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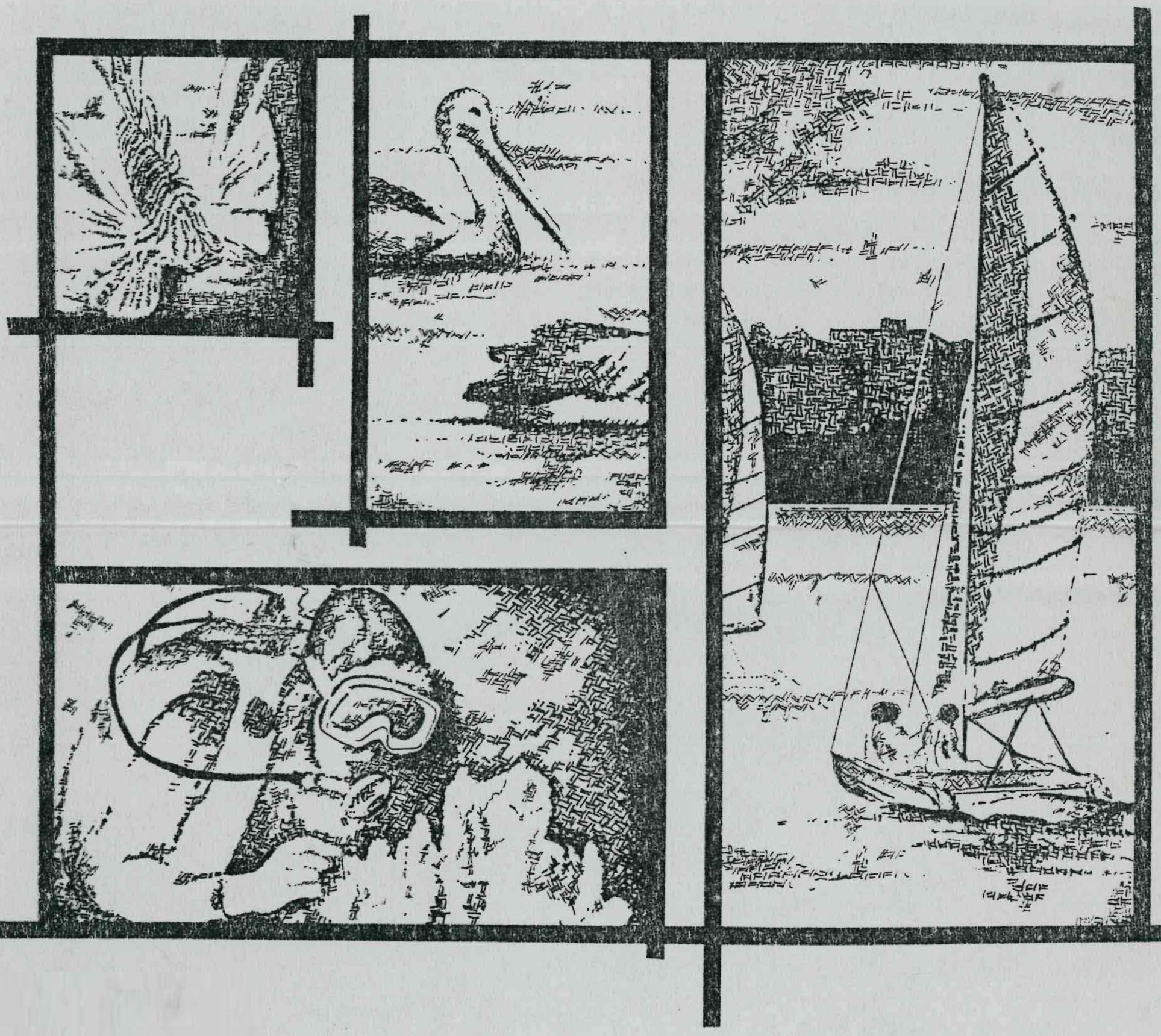
WESTERN AUSTRALIAN WATER QUALITY GUIDELINES FOR FRESH AND MARINE WATERS

adapted from the *Australian Water Quality Guidelines for Fresh and Marine Waters* (ANZECC 1992)



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PREFACE

The *Australian Water Quality Guidelines for Fresh and Marine Waters (ANZECC 1992)* was developed by the Australian and New Zealand Environment and Conservation Council (ANZECC) over a period of three years and was released in November 1992 after two rounds of extensive public consultation. The national document collates a vast body of scientific information and management experience on the water quality required to sustain the range of environmental values that Australian waters may support. In the development of the national guidelines, ANZECC recognised that a set of water quality guidelines cannot hope to apply to the whole range of water environments across Australia without modification to address local conditions.

In line with this, the *Western Australian Water Quality Guidelines for Marine and Fresh Waters* are a modified version of the Australian Guidelines. Deviations from the national document are minor and largely confined to Tables 2.1, 2.5 and 2.6. The changes have been restricted to additional parameters being included or a lowering of some of the guidelines suggested by ANZECC to make them more appropriate to local conditions and more consistent with the *Water Quality Criteria for Marine and Estuarine Waters of Western Australia* (Bulletin 103, Department of Conservation and Environment, 1981) which were developed specifically for Western Australian conditions.

This approach ensures that less stringent guidelines than those that are currently used are not applied by adopting the national guidelines in their entirety and is therefore consistent with the objective of the *National Water Quality Management Strategy* being developed cooperatively by ANZECC and the Australian Water Resources Council (AWRC) which is to '...achieve the sustainable use of the nation's water resources by protecting and enhancing their quality while maintaining economic and social development'.

The *Western Australian Water Quality Guidelines for Fresh and Marine Waters* provides the most up to date and comprehensive set of guidelines available for the range of aquatic environments found in Western Australia and, as such, should be regarded as the primary reference for dealing with water quality issues in this State.

ACKNOWLEDGEMENTS

Material included in this document is largely drawn from the *Australian Water Quality Guidelines for Fresh and Marine Waters* (ANZECC 1992), produced by the Australian and New Zealand Environment and Conservation Council, and this is duly acknowledged.

1. INTRODUCTION

Practically all of our activities affect the environment in some way. Society produces waste and currently most of this waste ultimately enters the environment. At the same time modern communities expect a clean, healthy environment.

The aim of the National Water Quality Management Strategy being jointly developed by the Australian and New Zealand Environment and Conservation Council (ANZECC) and the Australian Water Resources Council (AWRC) is to:

> *...achieve the sustainable use of the nation's water resources by protecting and enhancing their quality while maintaining economic and social development.* (ANZECC/AWRC 1992)

Although it is now technically possible to recycle much of the waste generated by society, even with the best recycling programs some proportion will always require disposal to the environment and a significant amount will enter inland or coastal water bodies. No matter how small the quantity of waste discharged, it will change that receiving environment in some way. Ecologically sustainable development depends upon ensuring that change is maintained within levels that are acceptable to society.

The level of change in a water body that is acceptable to society is determined after all existing and predicted future uses of that waterbody have been considered from a total community perspective. In areas that are clearly valuable to the community, such as conservation reserves, or drinking-water supply catchments, the level of acceptable change would generally be less than in waters used solely for other purposes such as commercial and industrial activities.

Every water body is used or valued in some way by society. In water quality management terms these community uses or values of the environment have been called Prescribed Uses, Beneficial Uses and Environmental Values. These terms are largely synonymous. ANZECC has adopted the term environmental value and has identified five such values:

- ecosystem protection (both inland and marine), including protection of waters used for shellfish and fish production and by wildlife;
- recreation and aesthetics;
- raw water for drinking water supply;
- agricultural water;
- industrial water.

The 16 Beneficial Uses defined in the *Water Quality Criteria for Marine and Estuarine Waters of Western Australia* (DCE 1981) are now categorised within these five Environmental Values. A guide for cross-referencing between Environmental Values and Beneficial Uses is provided below:

Table 1.1 Comparison between environmental values (used herein) and beneficial uses (Bulletin 103, DCE, 1981)

Environmental Value (this document)	Beneficial Use (Bulletin 103, DCE, 1981)
Protection of Aquatic Ecosystems	Harvesting of Aquatic Life (excluding Molluscs) for food Harvesting of Molluscs for food Harvesting of Aquatic Life for Non-edible Uses Passage of Fish and Other Aquatic Life Aquaculture of All Forms Maintenance and Preservation of Aquatic Ecosystems Maintenance and Preservation of Foreshores and Banks Scientific and Educational Uses Flushing Water and Water Replenishment
Recreational Water Quality and Aesthetics	Direct Contact Recreation
Raw Water for Drinking Water Supply	Potable Water Production
Agricultural Water Use	Agricultural Water Supply
Industrial Water Quality	Recovery of Minerals Industrial Water Supply Power Generation Navigation and Shipping

Each environmental value has a suite of physical, chemical and biological guidelines which, if exceeded, would result in that environmental value not being maintained. It should be noted that these water quality guidelines apply to ambient water quality and not to effluent quality.

However, even when the most stringent effluent limits are set and strict waste minimisation is practiced, effluents may be of poorer quality than the receiving water quality objectives. In these cases, it has been the practice of water quality managers to use the concept of the 'mixing zone', an explicitly defined area around an effluent discharge where certain environmental values are not protected. Effective discharge controls that consider both the concentration and the total mass of pollutants, combined with *in situ* dilution and waste treatment, should insure that the area of a mixing zone is limited and the values of the waterbody as a whole are not prejudiced. The environmental conditions within a mixing zone, and its size, are important community concerns, particularly because degraded areas around effluent discharges reduce the environmental benefits to the community.

1.1 APPLICATION OF THESE GUIDELINES

There are two contrasting types of aquatic ecosystem covered by these guidelines; 'marine' and 'freshwater'. Separate guideline values are provided for these two categories where appropriate. However, when applying these guidelines it must be recognised that there is a range of ecosystem types within each of these two basic categories, and each will respond uniquely to the same loadings or concentrations of pollutants.

Given the size of Western Australia and the range of aquatic environments contained within it, and the considerations discussed above, it is essential that local factors be taken into account when deriving water quality objectives or taking management action based on these guidelines.

1.1.1 Control approaches for different pollutant types

All chemical pollutants can be placed into two broad groups:

- *biostimulants*: primarily the nutrients nitrogen and phosphorus, and
- *toxicants*: such as heavy metals and PCB's

The ecological effect of these two groups of pollutants are quite different and therefore require different management approaches.

Toxicants
The extent to which most toxic substances affect aquatic biota is related to their concentration in water and extent to which they are bioaccumulated in certain organisms or biomagnified as they are passed along the food chain.

The suite of toxicants can be further subdivided into two groups; those that occur naturally, and those that are synthetic.

Naturally occurring substances
Most aquatic organisms have evolved a degree of resilience to the effects of toxic substances that are naturally occuring in the environment. Adverse effects do occur however when concentrations exceed certain critical thresholds. Therefore the best approach for managing the environmental impacts of these substances is through the application of water quality guidelines which are based on toxicological studies and include appropriate safety factors. These safety factors balance the degree of uncertainty in applying laboratory based relationships to complex ecosystems (see Section 1.2.).

Synthetic substances
The development of appropriate guidelines for synthetic substances is more problematic. Aquatic biota have not had the opportunity to evolve a natural degree of tolerance to synthetic substances as they only occur in nature as a result of human activities. In addition, there is limited scientific knowledge enabling predictions to be made of the short and long-term effects of most synthetic substances at the ecosystem level. This was dramatically demonstrated by the unforeseen bioaccumulatory effects of DDT which was first documented in the early 1960's. More recently, widespread effects of very low concentrations of TBT on gastropod populations have been reported and led to the ban or reduction of use of this antifoulant in most countries.

In keeping with the precautionary principle, extreme caution must be applied when determining 'safe' ambient concentrations for synthetic toxic substances; the safest control approach for the pollutants that do not occur naturally in the environment is containment/destruction.

Biostimulants
Nutrients are not toxic, except at very high concentrations. Instead of causing ecological change by retarding growth or causing mortality, they have the opposite

effect, they can stimulate nuisance plant growth which in itself is ecological change. Nutrients do not remain in solution for long as they are rapidly stripped out and assimilated by the plants making a nutrient concentration based management approach ineffective. A cumulative load or assimilative capacity based approach linking nutrient loadings and environmental response is a necessary management tool.

The 'Assimilative Capacity' or 'Critical Load' approach (see Masini et al. 1992) is to define the ecosystem boundary, quantify total cumulative load of nutrients to that ecosystem from all sources, identify the key pathway of nutrient conversion into organic matter and to link this with the the most sensitive/important component of the ecosystem in question. It is this final relationship, between nutrient load to the system and ecological response of the system that provides the information required to set appropriate loading limits.

This approach accommodates the error associated with the assimilative capacity estimate by using the lower error bound (the working assimilative capacity) as the initial maximum permissible load, coupled with tactical monitoring programs and periodic review. The combination of prediction, acknowledgment of uncertainty, monitoring and review allows management strategies the flexibility to be adapted to an improved knowledge base provided by well planned monitoring programs. This is the approach favoured by the WAEPA for managing nutrient effects on aquatic ecosystems.

Given the historical use and connotations applied to the term 'assimilative capacity', modern usage of this term should be restricted to the management of nutrient pollution and used within the context of cumulative impact and acceptable ecological change. This latter concept acknowledges that the system will change no matter how small the additional anthropogenic nutrient loading.

A range of nutrient concentrations appear in the section on Protection of Aquatic Ecosystems (ANZECC 1992) and have been reproduced here. These nutrient concentration ranges are not intended to be guidelines rather they provide a general indication of the range of concentrations that might be expected in four broad ranges of waterbody type ranging from rivers and streams to coastal waters.

1.2 DEVELOPMENT OF THE GUIDELINES

1.2.1 Definitions

The term 'guideline,' as adopted by ANZECC and used herein, is largely synonymous with the term 'criteria' as used previously in Western Australia (DCE 1981). The definitions, as used in ANZECC (1992), are briefly outlined below:

Criteria are the scientific and technical information used to provide an objective means for judging the quality needed to maintain a particular environmental value. Generally, they are the results of laboratory based toxicological studies of various pollutants on single species under controlled conditions.

Guidelines translate the Criteria into a form that can be used for management purposes. In many cases this will involve some value judgement on an acceptable

risk to human health or ecosystem impairment. (ie. incorporating an appropriate safety factor.)

Standards are what guidelines (perhaps further modified by social, political and/or economic considerations) become when compliance is enforced by law.

1.2.2 Rationale

The criteria and other information on which these guidelines have been derived are generally not referenced or discussed here. The users of these guidelines are refered to the national document (ANZECC 1992) for relevant background information on the derivation of each guideline unless otherwise stated.

PHYSICO-CHEMICAL INDICATORS

The physico-chemical indicators have been separated into two groups: toxic and bioaccumulated chemicals and other physico-chemical indicators.

Toxic and bioaccumulated chemicals
The rationale used by ANZECC (1992) in developing appropriate guidelines for toxic and bioaccumulated chemicals is reproduced below:

- All components of the aquatic ecosystem (e.g. phytoplankton, zooplankton, benthos, macrophytes, fish) were considered where data were available. When data were limited, tentative guidelines were deemed preferable to no guidelines.
- For all toxicants, an attempt was made to obtain a minimum set of acute and/or chronic toxicity data (defined by CCREM 1991, Appendix IX). In very few cases was it possible to obtain any toxicity data for indigenous Australian aquatic plants or animals, since there has been very little toxicity testing done here.
- The Canadian approach was followed to the extent that the guidelines are set:

  > . . . to protect all forms of aquatic life and all aspects of the aquatic life cycle . . . The intention is to protect all life stages during indefinite exposure to the water. *(CCREM 1991)*

  Overseas toxicity data were not considered if based on a single unsubstantiated value or a non-standard test.
- When only acute toxicity data were available, the following application factors were used to obtain 'safe' levels:
  - 0.05 x LC_{50} for materials that are non-persistent or are not accumulated;
  - 0.01 x LC_{50} for materials that are persistent or require additional caution because data are limited.
- Although it was recognised that natural variability should be considered in establishing guidelines for toxicants, it was considered that the detailed site-specific information needed to establish a statistical compliance level (e.g. 80 percentile, 95 percentile) must be obtained locally for each system.
- Analysis of the toxicant in an unfiltered sample is recommended. This approach is protective of the environment because it includes the measurement of forms of the toxicant that are unlikely to become biologically available. Analytical methods that measure the biologically active fractions directly are not

yet available (ANZECC 1992, Section 7.1.4). Again, there will be specific situations (e.g. extremely turbid rivers) where this approach may be overly cautious, but these should be assessed in the local context.

Other physico-chemical indicators

Depending upon geographical location, substantial differences can be found in the natural range of concentrations of indicators (such as salinity, dissolved and suspended solids and temperature) that occur naturally in aquatic systems. Local biological communities are adapted to local conditions. Thus, it is inappropriate to define guidelines for such water quality indicators without reference to local conditions.

BIOLOGICAL INDICATORS

Biological water quality assessment must become an essential tool of resource managers responsible for protecting aquatic ecosystems, as only these biological techniques can demonstrate that the integrity of the ecosystem is being maintained. The problems of natural spatial and temporal variability evident in physico-chemical indicators are even more pronounced with biological indicators. Thus, it will never be possible to propose meaningful simple numerical indicators (such as diversity index values or biotic index values) and expect that the numerical values generated can be used as absolute indicators. Rather, any biological assessment must depend on local comparisons to assess the relative quality of two or more sites, or of a single site at a series of different times. For these reasons, it is appropriate here to recommend biological assessment methods but not to recommend the absolute values of indicator summary statistics.

1.3 WATER QUALITY GUIDELINES AND ECOSYSTEM MANAGEMENT

Water quality guidelines provide a useful and important tool for environmental management and are essential for managing the effects of toxic materials. But in terms of ecosystem protection, the quality of the water in a waterbody is only an indicator of ecosystem health and should not be considered in isolation of the other components of the ecosystem. Biological indices such as, species diversity, species richness, the status of the sediments, are all important indices of ecosystem health in their own right, but are difficult to quantify on a generic level and hence set guidelines. These factors are ecosystem specific and it is up to the managers to understand the system they are protecting, choose appropriate indicators and manage from a broad rather than narrow perspective.

It is convenient to consider that compliance with water quality guidelines means that a particular waterbody is protected. Clearly this is not the case. There is a growing need to take aquatic ecosystem management further than just prescriptive monitoring and reliance on the types of measures of environmental health found in this document and explore alternative approaches. The aim is to develop a more holistic or ecosystem approach to environmental management of our water resources well into the next century. We must ensure that total loads of pollutants do not compromise environmental values. Total loads of toxicants must be such that the appropriate water quality guidelines are never exceeded. Total loads of biostimulants should be kept below the assimilative capacity so that the environmental values are not compromised.

The objective of the National Water Quality Management Strategy can be achieved if all activities are considered in terms of cumulative loads and cumulative impacts, a precautionary approach is adopted and tactical monitoring and management plans established that are designed to further reinforce our knowledge base and continually improve aquatic ecosystem management.

1.4 STRUCTURE OF THIS DOCUMENT

The structure of this document is consistent with the Australian Water Quality Guidelines for Marine and Fresh Waters (ANZECC 1992) to assist in cross-referencing between the two documents.

In addition to this introductory chapter, the Western Australian Water Quality Guidelines for Fresh and Marine Waters comprises five chapters, each covering one of the environmental values. These are abridged versions of the same chapters in ANZECC (1992). Chapter 2 covers ecosystem protection (both inland and marine), including protection of waters used for shellfish and fish production and for wildlife. Chapter 3 deals with water for recreation and aesthetic uses, Chapter 4 with raw water for drinking water supplies, Chapter 5 with agricultural water supplies, and Chapter 6 with industrial water supplies. Chapter 7 is taken directly from ANZECC (1992) and contains information on physico-chemical and biological methods for assessing water quality. A list of references is provided in the Appendix.

It is strongly recommended that the national document be consulted to provide further information and due perspective on the guidelines contained herein before management decisions are formulated.

2. PROTECTION OF AQUATIC ECOSYSTEMS

Aquatic ecosystems comprise the plant, animal and microbial communities that live in water and the physical environment and climate regime with which they interact.

This chapter specifies guidelines for the protection of freshwater and marine aquatic ecosystems.

The guidelines required to protect aquatic ecosystems are often the most stringent, and generally ensure that other related environmental values, such as edible fish and shellfish, and wildlife, are also protected. For this reason, the guidelines for edible fish and crustacea, shellfish culture and harvesting, and maintenance of wildlife have been included in this chapter. It is assumed that the general guidelines relevant to protection of an ecosystem (freshwater or marine) will be maintained for each of these environmental values.

The need for a broader, more holistic approach to ecosystem management was foreshadowed in Chapter 1. Such an approach would require consideration of all changes, not just those affecting the quality of the water compartment. Such changes could include seriously polluted sediments, reduction in stream flow (from damming and building of barriers), removal of habitat (de-snagging, draining wetlands) or significant catchment land use changes, any of which could cause significant deterioration of the ecosystem. The water quality guidelines documented here are a necessary, but only partially sufficient, tool for ecosystem management.

2.1 BIOLOGICAL FACTORS

It is recommended that four biological factors be used to assess the condition of ecosystem health: species richness, species composition, primary production and ecosystem function (estimated from the change in the production to respiration [P:R] ratio).

2.1.1 SPECIES RICHNESS

In any waterbody, the species richness of the predominant macrophyte, periphytic, phytoplanktonic, benthic and planktonic invertebrate or vertebrate assemblages, as measured by an appropriate standardised index, should not be altered.

2.1.2 SPECIES COMPOSITION

In any waterbody, impacts that result in significant changes in species composition compared with those in similar, local unimpacted systems should not be permitted.

2.1.3 PRIMARY PRODUCTION

In any waterbody, net primary production should not vary from the levels encountered in similar, local unimpacted habitats under similar light, temperature and nutrient loading regimes.

2.1.4 ECOSYSTEM FUNCTION

In any waterbody, changes that vary the relative importance of the detrital and grazing food chains should be minimised. Production to respiration ratios should not vary significantly from those of similar, local unimpacted systems.

2.2 NUTRIENTS, CHLOROPHYLL-A AND/OR NUISANCE PLANT GROWTH

General

Plant growth (via photosynthesis) is primarily dependent on sunlight and certain inorganic nutrients, and can be summarised by the following simplified equation:

$$\text{Sunlight} + 106\,CO_2 + 16NO_3^- + HPO_4^{2-} + 122\,H_2O + 18H^+ + (\text{trace elements}) \rightarrow \{(CH_2O)_{106}(NH_3)_{16}(H_3PO_4)\}\ (\text{plant biomass})$$

Light input or the supply of biologically available nitrogen and/or phosphorus usually limits biomass production. The most biologically available (bioavailable) form of phosphorus is orthophosphate (PO_4^{3-}) and the most bioavailable forms of nitrogen are ammonia (NH_3) and nitrate (NO_3^-).

Algal problems in estuarine and coastal regions generally occur in the upper and lower estuarine areas and in confined embayments and coastal lakes. The problems of the Peel/Harvey estuary, the Albany Harbours and Cockburn Sound are well documented and provide useful insight into the symptoms and causes of eutrophication in Western Australian ecosystems.

It is not possible to recommend a single set of nitrogen and phosphorus concentrations that will prevent phytoplankton problems in rivers and estuaries or macroalgal accumulations or loss of seagrasses in Western Australian aquatic ecosystems. Rather, it is strongly recommended that site-specific 'assimilative capacity' studies be undertaken to determine appropriate loadings for each particular system.

The concentration values or ranges listed below are provided as an indication of levels at or above which problems have been known to occur, depending upon a range of other factors.

Rivers and streams

The indicative concentration values or ranges are:

- Total-P 10–100 µg/L
- Total-N 100–750 µg/L.

Lakes and reservoirs

The classifications provided in Table 2.1 to assist Australian reservoir and lake managers are based on chlorophyll-a concentrations and are adapted from work reported by Quinn (1991) for New Zealand lakes.

Table 2.1 Annual mean and maximum chlorophyll-a concentrations for reservoirs and lakes

Annual mean (μg/L)	Annual maximum (μg/L)	Lake conditions
< 2	< 5	Oligotrophic, aesthetically pleasing, very low phytoplankton levels
2–5	5–15	Some algal turbidity, reduced aesthetic appeal, some oxygen depletion
5–15	15–40	Obvious algal turbidity, reduced aesthetic appeal, oxygen depletion
> 15	> 40	Eutrophic, high levels of phytoplankton growth, significantly reduced aesthetic appeal, serious oxygen depletion in bottom waters, reduction in other uses

The indicative concentration ranges are:

- Total-P: 5–50 μg/L
- Total-N: 100–500 μg/L
- Chlorophyll-a: 2–10 μg/L.

Estuaries and coastal waters

The indicative concentration values or ranges are:

	Estuaries & embayments	*Coastal waters*
• PO_4-P	5–15 μg/L	1–10 μg/L
• NO_3-N	10–100 μg/L	10–60 μg/L
• NH_4-N	< 5 μg/L	< 5 μg/L
• Chlorophyll-a	1–10 μg/L	< 1 μg/L.

2.3 TOXICANTS

The guidelines in this section relate to median concentrations of toxicants in unfiltered samples. They should be taken as guidance values only and, where possible, should be modified to reflect the actual conditions existing in the specific ecosystem. In addition, it is known that certain mixtures of heavy metals can have a toxicity greater than the added individual toxicities (synergism), and other combinations a reduced toxicity (antagonism). The present guidelines do not consider the possibility of these effects. If all toxicants were present at close to their guideline values, significant combined effects could be expected (Enserink et al. 1991). Where possible, waste dischargers should undertake toxicity testing of their effluents.

Table 2.2: Summary guidelines for protection of aquatic ecosystems

Indicator	Units	Fresh waters	Marine waters
Biological		It is premature to recommend specific values for these indicators. The need for biological evaluation is recognised, and these indicators are identified as important characteristics of ecosystem function (Section 2.2)	
Physico-chemical			
Colour & clarity		< 10% change in euphotic depth[1]	< 10% change in euphotic depth
Dissolved oxygen[2]	mg/L	> 6 (> 80–90% saturation)	> 6 (> 80–90% saturation)
Nutrients/nuisance growths		(Section 2.2)	(Section 2.2)
pH		6.5–9.0	< 0.2 pH unit change
Salinity	mg/L	< 1000 (about 1,500 mS/cm)	< 5% variation from background
Suspended particulate matter/turbidity		< 10% change seasonal mean concentration	< 10% change seasonal mean concentration
		(see also colour & clarity)	(see also colour & clarity)
Temperature[3]		< 2°C increase	< 2°C increase
Toxicants	all µg/L		
Inorganic toxicants			
Aluminium		< 5.0 (if pH < = 6.5) < 100.0 (if pH > 6.5)	NR
Ammonia		20.0–30.0 (Table 2.3)	NR
Antimony		30.0	500.0
Arsenic		50.0	50.0
Beryllium		4.0[4]	NR
Cadmium		0.2–2.0[5]	2.0
Chromium		10.0	50.0
Copper		2.0–5.0[5]	5.0
Cyanide		5.0	5.0
Fluoride		NR	2000.0*
Iron		1,000.0[6]	NR
Lead		1.0–5.0[5]	5.0
Mercury		0.1	0.1
Nickel		15.0–150.0[5]	15.0
Selenium		5.0	70.0
Silver		0.1	0.45*
Sulfide		2.0	2.0
Thallium		4.0	20.0
Tin (tributyltin)		0.008	0.002
Zinc		5.0–50.0[6]	20.0*
Organic toxicants			
Acrylonitrile		NR	NR
Benzidine		NR	NR
Dichlorobenzidine		NR	NR
Diphenylhydrazine		NR	NR
Surfactants		*0.05 times the ninety-six hour LC_{50} determined in the receiving water, on the most sensitive important species in the region.*	

Table 2.2 cont.: Summary guidelines for protection of aquatic ecosystems

Indicator	Units	Fresh waters	Marine waters
Halogenated aliphatic compounds			
Hexachlorobutadiene		0.1	0.3
Halogenated ethers		NR	NR
Hydrocarbons (total)**		NR	10.0*
Isophorone		NR	NR
Monocyclic aromatic compounds			
Benzene		300.0	1.0*
Chlorinated benzenes		(Table 2.4)	NR
Chlorinated phenols		(Table 2.5)	(Table 2.5)
Phenol		50.0	50.0
Toluene		300.0	NR
Nitrosamines		NR	NR
Pesticides			
Organochlorine		(Table 2.6)	(Table 2.6)
Organophosphate		(Table 2.6)	(Table 2.6)
Acrolein		0.2	0.2
Phthalate esters			
di-n-butylphthalate		4.0	NR
di(2-ethylhexyl)phthalate		0.6	NR
other phthalate esters		0.2	NR
Polyaromatic hydrocarbons			
Chlorinated naphthalenes		NR	NR
Polychlorinated biphenyls		0.001	0.001*
Polychlorinated dibenzo-*p*-dioxins		NR	NR
Polycyclic aromatic hydrocarbons		3.0	3.0

SPM: Suspended particulate matter; NR: no recommendation made at this time

Notes

1. For systems where depth is greater than 0.5 x euphotic depth (z_{eu}). For waters shallower than 0.5 z_{eu}, the maximum reduction in light at the sediment bed should not exceed 20%
2. Measured over at least one, but preferably several, diurnal cycles
3. Or use formula in Section 2.3.7 (ANZECC 1992); no data for temperature reductions
4. Higher values may be acceptable in hard waters
5. Depends upon hardness of water
6. Provided iron not present as Fe(II)

* Bulletin 103, DCE (1981)

** Interim guideline only

Table 2.3: Recommended guidelines for total ammonia concentration (mg/L as NH_3)

pH	Ammonia concentration at temperatures (°C)						
	0	5	10	15	20	25	30
6.5	2.5	2.4	2.2	2.2	1.49	1.04	0.73
6.75	2.5	2.4	2.2	2.2	1.49	1.04	0.73
7.0	2.5	2.4	2.2	2.2	1.49	1.04	0.74
7.25	2.5	2.4	2.2	2.2	1.5	1.04	0.74
7.5	2.5	2.4	2.2	2.2	1.5	1.05	0.74
7.75	2.3	2.2	2.1	2.0	1.4	0.99	0.71
8.0	1.53	1.44	1.37	1.33	0.93	0.66	0.47
8.25	0.87	0.82	0.78	0.76	0.54	0.39	0.28
8.5	0.49	0.47	0.45	0.44	0.32	0.23	0.17
8.75	0.28	0.27	0.26	0.27	0.19	0.16	0.11
9.0	0.16	0.16	0.16	0.16	0.13	0.1	0.08

Source: USEPA (1985g)

Table 2.4: Recommended guidelines for chlorinated benzenes in fresh waters. (There were insufficient data to establish numerical limits for the different chlorobenzenes in salt water (USEPA 1986)).

Chlorinated benzene	Guideline (µg/L)
Monochlorobenzene	15.0
1,2-dichlorobenzene	2.5
1,3-dichlorobenzene	2.5
1,4-dichlorobenzene	4.0
1,2,3-trichlorobenzene	0.9
1,2,4-trichlorobenzene	0.5
1,3,5-trichlorobenzene	0.7
1,2,3,4-tetrachlorobenzene	0.1
1,2,3,5-tetrachlorobenzene	0.1
1,2,4,5-tetrachlorobenzene	0.2
Pentachlorobenzene	0.03
Hexachlorobenzene	0.007

Source: adapted from CCREM (1991)

Table 2.5: Recommended guidelines for chlorinated phenols in fresh and marine waters

Chlorinated phenol	Guideline (µg/L)	
	Fresh water	Salt water
Monochlorophenol	7.0	–
2,4-dichlorophenol	0.2	–
Trichlorophenol (total)	18.0	–
2,4,5-trichlorophenol	–	8.0
Tetrachlorophenol	1.0	–
Pentachlorophenol	0.05	0.2

– Insufficient data
Sources: CCREM (1991), USEPA (1986, 1987d)

Pesticides

The developed guidelines given in Table 2.6 are primarily based on those proposed by Nicholson (1984), USEPA (1986) and CCREM (1991). Where no guidelines were available, the lowest acute or chronic toxicity level was reduced by factors of 0.001 and 0.01 respectively to establish a guideline.

Table 2.6: Recommended maximum concentrations for pesticides in unfiltered water samples

Pesticides	Guideline (ng/L)	
	Fresh water	Salt water
Organochlorines		
Aldrin*	2	2
Chlordane	4	4
DDE	14	14
DDT*	0.5	0.5
Dieldrin	2	2
Endosulfan*	0.7	0.7
Endrin	3	3
Heptachlor*	0.3	0.3
Lindane	3	3
Methoxychlor	40	40
Mirex	1	1
Toxaphene	8	8
Organophosphates		
Chlorpyrifos	1	1
Demeton	100	100
Guthion (Azinphos-methyl)	10	10
Malathion	70	100
Parathion	4	4
Other pesticides		
Acrolein	200	200

Sources: adapted from Nicholson (1984), USEPA (1986), CCREM (1991)

* Different to ANZECC (1992), consistent with Nicholson (1984).

2.4 WATER QUALITY GUIDELINES FOR THE PRODUCTION OF EDIBLE FISH, CRUSTACEA AND SHELLFISH

Guidelines for the protection of edible fish, crustacea and shellfish may be divided into two categories: those for the protection of the aquatic organisms and those for the protection of the human consumer.

2.4.1 GUIDELINES FOR THE PROTECTION OF FISH, CRUSTACEA AND SHELLFISH

Water quality guidelines are necessary to determine optimum environmental conditions for the growth and reproduction of edible fish, crustacea and shellfish. The guidelines for the protection of these species are generally those in Table 2.2.

2.4.2 GUIDELINES FOR THE PROTECTION OF THE HUMAN CONSUMER

Toxicants

Minimal risk concentrations in the water are required to protect consumers from toxicants that may accumulate in the tissue of fish, crustacea and shellfish, either directly from the water or by biomagnification in the food chain. If the guidelines for the protection of aquatic ecosystems given in Table 2.2 do not protect the human consumer, lower concentration levels of the toxicant concerned are listed in Table 2.7. If a toxicant is not listed in Table 2.7, the value given for the protection of aquatic ecosystems will also protect the human consumer.

Bacteria

In addition to toxicants, bacterial guidelines may also be important, especially if the organisms are eaten raw; for example, shellfish consumption has been implicated in transmitting infectious hepatitis in humans. Guidelines for bacteria are listed under biological indicators in Table 2.7. Biotoxins that can cause poisoning of the consumer are also listed in Table 2.7.

Tainting substances

Deterioration of the palatability of fish, crustacea and shellfish could have serious economic impacts on the fishing and harvesting industries. The chemical compounds found to cause tainting of the flesh of fish and other aquatic organisms are summarised in Table 2.8. The values given provide information on possible sources of tainting and the concentrations at which tainting will occur. The concentrations quoted should not be used as guideline levels for ecosystem protection.

2.5 GUIDELINES FOR THE PROTECTION OF WATER-ASSOCIATED WILDLIFE

In this document, wildlife is defined as all species of vertebrates other than fish and humans that depend on aquatic environments for drinking water, food or habitat requirements.

2.5.1 PROTECTION OF DRINKING WATER FOR WILDLIFE

Generally, the guidelines given for the protection of aquatic ecosystems (Section 2.1) will be sufficient to protect wildlife from detrimental effects associated with drinking contaminated water.

Table 2.7: Guidelines for the protection of human consumers of fish and other aquatic organisms

Indicator	Guideline (µg/L, if not otherwise stated)
Biological Indicators:	
Algae	No guideline. Toxins may be present in cyanobacteria and may be accumulated in other aquatic organisms
Biotoxins:	
Gonyaulax (=Alexandrium) toxins	< 0.8 µg/g shellfish
Ciguatera-like toxins	< 20 mouse units/100 g shellfish
Faecal 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.
Toxicants:	
Arsenic	0.02*
Beryllium	0.1*
Cadmium**	0.2[1]
Chromium (total)**	2.0[2]
Copper**	4.0[3]
Lead**	1.3[4]
Manganese	100.0
Nickel	100.0
Acrylonitrile	0.7*
Benzidine	0.0005*
Dichlorobenzidine	0.02*
Diphenylhydrazine	0.6*
Halogenated aliphatic compounds	
Chlorinated ethanes:	
1,2-dichloroethane	240.0*
1,1,2-trichloroethane	40.0*
1,1,2,2-tetrachloroethane	11.0*
Hexachloroethane	9.0
Chlorinated ethylenes	
Chloroethylene (vinyl chloride)	530.0*
1,1-dichloroethylene	2.0*
Trichloroethylene	80.0*
Tetrachloroethylene	9.0*
Halogenated methanes	
Carbon tetrachloride	7.0*
Chloroform	16.0
Other halogenated methanes	16.0*
Halogenated ethers	
bis(chloromethyl) ether	0.002*
bis (2-chloroethyl) ether	1.0*
Monocyclic aromatic compounds	
Benzene	40.0*
Chlorinated benzene	
1,2,4,5-tetrachlorobenzene	50.0
Pentachlorobenzene	80.0
Hexachlorobenzene	0.0007*

Table 2.7 cont.: **Guidelines for the protection of human consumers of fish and other aquatic organisms**

Indicator	Guideline (µg/L, if not otherwise stated)
Chlorinated phenols	
2,4,6-trinitrophenol	4.0*
Dinitrotoluene	9.0*
Nitrosamines	
N-nitrosodiethylamine	1.0*
N-nitrosodimethylamine	16.0*
N-nitrosodibuthylamine	0.6*
N-nitrosopyrrolidine	90.0*
N-nitrosodiphenylamine	16.0*
Pesticides	
Aldrin	0.08 ng/L*
Chlordane	0.5 ng/L*
DDT	0.03 ng/L*
Dieldrin	0.08 ng/L*
Heptachlor	0.3 ng/L*
PAH	0.03*
2,3,7,8-tetrachlorodibenzodioxin	0.00001 ng/L*
Radionuclides	0.4 Bq/L

MPN: Most probable number
* Potential carcinogen, risk level 1:1,000,000
Sources: adapted from USEPA (1986), NAS/NAE (1973), IWBDE (1972)
** Additional parameters to those in ANZECC (1992)
1 Talbot (1985)
2 Klapow and Schueller (1977)
3 Talbot et al (1985)
4 Talbot (1987)

Table 2.8: **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-dichlorophenol	0.0001-0.014

Table 2.8 cont.: **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)
2,5-dichlorophenol	0.02
2,6-dichlorophenol	0.03
3,4-dichlorophenol	0.0003
2-methyl-4-chlorophenol	2.0
2-methyl-6-chlorophenol	0.003
3-methyl-4-chlorophenol	0.02-3
o-phenylphenol	1.0
Pentachlorophenol	0.03
Phenol	1-10
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: adapted from NAS/NAE (1973)

2.5.2 PROTECTION OF FOOD FOR WILDLIFE

Many wildlife species are predators and, therefore, very vulnerable to substances that can bioaccumulate along the food chain. In these instances, environmental levels that are safe for fish and invertebrates do not necessarily convey safety for predators or even for scavengers that consume aquatic organisms. Stringent guidelines may therefore be required for the protection of wildlife from pollutants that are able to concentrate along the food chain. Many toxicants are known to bioconcentrate (Section 2.1), but little is known regarding the effects on the predator organisms. Table 2.9 summarises some well-known toxicants that can accumulate along the food chain.

Table 2.9: Guidelines for toxicants that can accumulate along the food chain

Parameter	Guideline (concentration in food organisms, µg/g wet wt.)
DDT	1.0
PCB	0.5
Mercury	0.5

Sources: NAS/NAE (1973), USEPA (1976)

2.5.3 PROTECTION OF HABITAT REQUIREMENTS FOR WILDLIFE

Generally, the guidelines given in Table 2.2 will be sufficient to protect wildlife habitat requirements.

3. RECREATIONAL WATER QUALITY AND AESTHETICS

Water-based recreational activities are highly regarded by Australians. Water quality guidelines are therefore necessary to protect these waters for recreational activities, such as swimming and boating, and to preserve the waters' aesthetic appeal.

Sporting activities can be divided into two categories:

- sports in which the user comes into frequent direct contact with water, either as part of the activity or accidently; for example, swimming or surfing (primary contact);
- sports that generally have less-frequent body contact with the water; for example, boating or fishing (secondary contact).

A third recreational category concerns the passive recreational use of waterbodies, mainly as pleasant places to be near or to look at (no body contact). The relevance of the different water quality guidelines to the three recreational categories is shown in Table 3.1. The detailed water quality guidelines for recreational water are summarised in Table 3.2. The recommended guidelines rely on the guidelines developed by NHMRC (1990), with additional indicators included where appropriate.

Table 3.1: Water quality characteristics relevant to recreational use

Characteristics	Primary contact (e.g. swimming)	Secondary contact (e.g. boating)	Visual use (no contact)
Microbiological guidelines	x	x	
Nuisance organisms (e.g. algae)	x	x	x
Physical and chemical guidelines:			
Aesthetics	x	x	x
Clarity	x	x	x
Colour	x	x	x
pH	x		
Temperature	x		
Toxic chemicals	x	x	
Oil, debris	x	x	x

Table 3.2: Summary of water quality guidelines for recreational waters

Parameter	Guideline
Microbiological	
Primary contact	The median bacterial content in fresh and marine waters taken over the bathing season should not exceed 150 faecal coliform organisms/100 mL *(minimum of five samples taken at regular intervals not exceeding one month, with four out of five samples containing less than 600 organisms/100 mL);* or
	35 enterococci organisms/100 mL *(maximum number in any one sample: 60–100 organisms/100 mL.*
	Pathogenic free-living protozoans should be absent from bodies of fresh water.*
Secondary contact	The median value in fresh and marine waters should not exceed 1,000 faecal coliform organisms/100 mL *(minimum of five samples taken at regular intervals not exceeding one month, with four out of five samples containing less than 4,000 organisms/100 mL);* or
	230 enterococci organisms/100 mL *(maximum number in any one sample 450–700 organisms/100 mL).*
Nuisance organisms	Macrophytes, phytoplankton scums, filamentous algal mats, sewage fungus, leeches etc. should not be present in excessive amounts.
	Direct contact activities should be discouraged if algal levels of 15,000–20,000 cells/mL are present, depending on the algal species.
	Large numbers of midges and aquatic worms should also be avoided.
Physical and chemical	
Visual clarity & colour	To protect the aesthetic quality of a waterbody: • the natural visual clarity should not be reduced by more than 20%; • the natural hue of the water should not be changed by more than 10 points on the Munsell Scale; • the natural reflectance of the water should not be changed by more than 50%.
	To protect the visual clarity of waters used for swimming, the horizontal sighting of a 200 mm diameter black disc should exceed 1.6 m.
pH	The pH of the water should be within the range 5.0–9.0, assuming that the buffering capacity of the water is low near the extremes of the pH limits.
Temperature	For prolonged exposure, temperatures should be in the range of 15–35°C.
Toxic chemicals	Water containing chemicals that are either toxic or irritating to the skin or mucous membranes are unsuitable for recreation. Toxic substances should not exceed levels given for untreated drinking waters.
Surface films	Oil and petrochemicals should not be noticeable as a visible film on the water nor should they be detectable by odour.

* *(It is not necessary to analyse water for these pathogens unless the temperature is greater than 24°C.)*

3.1 RECREATIONAL CATEGORIES

3.1.1 PRIMARY CONTACT

Water used for primary contact activities, such as swimming, bathing and other direct water-contact sports, should be sufficiently free from faecal contamination, pathogenic organisms and other hazards (e.g. poor visibility or toxic chemicals) to protect the health and safety of the user. The general guidelines desirable for aquatic scenery are also applicable for water used for primary contact.

3.1.2 SECONDARY CONTACT

Water used for secondary contact activities, such as boating and fishing, should also meet the guidelines suggested for aquatic scenery. Since there is less body contact with the water, the microbiological guidelines can generally be lower, although not in cases when shellfish might be taken from the waterbody. To protect water-skiers from injury and boating vessels from damage, the water should be free from floating or submerged logs and stumps and excessive growth of algae and other aquatic plants. The quality of the water should be maintained so that there is minimal alteration of the fish habitat (Chapter 2).

3.1.3 VISUAL USE

Surface waters used for visual recreational use (no-contact activity) should not be altered in any way that reduces their ability to support aesthetically valuable flora and fauna. Such alteration may be physical, such as dredging and dam construction, or may be due to addition of wastes to the water. Visual impact of the surface waters is important; they should be free from:

- floating debris, oil, grease and other objectionable matter;
- substances that produce undesirable colour, odour, taste or foaming;
- undesirable aquatic life, such as 'algal blooms', or dense growths of attached plants or insects.

All these factors have to be considered in areas used for aquatic scenery.

4. RAW WATER FOR DRINKING WATER SUPPLY

The most authoritative guidelines for Australian drinking waters are contained in the document 'Guidelines for Drinking Water Quality in Australia', produced jointly by NHMRC and AWRC in 1987. These guidelines are presently being updated, and it is expected that the updating will be completed in 1993. It is proposed that, when they become available, ANZECC will undertake a review of the current values listed in this section.

The new NHMRC/AWRC drinking water guidelines are expected to be based largely on the most recent WHO guidelines, but with some changes to make them more relevant to Australian conditions. Some specific changes are expected in the area of pesticide concentrations in drinking waters, where NHMRC and AWRC have indicated that they still intend to rely on the Maximum Residue Level procedure, which was the basis for the existing guidelines (NHMRC/AWRC 1987). In addition, the range of pesticides considered will be extended. It must be emphasised that the NHMRC/AWRC drinking water guidelines relate to 'at tap water quality' while the ANZECC guidelines in this chapter relate to 'raw water quality'.

Many water supplies in Australia require treatment to make them either drinkable or suitable for domestic and industrial use. In this chapter, 'raw water for drinking water supply' refers to water that is used as the intake source for public use. The majority of Australians obtain their drinking water from piped water supplies, most of which include some form of treatment between the raw water supply and delivery to the user. The purpose of the treatment process is to provide the user with drinking water that is safe, palatable and aesthetically pleasing. A major reason to fully treat surface waters for drinking purposes is to improve the aesthetic characteristics rather than for direct health reasons.

4.1 RAW WATER QUALITY

Two types of raw water are considered in this chapter: raw water subjected to coarse screening only and raw water subjected to coarse screening and disinfection. Given the wide range of treatment methods that could be used in particular situations (e.g. coagulation, flocculation, filtration, ion exchange, reverse osmosis, carbon adsorption columns), it has not been possible to specify raw water quality guidelines for the many types of water quality that could be involved.

4.1.1 RAW WATER SUBJECTED TO COARSE SCREENING ONLY

The guidelines listed in Table 4.1 apply to raw water that is not treated prior to consumption apart from the removal of coarse debris. These 'raw water' guidelines need to serve two purposes: firstly, they should protect people who consume untreated water and, secondly, they should provide guidance for catchment

managers who require values against which they can evaluate the water quality in their particular area. Untreated water used for drinking water supplies that contains substances at concentrations higher than those given in Table 4.1 may result in deleterious health effects or objections from consumers on aesthetic grounds.

4.1.2 RAW WATER SUBJECTED TO COARSE SCREENING AND DISINFECTION

Slightly poorer quality, primarily due to microbiological contamination, may be acceptable in raw water that is to be disinfected prior to delivery to the consumer. Additional treatment technology, such as coagulation, flocculation and filtration prior to chlorination, or alternative disinfection methods, have not been considered.

Turbidity and dissolved organic carbon (DOC) are the two major features that need special consideration in raw waters to be chlorinated only. Turbidity or suspended particulate matter can interfere with the efficiency of the disinfection process, while chlorination of DOC can result in the formation of chlorinated organic compounds. Although adequate disinfection can occur where the raw water turbidity is elevated, this depends upon the chlorine concentration and the contact period used. In such cases, the disinfection efficiency should be determined on a site-specific basis. Since chlorination efficiency also depends on pH, it is recommended that the pH range be the same as that for raw waters not being treated. Insufficient information is available at this time to allow an appropriate guideline to be recommended for DOC concentrations in raw waters.

4.1.3 CATCHMENT MANAGEMENT

Where possible, raw water for drinking purposes should be protected by appropriate management of the catchment supplying the water. Water supplies of a better quality than that described in Table 4.1 should not be allowed to deteriorate to the guideline levels. Where the raw water quality is less than that specified in the guidelines, the preferred option is to improve catchment management practices so that water quality also improves. The alternative is to supply adequate treatment prior to delivery of the water to the consumer, with the degree and type of treatment required depending on the extent to which the existing water quality does not meet the guidelines. Although it is possible to provide suitable treatment for almost any standard of raw water, this will not necessarily be the most preferable option.

Table 4.1 Summary of quality guidelines for raw waters for drinking purposes subjected to coarse screening

Parameter	Guideline values (mg/L, unless otherwise stated)
Biological parameters	
Micro-organisms:	
Total coliforms	Up to ten coliform organisms may be occasionally accepted in 100 mL. Coliform organisms should not be detectable in 100 mL of any two consecutive samples. Throughout any year, 95% of samples should not contain any coliform organisms in 100 mL
Faecal coliforms	No sample should contain any faecal coliforms in 100 mL
Algae	Up to 5,000 cells/mL may be tolerated; levels of 1,000–2,000 cells/mL of cyanobacteria may result in problems
Toxic parameters	
Inorganic:	
Arsenic	0.05
Asbestos	NR
Barium	1.0
Boron	1.0
Cadmium	0.005
Chromium	0.05
Cyanide	0.1
Lead	0.05
Mercury	0.001
Nickel	0.1
Nitrate-N	10.0
Nitrite-N	1.0
Selenium	0.01
Silver	0.05
Organic:	
Benzene	10.0 µg/L
Benzo(*a*)pyrene	0.01µg/L
Carbon tetrachloride	3.0 µg/L
1,1-Dichloroethene	0.3 µg/L
1,2-Dichloroethane	10.0 µg/L
Pentachlorophenol	10.0 µg/L
Pesticides	(Table 4.2)
Polychlorinated biphenyls	0.1 µg/L
Tetrachloroethene	10.0 µg/L
2,3,4,6-Tetrachlorophenol	1.0 µg/L
Trichloroethene	30.0 µg/L
2,4,5-Trichlorophenol	1.0 µg/L
2,4,6-Trichlorophenol	10.0 µg/L
Radiological:	
Gross alpha activity	0.1 Bq/L
Gross beta activity (excluding activity of ^{40}K)	0.1 Bq/L
Aesthetic parameters	
Physical:	
Colour	15.0 Pt-Co
Taste & odour	Not objectionable*
Turbidity	Site-specific determinant

Table 4.1 cont.: Summary of quality guidelines for raw waters for drinking purposes subjected to coarse screening

Parameter	Guideline values (mg/L, unless otherwise stated)
Chemical:	
Aluminium	0.2
Ammonia (as N)	0.1
Chloride	400.0
Copper	1.0
Oxygen	> 6.5 (> 80% saturation)**
Hardness (as $CaCO_3$)	500.0
Iron	0.3
Manganese	0.1
Organics (CCE & CAE)	0.2
pH	6.5–8.5
Phenolics	0.002
Sodium	300.0
Sulfate	400.0
Sulfide	0.05
Surfactant (MBAS)	0.2
Total dissolved solids	1,000.0***
Zinc	5.0

NR No guideline recommended at this time; MBAS Methylene blue active substances

* Engineering & Water Supply Department suggests combined concentration of geosmin and methylisoborneol should be less than 20 ng/L

** For aesthetic reasons; however, low oxygen concentrations are normal in groundwater supplies and may cause no problems

*** Levels in excess of 500 mg/L cause a deterioration in taste

Table 4.2: Guideline values for pesticides in raw water

Compound	Maximum concentration* (µg/L)	Compound	Maximum concentration* (µg/L)
Acephate	20.0	Fenvalerate	40.0
Alachlor	3.0	Flamprop-methyl	6.0
Aldrin	1.0	Fluometuron	100.0
Amitrol	1.0	Formothion	100.0
Asulam	100.0	Fosamine (ammonium salt)	3,000.0
Azinphos-methyl	10.0	Glyphosate	200.0
Barban	300.0	Heptachlor	3.0
Benomyl	200.0	Hexaflurate	60.0
Bentazone	400.0	Hexazinone	600.0
Bioresmethrin	60.0	Lindane	10.0
Bromazil	600.0	Maldision	100.0
Bromophos-ethyl	20.0	Methidathion	60.0
Bromoxynil	30.0	Methomyl	60.0
Carbaryl	60.0	Metolachlor	800.0
Carbendazim	200.0	Metribuzin	5.0
Carbofuran	30.0	Mevinphos	6.0
Carbophenothion	1.0	Molinate	1.0
Chlordane	6.0	Monocrotophos	2.0
Chlordimeform	20.0	Nabam	30.0
Chlorfenvinphos	10.0	Nitralin	1,000.0
Chloroxuron	30.0	Omethoate	0.4
Chlorpyrifos	2.0	Oryzalin	60.0
Clopzralid	1,000.0	Paraquat	40.0
Cyhexatin	200.0	Parathion	30.0
2,4-D	100.0	Parathion-methyl	6.0
DDT	3.0	Pendimethalin	600.0
Demeton	30.0	Perfluidone	20.0
Diazinon	10.0	Permethrin	300.0
Dicamba	300.0	Picloram	30.0
Dichlobenil	20.0	Piperonyl butoxide	200.0
3,6-Dichloropicolinic acid	1,000.0	Pirimicarb	100.0
Dichlorvos	20.0	Pirimiphos-ethyl	1.0
Diclofop-methyl	3.0	Pirimiphos-methyl	60.0
Dicofol	100.0	Profenofos	0.6
Dieldrin	1.0	Promecarb	60.0
Difenzoquat	200.0	Propanil	1,000.0
Dimethoate	100.0	Propargite	1,000.0
Diquat	10.0	Propoxur	1,000.0
Disulfoton	6.0	Pyrazophos	1,000.0
Diuron	40.0	Quintozene	6.0
DPA	500.0	Sulprofos	20.0
Endosulfan	40.0	2,4,5-T	2.0
Endothal	600.0	Temephos	30.0
Endrin	1.0	Thiobencarb	40.0
EPTC	60.0	Thiometon	20.0
Ethion	6.0	Thiophanate	100.0
Ethoprophos	1.0	Thiram	30.0
Fenchlorphos	60.0	Trichlorofon	10.0
Fenitrothion	20.0	Triclopyr	20.0
Fenoprop	20.0	Trifluralin	500.0
Fensulfothion	20.0		

*Values applicable to episodic occurrences only; Sources: NHMRC/AWRC (1987), NHMRC (1989)

5. AGRICULTURAL WATER USES

Water supply for agricultural purposes is a significant determinant of agricultural productivity in many areas of Australia and, as such, indirectly influences important export industries. By world standards, agricultural communities in Australia often face severely limited quantities of water of suitable quality. The problem is compounded as the increasing pressures of urbanisation, industrialisation and agricultural practices themselves threaten the quality of these water resources.

5.1 IRRIGATION

Because of its low relief and latitude, two-thirds of Australia is arid or semi-arid. Irrigation using both surface water and groundwater plays an important role in satisfactory agricultural use of this land, and constitutes about 70% of the water use in Australia (Department of Primary Industries & Energy 1987). However, this use of water resources has, in many cases, introduced salt and other chemical and microbiological contaminants into soils and plants. These contaminants can cause alteration of the soil, death and disease of livestock and contamination of food products. In the long term, if the irrigation water adversely affects the soil's physical and chemical properties, crop yields will also not be sustained.

Factors influencing irrigation water quality guidelines

Specific water quality guidelines depend on a complex interaction of different factors. Three important factors should be considered in applying the guidelines for irrigation water (Table 5.1):

- *Soil*: Soil texture, structure and organic matter determine percolation of water, holding capacity and exchange capacity. Therefore, the degree to which the irrigation water and its components will be leached out, remain available to plants or become fixed and unavailable to plants, depends largely on the soil characteristics. Nevertheless, insufficient rationale has been published in the scientific literature to establish soil categories as a standard part of water quality guidelines.
- *Crops*: Crops vary widely in their sensitivity to toxic substances. The guidelines contained in Table 5.1 are set to protect the most sensitive crop.
- *Climate and management*: Evapotranspiration and rainfall determine the frequency of irrigation required. In general, the potential toxicity of the substances in the irrigation water increases as more frequent irrigation is required. Nevertheless, application of water in excess of crop needs may provide protection of the crop through leaching of salts from the plant root zone when drainage is unrestricted. The type of irrigation method used is also important (e.g. flood, furrow or sprinkler methods) for the sensitivity of crops to toxic substances in the irrigation water (VIRASC 1980).

Table 5.1: Summary of guidelines for irrigation water quality

Parameter	Guideline (mg/L, unless otherwise stated)	Comment
Biological parameters		
Plant pathogens	–	*
Human and animal pathogens	1,000 faecal coliforms/100 mL	Tentative value. Geometric (log) mean of not less than 5 water samples taken per month; no more than 20% should exceed 4,000 organisms/100 mL
Algae	Should not be visible	
BOD_5	–	No guideline recommended
Major ions		
Bicarbonate	–	No guideline recommended due to interaction with other factors
Chloride	30–700 (<100 for sensitive sp.) (Tables 5.2, 5.3, 5.4)	Maximum concentration should be set according to sensitivity of crop
Sodium	Soils: Figure 5.1; crops Table 5.5	
Total dissolved solids	Tables 5.6 and 5.7	
*Heavy metals and trace ions***		
Aluminium	5.0	High toxicity in acid soils
Arsenic	0.1	
Beryllium	0.1	
Boron	0.5–6.0	Table 5.8
Cadmium	0.01	Higher toxicity in acid soils
Chromium	1.0	Limit chromium (VI) concentration to 0.1 mg/L
Cobalt	0.05	
Copper	0.2	
Fluoride	1.0	
Iron	1.0	
Lead	0.2	
Lithium	2.5	Citrus: 0.075 mg/L
Manganese	2.0	If acid soils, limit to 0.2 mg/L
Mercury	0.002	
Molybdenum	0.01	
Nickel	0.2	
pH ($CaCl_2$)	4.5–9.0	
Selenium	0.02	
Uranium	0.01	
Vanadium	0.1	
Zinc	2.0	1 mg/L is recommended for sandy soil below pH 6
Pesticides		
Insecticides	–	No guidelines recommended
Herbicides	Table 5.9	
Radioactivity	Gross Alpha 0.1 Bq/L	
	Gross Beta 0.1 Bq/L	(excluding ^{40}K)

* All surface waters used in WA plant nurseries in *Phytophthora* susceptible areas must be chlorinated to 2 mg/L residual chlorine

** Higher maximum concentrations may be recommended in neutral to alkaline soils, as discussed in Chapter 5, ANZECC (1992).

Guidelines for irrigation waters

The recommended water quality guidelines (Table 5.1) rely heavily on the criteria developed by NAS/NAE (1973) and Hart (1974), but are supplemented with more recent information where available. These criteria assume an annual application rate of irrigation water of 1,000 mm and retention of trace ions in the surface in the top 15 cm of the soil. Under these conditions, the recommended concentration of ions in the irrigation water should allow irrigation for a minimum 100 years before any phytotoxic levels are reached in the soil. In some parts of Australia, application rates may be significantly higher or lower than this figure. In these areas it is recommended that the guideline values may be adjusted to accommodate different loading rates for contaminants and different leaching characteristics of the soils.

Table 5.2: Chloride tolerance of fruit and woody crops by root uptake

Rootstocks	Chloride in irrigation water (mg/L)	Cultivars	Chloride in irrigation water (mg/L)
Grapes	710–960	Boysenberry	250
Stone-fruits (peaches, plums, etc.)	180–600	Blackberry Raspberry	
Strawberries	110–180		

Sources: Westcot and Ayers (1984); CCREM (1991)

Table 5.3: Chloride concentrations in irrigation water causing foliar damage

Sensitivity	Chloride (mg/L)	Affected crop
Sensitive	< 178	Almond, apricot, plum
Moderately sensitive	178–355	Grape, pepper, potato, tomato
Moderately tolerant	355–710	Alfalfa, barley, corn, cucumber
Tolerant	> 710	Cauliflower, cotton, safflower, sesame, sorghum, sugar-beet, sunflower

Source: Westcot and Ayers (1984)

Table 5.4: Tolerance of chloride sensitive crops to chloride in irrigation water

Crop	Irrigation method	Maximum chloride concentrations (mg/L)
Citrus	Overhead sprinklers	100
	Under-tree sprinkler	265
Stone-fruit	Overhead sprinklers	70
	Under-tree sprinkler	175
Vines	–	350
Tobacco	Overhead sprinklers	30

Sources: Callinan (1970), Jones (1972), AWRC (1969)

Table 5.5: Tolerance of crops to sodium

Tolerance	SAR of irrigation water	Crop	Condition
Very sensitive	2–8	Deciduous fruits, nuts, citrus, avocado	Leaf tip burn, leaf scorch
Sensitive	8–18	Beans	Stunted, soil structure favourable
Moderately tolerant	18–46	Clover, oats, tall fescue, rice	Stunted due to nutrition and soil structure
Tolerant	46–102	Wheat, lucerne, barley, tomatoes, beets, tall wheat grass, crested grass, fairway grass	Stunted due to poor soil structure

Source: Hart (1974)

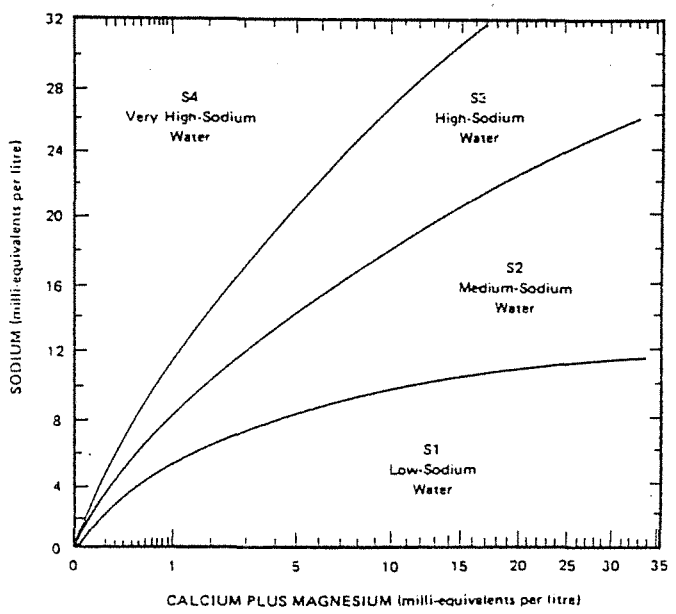

Figure 5.1: Water quality guidelines for sodium water

Notes:

Low-sodium water (S1) can be used for irrigation on almost all soils, with little danger of the development of a sodium problem. However, sodium-sensitive crops, such as stone-fruit trees and avocados, may accumulate harmful amounts of sodium in the leaves.

Medium-sodium water (S2) may present a moderate sodium problem in fine-textured (clay) soils unless there is gypsum in the soil. This water can be used on coarse-textured (sandy) or organic soils that take water well.

High-sodium water (S3) may produce sodium problems in most soils and requires special management, good drainage, high leaching and additions of organic matter. If there is plenty of gypsum in the soil, a serious problem may not develop for some time. If gypsum is not present it, or some similar material, may have to be added.

Very high-sodium water (S4) is generally unsatisfactory for irrigation except at low-salinity or medium-salinity levels, where the use of gypsum or some other additives makes it possible to use such water.

Table 5.6: General guidelines for salinity of irrigation water

Class	Comment	Electrical conductivity (µS/cm)	TDS (mg/L)*
1	Low-salinity water can be used with most crops on most soils and with all methods of water application with little likelihood that a salinity problem will develop. Some leaching is required, but this occurs under normal irrigation practices except in soils of extremely low permeability	0–280	0–175
2	Medium-salinity water can be used if moderate leaching occurs. Plants with medium salt tolerance can be grown, usually without special measures for salinity control. Sprinkler irrigation with the more-saline waters in this group may cause leaf scorch on salt-sensitive crops, especially at high temperatures in the daytime and with low application rates	280–800	175–500
3	High-salinity water cannot be used on soils with restricted drainage. Even with adequate drainage, special management for salinity control may be required, and the salt tolerance of the plants to be irrigated must be considered	800–2,300	500–1,500
4	Very high-salinity water is not suitable for irrigation water under ordinary conditions. For use, soils must be permeable, drainage adequate, water must be applied in excess to provide considerable leaching, and salt-tolerant crops should be selected	2,300–5,500	1,500–3,500
5	Extremely high-salinity water may be used only on permeable, well-drained soils under good management, especially in relation to leaching and for salt-tolerant crops, or for occasional emergency use	> 5,500	> 3,500

* TDS (mg/L) = 0.68 x electrical conductivity (µS/cm)
Source: Hart (1974)

Table 5.7: Relative tolerance of crop plants to saline irrigation water

Water class	EC (µS/cm)	TDS (mg/L)	Suggested plant				Precautions for irrigation uses
			Pastures and fodders	Fruit	Vegetables	Ornamentals	
1/2	0-800	0–500	Ladino clover	Persimmon	Parsnips	Violet	Avoid wetting leaves on hot, dry days
			Red clover	Loquat	Green beans	African violet	
			Alsike clover	Passionfruit	Celery	Primula	
			White Dutch clover	Strawberry	Radish	Gardenia	
			Subterranean clover	Avocado	Cucumber	Begonia	
				Almond	Squash	Azalea	
				Apricot	Peas	Camellia	
				Peach	Onion	Magnolia	
				Plum	Carrot	Fuchsia	
				Lemon	Potatoes	Dahlia	
				Grapefruit	Sweet corn		
				Orange	Lettuce		
				Grape	French beans		
				Walnut			
3	800–2,300	500–1,500	Cocksfoot	Mulberry	Cauliflower	Geranium	Avoid wetting leaves during daytime Avoid light, frequent waterings Water quickly and use continuous-wetting sprinklers if wetting the leaves
			Perennial ryegrass	Apple	Bell pepper	Gladiolus	
				Pear	Cabbage	Bauhinia	
				Raspberry	Broccoli	Zinnia	
				Quince	Tomato	Rose	
					Broad beans	Aster	
					Field beans	Poinsettia	
					Sweet potato	Musa	
					Artichoke	Podocarpus	

Table 5.7 cont.: Relative tolerance of crop plants to saline irrigation water

Water class	EC (µS/cm)	TDS (mg/L)	Suggested plant				Precautions for irrigation uses
			Pastures and fodders	Fruit	Vegetables	Ornamentals	
4	2,300–5,500	1,500–3,500	Oats (hay) Wheat (hay) Rye (hay) Lucerne Sudan grass *Paspalum dilatatum* Strawberry clover Sweet clovers Millet Wimmera ryegrass Rhodes grass Couch grass Barley Birdsfoot trefoil	Olive Fig Pomegranate Cantaloupe	Spinach Asparagus Kale Garden beets Gherkins	Stock Chrysanthemum Carnation Hibiscus Oleander Bougainvillea Vinca Aust. hop bush Coprosma (green and Variegated) Japanese pepper *Ficus spp.* in gen. *Ficus hillii* False acacia Qld pyramid tree NZ Christmas bush False mahogany Rottnest ti-tree *C. cuppressiformis* Rottnest cyprus *Acacia longifolia* Buffalo grass Kikuyu grass Portulaca Mesembryanthemum Boobyalla Morrel Swamp yate York gum Couch grass Bamboo Kondinin blackbutt	Avoid wetting leaves of most plants where possible Adequate leaching necessary

Table 5.7 cont.: Relative tolerance of crop plants to saline irrigation water

Water class	EC (µS/cm)	TDS (mg/L)	Suggested plant				Precautions for irrigation uses
			Pastures and fodders	Fruit	Vegetables	Ornamentals	
5	> 5,500	3,500	Seashore paspalum *Puccinella ciliata* Saltwater couch	Date palm		Canary palm *Paspalum vaginatum* Salt sheoaks Salt river gum Tamarisks (evergreen and deciduous) Saltbushes	Do not wet leaves where possible Excellent drainage and leaching essential

EC: Electrical conductivity

Note: The plant and water groupings are not meant to be rigid, but merely provide a general guide. Plants are arranged in approximate order of salt tolerance in each column, with the least tolerant at the top. Soil texture and drainage may be extremely important. Plants listed as suitable for saline water will grow better with less-saline water.

Source: Hart (1974)

Table 5.8: Relative tolerance of agricultural crops to boron

Tolerance*	Concentration of boron in soil water (mg/L)**	Agricultural crop
Very sensitive	< 0.5	Blackberry
Sensitive	0.5–1.0	Peach, cherry, plum, grape, cowpea, onion, garlic, sweet potato, wheat, barley, sunflower, mung bean, sesame, lupin, strawberry, Jerusalem artichoke, kidney beans, lima beans
Moderately sensitive	1.0–2.0	Red pepper, pea, carrot, radish, potato, cucumber
Moderately tolerant	2.0–4.0	Lettuce, cabbage, celery, turnip, Kentucky bluegrass, oat, corn, artichoke, tobacco, mustard, clover, squash, musk melon
Tolerant	4.0–6.0	Sorghum, tomato, alfalfa, purple, vetch, parsley, red beet, sugar-beet
Very tolerant	6.0–15.0	Asparagus

* Tolerance will vary with climate, soil conditions and crop varieties; values are to be used as a guideline only
** Maximum concentrations tolerated in irrigation water without reduction in yield or vegetative growth are approximately equal to soil water values
Source: Westcot and Ayers (1984).

5.2 LIVESTOCK

Groundwater is a major source of drinking water for livestock over a large area of Australia. It may contain large quantities of dissolved salts, depending on the soil and parent rock of the surrounding area and many other factors including rainfall, evaporation, vegetation and topography. Fertiliser and individual effluents may also be a major problem in certain areas.

Good water quality is an essential component of successful livestock production. Poor quality water may reduce production by, and interfere with the reproduction of, livestock. In extreme cases stock may die. Animal products, particularly milk, may become contaminated so that their consumption by humans must be restricted. A summary of recommended water quality guidelines is presented in Table 5.10. The recommended guidelines have been largely determined from field observations and not from rigorous experimentation.

The guidelines for drinking water for livestock must take into account the type of livestock, including age and condition; the daily water requirements, which depend on climate; and the concentrations of certain elements in the animal feed. A detailed discussion of these factors is given by Hart (1974) and VIRASC (1980). If drinking water for livestock contains high concentrations of certain compounds, the diet of the animals may require adjustment. Average daily water requirements are listed in Table 5.11.

Table 5.9: Herbicides registered for use in or near waters (mg/L)

Herbicide	Residue limits in irrigation water	Hazard to crops from residue in water**	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 (rutabag) > 3.5, corn 3.5
Amitrol	0.002	++	Lucerne 1,600, beans 1,200, carrots 1,600, corn 3,000, cotton 1,600, grains sorghum > 800, oats
Aromatic solvents (Xylene)	*	+	2,400, potatoes 1,300, wheat 1,200
Asulam	*	++	
Atrazine	*	++	
Bromazil	*	+++	
Chlorthiamid	*	++	
Copper sulfate	*	+	Apparently above concentrations used for weed control (see irrigation criterion for copper)
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	*	+++	
Terbutryne	*	++	
Triclopyr	*	++	

* Guideline not set except as a general limit (0.1 mg/L) for specific herbicides in Tasmania and all herbicides in New South Wales

** Hazard from residue at the expected maximum concentration: + = low, ++ = moderate, +++ = high

> Damage may occur at higher than this level

Sources: NHMRC (1985), Hart (1974), CCREM (1991), Demint et al. (1975), Bruns et al. (1971), Comes and Kelley (1979)

Table 5.10: Water quality guidelines for livestock watering (mg/L, unless otherwise stated)

Parameter	Guidelines	Comment
Biological parameter		
Pathogens and parasites	1,000 faecal coliforms/100 mL	Geometric mean for not less than 5 water samples taken per month; no more than 20% should exceed 5,000 organisms per 10 mL.
Algae	Up to 10,000 cells/mL may be tolerated, depending on the algal species present.	
Major ions and nutrients		
Calcium	1,000.0	
Nitrate-N	30.0	30 (horses), 40 (cattle), 60 (sheep)
Nitrite-N	10.0	
Sulfate	1,000.0	
Total dissolved solids	3,000.0	(Table 5.12)
Trace elements		
Aluminium	5.0	
Arsenic	0.5	
Beryllium	0.1	
Boron	5.0	
Cadmium	0.01	
Chromium	1.0	
Cobalt	1.0	
Copper	0.5	0.5 sheep, 1.0 pigs and poultry, 5.0 cattle
Fluoride	2.0	
Iron	–	No guideline recommended
Lead	0.1	
Magnesium		(Table 5.13)
Manganese	–	No guideline recommended
Mercury	0.002	
Molybdenum	0.01	
Nickel	1.0	
Selenium	0.02	
Uranium	0.2	
Vanadium	0.1	
Zinc	20.0	
Pesticides	See guidelines raw water for drinking water supply (Chapter 4)	
Radioactivity	See guidelines raw water for drinking water supply (Chapter 4)	
Other organic toxicants	See guidelines raw water for drinking water supply (Chapter 4)	

Table: 5.11 Average daily water requirements for livestock

Class of livestock	Daily water requirement (L)
Dairy cattle	46–91
Beef cattle	32–68
Horses	36–91
Pigs	9–23
Sheep	3–7
Chickens, per 100 birds	18–46

Source: Hart (1974)

Table 5.12: Total dissolved solids concentrations for drinking water for livestock (mg/L)*

Stock	Desirable maximum concentration for healthy growth	Maximum concentration at which good condition might be expected	Maximum concentration that may be safe for limited periods
Sheep, dry feed	6,000	13,000	**
Beef cattle	4,000	5,000	10,000
Dairy cattle	3,000	4,000	6,000
Horses	4,000	6,000	7,000
Pigs	2,000	3,000	4,000
Poultry	2,000	3,000	4,000

* Refer also to Table 5.13
** Level depends on type of feed
Source: Hart (1974)

Table 5.13: Magnesium and TDS concentrations in drinking water for livestock*

Category	Guideline	Comments
1	TDS below 5,000 mg/L Magnesium below 600 mg/L	Suitable for sheep & cattle of all ages
2	TDS of 5,000–10,000 mg/L, Magnesium below 600 mg/L	Generally unsuitable for lambs, calves & weaners. Caution needed with lactating stock if unaccustomed. Suitable for dry, mature sheep & cattle
3	TDS of 10,000–15,000 mg/L Magnesium below 600 mg/L	Suitable for dry, mature sheep. Caution needed with cattle if unaccustomed
4	TDS above 15,000 mg/L, Any magnesium level	Generally unsuitable for all stock
5	Any TDS level Magnesium above 600 mg/L	Generally unsuitable for all stock

* Refer also to Table 5.12
Source: Flinn (1984)

5.3 FARMSTEAD WATER SUPPLIES

On many farms throughout Australia, reticulated water is not available and water is usually obtained from rain-water tanks, streams, irrigation systems, farm dams or groundwater. Rain-water from tanks is generally of good quality but in short supply. Water from other sources may vary from satisfactory to unusable with respect to bacterial levels, TDS, toxic substances and/or turbidity.

Water can be used in the following areas:

- domestic use (including drinking water, washing, hot water supplies)
- dairy water supplies (washing, cooling etc.)
- water for produce preparation (e.g. washing of vegetables).

In order to protect people living on farms and the consumers of farm products, it is recommended that water of the quality outlined in Chapter 4 (domestic supply) should be used. Obviously, in some cases lower quality water will be used due to the

lack of water of desirable quality. The possible dangers associated with the use of lower quality water are discussed in Chapter 4 of ANZECC (1992).

Raw water supplies not meeting the requirements in Chapter 4 should be treated to yield a finished quality comparable to drinking water.

6. INDUSTRIAL WATER QUALITY

Water plays an important role in industrial processes and most industrial operations require adequate supplies. Water quality may affect the product by decaying (biological action), staining, corrosion, chemical reaction or contamination. It may affect the equipment by corrosion, scale formation or erosion, and plant efficiency by sludge formation, scale formation, foaming or organic growth (Hart 1974).

Water quality requirements differ widely among industries. Many industries are able to utilise the normal domestic water supply; however, other industries must rely on water from streams, lakes, underground supplies or estuaries. These water sources may need some type of treatment before use. Water treatment technology (e.g. screening, filtration, disinfection) has been refined to the point where water of any reasonable quality can be treated to the desired level of quality for industrial use. Although some treatment techniques may be costly, they are generally not the controlling factor in comparison with labour costs, market location, marketing costs and sources of other raw material. An increasing number of industries are recognising the importance of water reuse, which is resulting in a decrease in both water treatment and the need for additional supplies.

In 1985 about 5% (790 10^3 ML) of the total water use in Australia was for industrial purposes (Department of Primary Industries & Energy 1987), the three major uses being heat transfer (cooling and heating), power generation and processing (Hart 1974). The following industrial groups are discussed in this chapter:

- generic processes (heating and cooling)
- hydro-electric power generation
- textile industry
- chemical and allied industry
- food and beverage industry
- iron and steel industry
- tanning and leather industry
- pulp and paper industry
- petroleum industry.

6.1 GENERIC PROCESSES

6.1.1 HEATING AND STEAM GENERATION

Table 6.1 summarises the water quality parameters of concern regarding heating processes, and should provide a guide that can be used in conjunction with local knowledge.

Table 6.1: Industrial water requirements for heating and steam generation (values in mg/L unless otherwise indicated)

Parameter	Boiler feed water			
	0–1.0 MPa	1.0–4.8 MPa	4.8–10.3 MPa	10.3–34.4 MPa
pH (units)	8.0–10.0	8.2–10.0	8.2–9.0	8.8–9.2
Calcium	x	0.0	0.0	c
Magnesium	x	0.0	0.0	c
Iron	1.0	0.3	0.05	0.01
Manganese	0.3	0.1	0.01	c
Aluminium	5.0	0.1	0.01	0.01
Copper	0.5	0.05	0.05	0.01
Zinc	x	0.0	0.0	c
Ammonium	0.1	0.1	0.1	0.7
Bicarbonate (HCO_3)	170.0	120.0	48.0	c
Sulfate	x	x	x	c
Chloride	x	x	x	c
Silica	30.0	10.0	< 0.7	0.01
Hardness ($CaCO_3$)	20.0	0.0	0.0	
Alkalinity	140.0	100.0	40.0	0.0
Acidity	0.0	0.0	0.0	0.0
Filterable residue	700.0	500.0	200.0	0.5
Suspended solids	10.0	5.0	0.0	0.0
Dissolved oxygen	2.5	0.007	0.007	0.007
Chemical oxygen demand	5.0	5.0	0.5	0.0
Carbon tetrachloride extract	1.0	1.0	0.5	0.0
MBAS	1.0	1.0	0.5	0.0

x: Accepted as received, has never been a problem
c Controlled by treatment for other constituents
MBAS: Methylene blue active substances
Source: Hart (1974)

6.1.2 COOLING

Tables 6.2 and 6.3 summarise the recommended levels for cooling waters.

The largest proportion of water used by industry is employed for cooling purposes. Cooling-water systems consist of heat exchange equipment, which is used to remove heat from process fluids. These systems can be classified as once-through or recirculating.

Table 6.2: Water quality guidelines for once-through cooling and make-up water systems (all units in mg/L unless otherwise specified)

Parameter	Once-through		Make-up for recirculation	
	Fresh	Brackish*	Fresh	Brackish*
Silica	< 50.0	< 25.0	< 50.0	< 25.0
Aluminium	NS	NS	< 0.1	< 0.1
Iron	NS	NS	< 0.5	< 0.5
Manganese	NS	NS	< 0.5	< 0.02
Calcium	< 200.0	< 420.0	< 50.0	< 420.0
Bicarbonate	< 600.0	< 140.0	< 24.0	< 140.0
Sulfate	< 680.0	< 2,700.0	< 200.0	< 2,700.0
Chloride	< 600.0	< 19,000.0	< 500.0	< 19,000.0
Dissolved solids	< 1,000.0	< 35,000.0	< 500.0	< 35,000.0
Hardness	< 850.0	< 6,250.0	< 130.0	< 6,250.0
Alkalinity	< 500.0	< 115.0	< 20.0	< 115.0
pH	5.0–8.3	6.0–8.3	NS	NS
Organic material				
MBAS	NS	NS	< 1.0	<1.0
Carbon tetrachloride extract	NFO	NFO	< 1.0	<2.0
Chemical oxygen demand	< 75.0	< 75.0	< 75.0	< 75.0
Suspended solids	< 5,000.0	< 2,500.0	< 100.0	< 100.0

* Brackish water: dissolved solids concentrations > 1,000 mg/L
NS: Not specified; MBAS: Methylene blue active substances; NFO: No floating oil
Source: USEPA (1973)

Table 6.3: Water quality guidelines for cooling towers (Recirculating systems)

Parameter	Numerical limits (mg/L)		Comments
	Minimum	Maximum	
Langelier Saturation Index*	+0.5	+1.5	Non-chromate programs
Ryzner Stability Index	+6.5	+7.5	Non-chromate programs
pH units	≥ 6.0	≤ 8.0	
Calcium (as $CaCO_3$)	> 30.0	< 300.0	Non-chromate program
		< 400.0	Chromate program
Total iron	–	< 0.5	
Manganese	–	< 0.5	
Copper	–	< 0.08	
Aluminium	–	< 1.0	
Sulfide	–	< 5.0	
Silica	–	< 150.0	For pH < 7.5
	–	< 200.0	For pH > 7.5
[Ca] x [SO_4]	–	< 500,000.0	
Total dissolved solids	–	< 2,500.0	
Conductivity (µS/cm)	–	< 4,000.0	

* The limits for the Langelier Saturation Index (an indicator of $CaCO_3$) presume the presence of precipitation inhibitors in non-chromate treatment programs. In the absence of such additives, the limits would be reduced.
Source: Krisher (1978)

6.2 HYDRO-ELECTRIC POWER GENERATION

Table 6.4: Water quality guidelines for hydro-electric power generation supplies

Parameter	Concentration (mg/L)
pH (unit)	5.0–8.3
Acidity (as $CaCO_3$)	0.0
Alkalinity (as $CaCO_3$)	500.0
Hardness (as $CaCO_3$)	850.0
Suspended solids	5,000.0
MBAS	1.3
Carbon tetrachloride extract	No floating grease or oil
Nitrogen (total)	0.5
Phosphorous (total)	0.05
Obstructions	Water should be free of submerged or floating objects that could damage or block equipment

MBAS: Methylene blue active substances
Sources: VicEPA (1983), AEC (1987)

6.3 TEXTILE INDUSTRY

Table 6.5: Water quality guidelines for the textile industry (all concentrations in mg/L)

Parameter	Cotton, wool, synthetics				Viscose, rayon	
	Sizing	Scouring	Bleaching	Dyeing	Pulp manufacture	Manufacture
Iron	< 0.3	< 0.1	< 0.1	< 0.1	< 0.05*	ND
Manganese	< 0.05	< 0.01	< 0.01	< 0.01	< 0.03	ND
Copper	< 0.05	< 0.01	< 0.01	< 0.01	< 5.0	–
Dissolved solids	< 100.0	< 100.0	<100.0	<100.0	<100.0	–
Suspended solids	< 5.0	< 5.0	<5.0	<5.0	–	–
Hardness (as $CaCO_3$)	< 25.0	< 25.0	< 25.0	< 25.0	< 8.0	< 55.0
pH:						
Cotton	6.5–10.0	9.0–10.5	2.5–10.5	7.5–10.5	–	–
Synthetics	6.5–10.0	3.0–10.5	NA	6.5–7.5	–	–
Wool	6.5–10.0	3.0–5.0	2.5–5.0	3.5–6.0	–	–
Viscose & rayon	–	–	–	–	–	7.8–8.3
Colour (units)	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	–
Turbidity (NTU)	–	–	–	< 15.0	< 5.0	< 0.3
Aluminium	–	–	–	–	< 8.0	–
Silica	–	–	–	–	< 25.0	–
Alkalinity (as $CaCO_3$)	–	–	–	–	50.0–75.0	50.0–75.0

* Fe + Mn
ND: Not detectable; NA: Not applicable; NTU: Nephelometric turbidity units
Sources: McKee and Wolf (1963), Hart (1974), CCREM (1991)

6.4 CHEMICAL AND ALLIED INDUSTRIES

Due to the diversity and product specifics of the process water required for chemical and allied industries no water quality guidelines are given.

6.5 FOOD AND BEVERAGE INDUSTRY

Table 6.6 summarises the water quality guidelines for some specific food and beverage industries. Water for processing of products intended for human consumption should be of similar quality to raw waters for drinking water supply (Chapter 4).

6.6 IRON AND STEEL INDUSTRY

Water quality guidelines for the iron and steel industry are given in Table 6.7.

6.7 TANNING AND LEATHER INDUSTRY

A summary of the quality requirements for water in the leather and tanning industry is given in Table 6.8.

6.8 PULP AND PAPER INDUSTRY

Water quality guidelines for the pulp and paper industry are given in Table 6.9.

6.9 PETROLEUM INDUSTRY

A summary of the quality requirements for water in the petroleum industry is given in Table 6.10.

Table 6.6: Water quality guidelines recommended for some food and beverage industries (concentrations in mg/L unless otherwise indicated)

Parameter	Baking	Brewing	Carbonated beverages	Confectionery	Dairy	Food canning, freezing, dried/frozen	Food process (general)	Sugar manufacturing
pH (units)	–	6.5–7.0	< 6.9	> 7.0	–	6.5–8.5	–	–
Colour (units)	< 10.0	< 5.0	< 10.0	–	ND	< 5.0	5.0–10.0	–
Turbidity (NTU)	< 10.0	< 10.0	1–2	–	–	< 5.0	1.0–10.0	–
Taste, odour	low	low	ND	low	ND	ND	low	–
Suspended solids	–	–	–	50.0–100.0	< 500.0	< 10.0	–	ND
Dissolved solids	–	< 800.0	< 850.0	50.0–100.0	< 500.0	< 500.0	< 850.0	–
Calcium	NS*	< 100.0	–	–	–	< 100.0	–	< 20.0
Magnesium	–	< 30.0	–	–	–	–	–	< 10.0
Iron	< 0.2	0.1–1.0	< 0.1	< 0.2	0.1–0.3	< 0.2	< 0.2	< 1.0
Manganese	< 0.2**	< 0.1**	< 0.05	< 0.2**	0.03–0.1	< 0.2**	< 0.2	< 0.1
Copper	–	–	–	–	ND	–	–	–
Ammonium	–	–	–	–	trace	< 0.5	–	–
Bicarbonate	–	ND	–	–	–	–	–	< 100.0
Carbonate	–	< 50.0	< 5.0	–	–	–	–	–
Sulfate	–	< 100.0	< 200.0	–	< 60.0	< 250.0	–	< 20.0
Chloride	–	20.0–60.0	< 250.0	<250.0	< 30.0	< 250.0	–	< 20.0
Nitrate	–	< 10.0	–	–	< 20.0	< 10.0	–	–
Fluoride	–	< 1.0	0.2–1.0	–	–	< 1.0	< 1.0	–
Silica	–	< 50.0	ND	–	–	< 50.0	–	–
Hardness (as $CaCO_3$)	NS*	< 70.0	200.0–250.0	–	< 180.0	< 250.0	10.0–250.0	< 100.0
Alkalinity	–	< 85.0	50.0–128.0	–	–	30.0–250.0	30.0–250.0	–
Hydrogen sulfide	< 0.2	<0.2	< 0.2	< 0.2	–	–	–	–
Oxygen consumed	–	–	< 15.0	–	–	< 1.0	–	–
Carbon tetrachloride extract	–	–	slight	–	< 10.0	< 0.2	–	–
Chloroform extract	–	–	< 0.2	–	–	–	–	–
Acidity	–	–	–	–	–	ND	–	–
Phenol	–	ND	ND	–	–	ND	–	ND
Nitrite	–	–	–	–	–	ND	–	–
Organic matter	–	trace	trace	–	–	–	–	trace

* some requirements for yeast actions, excess retards fermentation

** Total Fe and Mn

ND: Not detected. NS: Not specified. NTU: Nephelometric turbidity unit

Sources: McKee and Wolf (1963), Eller et al. (1970), Hart (1974), CCREM (1991)

Table 6.7: Water quality guidelines for the iron and steel industry (concentrations in mg/L unless otherwise indicated)

Parameter	Hot-rolling, quenching	Cold-rolling	Rinse water: softened	Rinse water: demineralised	Steel manufacturing
pH	5.0–9.0	5.0–9.0	6.0–9.0	–	6.8–7.0
Suspended solids	< 25.0	< 10.0	ND	ND	–
Dissolved solids	< 1,000.0	< 1,000.0	ND	ND	–
Settleable solids	< 100.0	< 5.0	ND	ND	–
Dissolved oxygen	——————————minimum for aerobic conditions——————————				
Temperature (°C)	< 38.0	< 38.0	< 38.0	< 38.0	< 38.0
Hardness	NS*, **	NS*	< 100.0	< 0.1	< 50.0
Alkalinity	NS**	NS**	NS**	< 0.5	–
Sulfate	< 200.0	< 200.0	< 200.0	–	< 175.0
Chloride	< 150.0	< 150.0	< 150.0	ND	< 150.0
Oil	NS	ND	ND	ND	ND
Floating material	NS	ND	ND	ND	ND

ND: Not detectable; NS: Not specified
* Controlled by other treatments
** The parameter has never been a problem at concentrations encountered
Sources: USEPA (1973), Hart (1974), CCREM (1991)

Table 6.8: Water quality guidelines for tanning and leather industry (concentrations in mg/L unless otherwise indicated)

Parameters	Tanning processes	General finishing processes	Colouring
Alkalinity ($CaCO_3$)	< 130.0	NS*	NS
pH	6.0–8.0	6.0–8.0	6.0–8.0
Hardness ($CaCO_3$)	< 150.0	NS**	ND
Calcium	< 60.0	NS**	ND
Chloride	< 250.0	< 250.0	–
Sulfate	< 250.0	< 250.0	–
Iron	< 50.0	< 0.3	< 0.1
Manganese	–	< 0.2	< 0.01
Carbon chloroform extract	–	< 0.2	ND
Colour (units)	< 5.0	< 5.0	< 5.0
Coliform bacteria	NS†	NS†	–
Turbidity (NTU)	ND	ND	ND

NS: Not specified; ND: Not detectable; NTU: Nephelometric turbidity unit
* Water is usually acceptable as received
** Lime softened
† Should meet raw water for drinking water supply guidelines
Sources: Hart (1974), Ontario Ministry of the Environment (1974), CCREM (1991)

6.9 PETROLEUM INDUSTRY

A summary of the quality requirements for water in the petroleum industry is given in Table 6.10.

Table 6.9: Water quality guidelines for the pulp and paper industry (concentrations in mg/L unless otherwise indicated)

Parameter	Fine paper	Ground wood	Kraft		Chemical pulp & paper	
			Bleached	Unbleached	Bleached	Unbleached
pH (units)	–	6.0–8.0	–	–	6.0–8.0	6.0–8.0
Colour (units)	< 40.0	<100.0	<25.0	<100.0	<50.0	<100.0
Turbidity (NTU)	< 10.0	<20.0	<40.0	<100.0	<10.0	<20.0
Calcium	< 20.0	<20.0	–	–	<20.0	<20.0
Magnesium	< 12.0	<12.0	–	–	<12.0	<12.0
Iron	< 0.1	< 0.1	< 0.2	< 1.0	< 0.1	< 1.0
Manganese	< 0.3	< 0.1	< 0.1	< 0.5	< 0.05	< 0.5
Chloride	–	25.0–75.0	< 200.0	< 200.0	< 200.0	< 200.0
Silica	< 20.0	< 100.0	< 50.0	< 100.0	< 50.0	< 50.0
Hardness	< 100.0	< 100.0	< 100.0	< 100.0	< 100.0	< 100.0
Alkalinity	40.0–75.0	< 150.0	< 75.0	< 150.0	–	–
Dissolved solids	< 200.0	< 250.0	< 300.0	< 500.0	< 200.0	< 250.0
Suspended solids	10.0	–	–	–	< 10.0	< 10.0
Temperature (°C)	–	–	–	–	< 36.0	–
CO_2	< 10.0	<10.0	< 10.0	< 10.0	–	–
Corrosion tendency	Nil	Nil	Nil	Nil	Nil	Nil
Residual chloride	< 0.2	–	–	–	–	–

Sources: Hart (1974), Ontario Ministry of the Environment (1974), CCREM (1991)

Table 6.10: Water quality guidelines for the petroleum industry

Parameter	Concentration (mg/L)
pH (units)	6–9
Colour	NS
Calcium	< 75
Magnesium	< 25
Iron	< 1
Bicarbonate	NS
Sulfate	NS
Chloride	< 200
Nitrate	NS
Fluoride	NS
Silica	NS
Hardness ($CaCO_3$)	< 350
Dissolved solids	< 750
Suspended solids	< 10

NS Not specified, the parameter has never been a problem at concentrations encountered
Source: CCREM (1991)

7. ASSESSMENT METHODS

Monitoring of the environment is essential to ensure that the particular water quality management strategy in place is actually achieving the set objectives. In addition, the Australian Water Quality Guidelines contained in this document require that site-specific investigations be undertaken, particularly to provide a firm base for managing aquatic systems for ecosystem protection.

Both monitoring and site-specific investigations will require establishment of scientific protocols to ensure some national consistency in the sampling methods, physico-chemical and biological indicators, analytical methods and quality control programs that are adopted. Such protocols are not yet available for the aquatic environment, although a start has been made in the air quality area (AEC/NHMRC 1985). In the absence of set protocols, this chapter seeks to provide some guidance regarding the procedures to be adopted in conducting a water quality assessment program based on both physico-chemical and biological indicators. It is expected that ANZECC will implement a program to produce water quality monitoring and site investigation protocols in the near future.

7.1 PHYSICO-CHEMICAL WATER QUALITY ASSESSMENT

Given the diversity of techniques available for sampling and analysing waters, and the often operationally dependent nature of the results obtained, there is an obvious need to adopt uniform methods for physico-chemical water quality monitoring. It is not possible here to present a complete review of the relevant literature and to make recommendations on the most appropriate procedures to follow; however, the major features relevant to monitoring physico-chemical water quality are described. Key references that should be consulted include:

- the latest edition of 'Standard Methods for the Examination of Water and Wastewater' (APHA 1991), for information relating to sample containers, sample preservation, detailed analytical methods and quality control;
- the latest edition of 'Water and Environmental Technology', Volumes 11.01 to 11.04 (ASTM 1991), for information on sample containers, sample preservation, detailed analytical methods and quality control;
- Hunt and Wilson (1986) for information on general water analysis;
- Rayment and Higginson (1992) for information on water and soils analysis;
- Australian Standard 2031 (AS 1986) for information on selection of containers and preservation of water samples for chemical and microbiological analysis;
- Australian Standard 3506 (AS 1987) for information on a more preferable method for the determination of synthetic anionic surfactants than the MBAS method specified in APHA (1991);

- Ahlers et al. (1990) for information on the precautions necessary for obtaining meaningful results for heavy metal concentrations in pristine waters.

These key references provide conflicting advice in some cases, and this will need to be resolved when the final protocols are established. In the interim, one of the available alternatives should be selected and its appropriateness for the particular system being studied should be demonstrated.

Only limited reference has been made to the adoption of Australian standard methods at this stage for two reasons: first, there are a very limited number of determinands for which Australian standard methods are available and, second, there is almost international acceptance of the methods published in APHA (1991).

7.1.1 SAMPLING

The assessment of water quality using physico-chemical indicators generally involves the analysis of a small number of discrete samples from which the overall water quality is inferred. These samples often represent only a very small fraction of the waterbody being sampled and, unless due consideration is given to possible problems involving spatial and/or temporal variability, non-representative data may be used in such an assessment. Variability can occur because:

- the system being sampled is not homogeneous (e.g. top and bottom water in a stratified lake, or the junction of two dissimilar rivers);
- the determinand may not be homogeneously distributed through the sample (e.g. SPM);
- chemical, physical and/or biological reactions may occur to different extents in different regions of the aquatic system.

The wide range of waterbody types throughout Australia precludes, at this stage, the recommendation of a single sampling protocol that would be uniformly applicable. Nevertheless, there are a number of factors that should be considered when designing and implementing a water quality monitoring program. Some of the most important are discussed below. The reader is also advised to consult the extensive literature base that is available (e.g. Green 1979, in press; Hart 1982; Ward et al. 1990; Colman et al. 1991).

Location, frequency and timing of sampling

Location, frequency and timing of sampling need to be considered in relation to both the type of waterbody and the indicator(s) being determined. For example, it is well known that the total heavy metal concentrations in many rivers are closely related to river discharge, particularly during the early part of a flood event when increased concentrations of SPM and correspondingly higher concentrations of associated heavy metals occur. Therefore, if a river is only sampled at base flows, the resulting data will not truly represent the natural range of heavy metal concentrations in the system.

Dissolved oxygen and pH levels in lakes are commonly poorly measured because of a failure to take proper regard of the quite dramatic changes that can occur diurnally through the processes of algal photosynthesis and respiration. The practice of sampling at a certain time of day, without regard to the cycling that occurs between daylight and darkness, can therefore result in misleading data.

The choice of sampling site(s) is also an important consideration when planning a water quality monitoring program. For example, in a stratified lake or reservoir the depth at which samples are taken is an important consideration, since the concentrations of many indicators (e.g. pH, dissolved oxygen, nitrate, hydrogen sulfide) can vary significantly between the top and bottom water. Similarly, samples taken from the edge of a river are likely to contain quite different concentrations of SPM than samples taken from mid-stream.

Method of sampling

The choice of sampling method depends on the indicator to be measured and the nature of the information required. For example, the benefits associated with obtaining instantaneous grab samples versus time (or flow) integrated samples (in terms of sample preservation, minimisation of contamination and sample volume) need to be weighed against the information obtained from the two types of sampling method. Similar considerations are involved in the choice of surface samples versus depth or depth-integrated samples, or specially prepared sampling gear (e.g. Teflon-coated, acid-washed Niskin bottles for taking trace metal samples at depth).

Sample size

Sample size is governed largely by the needs of the analyst and logistic considerations. Nevertheless, sample size can affect how well the sample represents the system, with small sample volumes being more likely to result in non-representative samples.

Number of samples

There is a considerable literature on the criteria for deciding the number of samples to be taken and the degree of replication (e.g. Green 1979; Sanders et al. 1983; Ward et al. 1990; Fairweather 1991). The required number of samples should be specified by reference to a prescribed level of uncertainty that is to be associated with the results, generally the 95% confidence level. Adequate numbers of replicates are taken for very few monitoring programs

Contamination

Contamination may occur at any point between sample collection and final analysis. In the laboratory, contamination may occur during preparation and handling prior to analysis, during sample introduction into the analytical instrument and during the subsequent analysis.

Consideration of contamination again depends on the nature of the waterbody being sampled and the particular indicator being analysed. For example, sampling of pristine waters requires more stringent precautionary measures than those required for taking samples from an urban stream or stock dam. Similarly, the use of ultra-pure preservatives versus analytical grade chemicals also depends on the type of sample to be analysed.

The preferred approach to minimising contamination, and hence ensuring the integrity of the data, involves the design and implementation of appropriate quality control procedures. This is addressed in more detail in Section 7.1.5, and involves the use of blanks, standard reference materials, known additions of analyte, and

duplicate samples. In essence, the only way to ensure low levels of contamination is to adopt the measures suggested in the key references given below, test to ascertain their efficacy and modify as appropriate.

7.1.2 SAMPLE PRESERVATION

There is often a need for a sample to be preserved after collection to maintain its integrity. Water samples reflect a chemically dynamic state in the system at a particular time, and many processes (e.g. volatilisation, adsorption, diffusion, precipitation, air oxidation, photochemical processes and microbiological degradation) can result in changes to the indicator of interest prior to its analysis. Although there is no completely satisfactory method for overcoming sample deterioration, a number of commonly accepted methods for sample preservation are available, including:

- acidification to pH less than 2 using either nitric or hydrochloric acids for samples for trace metal analysis;
- refrigeration or freezing of samples for nutrient analysis;
- refrigeration of samples for selected organic analyses;
- addition of sodium hydroxide to pH greater than 12 and refrigeration in the dark for samples for cyanide analysis.

For a number of determinands, there is far from complete agreement in the literature regarding the best preservation method. For example, two preservation methods are recommended for mercury in water samples: the addition of nitric acid to pH less than 2 and subsequent refrigeration, or the addition of potassium dichromate and nitric acid to pH 1. In such cases, it is important that the validity of the chosen method is verified for the particular circumstances in which it is being used.

Choice of the appropriate preservation method also involves a decision regarding the type of sample container to be used (e.g. glass, plastic or some other type of material). Fortunately, references concerned with preservation methods also generally discuss container types in conjunction with the preservation techniques.

7.1.3 HOLDING TIME

The holding time is the period of time during which a sample can be stored after collection and preservation without significantly affecting the accuracy of the analysis. As for preservation methods, the holding times recommended by various references can vary, sometimes substantially. Again, verification of the procedure chosen for a particular circumstance is required.

7.1.4 ANALYSIS METHODS

Possibly the most contentious issue with respect to the successful implementation of water quality guidelines is the specification of analytical methods for each of the indicators chosen. Even for apparently straightforward indicators such as pH and conductivity, inter-laboratory studies have shown significant variation in results obtained for replicate samples analysed by laboratories using slightly different methods. The problems become more acute with respect to preparation of samples prior to analysis for toxicants, especially in waters containing appreciable

concentrations of SPM. As an interim measure, it is recommended that the procedures described in the key references nominated above be adopted.

Unfiltered water samples should be used for the determination of inorganic and organic toxicants. This will inevitably result in an over-estimation of the biologically active toxicant concentrations; however, this approach is preferable to the use of arbitrary sample preparation methods involving steps such as filtration or centrifugation. Further, it is recommended that the treatment for samples prior to the determination of heavy metal concentrations be restricted to that described in the section 'Preliminary Treatment of Acid-Extractable Metals' in APHA (1991).

7.1.5 QUALITY CONTROL

The validity of reported data can only be assured by the incorporation of a rigorous quality control program involving sampling, analysis and reporting. As a minimum, this involves:

- use of field blanks and replicate sampling of a selected number of samples;
- preparation and analysis of known additions, reference materials, reagent blanks and duplicate samples;
- checking of instrumental read-outs, calculations and final reports by an independent party;
- use of control charts;
- giving consideration to the use of a second laboratory to undertake check analyses.

An estimated 10–15% of the total effort of a water quality monitoring program should be devoted to quality control. Preferably all laboratories undertaking the analysis of water samples should be accredited by the National Association of Testing Authorities (NATA).

7.1.6 REPORTING

When reporting the results of a water quality monitoring program, the following should be available to the end-user of the information, and should preferably accompany the data:

- sampling details, including site descriptions and tests for sample representativeness;
- details of sample preservation, holding times and the dates of sampling and sample analysis;
- reference to the analytical methods, including details of the precision, accuracy and detection limit of each method used, and any deviations from the standard procedure;
- quality control details, including the results obtained for the quality control analyses described previously and control charts (if appropriate);
- the results in the appropriate units and incorporating the appropriate number of significant figures.

It is also recommended that the data be subjected initially to non-parametric statistical analysis, unless parametric tests are shown to be appropriate. At the

simplest level, this means expressing the data in terms of tenth, fiftieth and ninetieth percentile values. There are now quite a number of computer packages available to undertake such statistical analysis (e.g. SYSTAT).

7.2 BIOLOGICAL WATER QUALITY ASSESSMENT

As noted in Section 1.3, biological water quality assessment must become an essential tool of resource managers with responsibility for protecting aquatic ecosystems. However, the development of biological assessment protocols applicable to the protection of aquatic ecosystems is in its infancy in Australia (Marchant & Chessman 1989; Underwood 1991a, 1991b) and elsewhere (USEPA 1990; Metcalfe-Smith 1992). The lack of recognised national biological water quality assessment protocols has severely limited the application of these techniques throughout Australia.

In the absence of a national protocol for biological assessment, this section aims to provide some discussion on the key aspects that need to be considered when planning a biological water quality assessment program. Because of the wide range of aquatic ecosystems throughout Australia, it is not possible to prescribe the component of the biota to investigate, the sampling techniques or, indeed, the data analysis procedures to be used. The exact nature of the biological assessment program developed will depend on the specific circumstances existing for each system and, for this reason, the involvement of a professional biologist is necessary to design and carry out the most appropriate program.

A number of manuals have been published recently that review methods for the design, sampling, sample processing and evaluation of aquatic biological communities (Stark 1985; Britton & Greeson 1987; Hellawell 1978, 1986; Klemm et al. 1990; Smith et al. 1989). As far as is possible, sampling should be quantitative and comparisons made between only samples collected using the same technique.

A shortcoming of biological monitoring programs generally has been the length of time required to process the samples following collection. This is true for plankton, periphyton and benthic invertebrate samples, where the organisms must usually be separated from organic and inorganic debris and then subjected to microscopical examination in order to identify and enumerate them. It is not a difficulty for fish samples, and this constitutes a significant advantage of fish monitoring over other components of the biota. In response to these shortcomings, USEPA has developed a series of rapid biological assessment protocols (Plafkin et al. 1989). If these protocols prove to be successful, they promise a considerable saving in time and cost and would be well worth investigation in Australia.

7.2.1 UNDERSTANDING THE SYSTEM

A key difficulty in the management of ecological systems, particularly in Australia, is the individuality and natural variability of the systems to be managed. Each system provides a unique combination of species, physical and chemical characteristics and management problems. A key role for any management agency must be to develop, as far as possible, an understanding of the processes operating in the systems for which it has responsibility. In terms of the biological communities this may require the establishment of collections of preserved animals and plants as reference voucher collections and for staff training. The encouragement of and collation of data from local amateur naturalists may also be of great potential long-

term value. Efforts to establish the natural variability of water quality parameters in the management region are also necessary.

Ultimately, environmental changes can only be assessed if they can be compared against the background of natural variation; however, this background might involve variation in space and time on a number of scales, and the variations might not be synchronised at different sites. Invariably, these situations will require complex sampling designs and statistical analysis of the data collected (Underwood & Peterson 1988; Underwood 1991a, in press).

7.2.2 BIOLOGICAL INDICATORS

The comparative roles of biological and physico-chemical indicators of water quality have been discussed elsewhere (e.g. Campbell 1982). Biological indicators are less specific than physico-chemical indicators, responding to the whole range of stressors but not necessarily indicating the precise stressor to which they have responded. Physico-chemical indicators on the other hand are highly specific, which is advantageous when a stressor can be predicted but necessarily may fail to detect unpredicted stressors. As a result, biological indicators should always be used where ecosystem function is to be protected and for broad-scale, non-specific, ambient monitoring.

The choice of the most appropriate component of the biota to investigate in any particular situation will vary. Benthic invertebrates, phytoplankton, zooplankton, periphyton and fish have all been used more or less extensively as biological indicators of water quality. In inland waters in south-eastern Australia, where the fish fauna is relatively depauperate, fish community composition is likely to be a poor indicator. However, fish community composition may be extremely valuable in marine situations and tropical inland waters. Invertebrate fauna seem likely to be useful indicators of ecosystem condition in both inland and marine systems, and attached algal assemblages are also useful in a broad range of habitats. In particular situations, specific indicators such as the frequency of deformities in fish or invertebrate species may also be an appropriate monitoring techniques. Underwood and Peterson (1988) have argued that population-level monitoring has at least as much validity as other levels, even in complex systems.

As a general principle, wherever possible, it is best to use more than one component of the biota and several different measures of ecosystem condition.

7.2.3 SAMPLING METHODS

Methods for biological sampling of aquatic ecosystems have been the subject of several extensive reviews. Particularly notable are those by Hellawell (1978), Britton and Greeson (1987) and Klemm et al. (1990). Regardless of the physical sampling technique selected, a number of general principles should be borne in mind.

Samples are relatively cheap and simple to collect and store, but slow and expensive to process. If there is any doubt as to how many may be required, it is usually advisable to collect additional samples.

At the outset of a monitoring program it is essential to define what biological indicators are to be monitored, both in terms of the biological community of interest

(i.e. fish or invertebrates) and the parameter(s) of interest, for example community composition, diversity, population density (Underwood & Peterson 1988). The size of the minimum acceptable detectable change needs to be decided, and the implications of that decision for the sampling program must be considered. Power analysis, in conjunction with a pilot study, should be used to evaluate the feasibility of the program (Cohen 1988; Colman et al. 1991). It is often difficult to predict the amount of time that will be required to process samples as this may depend on the substrate being sampled; the amount and nature of any debris collected with the biota; the nature, diversity and taxonomic difficulty of the group being used as indicators; and the extent to which sub-sampling and other sample processing aids can or are being used.

7.2.4 TAXONOMIC DISCRIMINATION

Biota have generally been identified to species level. However, recent work in both freshwater (Marchant, R., Museum of Victoria, pers. comm., July 1992; Tiller, D., VicEPA, pers. comm., June 1992) and marine (Warwick, in press) systems, suggests that identification to higher taxonomic levels (e.g. family) may detect almost all the pattern detected by species-level identification and at far lower cost. These approaches warrant further development.

7.2.5 PRESERVATION OF SAMPLES

Sample preservation is not as difficult with biological samples as it is for samples for physico-chemical analysis. The appropriate preservative depends on the organisms being collected and the nature of the intended analyses. The use of formaldehyde as a preservative should be avoided if possible because of its irritant effects and concern about possible carcinogenesis. Equally, care should be taken with the handling of any biological tissue fixatives, many of which contain carcinogenic components.

7.2.6 QUALITY CONTROL

Standard operating procedures for both field collection and laboratory processing of samples must be precisely defined and documented in written format. This documentation should detail procedural steps for the collection and labelling of samples, recording in field record books the samples collected and relevant physical and chemical information and sample preservation methods. In the laboratory, procedures must be specified for the processing of samples, including sub-sampling, use of taxonomic keys (with a specification of the keys to be used) and other taxonomic references to be consulted. Representative specimens should be sent to taxonomic experts for confirmation of the identifications, and a voucher collection should be retained in the laboratory for future consultation. Any variations from the standard operating procedures should be documented in laboratory record books together with the reasons for the deviation and a note on the possible effects on the data.

7.2.7 DATA ANALYSIS

Biological data may be analysed in a variety of ways and, generally, the more different types of analysis applied to a single robust data set the better. The data analysis methods to be used need to be considered as the sampling program is being developed. Techniques such as power analysis (Cohen 1988; Colman et al. 1991), combined with pilot sampling programs, should be used to ensure that the sampling program is likely to be adequate and that the data generated is sufficiently sensitive

to detect, with statistical confidence, the kinds of effects likely to occur. Univariate statistical techniques are generally more powerful than multivariate methods and, as yet, multivariate hypothesis testing methods are not well developed. Although the experimental constraints on univariate methods, such as analysis of variance, may limit their usefulness, their power is such that they should be the first option considered as a statistical analysis tool. Use of analysis of variance has been reviewed by Underwood (1981).

However, as biological community data are by nature multivariate, multivariate data analysis methods will often be the most appropriate analytical techniques. Simple metrics such as species richness are often highly sensitive, and should not be overlooked solely because of their simplicity. Such measures must be used in a context that allows confidence intervals to be placed on them and assessment of statistical significance of differences between sites and between times. More sophisticated analyses (such as cluster analyses, TWINSPAN, and various types of ordination techniques such as DECORANA) are now readily available in forms suitable for processing quite large data sets on personal computers (e.g. McCune 1989). Gauch (1982) noted that these techniques are intended primarily for data exploration, and has stressed that a variety of techniques should be applied to any given data set. However, the field is rapidly developing, with techniques becoming more powerful and statistical hypothesis testing becoming increasingly possible (Clarke, in press). These multivariate methods are now approaching the power of univariate methods to test hypotheses.

APPENDIX

References

APPENDIX: References

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