8.5 Priorities for research and development

8.5.1 Biological assessment

Priorities for research and development for biomonitoring of water quality can be divided into four main areas, that are not completely mutually exclusive.

8.5.1.1 Indicator development

The need to both test existing and develop new biological indicators of water quality is seen as a high priority for further investment, though within a well-defined context. Biological monitoring allows the links between changes in biological structure or function and water quality to be identified and used as a diagnostic tool. However, it should be realised that any one bioassessment tool provides a specific window on aspects of ecosystem structure or function. A comprehensive approach to water quality monitoring uses both bioassessment tools and water quality parameters. Both are usually required for an integrated assessment of ecosystem health, accompanied by habitat assessment. Attempts to view or 'sell' bioassessment tools as either mere surrogates for water quality monitoring, or at the other extreme, holistic measures of ecosystem health, should be avoided.

New indicators

Biological indicators

Further development is required of both rapid and intensive quantitative biological indicators of water quality. These should be both structural (e.g. community composition and relative abundances) and process oriented. Structural rapid indicators focussed on benthic invertebrates and fish in freshwater are either well advanced or being actively developed, but have progressed little in estuarine, coastal or marine environments. Rapid assessment using algae (both attached and planktonic), macrophytes and microbes also require development and testing. The focus in developing such tools should be on their relationship to specific values and uses of aquatic ecosystems, the appropriate temporal and spatial scales that will allow detection of important levels of change, and their utility for assessing changes in, and impacts of, specific water quality parameters.

Rapid assessment approaches do not substitute for well designed, quantitative biological monitoring. Quantitative assessment approaches for aquatic biological structural (e.g. population and community composition) and process (e.g. nutrient, energy and mass dynamics) should be formalised and evaluated for their utility in detecting, quantifying and diagnosing water quality impacts. Process-based approaches should focus not only on rates, but also on spatial distribution, timing and variability. A principal focus of this research should be on design, power and sensitivity to detect changes that are considered to be important for the ecosystems, and not merely on sampling techniques.

Some comparative research is required on the relative sensitivities of the different biotic structural and process measures, as well as on the potential for other rapid surrogates of biological condition.

Rapid habitat indicators

A key aspect of ecosystem change concerns habitat, but most current assessment is too local and short term, and is typically superficial. Indicators are required to assess river or wetland habitat by integrating its extent and/or distribution with measures of the character or quality of the habitat. There are many possible measures of habitat condition. They should be relatively simple and rapid to apply, to allow assessment in remote locations and by non-expert users. There are several existing possibilities that require further development; examples are:

- General schemes imported from overseas and modified for local use. An example is the RCE (Riparian-Channel-Environmental) inventory devised for Northern Hemisphere rivers by Petersen (1992) and recently applied with modification in an Australian river by Chessman et al. (1997). These schemes can often be readily modified to apply in local versions of a general class of habitat (e.g. small streams in agricultural landscapes), but require further testing.
- Habitat assessment is being conducted in NSW and Queensland using the State of the Rivers methodology developed by John Anderson, Southern Cross University. Victorian DCNR and others have also developed the Index of Stream Condition, that expands aspects of this with biological information. Both approaches require some formal review and evaluation in terms of their utility for rapid combined habitat and water quality assessment.
- Rapid assessment schemes that directly address Australian conditions and management issues at local and/or regional scales are also needed. A current example is the rapid appraisal index of wetland condition (Spencer et al. 1998) being developed for landowners to assess wetlands in southern NSW and northern Victoria. Field trials against both local knowledge and expert views have been built into this development.

Remote sensing procedures

There is a need to trial nationally remote sensing for a selected suite of indicators in a range of representative case studies.

Transfer of indicators

A number of biological indicators, particularly of processes, exist in other environmental sectors (e.g. terrestrial soil and vegetation). There is scope for the evaluation of their utility in fresh and marine waters.

Test and compare indicators

The need to formally test and evaluate the performance of a number of biological indicators of water quality is pressing, considering the large number of both quantitative and rapid semi-quantitative indicators that currently are in use. A series of formal tests of the sensitivity, replicability, precision, applicability, cost and practicality of a suite of indicators should be conducted at selected case study sites in both fresh and marine waters. From this evaluation a preferred set of indicators and hence procedures should be recommended for specific or general water quality issues. The process should be explicitly designed and implemented as a test of the relative effectiveness of typically-used (or recommended) indicators at detecting important changes. The outcomes could be formed into an explicit set of evaluations using appropriate statistical tools, and be extrapolated for use in decision-support systems (see below).

8.5.1.2 Procedures

Standard operating procedures

Given the uneven distribution and quality of both physico-chemical and biological data from fresh and marine waters at regional, state and national scales, sets of Standard Operating Procedures are needed for the conduct of biological assessment of water quality. These SOPs should include the design, conduct, analysis and interpretation of bioassessment (both structural and process based, and both rapid and quantitative) for microbes, macro-algae, invertebrates (micro-, macro- and large), fish and macrophytes in both fresh and marine waters.

Different SOPs should be developed for different waters (e.g. instream, wetland, estuarine, coastal, deep water marine etc.) and biota. SOPs for existing process-based assessment techniques should also be developed.

For each key biological assessment technique, the design, development and trialing of a National Standard Operating Procedure should proceed to permit (and encourage) comparable data collection in a wide variety of situations. Each SOP should be developed in relation to three important levels of effort and expertise:

- procedures for intensive and expert data capture and analysis;
- procedures for routine but intensive data capture and analysis ;
- procedures for volunteers and community groups (where appropriate).

A typical Standard Operating Procedure would address the following matters:

1 Objectives

2 Approaches

3 Sampling design — reference/controls, temporal and spatial replication

4 Equipment and resources required

5 Sample collection locations

6 Sampling procedures and logistics

7 Taxonomic guidance

8 Equipment maintenance

9 Safe operating procedures

10 Data formats, recording and data management

11 Data analysis

12 Reporting outputs

13 Quality assurance and control (QA/QC): design and reporting

14 Real-time reporting and distribution of data.

Linkage between SOPs and other QA/QC processes such as ISO and NATA standards should also be established.

8.5.1.3 Decision support

Effects sizes of key biological indicators

A fundamental aspect of using ambient conditions as controls or references to detect biological changes due to changed water quality is the ability to determine and defend an appropriate ‘effect size’. A number of activities are required to provide critical evaluation tools for supporting decisions on the degree of biological change associated with water quality impacts (‘the size of the effect’) and how that might relate to socially-derived perceptions of degrees of acceptable change in ecosystems and their biological components (the ‘important’ effect). Research into methods for articulating degrees of acceptable change relative to control or reference conditions, as well as into what constitutes an acceptable reference condition is required.

Framework for ecological health

A nationally-agreed framework that can be used to define ecosystem health for any size ecosystem, and the indicators which should be used to assess it, should be developed and articulated for inland, coastal and marine waters. This should then be supported by a national set of SOPs for each type of indicator that takes into account the nature of the ecosystem concerned and the relative capacity of each to have monitoring programs implemented.

Temporal variability

Several statistical tools are required to assist with taking natural temporal variability into account in bioassessment. In many statistical approaches, critical evaluation of the degree of independence of sampling areas and times in aquatic systems is required, accompanied by development of criteria and/or experimental designs to test assumptions of independence. Tidal systems, wetlands and rivers each have different problems, and for some statistical procedures assumptions about the independence of sample data require close and critical examination.

More research is required for rapid bioassessment methods on incorporating spatial and temporal variability, especially in terms of acquiring consistent results from the same site, and on the influence of extreme natural events (e.g. droughts, floods) on the users’ ability to make assessments.

Interface to spatial/temporal dependency

The use of bioassessment tools to track or predict water quality is dependent, in any typical field situation, on the interaction between biological and environmental parameters. This is because both ecosystems and the environment are not static, or at equilibrium, and procedures for both estimating or measuring the effects of pollutants have to be set in a dynamic (space and time) context. So, understanding how bioassessment tools using indicators can be effectively used in dynamic models is a central problem facing aquatic managers.

Research is required to develop effective ecological models that can combine toxicological information with the spatial and temporal distribution of key species, assemblages and habitats, the toxicants and their time-dependent decay processes, and environmental factors such as salinity, wind, waves and currents, to be able to make predictions about the distribution and severity of impacts from, say, a predicted toxicant discharge. Such modelling capacity could also be used to establish highly sensitive and powerful monitoring designs for use in tracking existing developments or issues.

8.5.1.4 Biological impacts of changes in water quality

Our understanding of the real impacts of toxicants in most aquatic ecosystems is primitive, and this is particularly true in the more dynamic ecosystems of lakes, estuaries and coastal marine waters where environmental interactions and biological assemblages are highly complex. Careful evaluation of impacts of toxicants will lead to the development of more robust and effective surrogates for effects *per se*. The development of cost-effective ecotoxicological measures of impact (or surrogates thereof) that are relatively easy to use, generally applicable and underpinned with process understanding should be encouraged.

There is a need for a better understanding of biological responses to water quality changes, in settings more reflective of the 'real world'. Thus biological community and process responses to common Australian water quality stressors such as salinity, sediments and nutrients, as well as a range of toxicants, should be experimentally evaluated. Multi-species ecotoxicological manipulative, controlled or field experiments should be conducted to extend Australia's limited ecotoxicological Research and Development effort. The latter is still largely focussed on simple single-species tests, the results of which may be difficult to extrapolate to field conditions because of the mismatch between the scale and complexity of experiments and those of the ecosystems where management decisions must be implemented.

Inland waters

Multi-species tests are required to evaluate responses of fish and invertebrates to sediments, nutrients, agricultural chemicals and other toxicants under a range of salinities, turbidities, temperatures and dissolved oxygen levels. These should be done using established mesocosm or field enclosure experimental procedures, with Australian and New Zealand aquatic biota. Results should be used to develop standard, ecotoxicological procedures for assessing water quality, as well as to develop new biological indicators. Where possible, links to 'rapid' biochemical or physiological response indicators should be explored to assess the latter's ability to detect change at population, community or ecosystem level.

Our knowledge of the effects of even the most common toxicants on the common species, assemblages and habitats in surface water ecosystems is very poor. The use of mesocosms can form an important bridge between laboratory studies of toxicity and the need for cause-effect models that can be used to predict the effects of developments and pollution.

Marine and estuarine waters

Multi-species mesocosm tests to evaluate responses of fish, plankton macrophytes, and benthic invertebrates to nutrients, agricultural chemicals and other toxicants, are critical for Australia and New Zealand. Our estuaries and coastal ecosystems, as for inland waters, are highly valued and have a largely unique biodiversity. The comments above regarding mesocosms apply equally here.

8.5.2 Physical and chemical stressors

As remarked elsewhere in this publication, one objective of the revised Guidelines is to encourage a new approach to ecosystem protection. This approach acknowledges the importance of biological indicators in a more explicit way and seeks to incorporate biological monitoring as an integral component of aquatic ecosystem assessment and management.

Nevertheless, additional research on physical and chemical stressors is required, particularly to clarify the relationship between these and the observed biological characteristics of ecosystems. In doing so, the definition of what constitutes a physical stressor has been broadened to include indicators such as introduced biological species and habitat modification. The following section provides specific recommendations for future work.

8.5.2.1 Further development of new approach

Ecosystem classification

Needs: Further refinement of the ecosystem classification scheme is required, including the need for more data from almost all geographical regions of Australia and New Zealand. Additional ecological studies are also required to provide answers to the following key questions: what are the most appropriate ecosystem units and what are the best criteria (e.g. water quality, ecosystem structure, ecosystem processes) to distinguish between these units; how do these ecosystem units change with geographical area and/or climate zone; how do the biological communities making up these ecosystem units change temporally and spatially; and what are the key ecological processes that structure the different ecosystem units?

> ***Recommendation 1***
>
> ***That targeted research be commissioned to identify the smallest manageable ecosystem units that are relevant to particular geographical areas, together with research to provide an understanding of how each ecosystem unit functions.***

Setting biological targets

Needs: Water resource management agencies require realistic targets to focus their action plans. Targets for the protection, maintenance and rehabilitation of ecosystems should preferably be written in terms of the biota to be protected. However, very few agencies in Australia and New Zealand use biological targets as the basis for their management of aquatic ecosystems. One exception is the Yarra River in Victoria where the State Environmental Protection Policy for this river has specified particular targets for fish and macroinvertebrates. There is still considerable work needed to develop protocols for setting biological targets for ecosystem protection, maintenance and rehabilitation. This is particularly true for ‘modified’ ecosystems where there are no realistic ‘reference’ systems for comparison. In the case of ‘unmodified’ and ‘slightly disturbed’ ecosystems, the ‘reference’ ecosystem concept has been recommended in these new ANZECC/ARMCANZ guidelines as a means of obtaining information on the biological targets that should be achieved.

> ***Recommendation 2***
>
> ***That protocols be established to develop sensible biological targets for managing different ecosystems types, taking into consideration that different levels of protection and rehabilitation (e.g. for modified ecosystems) may be desired by the community.***

Low-risk trigger values

Needs: The new ANZECC/ARMCANZ guidelines have introduced the concept of low-risk trigger values and a recommended and default approach to obtaining these values. The recommended approach involves relating the statistical distribution of water quality data to outcomes of studies on ecological effects of physical and chemical stressors. Where the effects data are not available, trigger values derived from the percentile distribution of reference site data should be used, together with professional judgement. Where neither effects data nor reference data are available, a default approach using regionalised low-risk trigger values supplied by research and regulatory organisations is provided. Three components of this approach need further work.

i) The validity of the method used to obtain the default low-risk trigger values (80^{th} percentile of the data distribution, or 20^{th} percentile for indicators where low value is of relevance) needs to be better tested, particularly the ecological validity and relevance of the approach.

ii) The quality of the data and the applicability of the geo-regional division of default trigger values needs further testing. A set of interim low-risk trigger values have been recommended on the basis of available data. However, for a number of ecosystem types, available data was limited and in some cases biased to one geographical region. There is an urgent need to collect more data for unmodified and slightly disturbed reference ecosystems within Australia and New Zealand and to continue to refine regional trigger values.

iii) The approach recommended in the new guidelines refers largely to unmodified ecosystem types. There is a need to develop a similar database for a range of 'modified' ecosystems of each type to provide information relevant to agencies who wish to manage particular ecosystems to a lower level of protection or rehabilitation. Criteria for judging the degree of modification will also need to be determined.

> ***Recommendation 3***
>
> ***That the (unmodified/slightly disturbed ecosystems) geo-regionalised division in default trigger values be assessed to determine if it has relevance in separating water quality indicators, and that targeted research be commissioned to further refine the risk-based, trigger value methodology for application to 'modified' ecosystems of each ecosystem type.***

Risk-based approach

Needs: The new ANZECC/ARMCANZ Guidelines introduce for the first time a risk-based approach for establishing water quality guidelines. This approach seeks to integrate the various factors contributing to a particular aquatic ecosystem problem to produce a probability or risk as output. An example of such an integrated approach is provided by the cyanobacterial problems experienced in lowland rivers. In such ecosystems, algal growth is primarily dependent upon the bioavailable nutrient concentrations and loads, but also on factors such as light availability, flow, stratification, and nutrient releases from bottom sediments. At present there are few models available to integrate these factors, but this must be the focus of research in the future. Additionally, the risk-based approach introduced into the new Guidelines needs further development in its own right, and also to make it consistent with other ecological risk assessment approaches, for example, that recently introduced in Australia for contaminated sites.

> ***Recommendation 4***
>
> ***That a national framework for ecological risk assessment of aquatic ecosystems be developed, and that research be supported to develop a range of models for integrating the main factors to be considered in assessing the risk that particular ecosystem problems will occur.***

Guideline packages

Needs: The new Guidelines also introduce for the first time the concept of 'guideline packages' relating to each issue and to each ecosystem type. Each package consists of low-risk trigger values for the key indicators and a protocol for further investigating the risk in those cases where the trigger value is exceeded (including the effects of environmental modifiers where appropriate) (see Section 3.3.3). Essentially, each guideline package is based on an explicit conceptual model covering how each particular ecosystem type functions, and therefore how the site-specific factors modify the biological effect of the stressor in question. These conceptual models need to be further developed and tested for their applicability across each ecosystem type. For some ecosystems, insufficient information exists to test the conceptual models and commissioned research will be needed to fill the gaps. Ideally, with the current 6 ecosystem types and 8 issues related to physical and chemical stressors, there would be 48 guideline packages specified. Unfortunately, this has not been possible at this stage because of a lack of data on some ecosystem types. There is a need to develop improved quantitative relationships between the targets and the manageable factors (e.g. between cyanobacterial cell numbers and nutrient concentrations and loads, light climate and flow). Some case studies are provided in Sections 3.3.3 and 8.2.3 of these guidelines, but these are only a start.

Recommendation 5

That targeted research be commissioned to review water quality issues in Australian ecosystems and assign priorities for the most important guideline packages that still need to be developed, that guideline trigger values be established for priority guideline packages, and that models be developed to take into account site-specific modifiers.

Load-based guidelines

Needs: The concept of load-based guidelines has been introduced in the new Guidelines for situations where it is more appropriate to consider the flux or loading of a particular stressor, rather than concentration (Section 3.3.2.8). In particular, case studies have been provided in the new Guidelines for nutrients, bioavailable organic matter and suspended particulate matter. These case studies provide some guidance on the types of approaches available, particularly those involving predictive modelling, to determine the sustainable load of particular materials for particular ecosystems. However, there is an urgent need for more load-based approaches to be developed.

Recommendation 6

That targeted research be supported to develop load-based guideline packages for situations where loads rather than concentrations are appropriate.

8.5.2.2 Research needs related to each specific issue and stressor

Nuisance plant growth and nutrients

Needs: The relationships between key indicators (e.g. nutrient concentrations and loads) and the adverse biological effects (e.g. cyanobacterial bloom) are poorly established. Several models exists for key ecosystems (e.g. Port Phillip Bay, Hawkesbury-Nepean system, WA coastal waters), but few of these are relevant for the many lowland river systems currently experiencing major problems in Australia. Specifically, there is a need for (a) better predictive models relating nutrient concentrations and loads, sediment uptake and release, light climate and turbidity, hydrodynamics (flow, stratification), and aquatic plant growth; and (b) better sediment uptake and release models, particularly for lowland rivers.

Recommendation 7

That predictive models for nuisance plant growth in Australian and New Zealand aquatic systems (lowland rivers, wetlands, lakes and reservoirs, estuaries, coastal lagoons) be further developed.

Organic matter/dissolved oxygen

Needs: Organic matter contributed to lakes, rivers and estuaries from the catchment or *in situ* plant growth, can result in low dissolved oxygen (DO) concentrations that in turn may lead to the death of fish and other biota. Unfortunately, for many Australian aquatic organisms there is little information on the range of DO concentrations that can be tolerated (and for how long). A number of computer-based models are now available to calculate the DO conditions given the load and type of organic matter and the hydrodynamic conditions of the waterbody.

> ***Recommendation 8***
>
> ***That a critical review of the available models for predicting DO concentrations on the basis of organic matter inputs and mixing be undertaken, and that further work be undertaken to identify key Australian aquatic biota that are susceptible to low DO concentrations, and where this information is not available to undertake the necessary bioassay studies.***

Suspended particulate matter

Needs: The evidence for direct adverse effects of suspended particulate matter to aquatic biota is rather limited. However, there is more evidence for indirect effects such as the smothering of benthic fauna or their habitat, adsorption of nutrients (e.g. phosphorus) leading to nutrient limitation, and reduction of light penetration leading to lower aquatic plant growth. Unfortunately, there are very few quantitative relationships relating suspended particulate matter concentrations (or loads) to the possible adverse effects listed above.

> ***Recommendation 9***
>
> ***That targeted research be supported to develop quantitative relationships between suspended particulate matter concentrations (or loads) and the consequential adverse biological effects, such as smothering of benthic fauna or their habitat, adsorption of nutrients and reduction of light penetration.***

Salinity

Needs: Many parts of Australia are experiencing increases in salinity, so that there is now heightened concern about the possible adverse effects on aquatic biota, particularly those associated with wetlands and lowland rivers. The available evidence suggests that adverse biological effects would be expected in Australian aquatic ecosystems if salinity was allowed to increase to around 1000 mg/L (or about 1500 µS/cm). However, there is very little information on sub-lethal or long-term effects, or possible effects on more sensitive life stages, that might occur at lower salinity levels. Clearly, more research is needed on the effects of increased salinity on key plants and animals in Australian wetlands and lowland rivers.

> ***Recommendation 10***
>
> ***That targeted research be commissioned to investigate the sub-lethal and long-term effects of change of salinity on key wetland and lowland river plants and animals.***

Temperature

Needs: Both increases and decreases in temperature can adversely affect the physiology of aquatic biota, and both types of changes need to be considered. There is considerable worldwide information available on the adverse effects of increases in temperature, although little of this relates to the temperature tolerance of Australian and New Zealand aquatic organisms. The biological effects of cold water releases, for example from the bottom of deep reservoirs, is less well known, and this issue needs considerably more research.

Recommendation 11

That targeted research be commissioned to quantify the biological effects of cold water releases to rivers and wetlands, and that where necessary, laboratory studies be undertaken to determine the temperature tolerance of key Australian and New Zealand organisms.

Environmental flows

Needs: Interim guidelines for establishing the flow requirements needed to sustain the ecological values of rivers are provided for the first time in the new Guidelines. However, present knowledge has been sufficient only to recommend a generic approach. There are still many unknowns associated with the setting of flow requirements. In particular, the detailed relationships between flow, reproduction triggers, habitat requirements and key ecological processes, are poorly known.

Recommendation 12

That targeted research be commissioned to establish quantitative relationships between river flows and the factors needed to sustain river ecosystems.

8.5.2.3 Fact sheets

Needs: Fact Sheets related to each key stressor or issue have been prepared. These summarise current information available from Australia and New Zealand and, where relevant, from other parts of the world. However, relevant new information is being produced all the time, and this needs to be captured, the essential elements distilled and the information added to the existing Fact Sheets at regular intervals. This will only occur if an adequate organisational structure is put in place to undertake this work.

Recommendation 13

That an appropriate organisational structure be established so that the existing Fact Sheets can be updated at regular intervals (say annually), and that this new information be made widely available (e.g. on the Web).

8.5.2.4 Stressors not covered in these guidelines

Needs: Ideally, water quality guidelines for ecosystem protection should cover all physical, chemical and biological stressors that could adversely affect the ecosystem type being considered. The new Guidelines have gone a long way towards addressing most of the important stressors. An important inclusion in the new Guidelines is a section on environmental flow. However, at least two important stressors — introduced biological species (flora and fauna) and habitat modification — have not been covered, and these should be addressed in the next revision of the Guidelines.

Recommendation 14

That guideline packages be developed to address stressors not yet covered in the ANZECC/ARMCANZ Guidelines, particularly introduced aquatic flora and fauna and habitat modifications.

8.5.3 Toxicants

8.5.3.1 Extending and improving the toxicological database for guideline determination

The application of an ecotoxicological approach to the establishment of numerical guidelines for aquatic ecosystem protection is deficient in many respects. These deficiencies can partly be addressed through a vigorous program of research and development. Some suggestions for additional work in this field are outlined below.

- Incorporating bioaccumulation into guidelines. There were few data available to use in the few available models, and the models themselves are deficient in several areas. It is not clearly known how and whether potentially bioaccumulating chemicals accumulate at the low ('no effect') guideline levels.
- Data gaps for water quality guidelines. There were many instances where the absence of data from just one taxonomic group forced the calculation of guidelines using less reliable and preferred methods or prevented calculation at all. The absence of algal and macrophyte data for many herbicides was of concern.
- Australian and New Zealand toxicological data are lacking on some key chemicals. It is not considered necessary to reproduce such data on every chemical, or even most chemicals, but it is important to have an understanding of how key local species are reacting to important chemical groups. The assumption that there are no significant differences between northern hemisphere and Australian and New Zealand species requires more rigorous testing.
- Further to the above, data are lacking on freshwater macroinvertebrates, a key component of New Zealand and Australian ecosystems.
- There needs to be considerably more information on the manner in which key chemicals interact with important water quality parameters such as temperature, pH, etc. The eventual aim should be to develop useable algorithms, similar to hardness algorithms for metals. There is little understanding on the issue of bioavailability of organic chemicals.
- Hardness algorithms need more data support using laboratory tests under controlled conditions. Algorithms are missing for vanadium, chromium (VI), aluminium and uranium.
- The interaction between organic chemicals and suspended matter is particularly poorly understood. Specifically designed experiments need to provide an understanding of both adsorption and desorption of key chemicals.
- Salinity effects require particular attention with the specific aim of using the decision scheme in estuarine environments.
- More specific guidance will need to be given on use of background concentrations and how these are arrived at — not to be too prescriptive but to minimise disputes.
- Sediment toxicity tests require further development (including chronic end-points), so as to provide the support, in a 'triad' context for chemical and field biological data.
- Toxicity of mixtures. The TTM model requires validation in the field at the very low guideline concentration.

- The Australasian database requires support and adjustment to facilitate its use in future revisions.
- Further work is required to establish what is the minimum required dataset for use in the statistical distribution model (Campbell et al. 2000) to calculate trigger values.
- Field validation and assessment of guideline values for key chemicals is required in site-specific situations.
- Future guidelines need to be able to assist in establishing if there is a relationship between the guideline figures for chronic exposure and short-term impacts from episodic exposure and, where appropriate, to provide short-term protection figures.

8.5.3.2 Direct toxicity assessment (DTA)

Direct toxicity assessment (DTA) differs from research concerned with extending the toxicological database, as described above. Database extension usually involves measuring the response of organisms to single chemicals, or simple mixtures of well-defined composition. Conversely, DTA addresses the issue of estimating the toxicity of complex mixtures, often of poorly defined or variable composition. For this reason it is sometimes called *whole effluent toxicity testing*. This field of toxicity assessment is now emerging as a practical tool, as numerous technical and logistical difficulties are progressively overcome. It therefore provides fertile ground for future research. The following are some priority areas.

- Standard methods/guidelines for the preparation of effluents and ambient waters prior to testing need to be developed.
- There are too few recommended DTA protocols at present. More protocols need to be developed in order to sufficiently cover all geographical regions. Alternatively, protocols using more broadly applicable (ubiquitous) test species could be developed.
- Related to point no. 2, criteria for selection of DTA species (and end-points) need to be further developed.
- Sediment DTA methods need to be further developed (this is more related to SQGs).
- The use of appropriate/superior statistical estimates for making decisions and deriving 'safe' effluent or guideline values (i.e. NOEC/LOEC versus alternatives) requires further investigation.
- Further work into the factors that may need to be applied to DTA results for protection of the environment is required.

8.5.3.3 Metal speciation

Because metal speciation is dependent on the nature and concentration of chemical species in water, other than the metals themselves, some form of mathematical treatment of analytical data is usually required. The development of algorithms, particularly for 'spectator' species, such as the components of water hardness, provides rich opportunities for future research endeavours. More precisely, less labour-intensive means for determining and understanding metal bioavailability are also urgently needed. A detailed discussion of important research priorities is presented below.

- There is an implicit assumption that the hardness-dependent algorithms describing water quality guidelines for different metals, derived from North American data, are appropriate for Australian and New Zealand species and conditions. However, the limited studies that have compared the toxicity of metals to Australian and North American freshwater species (within phyla) have generally concluded that differences are minimal [see review by Markich & Camilleri (1997)]. The validity of this assumption can be assessed as more Australian and New Zealand toxicity data are generated and/or compiled. North American toxicity data should be replaced by Australian and New Zealand toxicity data when the latter become available.

- There is some evidence which indicates that the uptake and toxicity of aluminium, chromium(VI), uranium and vanadium in freshwater organisms is also reduced with increasing water hardness, but insufficient data are currently available to develop hardness-dependent algorithms.
- One potential shortcoming with the use of generic hardness-dependent algorithms for each metal is that hardness and alkalinity, although frequently related, in certain circumstances may be uncoupled. For example, a fresh surface water with a high natural hardness could possibly exhibit low alkalinity as a result of acid drainage. This scenario has the potential to be underprotective to freshwater life, for a particular water hardness, given that the ameliorative capacity of the alkalinity component has been reduced.
- Apart from water hardness, metal uptake and toxicity in freshwater organisms can be strongly affected by a range of other important water quality parameters, including pH and the concentration of natural DOM. As there were insufficient data, no algorithms are presently available to describe how water quality guidelines for metals may vary as a function of pH or natural DOM concentration. Moreover, in freshwaters, water hardness co-varies with pH and DOM, as well as other water quality parameters. A multiple regression algorithm, that included water hardness, alkalinity, pH and natural DOM to describe a water quality guideline for a given metal, would be potentially more beneficial for environmental protection than just the use of water hardness.
- At present, no universally applicable technique for determining metal bioavailability exists. Although toxicity testing provides a direct determination of metal bioavailability, it is labour intensive and can be costly. Analytical measurements (e.g. ion-selective electrode, anodic stripping voltammetry) that are specific for determining particular metal species (i.e. free metal ion or labile species) are also labour intensive and costly, but provide a more equivocal indication of metal bioavailability than direct toxicity testing. Geochemical speciation modelling, using routine packages (e.g. MINTEQ), is perhaps the most cost-effective technique available, with the added advantage of providing a predictive capability, but suffers from being the most equivocal in determining metal bioavailability. Analytical measurements and speciation modelling may serve as valuable tools if performed in conjunction with toxicity tests, where particular metal species (e.g. free metal ion or labile species) can be related to a toxic response. These techniques are not trivial and should only be undertaken by appropriately experienced personnel.
- The latest research has identified surface complexation of metals to cell membranes as a major determinant of metal bioavailability to aquatic organisms, and is attempting to predict metal bioavailability by incorporating the binding constants of metals to cell membranes (e.g. gills) into speciation models (Bergman & Dorward-King 1997). This approach aims to bridge the gap between speciation modelling and toxicity testing, but at present there are insufficient data for metals other than copper and cadmium.

8.5.4 Sediment quality

Research into sediment chemistry and biology is currently addressing many of the areas that might be considered as priorities. One important area is that of anoxic sediments, and the processes therein. Until recently, most investigations have focussed on oxic sediments, although these represent only a minor component of the total sediments. Rates of sediment oxidation and contaminant release from anoxic sediments are particularly important for metals. Two priority areas that do need further investigation to progress the sediment quality guidelines are outlined below:

- The role of sediment ingestion vs pore water uptake as a source of bioavailable contaminants is being studied, and more research is needed in this area, for both metals and organics. For organic contaminants, the use of tissue residues to derive sediment quality guidelines has been advocated based on biota-sediment accumulation factors. More data are required to determine the acceptability of this approach.
- The next stage in sediment guideline development is the derivation of values based on Australian and New Zealand data. The cost and effort to undertake the necessary chemical analyses and toxicity testing on local sediments will be considerable. As a priority, a focussed program involving a number of key contaminants would be justifiable to see how locally-derived data compare with guidelines using overseas species.