower production costs.

4.4.5 Water quality guidelines for the protection of human consumers of aquatic foods

4.4.5.1 Overview of approach

Although guidelines are provided for biological contaminants and for the tainting of animal flesh, a search of the available data has produced insufficient information for deriving water quality guidelines that will ensure the Australian and New Zealand food standards will be met. Consequently, relevant food standards from the *Food Standards Code* (ANZFA 1996, and updates) established by the Australia New Zealand Food Authority (ANZFA) are provided as guidance and discussed below.[b]

[b] Section 9.4.3

4.4.5.2 Using the guidelines

The guidelines for the protection of human consumers of aquatic foods are intended to be used in conjunction with the *Food Standards Code* (ANZFA 1996, and updates) to protect the health of human consumers of aquatic foods from the effects of toxicants, whether the foods be derived from aquaculture, recreational fishing, commercial fishing or indigenous fishing. Essentially, they provide useful background information and some guidance to complement the ANZFA food standards. In particular, they give detailed information on measures for predicting the tissue concentrations of contaminants before, rather than after, harvest. Such approaches may form the basis for the future development of guidelines for the protection of human consumers of aquatic foods.

The ANZFA food standards for contamination of aquatic foods are enforceable through legislation and must be adhered to. However, it is important to note that at the time of publication of these Water Quality Guidelines, the ANZFA food standards were under review and subject to change. Thus, aquaculturists and other users of these guidelines should ensure they obtain the most recent ANZFA information (for Australia: www.anzfa.gov.au; for New Zealand: www.anzfa.govt.nz).

4.4.5.3 The guidelines

The food standards developed by ANZFA and published in the *Food Standards Code* (ANZFA 1996, and updates) aim to protect consumers from chemically contaminated foods, including aquatic species. Standards for aquatic species are based on the notion of acceptable daily intake (ADI) or acceptable weekly intake (AWI). See Zweig et al. (1999) for the World Health Organization (WHO) provisional tolerable weekly intakes for selected elements, as well as import regulations for residues. Guidelines are also provided for biological contaminants and for the tainting of animal flesh.

1 Chemical contaminants (toxicants)

Chemical contaminants can be categorised into three broad groups:[a]

a See Section 9.4.3.2 (Vol. 3) for ANZFA standards

i) Inorganic toxicants (mostly heavy metals)

Inorganic toxicants (mainly heavy metals) are a potential problem for human health, particularly through bivalved molluscs in which bioaccumulation increases the concentrations of inorganic toxicants. The rate of accumulation is species-specific and depends on the mechanisms of absorption and tissue distribution.

ii) Organic toxicants (e.g. hydrocarbons, pesticides)

The broad group comprising organic toxicants such as hydrocarbons and pesticides includes synthetic compounds which through either bioaccumulation or residue concentrations are potentially toxic to human consumers of contaminated aquatic foods.

iii) Radionuclides (radioactive elements)

At present, ANZFA does not specify maximum permitted concentrations (MPCs) for radionuclides in edible tissues. Many countries have limits set on imported foods, particularly for caesium-137 (Cs-137). Environmental levels of Cs-137 are considerably lower in the southern hemisphere than in the northern hemisphere, and exporters in Australia and New Zealand should not generally experience difficulty in meeting such limits.

2 Biological contaminants

There are a number of biological contaminants that can affect human consumers of aquatic foods. The guidelines for biological contaminants are based on either a concentration of the contaminant in the water (e.g. cells/L) or the level which is considered safe in edible soft tissue of fish, crustaceans and molluscs (e.g. mg/kg, number/g). Summary information on the major biological contaminants is provided below.[b]

b Section 9.4.3.3 for ANZFA standards

i) Bacteria

Aquatic bacterial food-borne diseases in humans can originate either from bacteria naturally present in water and/or sediments, or from bacteria introduced into aquatic environments through human and/or animal faeces. Aquatic foods can become contaminated with bacteria from exposure within the aquatic environment and/or during post-harvest activities. The present guidelines only deal with exposure within the aquatic environment.

The guidelines in table 4.4.4 are provided to assist managers to minimise the exposure of human consumers of aquatic food species (e.g. recreational fishermen) to bacterial borne disease.

Table 4.4.4 Guidelines for the protection of human consumers of fish and other aquatic organisms from bacterial infection

Toxicant	**Guideline** ***in shellfishing water***	**Standard** ***in edible tissue***
Faecal (thermotolerant) coliforms	The median faecal coliform bacterial concentration should not exceed 14 MPN/100 mL, with no more than 10% of the samples exceeding 43 MPN/100 mL	Fish destined for human consumption should not exceed a limit of 2.3 MPN *E. coli* /g of flesh with a standard plate count of 100 000 organisms/g

MPN: Most probable number
The guideline for faecal (thermotolerant) coliforms should only be used in conjunction with the data from a sanitary survey of the shellfish harvesting areas for the purpose of harvesting area classification. Source: USEPA (1986), NAS/NAE (1973), IWBDE (1972).

A two-tiered approach is usually used to reduce bacterial loads in cultured species:

- risk-based classification of waters to allow only certain waters and times for rearing or harvesting of shellfish;[a]
- treatment of shellfish to remove or destroy the bacteria (e.g. heat treatment or irradiation).

a See Section 4.4.5.3/4

Depuration is an integral part of removing bacteria from shellfish, and is a statutory requirement in NSW only.[b]

b Section 9.4.3.3/1

ii) Viruses

Viruses that infect humans following consumption of aquatic food are of human origin, having entered aquatic ecosystems in sewage effluent. These enteric viruses are able to remain viable in the aquatic environment for long periods (Goyal et al. 1984).

Shellfish are able to accumulate viruses in their gastrointestinal tracts, digestive glands and other tissues, but the rate of accumulation is dependent on the viral species and the shellfish species. Viruses are very difficult to detect, and other species (e.g. *Escherichia coli*, faecal coliforms) are usually used to indicate exposure to sewage-related pollution. While such sanitary surveys may not be as reliable as once thought, they are still relevant and are used in Australia and New Zealand as well as a number of other countries.[c]

c See part 4 below & Section 9.4.3.3/2

Heat treatment and depuration are generally not as efficient at reducing viral loads as they are bacterial loads. Normal cooking/steaming times for shellfish may not be sufficient to inactivate viruses (University of California, Davis 1997). Similarly, depuration may not remove all viruses from shellfish (Jackson & Ogburn 1998).

iii) Parasites

There is no evidence of transmission of parasites to humans following aquatic food consumption in Australia or New Zealand. Thus, no guidelines are provided. However, the presence of parasites, cysts and necrotic tissue resulting from parasitic infections will reduce the marketability of product.

iv) Marine biotoxins

A number of marine biotoxins, most of them associated with marine algae, represent a threat to human consumers of aquatic foods. Aquatic animals accumulate the toxins when they graze on the algae or on other consumers of the algae.

There are five recognised types of microalgal toxins:

- paralytic shellfish poisoning (PSP),
- diarrhetic shellfish poisoning (DSP),
- amnesic shellfish poisoning (ASP),
- neurotoxic shellfish poisoning (NSP),
- ciguatera fish poisoning (CFP).

Three naturally-occurring toxins that are not related to algae are (University of California, Davis 1997):

- gempylotoxin,
- tetramine,
- tetrodotoxin.

Important background information on the above biotoxins is provided in Section 9.4.3.3 (Volume 3), including guidelines for water and standards for edible tissue (MBMB 1996, K Jackson pers. comm. 2000). For a detailed discussion of biotoxins in New Zealand, refer to MBMB (1996). University of California, Davis (1997) also provides useful guidance and background information.

3 Off-flavour compounds

Off-flavour compounds, also known as tainting substances, can seriously affect the palatability of aquatic food. They can result in major adverse impacts to the aquaculture and wild-capture fishing industries. Table 4.4.5 lists threshold concentrations at which tainting will occur for a variety of off-flavour compounds.[a]

a See also Section 9.4.3.4

Table 4.4.5 Guidelines for chemical compounds in water found to cause tainting of fish flesh and other aquatic organisms

Parameter	Estimated threshold level in water (mg/L)
Acenaphthene	0.02
Acetophenone	0.5
Acrylonitrile	18.0
Copper	1.0
m-cresol	0.2
o-cresol	0.4
p-cresol	0.1
Cresylic acids (meta, para)	0.2
Chlorobenzene	0.02
n-butylmercaptan	0.06
o-sec. butylphenol	0.3
p-tert. butylphenol	0.03
o-chlorophenol	0.0001–0.015
p-chlorophenol	0.0001
2,3-dinitrophenol	0.08
2,4,6-trinitrophenol	0.002
2,4-dichlorophenol	0.0001–0.014
2,5-dichlorophenol	0.02
2,6-dichlorophenol	0.03
3,4-dichlorophenol	0.0003
2-methyl-4-chlorophenol	2.0
2-methyl-6-cholorophenol	0.003
3-methyl-4-chlorophenol	0.02–3.0
o-phenylphenol	1.0
Pentachlorophenol	0.03
Phenol	1.0–10.0
Phenols in polluted rivers	0.15–0.02
2,3,4,6-tetrachlorophenol	0.001
2,3,5-trichlorophenol	0.001
2,4,6-trichlorophenol	0.002
2,4-dimethylphenol	0.4
Dimethylamine	7.0
Diphenyloxide	0.05
B,B-dichlorodiethyl ether	0.09–1
o-dichlorobenzene	<0.25
Ethylbenzene	0.25
Ethanethiol	0.2
Ethylacrylate	0.6
Formaldehyde	95.0
Gasoline	0.005
Guaicol	0.08
Kerosene	0.1
Kerosene plus kaolin	1.0
Hexachlorocyclopentadiene	0.001
Isopropylbenzene	<0.25
Naphtha	0.1
Naphthalene	1.0
Naphthol	0.5
2-Naphthol	0.3
Nitrobenzene	0.03
a-methylstyrene	0.25
Oil, emulsifiable	>15.0
Pyridine	5–28
Pyrocatechol	0.8–5
Pyrogallol	20–30
Quinoline	0.5–1
p-quinone	0.5
Styrene	0.25
Toluene	0.25
Outboard motor fuel as exhaust	7.2
Zinc	5.0

Source: Reproduced from ANZECC (1992), an adaptation of NAS/NAE (1973)

According to Zweig et al. (1999), sophisticated analytical equipment is usually not necessary for detecting tainting substances; water that tastes or smells unusual may result in off-flavours, and sensory assessments (i.e. taste, smell) are often preferable to chemical analyses.

In addition to the chemical contaminants, a number of freshwater blue-green microalgae and bacteria can cause off-flavours in native fish. The most common is the earthy or musty flavour often referred to as ‘muddy’ taste, which often occurs in silver perch (*Bidyanus bidyanus*). Decaying organic matter can also cause off-flavour. The incidence of off-flavours is highest in warmer months, during blooms of blue-green algae and in ponds with high stocking and feeding rates. Most off-flavours can be readily purged by placing fish in clean water such as underground or spring water, domestic (dechlorinated) or rainwater.

4 Preventative and management approaches

It is generally accepted that food species should not be grown in, or harvested from, waters likely to be exposed to contamination. If a contamination event should occur, the aquatic organisms should be regularly analysed to ensure that the ANZFA standards are not exceeded in harvested product. However, chemical analysis for the detection of contaminants in aquatic food can be an expensive process. For planning purposes a method of product quality prediction would be preferable. This problem may be illustrated by the following examples:

- The viability of the setup of an aquaculture business is being investigated. How can the investors predict whether, on harvesting, the product will be suitable for sale for human consumption?
- It is proposed to start up an industrial/sewage plant upstream of a commercial fishery. How can we predict whether effluent from the plant will have a significant adverse effect on the fishery product quality?

Section 9.4.3.5 (Volume 3) provides detailed information and guidance on several approaches for predicting water quality or safety of the aquatic food product. Due to the complexities involved, uncertainties will be associated with any prediction. Predictions cannot replace product testing, but they may enable problems to be identified and resolved before they affect an industry. Summaries of four predictive approaches are provided below.

i) Bioconcentration factor approach

Bioaccumulation can be predicted using the bioconcentration factor approach. Since circumstances will vary enormously from case to case, this approach is only intended as a general guide, not as a set of prescriptive rules; it has several limitations. The underlying principle of the bioconcentration factor approach is that where the uptake of a chemical is not controlled by the organism’s metabolism, a concentration of the chemical in the organism will be proportional to the concentration of the chemical in the water or food (or sediment).

ii) Area classification approach

The area classification approach is used by the Australian Shellfish Quality Assurance Program (ASQAP) and the New Zealand Shellfish Quality Assurance Program (NZSQAP) to identify safe shellfish-growing areas to permit commercial harvesting for the domestic market and/or for export. The programs provide a risk-based system of procedures and guidelines for regulating shellfish-growing areas, harvesting, processing and distribution of shellfish. In general, they cover:

- classification and survey of growing areas,
- relaying (relocation) and harvesting controls,
- post-harvest handling, storage, processing and transportation.

The shellfish harvesting area classification systems rely on the Sanitary Survey approach to ensure that molluscan shellfish harvested for human consumption are safe. The Sanitary Survey consists of:

- the identification and evaluation of all potential and actual pollution sources (i.e. Shoreline Survey),
- the monitoring of growing waters and shellfish to determine the most suitable classification for the shellfish harvesting area (i.e. Bacteriological Survey).

The categories of classification are based on levels of contamination from sewage, poisonous or deleterious substances, other pathogenic organisms of non-faecal origin and biotoxin-producing organisms, radionuclides, and toxic wastes (ASSAC 1997). A number of classifications can result from the Sanitary Surveys, but they differ slightly between countries.[a]

a See Section 9.4.3.5/2

iii) Phytoplankton monitoring

The purpose of phytoplankton monitoring is to predict marine biotoxins in shellfish. In New Zealand, phytoplankton monitoring is mandatory for all commercial harvested areas under the marine biotoxin monitoring program, while a similar program is operated by the Ministry of Health for all recreational shellfish harvesting sites. A combination of phytoplankton and flesh tests are used to monitor for biotoxin activity. Commercial areas are sampled weekly for biotoxin activity and if mandated trigger values are reached for a number of species, flesh testing is invoked immediately. Little such monitoring is undertaken in Australia.

Trigger values for a number of phytoplankton species under the New Zealand program (MBMB 1996) are provided in Section 9.4.3.5/3 (Volume 3).

iv) Three-phased screening approach

The three-phased screening approach is a tiered process designed for aquaculture operations to evaluate source water quality in a step-by-step process of increasing detail and complexity, in order to minimise costs (Zweig et al. 1999). Phase I screening involves the analysis of basic physico-chemical properties necessary to sustain culture species. Phase II is designed to screen source water for anthropogenic contaminants (chemical and biological). Phase III involves field assessments of the capacity of the source water to culture the selected species, using management/culture techniques similar to those of the proposed operation (i.e. a pilot study).[b]

b Section 9.4.3.5/4

4.4.6 Some precautionary comments

Section 9.4.4 (Volume 3) provides a detailed discussion of the limitations of the current guidelines for the protection of aquaculture species and human consumers of aquatic foods, and it is strongly recommended that it be read. A brief summary of the major issues is given below.

Two of the major limitations of the current guidelines are the lack of data and the variability of the data. Data variability can be attributed to several factors, including the use of different test methods (e.g. time and duration of exposure, size and age of fish, test conditions) over time, and analytical advances over time. Where differences in acceptable or tolerated concentrations are extreme between different guideline documents, it is suggested that the general/recommended guideline value provided in the current guidelines be applied, exercising some caution.

To relate laboratory toxicity studies to aquaculture operations is not a straightforward process. Many of the limitations and uncertainties are similar to those that apply when extrapolating laboratory toxicity data to natural aquatic ecosystems.[a] Some that are more specific to aquaculture operations include:

- aquaculture environments possess very different characteristics to natural environments (e.g. avoidance is not an option, feed is often derived from external sources, culture species may be regularly handled, stocking densities may be higher than in natural environments);
- very few ecotoxicological studies test aquaculture species;
- tolerance to individual contaminants is very variable between aquaculture species, even within the species groups outlined in table 4.4.1;
- toxicity test durations (i.e. usually ≤96 h) are not applicable to aquaculture operations, where organisms are constrained to an area and particular water quality for periods longer than toxicity test durations.

[a] See Section 9.4.4 for more detail

4.4.7 Priorities for research and development

As these guidelines are the first synthesis of water quality information for the aquaculture industry in Australia and New Zealand, a substantial number of information gaps and research needs have been identified. These are described in full in Section 9.4.5 (Volume 3).