# Appendix 1
# National Water Quality Management Strategy

The Australian and New Zealand Environment and Conservation Council (ANZECC) and the Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) are working together to develop the National Water Quality Management Strategy (NWQMS). The National Health and Medical Research Council (NHMRC) is involved in aspects of the NWQMS which affect public health.

The NWQMS has three major elements: policies, process and guidelines.

### *Policies*

The main policy objective of the NWQMS is set out in NWQMS Paper No. 2, *Policies and Principles — A Reference Document* (ANZECC & ARMCANZ 1994) and is

> to achieve sustainable use of the nation's water resources by protecting and enhancing their quality while maintaining economic and social development.

This objective is being pursued through a strategy based on high-status national guidelines with local implementation.

*Policies and Principles — A Reference Document* emphasises the importance of:

- ecologically sustainable development;
- integrated (or total) catchment management;
- best management practices, including the use of acceptable modern technology and waste minimisation and utilisation; and
- the role of economic measures, including 'user-pays' and 'polluter-pays' approaches.

### *Process*

The process for water quality management starts with the community working in concert with government to develop a management plan for each catchment, aquifer, estuary, coastal water or other waterbody. The plan should take account of all existing and proposed activities and developments; it should contain feasible management options that aim to achieve the environmental values that have been agreed for that waterbody. The process is outlined in NWQMS Paper No. 3, *Implementation Guidelines* (ANZECC & ARMCANZ 1998) and is schematically represented in Figure A1.1. The NWQMS envisages use of both regulatory and market-based approaches.

Management of water resources is mainly a state and territory responsibility, but the NWQMS will be implemented in the context of:

- the NWQMS guidelines;
- state and territory water policies;
- community preferences on the use and values of local waters;
- the current water quality of local waters; and
- the economic and social impacts of maintaining current water quality or of meeting new local water quality goals.

Implementation of the NWQMS should include:

- catchment, groundwater and coastal water quality management plans;
- an appropriate level of water and sewerage services provided by water authorities; and
- further development of regulatory and market frameworks.

Community views form a crucial part of the NWQMS and public comment is sought during both the development and the implementation of the strategy.

Environmental values and water quality (NWQMS) guidelines are described in the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC & ARMCANZ 2000).

### *National Guidelines*

The national guidelines are technical papers providing guidance on many aspects of the water cycle including ambient and drinking water quality, monitoring, groundwater, rural land and water, urban stormwater, sewerage systems and effluent management for specific industries. The full list of NWQMS documents, with their current status (19 completed so far out of 21), is in Table A1.1. The list, together with other information, is also on the NWQMS web site at http://www.affa.gov.au/nwqms.

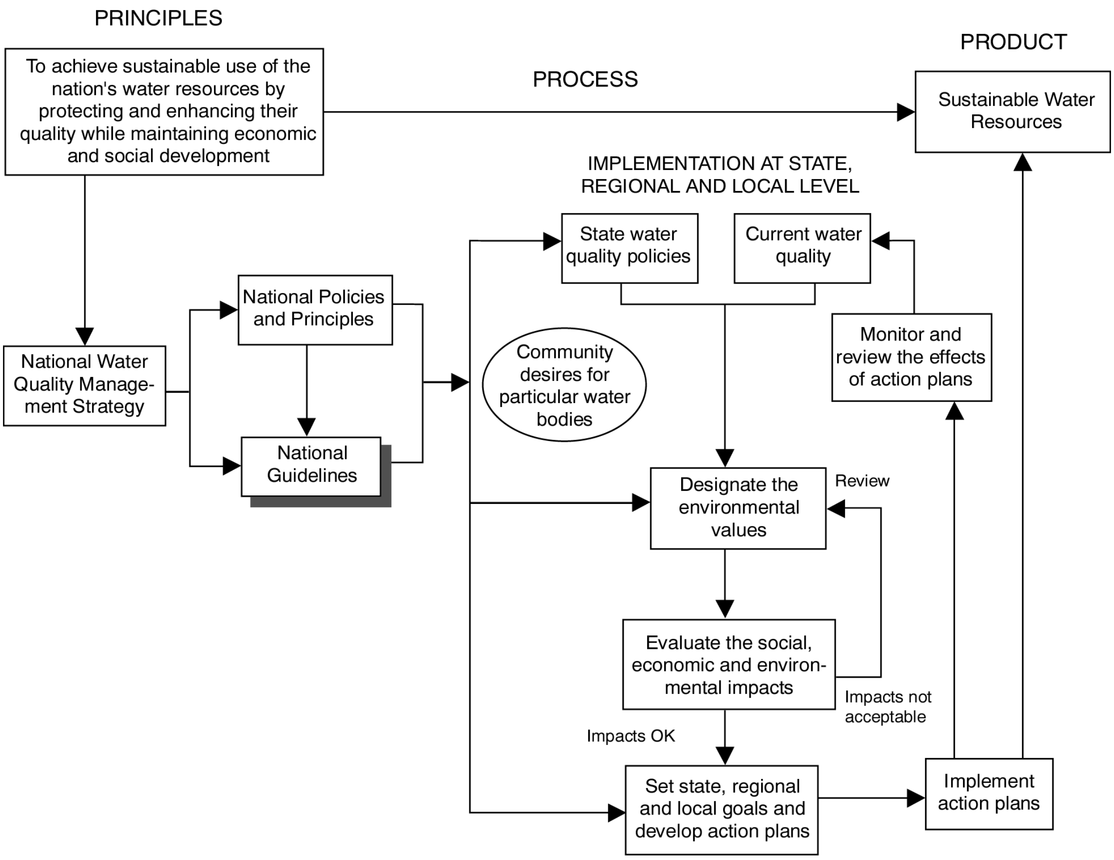


**Figure A1.1.** National Water Quality Management Strategy

**Table A1.1.** The technical papers of the National Water Quality Management Strategy, by category

**Policies and Process for Water Quality Management**

Paper no. 1. *Water Quality Management — An Outline of the Policies*

Paper no. 2. *Policies and Principles — A Reference Document*

Paper no. 3. *Implementation Guidelines*

**Water Quality Benchmarks**

Paper no. 4. *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*

Paper no. 4a. *An Introduction to the Australian and New Zealand Guidelines for Fresh and Marine Water Quality*[S]

Paper no. 5. *Australian Drinking Water Guidelines — Summary*

Paper no. 6. *Australian Drinking Water Guidelines*

Paper no. 7. *Australian Guidelines for Water Quality Monitoring and Reporting*

Paper no. 7a. *Australian Guidelines for Water Quality Monitoring and Reporting — Summary*[S]

**Groundwater Management**

Paper no. 8. *Guidelines for Groundwater Protection*

**Guidelines for Diffuse and Point Sources***

Paper no. 9. *Rural Land Uses and Water Quality — A Community Resource Document*

Paper no. 10. *Guidelines for Urban Stormwater Management*

Paper no. 11. *Guidelines for Sewerage Systems — Effluent Management*

Paper no. 12. *Guidelines for Sewerage Systems — Acceptance of Trade Waste (Industrial Waste)*

Paper no. 13. *Guidelines for Sewerage Systems — Sludge (Biosolids) Management*[#]

Paper no. 14. *Guidelines for Sewerage Systems — Use of Reclaimed Water*

Paper no. 15. *Guidelines for Sewerage Systems — Sewerage System Overflows*[#]

Paper no. 16a. *Effluent Management Guidelines for Dairy Sheds*

Paper no. 16b. *Effluent Management Guidelines for Dairy Processing Plants*

Paper no. 17. *Effluent Management Guidelines for Intensive Piggeries*

Paper no. 18. *Effluent Management Guidelines for Aqueous Wool Scouring and Carbonising*

Paper no. 19. *Effluent Management Guidelines for Tanning and Related Industries in Australia*

Paper no. 20. *Effluent Management Guidelines for Australian Wineries and Distilleries*

*The guidelines for diffuse and point sources are national guidelines that aim to ensure high levels of environmental protection that are broadly consistent across Australia.

[#] Not yet released in final form

[S] This document is available with its main document, but not as a separate item.

# Appendix 2
# The Council of Australian Governments' Water Reform Framework

In 1994, the Council of Australian Governments (COAG) met to discuss water resource policy, including the establishment of a Water Reform Framework, as outlined in *Managing Australia's Inland Waters: Roles for Science and Technology* (a report to the Prime Minister's Science and Technology Council, Commonwealth of Australia 1996, Appendix 3, pages 136–142). The Council comprises the Prime Minister, Premiers and Chief Ministers and the President of the Local Government Association. The detailed decisions of the Council were as below.

### *Water Resource Policy*

In relation to water resource policy, the Council agreed:

1. that action needs to be taken to arrest widespread natural resource degradation in all jurisdictions occasioned, in part, by water use and that a package of measures is required to address the economic, environmental and social implications of future water reform;

2. to implement a strategic framework to achieve an efficient and sustainable water industry comprising the elements set out in (3) through (8) below;

3. in relation to pricing:

(a) in general —

(i) to the adoption of pricing regimes based on the principles of consumption-based pricing, full-cost recovery and, desirably, the removal of cross-subsidies which are not consistent with efficient and effective service, use and provision; where cross-subsidies continue to exist, they be made transparent,

— Queensland, South Australia and Tasmania endorsed these pricing principles but have concerns on the detail of the recommendations,

(ii) that where service deliverers are required to provide water services to classes of customer at less than full cost, the cost of this be fully disclosed and ideally be paid to the service deliverer as a community service obligation;

(b) for urban water services —

(i) to the adoption by no later than 1998 of charging arrangements for water services comprising an access or connection component together with an additional component or components to reflect usage where this is cost-effective,

(ii) that in order to assist jurisdictions to adopt the aforementioned pricing arrangements, an expert group, on which all jurisdictions are to be represented, report to COAG at its first meeting in 1995 on asset valuation methods and cost-recovery definitions, and

(iii) that supplying organisations, where they are publicly owned, aim to earn a real rate of return on the written-down replacement cost of their assets, commensurate with the equity arrangements of their public ownership;

(c) for metropolitan bulk-water suppliers —

(i) to charging on a volumetric basis to recover all costs and earn a positive real rate of return on the written-down replacement cost of their assets;

(d) for rural water supply —

(i) that where charges do not currently fully cover the costs of supplying water to users, that charges and costs be progressively reviewed so that no later than 2001 they comply with the principle of full-cost recovery with any subsidies made transparent consistent with 3(a)(ii) above,

(ii) to achieve positive real rates of return on the written-down replacement costs of assets in rural water supply by 2001, wherever practicable, that future investment in new schemes or extensions to existing schemes be undertaken only after appraisal indicates it is economically viable and ecologically sustainable,

(iii) where trading in water could occur across State borders, that pricing and asset valuation arrangements be consistent,

(iv) where it is not currently the case, to the setting aside of funds for future asset refurbishment and/or upgrading of government-supplied water infrastructure, and

(v) in the case of the Murray-Darling Basin Commission, to the Murray-Darling Basin Ministerial Council putting in place arrangements so that, out of charges for water, funds for the future maintenance, refurbishment and/or upgrading of the headworks and other structures under the Commission's control be provided;

(e) for groundwater —

(i) that management arrangements relating to groundwater be considered by the Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) by early 1995 and advice from such considerations be provided to individual jurisdictions and the report be provided to COAG.

4. In relation to water resource policy, the Council agreed, in relation to water allocation or entitlements:

(a) that State Government members of the Council would implement comprehensive systems of water allocations or entitlements backed by separation of water property rights from land title and clear specification of entitlements in terms of ownership, volume, reliability, transferability and, if appropriate, quality,

(b) where they have not already done so, States would give priority to formally determining allocations or entitlements to water, including allocations for the environment as a legitimate user of water,

(c) in allocating water to the environment, member governments would have regard to the work undertaken by ARMCANZ and the Australian and New Zealand Environment and Conservation Council (ANZECC) in this area,

(d) that the environmental requirements, wherever possible, will be determined on the best scientific information available and have regard to the inter-temporal and inter-spatial water needs required to maintain the health and viability of river systems and groundwater basins. In cases where river systems have been over-allocated, or are deemed to be stressed, arrangements will be instituted and substantial progress made by 1998 to provide a better balance in water resource use including appropriate allocations to the environment in order to enhance/restore the health of river systems,

(e) in undertaking this work, jurisdictions would consider establishing environmental contingency allocations which provide for a review of the allocations five years after they have been determined, and

(f) where significant future irrigation activity or dam construction is contemplated, appropriate assessments would be undertaken to, inter alia, allow natural resource managers to satisfy themselves that the environmental requirements of the river systems would be adequately met before any harvesting of the water resource occurs.

5. In relation to water resource policy, the Council agreed, in relation to trading in water allocation or entitlements:

(a) that water be used to maximise its contribution to national income and welfare, within the social, physical and ecological constraints of catchments,

(b) where it is not already the case, that trading arrangements in water allocations or entitlements be instituted once the entitlement arrangements have been settled. This should occur no later than 1998,

(c) where cross-border trading is possible, that the trading arrangements be consistent and facilitate cross-border sales where this is socially, physically and ecologically sustainable, and

(d) that individual jurisdictions would develop, where they do not already exist, the necessary institutional arrangements, from a natural resource management perspective, to facilitate trade in water, with the proviso that in the Murray-Darling Basin the Murray-Darling Basin Commission be satisfied as to the sustainability of proposed trading transactions.

6. In relation to water resource policy, the Council agreed, in relation to institutional reform:

(a) that where they have not already done so, governments would develop administrative arrangements and decision-making processes to ensure an integrated approach to natural resource management,

(b) to the adoption, where this is not already practised, of an integrated catchment management approach to water resource management, and to set in place arrangements to consult with the representatives of local government and the wider community in individual catchments,

(c) to the principle that, as far as possible, the roles of water resource management, standard setting and regulatory enforcement and service provision be separated institutionally,

(d) that this occur, where appropriate, as soon as practicable, but certainly no later than 1998,

(e) to the need for water services to be delivered as efficiently as possible and that ARMCANZ, in conjunction with the Steering Committee on National Performance Monitoring of Government Trading Enterprises, further develop its comparisons of inter-agency performance, with service providers seeking to achieve international best practice,

(f) that the arrangements in respect of service delivery organisations in metropolitan areas in particular should have a commercial focus, and, whether achieved by contracting-out, corporatised entities or privatised bodies, this be a matter for each jurisdiction to determine in the light of its own circumstances, and

(g) to the principle that constituents be given a greater degree of responsibility in the management of irrigation areas, for example, through operational responsibility being devolved to local bodies, subject to appropriate regulatory frameworks being established.

7. In relation to water resource policy, the Council agreed, in relation to consultation and public education:

(a) to the principle of public consultation by government agencies and service deliverers where change and/or new initiatives are contemplated involving water resources,

(b) that where public consultation processes are not already in train in relation to recommendations (3)(b), (3)(d), (4) and (5) in particular, such processes will be embarked upon,

(c) that jurisdictions individually and jointly develop public education programs in relation to water use and the need for, and benefits from, reform,

(d) that responsible water agencies work with education authorities to develop a more extensive range of resource materials on water resources for use in schools, and

(e) that water agencies should develop, individually and jointly, public education programs illustrating the cause and effect relationship between infrastructure performance, standards of service, and related costs, with a view to promoting levels of service that represent the best value for money to the community.

8. In relation to water resource policy, the Council agreed, in relation to the environment:

(a) that ARMCANZ, ANZECC and the Ministerial Council for Planning, Housing and Local Government examine the management and ramifications of making greater use of waste water in urban areas and strategies for handling stormwater, including its use, and report to the first Council of Australian Governments meeting in 1995 on progress,

(b) to support ARMCANZ and ANZECC in their development of the National Water Quality Management Strategy, through the adoption of a package of market-based and regulatory measures, including the establishment of appropriate water quality monitoring and catchment management policies and community consultation and awareness,

(c) to support consideration being given to establishment of landcare practices that protect areas of river which have a high environmental value or are sensitive for other reasons, and

(d) to request ARMCANZ and ANZECC, in their development of the National Water Quality Management Strategy, to undertake an early review of current approaches to town waste water and sewage disposal to sensitive environments, noting that action is under way to reduce accessions to water courses from key centres on the Darling River system (it was noted that the National Water Quality Management Strategy is yet to be finalised and endorsed by governments).

9. In relation to water resource policy, the Council agreed, in relation to water and related research:

(a) to give higher priority to the research necessary to progress implementation of the strategic framework, including consistent methodologies for determining environmental flow requirements, and

(b) to greater coordination and liaison between research agencies to more effectively utilise the expertise of bodies such as the Land and Water Resources Research and Development Corporation, the Murray-Darling Basin Commission and other State and Commonwealth organisations.

10. In relation to water resource policy, the Council agreed, in relation to taxation:

(a) that a sub-committee of Commonwealth and State officials, established by the Working Group on Micro-economic Reform, meet to discuss taxation issues of relevance to the water industry with a view to reporting, through the Working Group, to the Council within 12 months,

(b) to support water-related taxation issues being examined in the proposed Industry Commission Inquiry into Private Sector Infrastructure Funding, and

(c) to accept any future consideration of tax compensation payments involving the water industry being dealt with through the Commonwealth–State Working Group established at the July 1993 financial Premiers' Conference.

11. In relation to water resource policy, the Council agreed, in relation to recommendations (3) through (8):

(a) that the Working Group on Water Resource Policy would coordinate a report to the Council for its first meeting in 1995 on progress achieved in implementing this framework including reductions in cross-subsidies, movement towards full-cost recovery pricing in urban and rural areas and the establishment of transferable water entitlements, and

(b) that as part of the monitoring and review process, ARMCANZ, ANZECC and, where appropriate, the Murray-Darling Basin Ministerial Council and the Ministerial Council for Planning, Housing and Local Government, would report annually over the succeeding four years, and again at its first meeting in 2001, to the Council of Australian Governments on progress in implementing the various initiatives and reforms covered in this strategic framework.

# Appendix 3
# Current Monitoring Approaches

## A3.1. Background

Water quality monitoring is undertaken by Commonwealth, state, territory and local governments, universities, research organisations, private companies, schools and community organisations.

The Environment Protection Group of Environment Australia commissioned Aquatech Pty Ltd to investigate water quality monitoring in Australia (DEST 1995). This work has since been updated in a new survey (EA/NLWRA 2000). The consultant noted that water quality monitoring is relatively well organised, although there is scope for improvement in a number of areas, such as better coordination and design of monitoring programs. In 1993–94, about 1500 distinct water quality monitoring programs were operated by 214 organisations (EA/NLWRA 2000). Mining companies did a significant amount of monitoring in Western Australia and the Northern Territory. In 1998–99, about 1000 programs were in progress, operated by 118 organisations, but it is probable that former small programs had been rationalised into larger programs, causing the apparent reduction.

The numbers of water quality monitoring programs for various categories of water are given in Table A3.1. Of these programs, 72% were conducted by state, territory or local governments in 1993–94 compared to 90% in 1998–99. The total cost for all organisations in 1993–94 was estimated by Aquatech to be around $60 million, while in 1998–99 it was $112 million (EA/NLWRA 2000).

**Table A3.1.** Numbers of water quality monitoring programs across Australia in 1993–94 and in 1998–99 conducted by governments, universities, research organisations, private companies and community organisations

| Category | Number in 1993–94 | Number in 1998–99 |
|---|---|---|
| Total | 1489 | 999 |
| *Some of the types of waterbody monitored* | | |
| Drinking water supply reservoirs | 174 | n.a. |
| Reservoirs and lakes | n.a. | 113 |
| Lakes and dams | 154 | n.a. |
| Rivers and creeks | 210 | 291 |
| General riverine environments | 89 | n.a. |
| Urban stormwater | 43 | 14 |
| Groundwaters | 112 | 69 |
| Estuaries | 48 | 83 |
| Coastal waters | 52 | 46 |
| Industrial water supply and process effluent | 321 | n.a. |
| Industrial effluent | n.a. | 177 |
| Agricultural runoff | 17 | 6 |

The community is playing an increasing role with programs such as Waterwatch, and its contribution is vital. The majority of waters tested tend to be industrial water supplies and effluent, followed by drinking water reticulated systems, rivers and streams, drinking water reservoirs, dams, groundwaters, riverine environs and coastal waters; agricultural runoff waters are the least tested. Currently about 20% of monitoring programs monitor biological parameters. In the current programs, attached algae, macrophytes, invertebrates, fish, birds and animals are tested. About 23% of monitoring programs include water flow measurements. These data can assist in determining nutrient loads and trends.

## A3.2. Stakeholders Involved in Water Quality Monitoring in Australia

The roles of several stakeholders in the water quality monitoring industry are outlined below. Stakeholders may both provide and use information from water quality monitoring.

### A3.2.1. Commonwealth Government

The Commonwealth Government has an interest in water quality issues because of their potential significance to the national economy. The Government is concerned that the community has access to clean water, and it has international responsibilities for the maintenance of environmental resources. It also recognises that national involvement and leadership help ensure that the monitoring actions taken are coordinated and in the national interest.

The Commonwealth provides funding for research and ongoing water quality monitoring programs by the states and the community, and for educational material: for example, it runs the national State of the Environment Reporting System and the Waterwatch national office as well as water research institutions.

The Commonwealth has direct responsibility for meteorology and the Exclusive Economic Zone. It cooperates with states and territories on water issues through Councils such as ANZECC, ARMCANZ and NHMRC. The Commonwealth’s role in water quality monitoring is maintained through its involvement in the National Water Quality Management Strategy (NWQMS), through the promotion of consistent approaches to monitoring across Australia, and information dissemination.

Significant research programs on water issues are conducted by CSIRO, the universities and several Cooperative Research Centres (CRCs). The main water research brokering and funding body is the Land and Water Resources Research and Development Corporation (LWRRDC), which covers the rural environment. Urban water research issues are covered by the Urban Water Research Association of Australia (UWRAA). (The UWRAA is not a Commonwealth body, but is a Division of the Water Services Association of Australia.)

### A3.2.2. State and Territory Governments

The management of Australia’s water resources is the responsibility of individual state and territory governments. State and territory government water resource agencies are responsible for the monitoring of ambient water quality in streams and storages. However, the setting of water quality standards and guidelines, ensuring that specific monitoring of waste discharges is carried out, is the responsibility of environmental protection agencies which also run monitoring programs. To meet these obligations, in part, state and territory agencies monitor ambient water quality throughout their states as well as carrying out specific monitoring in government-owned irrigation areas and projects. Governments generally have an interest in the monitoring of water quality, not only for its own intrinsic value, but also because water quality has the potential to be an overall indicator of the condition of catchments and the effectiveness of integrated natural resource management and catchment management.

The day-to-day management of pollution control and water quality monitoring is the responsibility of state and territory governments in accordance with their responsibilities under the Australian Constitution. State, territory and also local governments conduct the majority of water quality monitoring programs.

Water administration in major urban areas is done by water management authorities, such as Sydney Water and Melbourne Water, which have responsibility for treatment, supply and sewerage.

The environment protection agencies regulate industry, manage legislative responsibilities and determine conditions for industry compliance, policing and monitoring. Also, there is a range of other state and territory departments, such as public works and services, health, agriculture, fisheries, mines, national parks, conservation, and planning, which are involved to some degree in environmental management leading to water quality monitoring.

### A3.2.3. Local Governments

Local governments are increasingly involved in issues relating to environmental management within their jurisdictions, particularly in the planning context. In addition, in some of the eastern states of Australia, local councils are responsible for the provision of water and sewerage and stormwater disposal. Adequate monitoring and reporting is essential for ensuring that these responsibilities are discharged in a safe and environmentally sensitive manner.

### A3.2.4. Universities and Research Organisations

Contributions from universities and other research organisations include the development of water monitoring techniques, and the uptake of new technology and research into a wide range of related issues. They generate a significant amount of raw data on a range of water quality issues and techniques. These bodies interface with industry and governments through the CRCs, and assist in information dissemination and fund a variety of water-related research and training programs.

### A3.2.5. Industry

Operators in various industries are often required to collect data regarding waste streams and ambient water conditions on an ongoing basis. In addition, operators in industries that pose a potential threat to surface or groundwater are often required to monitor, to ensure the integrity of their operations. Increasingly, industry is encouraged to be self-regulating, backed up by regular comparative sampling by government agencies.

Private companies undertook about 2% of monitoring programs in 1998–99. Mining companies and a variety of industries undertook a large proportion of this monitoring as a requirement of their various licences.

### A3.2.6. The Community

In its widest sense, the community represents both the ultimate source of water quality problems and the ultimate recipient of benefits flowing from their amelioration. To contribute to the long-term solution to water quality problems, the community must accept that it needs to modify existing behaviours. To facilitate this, the NWQMS and other initiatives have sought to engender an ethos of ‘ownership’ or participation among the community.

A role exists for local government, total catchment management committees, Landcare groups and other community-based organisations to encourage and foster wider community awareness and involvement in water quality monitoring and reporting. This is being done through programs such as Waterwatch. This involvement primarily educates the wider community but also promotes its ownership of the monitoring program and the practical measures necessary to make key improvements.

It is preferable here to establish links with and to build successfully on existing public and community organisations in this field, rather than to try to develop new networks focused solely on water quality issues.

## A3.3. Australian State of the Environment Reporting System

### A3.3.1. Background

The Commonwealth State of the Environment Reporting system is an ongoing process for enhancing the quality, accessibility and relevance of data relating to ecologically sustainable development. The first major product of the system was *Australia: State of the Environment 1996* — an independent, nation-wide assessment of the status of Australia's environment. The recent *Environment Protection and Biodiversity Conservation Act 1999* now makes preparation of State of the Environment reports, and their tabling in Parliament, a legislative requirement. The Minister must cause a report on the environment in the Australian jurisdiction to be prepared in accordance with the regulations (if any) every five years (516B, EPBC Act 1999).

Arrangements are well under way for production of the 2001 Australian State of the Environment (SoE) Report, to be prepared by 31 December 2001 in accordance with the EPBC Act 1999. The 2001 SoE Report will concentrate on changes since the last report, cover new and emerging issues and pioneer the use of environmental indicators on a continental scale.

### A3.3.2. Environmental Indicators for National State of the Environment Reporting

In the lead-up to the 2001 SoE Report the Australian State of the Environment Section (Environment Australia) has commissioned world-leading research culminating in the development of the series '*Environmental Indicators for National State of the Environment Reporting*'. The reports recommend indicators for each of the themes on which Commonwealth SoE Reporting is based: i.e. Human Settlements; Biodiversity; The Atmosphere; The Land; Inland Waters; Estuaries and the Sea; and Natural and Cultural Heritage. The advice embodied in these reports is also being used as an input to other initiatives, such as the National Land and Water Resources Audit (NLWRA) and the Australian Local Government Association's Regional Environmental Strategies.

The theoretical framework and sets of environmental indicators documented in these reports underpin the implementation of environmental indicators for the 2001 Report and future SoE Reports for Australia. Over the current reporting cycle, the Australian State of the Environment Section is working to secure access to relevant data for the 2001 SoE Report. For example, many data for environmental indicators for the State of the Environment reporting process are available from data sets managed by Commonwealth, state and territory agencies and data sets managed by Environment Australia.

Additional data for indicators will become available through existing sources and processes, and Environment Australia is continually looking to develop links with other agencies collecting and collating related data. The aim of these links is to maximise the effectiveness and efficiency of data gathering, particularly by avoiding duplication in establishing data sources. For instance, significant progress has been made between the Australian State of the Environment Section, the NLWRA and the states and territories with a joint water quality project that aims to: (i) implement environmental indicators related to exceedances of the water quality guidelines; and (ii) work towards the comparable analysis of water quality status and trends across all states and territories.

### A3.3.3. Monitoring Needs and Strategies

The environmental indicators directly recommended for the Inland Waters theme are documented in Fairweather and Napier (1998) and indicators for the Estuaries and the Sea theme (now referred to as Coasts and Oceans) are documented in Ward et al. (1998). The reports identify suitable monitoring strategies for each indicator; including measurement techniques, appropriate temporal and spatial scales for measurement and reporting, data storage and presentation techniques, and the appropriate geographical extent of monitoring.

### A3.3.4. Development of a Core Set of Environmental Indicators

The SoE environmental indicator series is being further complemented by a nationally agreed set of indicators, known as the 'Core Set', currently under development through the ANZECC State of the Environment Reporting Taskforce (ANZECC 1998). The Core Set represents those indicators that have been identified as useful for monitoring environmental trends at all spatial scales and therefore require consistent monitoring across jurisdictions. The endorsement of the core indicators would form an agreed framework for State of the Environment reporting across all state and territory jurisdictions.

Through this process, the core indicators will assist each jurisdiction to further develop its environmental monitoring, and will help to build a national picture of trends and the condition of our environment.

Further information can be obtained from the Australian State of the Environment Reporting Section (phone (02) 6274 1855).

## A3.4. The Waterwatch Program

### A3.4.1. General Information

Waterwatch Australia is a national network of more than 50 000 people who share a vision of healthy waterways. Waterwatch promotes water quality monitoring as a tool to involve the Australian community in land and water management at the local and catchment scales. Through monitoring their local waterways, communities are geared into action to address water quality issues and work together to protect and rehabilitate waterways.

Volunteer monitors identify problems and build up a long-term picture of the health of a waterway so that appropriate actions can be taken. Community-collected data can be used for a number of different purposes including teaching students about the importance of healthy waterways, as an early warning heralding particular water quality issues in a local waterway or wetland for local catchment planning, or as a contribution to State of the Environment reporting.

Waterwatch Australia is an umbrella program providing a national focus for state programs which include Waterwatch Victoria, Waterwatch South Australia, Waterwatch WA, Waterwatch NT, Waterwatch Queensland, Waterwatch NSW, Waterwatch ACT and Waterwatch Tasmania.

At present, more than 120 regionally-based coordinators are supported to varying degrees by Waterwatch Australia. These community employees are training others to get involved in Waterwatch and to 'read' the results of their monitoring so they can design projects to tackle the problems they detect. The Waterwatch network includes a State Facilitator in each state and territory and a National Facilitator in the National Office which is based in Environment Australia, the Commonwealth department for the environment, in Canberra. The Waterwatch Australia Steering Committee has also been established to provide direction and support for the program and to make program policy decisions on behalf of the network.

Since 1993, the Waterwatch Australia program has grown from 200 groups monitoring in 16 catchments, to nearly 1800 groups monitoring in more than 150 catchments. It is estimated that at present there are over 4000 Waterwatch sites being monitored by over 50 000 people across Australia.

Definition of the objective of monitoring and identification of the purpose of the data are both part of the Waterwatch monitoring plan. Potential data users include teachers, community groups, local governments, catchment management committees, industries and state agencies. Each of these users has different requirements of the data. The purpose for which the data will be used determines how reliable the data need to be and the required precision, accuracy and sensitivity of the equipment, and sampling and analysis procedures.

A number of resources and guidelines have been developed by Waterwatch Australia to assist community groups and individuals to collect credible, consistent and accurate data. Regional coordinators have been appointed to assist community groups to collect water quality data, to provide a focal point for the collation and interpretation of data and to facilitate the feeding of the collected information into local and catchment management planning processes. Regional coordinators provide training and support to the rest of the community. All the groups and individuals within a catchment are linked through the regional or catchment coordinator, ensuring that all data collected are interpreted in the context of the whole catchment. Coordinators provide regular feedback to volunteer monitors and other sectors of the community.

### A3.4.2. Waterwatch Resources

The following resources assist the regional coordinators to provide support to the network.

(i) The Waterwatch Australia Manual (in preparation)

Title: *The National Technical Manual*

Availability: contact Waterwatch Australia

Description: The Waterwatch Australia Manual is a guide to monitoring for community groups and Waterwatch regional coordinators. The manual describes how to design a good quality monitoring program; how to monitor a large range of physical, chemical and biological parameters; quality control; how to interpret the results of Waterwatch monitoring; data management; and moving from monitoring to action.

(ii) The Waterwatch Australia Data Management system. This system has resulted from the need to integrate the range of data management and communication tools available to Waterwatch coordinators around Australia. A number of software tools have been developed to assist community groups to manage their data. These tools include:

- a Data Entry Program ensuring that all Waterwatch-collected data are recorded in a consistent manner across Australia. The Data Entry Program also provides a degree of validation and is available on CD-ROM or can be downloaded from the Waterwatch homepage, www.waterwatch.org.au;
- the Waterwatch Australia Database program, that enables regional networks to store, retrieve and report on their data; and
- GIS applications (state programs are currently developing tools to enable the Waterwatch network to link their water quality data to a GIS (geographic information system) to enable them to map, analyse and link information).

These tools may be used jointly or independently according to the needs of the individual coordinators.

The Waterwatch Offline data entry program is now available on www.waterwatch.org.au, the Waterwatch national web site.

**Box A3.1.** Draft Waterwatch sampling form, showing types of information that can be collected

### Site Details Section

Site details are an essential part of the Waterwatch program. Accurate details of site locality — for example, grid references, catchment name and land use — are important for making comparisons between sites. This information can also be used to generate maps of the catchments to assist in further interpretation of results.

Group [....................], Contact [.........................................................................................], Postcode [............]

Sample date and time [..........................................]

State [..], Division [..], Basin [..], Catchment [..], Sub-catchment [..], Site name [..], Zone [..], Map no. [..] Altitude [..], Easting [..], Northing [..]

Land uses [..], Waterbody [..], Sample depth [..], Sample width [..], Rainfall [..]

### Habitat Survey Section

A habitat survey involves visual assessment of the habitat value of the area immediately adjacent to your monitoring site. The condition of the vegetation in and around the waterbody provides a good indication of the likely condition of the aquatic environment. If the stream-side vegetation is intact, it provides a good buffer against erosion and the transport of sediment into streams and waterbodies. When stream-side vegetation is degraded, there is less protection against land use impacts and there may be subsequent deterioration of water quality.

Bank vegetation [..], Verge vegetation [..], Stream cover [..], Bank stability [..], Riffles, pools & bends [..]

### Biological Monitoring Section

Biological sampling of water for quality focuses on macroinvertebrates and algae. Macroinvertebrates are central to the food chains in aquatic systems and are a good indication of stream health. They are sensitive to quite mild pollution or changes in water quality.

*Macroinvertebrate Rating* [....] *Diversity* [....]:

Beetles[..], Beetle larvae [...], Riffle beetles [..], Diving beetles [..], Water scavenger beetles [..], Whirligig beetles [..], Water pennies [..], Damselflies [..], Dragonflies [...], True bugs [...], Backswimmers [..], Water boatmen [..], Water scorpions [..], Water measurers [...], Water striders [...], Small water striders [..], Black fly larvae [...], Mosquitos [..], Chironomids [...], Biting-midges [..], Crane-flies [...], Stonefly larvae [...], Mayfly larvae [...], Caddis-fly larvae [...], Dobson-flies/Alderflies [...], Springtails [...], Water fleas [...], Clam shrimps [...], Yabbies/Marron/Gilgie [...], Freshwater shrimp [...], Freshwater prawn [...], Freshwater crab [..], Side swimmers [..], Freshwater slater [..], Water mites [..], Bristleworm [..], Leeches [..], Segmented worms [..], Snails [..], Limpets [..], Bivalves [..], Flatworms [..], Roundworms [..], Hydra [..].

### Chemical and Physical Testing Section

Chemical and physical testing of water can provide an accurate analysis of the water in one particular place at one specific time. It gives a picture of the water composition and can confirm the presence of a particular type of pollution. Over an extended period, it can establish the normal levels for the waterbody and the typical range of values to be expected for the parameters measured.

Dissolved oxygen [..], % Dissolved oxygen [..], Water temperature [..], Velocity [..], Flow [..], pH [..], Electrical conductivity [..], Turbidity [..], Orthophosphate as P [..], Total P as phosphorus [..], Nitrate as N [..], Faecal coliforms [..], *E. coli* [..].

### Other Information:

### A3.4.3. Use of the Waterwatch Australia Data Management System

The three major components of the Waterwatch Australia Data Management System integrate the range of communication tools and data management techniques used by Waterwatch groups and coordinators around Australia. The package improves efficiency in the analysis and reporting of waterway monitoring information, it centralises the data at the regional scale, and it stores them in a uniform format.

The data are entered into four sections: site details data, habitat data, biological data and chemical and physical data (see Box A3.1). As well as results from monitoring, the data entered into the database include site location details (eastings/northings, latitude/longitude), group information, monitoring dates, frequency of monitoring, and sub-catchment/waterway information.

At present, statistical information is not generated at a national scale, although it may be generated at that scale in the future. The package can be used to compare, map, and graph data at a state and regional scale depending on how many regional coordinators are using the package to store data.

Data have been used by some groups to generate catchment/waterway reports that in some cases are printed in the local newspapers for general community environmental awareness.

### A3.4.4. Preparation of Monitoring Plans

Waterwatch monitoring groups are encouraged to consider a range of issues when preparing a monitoring plan. The following questions are used to help a group to design an effective monitoring plan:

- why is the group monitoring a particular waterway or site?
- who will use the monitoring data?
- how will the data be used?
- what parameters will each group monitor?
- what level of reliability of data does each group want?
- what methods for data collection will the group use?
- where will each group monitor?
- when and how often is the group able to monitor?
- who will be involved and in what way?
- how will the data be managed and reported?
- what quality control measures will be used to ensure accuracy, reliability and credibility?

The Waterwatch Australia Manual discusses the processes for developing monitoring plans and the issues that need to be considered by monitoring groups.

### A3.4.5. Unique Site Codes

To ensure that Waterwatch data are able to be stored and retrieved at a state and national level, a unique site code system has been developed. The unique site code system is based on the Australian Water Resources Commission drainage divisions and basins and comprises an AWRC basin, a three-letter catchment code and a three-digit number. Every Waterwatch monitoring site in Australia has a unique site code.

### A3.4.6. Quality Control

Waterwatch data are being used for local community action plans, local government planning processes, catchment management planning, environmental impact statements and as baseline information in catchments where there have never been monitoring programs. The community has developed increased skills and knowledge in monitoring procedures, and both the data collectors and the data users are placing greater demands on the data to be accurate and reliable.

In response to this demand Waterwatch has developed a Draft Data Confidence Plan that provides protocols and procedures to enable the community to collect data that are of a level of quality for the purpose for which they are to be used.

### A3.4.7. Waterwatch Contact Details

Details of Waterwatch Contacts are given in Table A3.2. Web site addresses are also provided for the state/territory programs. These web sites provide technical information and forums where individuals and groups can share information and seek advice from others in the network. Sharing of information throughout the network should enhance the quality of the information collected about individual waterways.

**Table A3.2.** Waterwatch contacts

| | |
|---|---|
| **National Facilitator**<br>Kate Gowland<br>Environment Australia<br>GPO Box 787, Canberra ACT 2601<br>ph: 02 6274 2797; fax: 02 6274 2735<br>email: kate.gowland@ea.gov.au<br>www.waterwatch.org.au | **South Australia**<br>Ross Wissing<br>Environment Protection Agency<br>Dept for Environment and Heritage<br>GPO Box 2607, Adelaide SA 5001<br>ph: 08 8204 9117; fax: 08 8204 9761<br>email: rwissing@deh.sa.gov.au<br>www.sa.waterwatch.org.au |
| **New South Wales**<br>Geoffrey Smith<br>Dept of Land & Water Conservation<br>GPO Box 39, Sydney NSW 2001<br>ph: 02 9228 6571; fax: 02 9228 6464<br>email: gsmith@dlwc.nsw.gov.au<br>www.streamwatch.org.au | **Northern Territory**<br>Leslie Alford<br>Natural Resources Division<br>Dept of Lands, Planning and Environment<br>PO Box 30, Palmerston NT 0831<br>ph: 08 8999 4456; fax: 08 8999 4445<br>email: leslie.alford@nt.gov.au<br>www.lpe.nt.gov.au/waterwatch |
| **Australian Capital Territory**<br>Jane Horniblow<br>Environment ACT<br>PO Box 144, Lyneham ACT 2602<br>ph: 02 6207 2246; fax: 02 6207 6084<br>email: jane.horniblow@act.gov.au<br>www.act.waterwatch.org.au | **Queensland**<br>Christina Dwyer<br>Dept of Natural Resources, Resource Science Centre<br>Gate 4 Block 80 Meiers Rd, Indooroopilly QLD 4068<br>ph: 07 3896 9737; fax: 07 3896 9625<br>email: Christina.Dwyer@dnr.qld.gov.au<br>www.qld.waterwatch.org.au |
| **Tasmania**<br>Michael Cassidy<br>Dept of Primary Industry, Water & Environment<br>PO Box 46, Kings Meadow TAS 7249<br>ph: 03 6336 5254; fax: 03 6336 5311<br>email: Michael.Cassidy@dpiwe.tas.gov.au | **Western Australia**<br>Julie-Anne Smith<br>PO Box 6740, Hay St<br>East Perth WA 6872<br>ph: 08 9278 0359; fax: 08 9278 0301<br>email: julie-anne.smith@wrc.wa.gov.au<br>www.wrc.wa.gov.au/ribbons |
| **Victoria**<br>Vera Lubczenko<br>Dept of Natural Resources & Environment<br>PO Box 41, East Melbourne VIC 3002<br>ph: 03 9412 4663; fax: 03 9412 4039<br>email: Vera.Lubczenko@nre.vic.gov.au<br>www.vic.waterwatch.org.au | |

## A3.5. Future Directions

### A3.5.1. Coordination

#### *Reducing Overlap*

There is potential for overlap and duplication between the agencies which undertake monitoring. Some states have lead agencies to coordinate monitoring, and statewide databases are being developed. For an example, now available on the Internet, see www.vicwaterdata.net/.

Moves towards regular wide reporting of monitoring results should be encouraged, including expansion of existing internal reporting towards future 'State of Rivers' reports, leading in time to State of the Environment reports. It is expected that this kind of reporting, in itself, will generate a requirement for specific kinds of data.

#### *Development of Protocols*

A number of bodies have publicly available protocols, but it is not clear how universally they can be applied across Australia. The importance of consistency of reporting and comparability of data dictates that consistent or standardised protocols should be developed. These Monitoring Guidelines are a useful start in that direction. DEST (1995) found that, although there were many monitoring programs, some of the data collected so far had not provided adequate information for ongoing management of water resources (i.e. the 'data rich–information poor' syndrome), and there were still significant gaps in water quality information which needed to be addressed.

This is a major task though it is possible to confine it by only having protocols for certain key indicators. A mechanism is needed for agreeing on prioritised standard protocols and the ongoing adoption of such protocols.

### A3.5.2. Future Directions in Monitoring Technology

Future programs will make greater use of continuous electronic remote monitoring equipment that can indicate physical and chemical changes that affect aquatic organisms and the surrounding biota. These techniques will need to be tuned to specific water quality monitoring needs.

Developments in monitoring technology are progressing towards continuous, automated sampling systems that are sensitive to a broad range of chemicals and can be monitored remotely using satellite technology. Sensor technology and sampler design and the establishment of uniform monitoring and equipment guidelines will result in analytical data of high validity and quality.

If data acquired by on-site water samplers can be available by remote access, the labour costs involved will be reduced, and accurate real-time data will be obtainable from isolated areas.

Some significant recent developments in terms of water quality monitoring technology include:

- the CSIRO developed 'Sewer Sentinel' which is capable of continuously monitoring the temperature, pH, conductivity, dissolved oxygen, and turbidity of raw sewage. Sewer Sentinels have been extensively trialled in a range of domestic and industrial sewers and have shown great potential.
- a device for the real-time monitoring of dissolved phosphate in final tertiary-treated plant effluent, developed jointly by Monash University Water Studies Centre, University of NSW Centre for Membrane Science and Technology, the Science and Environment Division of Australian Water Technology, and BHP Research;
- an automated analytical device developed by CSIRO and commercialised by Greenspan that uses physical, electrochemical and spectrophotometric sensors to measure a wide range of variables simultaneously. The unit is solar powered, features a highly accurate automatic calibration system and built in logger, and can be accessed remotely via satellite.

- research by La Trobe University into electrochemical sensor technology. Projects include the development of a voltametric analytical instrument for the simultaneous measurement of K, Ca, $NO_3$ and Cl ions in waste water.
- an acoustic Doppler current meter developed by the University of Western Australia which measures water flow with great accuracy.

Standard approaches to sampling, analysis and statistics will enable increased use of data from a range of monitoring programs by different organisations.

Areas that have been targeted for further development include:

- sensors that can provide greater detail about particular forms of contaminants and that can detect lower concentrations of toxic organic compounds in natural waters;
- new methods for the handling and processing of ‘dirty’ and heterogeneous samples;
- real-time methods for the assessment of microbial quality of waters; and
- a design for a suitable platform to house and protect the electronic sensors used for continuous measurement. The huge range between wet and dry in some rivers poses problems in terms of securing the equipment and sourcing units for long-term operation.

The main challenge in manufacturing real-time monitoring equipment for remote areas is to produce instruments that are as reliable, robust and low in maintenance as possible. These instruments either should not require frequent calibration or should perform self-calibration as often as required.

### A3.5.3. Biomonitoring

Future surface water quality monitoring will use the latest biological monitoring techniques and directly measure changes in population dynamics that can show the effects of combined environmental stresses and inefficient management practices. ‘Low-technology’ monitoring techniques such as biomonitoring are attracting increasing interest because of the need to combine physical, chemical and biological information to make meaningful environmental interpretations.

Biomonitoring measures the responses of aquatic organisms to contaminants and environmental conditions. The data obtained from biomonitoring programs are useful in conjunction with physical and chemical data. Macroinvertebrates are most commonly used because they are easy to identify. The group comprises a wide range of organisms and therefore a variety of responses can be observed; their sedentary habits are conducive to spatial sampling and their relatively long life spans permit temporal changes to be observed.

Biomonitoring techniques have been used for many years in the UK, USA and Canada, but Australia has some unique characteristics in contrast to other developed countries, such as the highly variable but generally low flow, and the time of peak detritus input. Therefore, these techniques need further development for Australian conditions. Research in Australia into rapid bioassessment techniques, based largely on macroinvertebrates, is being undertaken by various institutions and individuals including Victorian agencies, the Cooperative Research Centre for Freshwater Ecology, and groups associated with the National River Health Program (NRHP). The NRHP is focusing on macroinvertebrates but also considering algae, diatoms, macrophytes and fish.

Rapid bioassessment techniques reduce the time and costs involved in the assessment of environmental conditions, and facilitate the presentation of data that can be easily interpreted and understood.

# Appendix 4
# Water Quality Monitoring Case Studies

## A4.1. Case Study 1: http://www.environment.gov.au/soe/envindicators/estuaries-ind.html

### A4.1.1. Objectives and Information Requirements

Following earlier water quality and ecological investigations of the Upper Murrumbidgee River and Burrinjuck Reservoir an extensive ongoing monitoring program was initiated of the Murrumbidgee River, downstream of Canberra. The study objective was to monitor the water quality and aquatic ecology of the Murrumbidgee River and its associated catchment in relation to efforts to ameliorate eutrophication in the Upper Murrumbidgee River and Burrinjuck Dam.

The following information requirements were identified at the beginning of the study:

- What is the nature and extent of nuisance algal growths in the river and Burrinjuck Reservoir?
- What are the current environmental and use values of downstream waters, and what are the water quality guidelines consistent with meeting these values?
- What are the critical contaminants causing the nuisance algal growth, and what is the sustainable level of loading consistent with restoring acceptable levels of water quality?
- What are the major sources of nutrients causing the nuisance algal growth?
- What is the role of climate (catchment runoff) in modifying the levels of nutrients discharged and the responses of the receiving water?
- How should the new Canberra sewage treatment facility be operated to minimise the problem?
- What are the management practices in respect to other land uses across the catchment?

### A4.1.2. Study Design

***Conceptual Model***

These were the initial assumptions or conceptual models interrelating pressure and state conditions.

- Algal biomass levels in Burrinjuck Reservoir depend on the annual external loading of phosphorus, and water loading or hydraulic residence time.
- A substantial mass of nutrients is contributed by the catchment during non-point source discharge events: both non-point source event discharges and point source discharges during periods of low flow are important.
- Contaminant levels gradually decay downstream of discharge points as a result of biological uptake and oxidation of waters.

More recently, there has been an improved understanding of nutrient pathways and transformation processes. When water enters the system during rain events, high in suspended solids, the nutrients are rapidly adsorbed onto suspended particles and removed from the water column by sedimentation. During low flow conditions, when the water has relatively few suspended solids, ex-sewage nutrients may be taken up by algae, either attached or planktonic. The algae ultimately die and settle to the sediments, imposing a significant loading of organic carbon on the sediments. Subsequently, sedimented phosphorus is made bioavailable during the chemical reduction of sediments and remobilisation of phosphorus as orthophosphate. Sediment reduction is driven by the loading of organic carbon (BOD) and the mixing conditions (oxygen transfer rates offsetting the BOD) for the particular waterbody; that is, discharged phosphorus may be only indirectly involved in driving the in-stream remobilisation of sedimented phosphorus and subsequent algal growth.

#### *Study Boundaries*

The monitoring area covers the catchment and streams upstream of Canberra, and the catchment area and streams downstream to and including Burrinjuck Reservoir.

#### *Measurement Parameters*

To respond to study objectives, it was necessary to monitor:

- the mass of contaminants discharged from the catchment during non-point source discharges, expressed as a function of depth of runoff, and land use and management practice;
- the mass of contaminants discharged from point sources, expressed as a function of discharge rate and treatment facility;
- the transport losses by sedimentation, or the gains by re-suspension or microbial remobilisation, as a function of distance downstream from the discharge point, travel time, and flow rate or reach loading;
- the algal response to the composition, concentration or load of nutrients, and mixing and light conditions;
- the modification to algal composition and biomass as a result of zooplankton grazing.

Table A4.1 lists the parameters that were recorded during the study. It was important to identify the specific variables that were used to address the conceptual model of the study. Phosphorus concentrations were a major theme within this study because this nutrient's concentrations were related to algal counts and were also used to identify the point source and non-point source contaminant sites within the catchment. Another variable that interacted with the relationship between phosphorus concentrations and algal counts was turbidity. Apart from the external sources of phosphorus, it was possible that the lake sediment would need to be analysed. All these types of relationship needed to be determined as part of the study design.

**Table A4.1.** List of parameters sampled in streams and lakes

| Type | Parameter |
|---|---|
| Physical | Turbidity, temperature, colour, electrical conductivity, total dissolved salts, total suspended solids* |
| Chemical | pH, dissolved oxygen, alkalinity, ammonia, nitrate+nitrite, organic nitrogen*, total phosphorus, orthophosphate, dissolved organic carbon, chloride[88], silica[88], sodium[88], calcium[88], magnesium[88], iron[88], manganese[88], potassium[88], zinc[88], copper[88], nickel[88], sulfate[88], chlorophyll-*a* |
| Biological | Algal cell numbers and composition, zooplankton numbers and composition, *E. coli* |

* Included since 1983; [88] Occasional analysis only

#### *Sampling Sites and Frequency*

The selection of the monitoring sites, sampling frequency and selection of analytes was guided by the following principles:

- the need to monitor loads upstream and downstream of Canberra, including in-stream decay in loads downstream of discharge points;

- the need for event-based monitoring, in addition to routine monitoring of point source discharges;
- the need for special studies to better describe in-stream physical, chemical and biological processes:
  – analysis of in-stream mixing and diffusion processes, using dyes;
  – role of stratification within the Burrinjuck Reservoir (depth profiles);
  – biological composition of streams (macroinvertebrate sampling, fish surveys);
  – nutrient spiking of macro-enclosures to assess algal responses to different nutrient regimes;
  – analysis of nutrient release from Burrinjuck sediment cores under anaerobic conditions;
- the need for an initially intensive sampling frequency (5-day), to see how frequent the sampling had to be to adequately assess variability in the system;
- the need to target both phosphorus and nitrogen as possible critical contaminants;
- the need to select sampling points that provided representative (well mixed) samples and were linked with stream gauging information;
- the need to adopt auto-samplers as the only viable basis for obtaining event samples in urban catchments;
- the need to adopt a range of biological surveys to assess the health of the system.

In view of the contaminant pathways and transformation pathways unique to each sub-system, and their individual temporal and spatial variability properties, it was necessary to address sampling design at least at the sub-system level.

In the case of the Murrumbidgee and Burrinjuck system, there were four distinct sub-systems:

- rural catchment and streams upstream of major sewage effluent discharges;
- urban catchments and streams;
- major streams downstream of major sewage effluent discharges (Canberra, Queanbeyan);
- large downstream lakes (Burrinjuck Reservoir, Lake Burley Griffin).

The location of the sampling was also a factor that had to be considered. It was important to gain representative samples of the sub-systems being studied. The frequency of the sampling was highly related to the sub-systems' hydrological characteristics. The events that occur within an urban environment take place very rapidly with high energy outputs, compared to upper reaches in which events may still be detected weeks later downstream.

Assessment of required sampling frequency:

- in-stream water quality (non-event conditions)
  0–3% error in site median values for 14-day-based sampling versus 5-day;
- in-stream water quality (event conditions)
  8-hour-based sampling for primary streams, 20-minutes-based sampling for urban streams and drains;
- in-lake water quality
  3–8% error in site median values for 14-day-based sampling versus 7-day.

### A4.1.3. Sampling and Analysis

#### *Field Measurements*

The turbidity, temperature, colour, conductivity, pH and dissolved oxygen were all measured in situ. All the electronic equipment was calibrated before sampling. The in-field staff that performed the sampling were trained in the appropriate sampling procedures. Alkalinity was determined via a simple in-field titration using dilute acid and methyl indicator.

#### *Laboratory Analysis*

All the analyses performed within the laboratory followed standard methods that are specified by *Standard Methods for the Examination of Water and Wastewater* (APHA 1998) or USEPA sampling and analysis methods (Keith 1991). As part of the analysis the samples analysed were documented in detail. The laboratory facilities and analytical equipment were maintained to a very high standard to ensure minimal contamination. All staff that performed the analysis were competent and followed up the analysis by documenting the analytical methods used, and using appropriate QA/QC.

#### *Data Management*

There was early recognition of the importance of establishing an archive for water quality data, with checking and validation protocols for the entry and management of data, and documentation of sampling and analytical techniques and methods.

In view of the volume of data and the range of groups participating in sampling and analysis, only by this means could the monitoring program ensure:

- systematic logging, validation and entry of data;
- secure storage;
- consistent nomenclature, procedures and analytical methods;
- ease of data access.

Entries into the archive comprised information on the sample data, field observations or comments, sampling methods, site descriptions and river flows at the time of sampling. User-specified reports were based on site description (number), date and parameters required, and the laboratory undertaking the analysis.

For quality assurance/quality control,

- validation checks were standard for various fields in the database to minimise data entry errors;
- data analysis and interpretation were peer reviewed.

### A4.1.4. Data Analysis and Interpretation

The initial data analysis comprised statistical analysis of medians, ranges, trends (time and distance downstream), and correlation analysis of the parameters.

The explanatory power (validation) of a range of conceptual models was tested; the models included:

- in-stream steady-state first-order time-based decay of contaminants;
- in-stream time-series-based analysis (Centre for Resources and Environmental Studies CAPTAIN package);
- in-stream load, sedimentation and remobilisation or re-suspension-based models (AQUALM);
- in-lake load- and retention-time-based algal response relationships (Vollenweider).

A range of restoration measures was adopted as part of an integrated catchment management strategy. They included the tertiary treatment of Canberra sewage (98% removal of phosphorus, 95% removal of nitrogen, and 98% removal of phosphorus alone), and urban stormwater pollution control ponds, gross pollutant traps and ‘at-source’ controls (80% removal of suspended solids and 70% removal of total phosphorus).

Since the restoration measures were set up, the monitoring analysis has included:

- time-based trend analysis;
- comparison of average summer algal levels, normalised for varying streamflow or water loading conditions (modified loading-based model);
- changes in biological indices of river health (AUSRIVAS).

Currently, the Burrinjuck physical mixing conditions, external and internal loading, and algal biomass and composition are being reviewed for the 22 years of data (National Eutrophication Management Program: Burrinjuck Algal Succession Project).

### A4.1.5. Reporting

Reporting has comprised Project Reports, annual reviews of water quality, and web-based information. Access to the water quality database is available through the World Wide Web.

A range of techniques have been used to present the data analysis, including:

- time-based trend lines of water quality;
- box and whisker plots (medians, 90th and 10th percentile values) for a range of sites and determinands;
- charts based on nutrient and water load – algal response, for the major lakes and reservoirs;
- River Health Indices for a range of sites.

## A4.2. Case Study 2: A Groundwater Quality Assessment of the Alluvial Aquifers in the Logan–Albert Catchment, SE Queensland

### A4.2.1. Objectives and Information Requirements

Natural resources in the Logan–Albert Catchment are being subjected to increasing pressure as a direct result of population growth in South-East Queensland. This has prompted an investigation of the aquifer that supplies this region with its groundwater. The study was initiated in June–July 1994.

The major objective was to establish a groundwater quality condition benchmark for use in subsequent monitoring, to identify and understand the processes degrading groundwater quality in the aquifer, and to integrate the information obtained and provide advice to the responsible natural resource managers.

These information requirements were identified during the design phase:

- What is the geology of the Logan–Albert catchment?
- What are the hydrological characteristic of the three tributaries in the catchment, the Logan River, Albert River and the Teviot Brook?
- What are the existing physiography, climate and soils of the areas under investigation?
- What land uses exist within the catchment and is there a correlation between the use and physiographic features?
- What is the current, and past, water consumption within the catchment?
- What are the aquifer yields within the catchment, and does this relate to the aquifer type, i.e. unconsolidated sediment, sedimentary rock, fractured rock?
- What is the current water quality, in relation both to human consumption and irrigation quality criteria, of the identified aquifer types?
- Do water and sewage treatment plants exist within the catchment, and do these plants affect the aquifer water quality?

### A4.2.2. Study Design

***Conceptual Model***

The initial assumptions and conceptual models interrelating pressure and state conditions were:

- aquifer water quality is related to land use practices within the catchment;
- the geology of the catchment directly relates to the physical characteristics of the alluvial aquifer;
- increasing land use pressures are leading to poorer groundwater quality.

Before this study, there had been very few projects that focus on groundwater within the Logan–Albert catchment. The main reasons stated by Please et al. (1997) for this were:

1) the primary source of public supply water is from surface water. The main use of groundwater is for irrigation and private supplies for farms.
2) this region is an undeclared zone, so the government has no statutory power to license private bores. Therefore, there is no requirement for private bore data to be passed on to government bodies for storage and use in investigations.

The major theme in early investigations had related to surface water quality; groundwater was neglected. It was not until 1979 that an attempt was made to investigate groundwater quality. This investigation, initiated by Quarantotto (1979) (cited in Please et al. 1997) concluded that the Logan–Albert region had poor groundwater quality which was potentially due to the poor yields and/or poor water quality in the main hydrological provinces. In subsequent years several projects were undertaken to determine groundwater quality (Please et al. 1997), focusing mainly on in-fill information, inorganic constituents including trace metals and nutrients, and analysis of a few trace organic compounds and pesticides. Throughout all these investigations the Quaternary alluvial aquifer was the major theme. This system supplies and regulates the groundwater within the catchment. The geological characteristics of a given area will directly affect the groundwater quality.

***Study Boundaries***

The study was confined to the Logan–Albert catchment.

***Measurement Parameters***

To respond to the issues identified, the following monitoring information was required:

- water yields from the Quaternary alluvial aquifer, based on the location within the Logan–Albert catchment;
- assessment of physical parameters, inorganic chemistry (including metals and environmental isotopes), nutrients, contaminant and indigenous microbes, and pesticides within the groundwater of the Logan–Albert catchment;
- assessment of the potential sources of contaminants to the groundwater system. This was based on identifying specific areas and monitoring them in relation to their output of hydrological parameters.

The design of the sampling sites, sampling frequency and selection of analytes was guided by the following principles:

- the need to choose bore sites for groundwater quality sampling based on the existence of bores and associated data, availability, accessibility, bore diameter, flow rates and general quality, and spatial coverage;
- the need to pre-test cores to identify suitable study cores;
- the need to place bore lines strategically within the catchment to gain a representative indication of each individual river system's association with the aquifer;
- the need to establish a groundwater quality condition benchmark within the Logan–Albert catchment, based on ambient concentrations of identified hydrological parameters and the physical condition of each site;

- the need to identify and understand processes affecting groundwater quality in the aquifer;
- the need to integrate information obtained and provide data that would be useful to resource managers;
- the need for special studies to better describe chemical and biological processes in the aquifer:
  – the fate of contaminants after they enter the aquifer;
  – the effects of excessive nutrient input on aquifer water quality, biological and chemical perspectives;
  – the physical characteristics of the aquifer that would promote the entry of contaminants;
  – contaminant spiking to assess the transportation pathways of contaminants within the aquifer;
  – assessment of the temporal and spatial characteristics of contaminants within the aquifer.

The following measurement parameters were selected:

(i) major and minor inorganic constituents:

- sodium, potassium, calcium, magnesium, sulfate, chloride, bicarbonate;
- trace elements and metals;
- alkali metals — lithium;
- alkaline earth metals — barium, strontium;
- metallic elements — aluminium, cadmium, chromium, cobalt, copper, gold, lead, mercury, molybdenum, nickel, silver, tin, vanadium, zinc;
- non-metals — antimony, arsenic, boron, selenium;
- radioactive elements — uranium;

(ii) nutrients and carbon:

- an analysis of nitrate species for each location was performed, and ammonium-N was determined in conjunction with this analysis;
- phosphorus/phosphate concentrations;
- dissolved organic carbon;
- herbicides including triazines;
- insecticides including organochlorines;
- fungicides including conazoles;

(iii) microorganisms:

- faecal indicator bacteria;

(iv) environmental isotopes:

- tritium;
- deuterium oxygen;
- chlorine-36.

### A4.2.3. Sampling and Analysis

***Sampling Sites***

In all, 36 (QDNR) observation bores were sampled along 17 borelines, with 12 bores being analysed from each catchment during the study period (Table A4.2). The data required included physical parameters, inorganic chemistry (including metals and environmental isotopes), nutrients, contaminant and indigenous microbes, and pesticides. Potential sources of contamination to the alluvial aquifer from human activities include agricultural and rural industrial land uses, particularly from beef and dairy production. Within the Logan–Albert catchment there are many pre-existing bores that are potential sampling locations. Based on this selection of bores, sampling locations were chosen that would best represent the three individual catchments. Before any sampling, pre-testing was undertaken to establish which bores were suitable for analysis.

**Table A4.2.** Groundwater bores drilled, tested and sampled

| | Logan Catchment | Albert Catchment | Teviot Brook Catchment | Total |
|---|---|---|---|---|
| Drilled | 63 | 44 | 25 | 132 |
| Pre-tested (May 1994) | 15 | 13 | none — all considered to be low risk | 28 |
| Sampled (June–July) | 12 | 12 | 12 | 36 |

Note: one surface water sample taken from Logan River next to Round Mountain bore line

### *Field Measurements*

Five field measurements were taken at each bore:

1. total dissolved solids (TDS),
2. pH,
3. electrical conductivity (EC),
4. redox potential (Eh),
5. dissolved oxygen (DO).

The quality assurance and quality control guidelines relating to field data collection were as follows:

- adhere to standard sampling protocols;
- use correct sampling equipment, and transport and store samples in the appropriate manner;
- ensure that all equipment is calibrated before use.

### *Laboratory Analyses*

The quality assurance and quality control guidelines relating to laboratory analysis were divided into three categories.

(i) Blanks were used to monitor contamination during any stage of the sampling and analytical process. Blanks were taken at the beginning of the trip, mid-way and at the end of the trip. A 'before' and 'after' blank was taken at each time, i.e. the distilled water before and after it had been through the decontaminated pump system. Separate blank samples were used for chemical, microbiological and isotopic analyses. 'Before' and 'after' blanks were taken at more frequent intervals for microbiological samples.

(ii) Duplicate samples were taken as a test of precision in sampling and analysis. They were taken every tenth sample and processed in exactly the same way as the 'normal' samples.

(iii) Standard additions were used to test the accuracy of the analytical instruments. In this project the samples were spiked in the field to determine degradation between collection and analysis. A spiked sample was prepared every time a duplicate sample was taken. Spiked samples were prepared for major and minor ions, metals and nutrient analyses.

Pesticide analysis involved specific QA/QC procedures.

(i) Blanks were collected on three occasions throughout the sampling period. These ensured that the rinsing procedure between sampling was efficient and that there was no contamination. 'Before' blanks were performed by extracting pesticide-free water. 'After' blanks were performed on pesticide-free water which had passed through the pump equipment after the routine cleaning of the equipment with detergent, pesticide-free water and analytical methanol.

(ii) Duplicate samples were taken on three occasions for the normal extractions. The duplicate results monitored precision of sampling, extraction and analytical methods.

(iii) Triplicate samples were spiked with a range of compounds, representing those pesticides of interest. These recoveries gave an indication of the extraction efficiency of a range of compounds, matrix effects and degradation of analytes with storage. Acidified cartridges were also spiked on three occasions with a mixture of acid herbicides.

(iv) Each sample was spiked with a known quantity of surrogate solution before extraction. This solution consisted of the following compounds: difluoro-DDE; dibromo-DDE; deuterium-labelled terphenyl ($\delta_{14}$). The recovery of these compounds indicates the efficiency of the individual cartridge extraction.

One grab sample was taken at the Logan River. This site was chosen to detect possible surface–groundwater interactions with the closest bore sample.

#### *Data Archive*

There was early recognition of the importance of establishing a water quality data archive, including checking and validation protocols, for the entry and management of data, and documentation of sampling and analytical techniques and methods.

In view of the volume of the data and range of groups participating in sampling and analysis, only by this means could there be:

- systematic logging, validation and entry of data;
- secure storage;
- consistent nomenclature, procedures and analytical methods;
- ease of data access.

Entries into the archive comprised information on the sample data, field observations or comments, sampling method, site description and condition at the time of sampling. User-specified reports were based on site description (number), date and determinands required, and the laboratory undertaking the analysis.

For quality assurance/quality control:

- validation checks were standard for various fields in the database to minimise data entry errors;
- data analysis and interpretation were peer reviewed.

### A4.2.4. Data Analysis and Interpretation

The interpretation of the data was based on four main objectives:

- to set a benchmark for groundwater quality for 1994. This involved clear display of the analytical results for quick assessment and characterisation of groundwater quality.
- to understand the hydrological processes of the region through hydrochemical evaluation;
- to define any zones that could be affected by human activities;
- to provide information to assist in the sustainable management of natural resources.

With these guiding objectives in mind the interpretation of the data could be undertaken.

Several specific types of data evaluation methods were employed to illustrate and better understand what the data were representing:

- bar graphs of hydrochemical parameters against core number,
- spatial distribution of key parameters graphed on a schematic diagram,
- *X–Y* graphs for selected parameters,
- piper triliner diagrams for major ions,
- schematic diagrams showing isotopic concentrations.

### A4.2.5. Reporting

All field parameters were presented in bar graphs. Incorporated into these was a comparison of the in-field measurements and laboratory measurements. All the major and minor inorganic constituents' results were presented in bar charts, and also graphed against total ion concentration to identify any correlations. Sulfate concentrations were represented in *X–Y* graphs against dissolved oxygen, to identify any correlation between these two parameters. As well, iron and manganese concentrations were graphed against dissolved oxygen, Eh, pH and $SO_4$.

Trace element and metal parameters were all presented in bar graphs. Also, there was regression analysis of strontium and calcium concentrations and of aluminium and silicon. A graph of vanadium vs. Eh was also included in this section.

Nutrient concentrations were presented as bar graphs, with comparison between selected parameters. Nitrate was graphed against ammonium concentrations. Nitrate was also graphed against electrical conductivity, Eh, dissolved oxygen, depth of sample and depth to potentiometric surface (with and without removal of 'non-detects'). Orthophosphate was graphed against total phosphorus, and total phosphorus was also graphed against total nitrogen. Dissolved organic carbon was graphed against manganese, iron and sulfate.

Faecal indicator bacteria (FIB) concentrations (colony forming units, CFU) were presented in a table, with dissolved organic carbon. A schematic map of the FIB contamination in the individual catchments was also provided.

The environmental isotope concentrations of tritium, chlorine and deuterium were all presented in bar graphs. They were also displayed in schematic maps showing their activity in the catchments. Tritium was also graphed against dissolved oxygen, Eh, bicarbonate or total major anions and nitrate. Tritium and chlorine were graphed against each other for all catchments.

## A4.3. Case Study 3: Water Pollution in the Derwent Estuary, Tasmania

### A4.3.1. Objectives and Information Requirements

The Derwent Estuary in Hobart has sustained extensive organic, heavy metal, nutrient and pathogen pollution since the 1920–30s, from paper processing, zinc processing and sewage discharges. The contaminants have disturbed the ecology of the estuary, and its commercial fishery and recreation. There are also concerns about the effects of introduced marine organisms on local estuarine ecology.

The Department of Environment and Land Management (now E&P/DELM) established a variety of medium- to long-term monitoring programs, covering toxicants, nutrients, algae and bacteria, with the objective of ascertaining the current environmental health of the estuary. In addition, the Department has required annual surveys of heavy metals in aquatic organisms (by Pasminco Hobart Smelter), since 1972.

The objectives driving the monitoring and related studies have been:

- to determine the water quality guidelines appropriate for protecting and restoring the environmental values of the estuary;
- to determine the range of measures necessary to restore the water quality and ecology of the estuary, and the priorities for implementing the measures;
- to determine the appropriate emission control standards.

Currently, the monitoring studies have the objective of documenting existing conditions, tracking long-term trends, and determining if the estuary waters are suitable for primary contact recreation.

A 'State of the Derwent Estuary' review (Coughanowr 1997) was undertaken to identify significant pollution sources and to evaluate proposed remedial works. Information from various monitoring programs, environmental quality investigations and modelling studies from 1970 to 1997 was gathered and summarised to:

- identify and quantify (where possible) major sources of pollution and pollution loads to provide a '1996 snapshot';
- identify, compile and review existing data on water quality, sediments and biota prior to 1997;
- inform and educate resource managers and the public;
- identify gaps in the existing information database; and
- establish benchmarks for determining trends and improvements in the environmental quality of the estuary.

This is an example of a study that aims to develop a more focused water quality monitoring program by examining existing information and highlighting objectives, management issues, water quality concerns, monitoring and sampling design limitations and environmental processes.

### A4.3.2. Study Design

#### *Conceptual Model*

These were the initial assumptions or conceptual models interrelating pressure and state conditions:

- This is a highly dynamic system, with tidal exchange, variable inflows from the Derwent River, pulses of industrial organic and heavy metal wastes, and sewage discharges high in nutrients, organic material and pathogens.
- There is substantial diurnal mixing and diffusion as a result of tidal exchange in the lower reach, with salinity stratification of waters in the middle and upper reaches, exacerbating pollution processes.
- Sediments hold significant stores of contaminants and are sources of contaminants as a result of remobilisation and re-suspension.
- Reductions in the contaminant loads will yield improved water quality and the recovery of ecology.

#### *Study Boundaries*

The monitoring extends from the Derwent River at New Norfolk to the Derwent Estuary discharge into Stormwater Bay.

#### *Measurement Parameters*

The following measurements were required, to respond to the information requirements:

- the mass of contaminants discharged from the catchment during non-point source discharges;
- the mass of contaminants discharged from point sources;
- the mass of contaminants introduced by tidal inflows, including variability in Storm Bay nutrient levels;
- the mass of contaminants discharged in tidal outflows;
- the contaminant transport and transformation pathways for a range of mixing conditions;
- the internal loading on the estuary (sediment reduction or re-mobilisation rates);
- the oxygen budgets and relationship to sediment BOD -de-oxygenation in stratified zones;
- the concentration and bioavailability of toxicants as a function of direct and indirect loading, and their effects on biota;

- the algal response to the composition, concentration or load of nutrients, and to mixing and light conditions;
- the seagrass response to increases in suspended solids and dissolved nutrient–epiphytic density.

Specific measurement parameters selected are shown in Table A4.3. The table also shows the parameters being measured in the most recent studies, initiated in 1999.

### A4.3.3. Sampling and Analysis

Monitoring programs have been severely constrained by budgetary limitations. Consequently, it has not been possible to intensively monitor the following issues:

- non-point source load conditions during major river discharges;
- tidal inflows and outflows over tidal cycles;
- transport and transformation pathways along the estuary.

Monitoring has been largely limited to routine sampling of water quality through the estuary, as the basis for establishing the water quality prevailing as a result of current loading regimes and tidal exchange and river inflow conditions.

Knowledge of tidal exchange and mixing conditions is fundamental to understanding the dominant pollutant transport and transformation pathways. Only relatively recently has there been an attempt to develop a mixing and tidal exchange model for the estuary, on which a more integrated and systematic monitoring program might be based. A number of studies have been conducted to understand the circulation and mixing of the Derwent Estuary, including the recent study under the CSIRO Coastal Zone Program.

The design of the monitoring sites, sampling frequency and selection of analytes was guided by the following principles:

- the need to monitor discharges of industrial and municipal waste waters to the estuary;
- the need to monitor water quality of estuary waters at sufficient frequency and sites along the estuary to describe the prevailing water quality;
- the need to periodically survey sediments to assess net increase or loss in pollutants;
- the need to sample a range of biota to assess toxicant uptake rates and levels;
- the need to periodically survey biota (including seagrass, algae, benthic macroinvertebrates, fish) to assess changes in the ecological impacts.

A variety of water quality monitoring programs have been established. There have been semi-annual (2–5 times per year) water quality surveys of physical determinands, heavy metals and faecal bacteria (by E&P/DELM), during 1971–88, 1993–98 at 14 sites. There have been annual surveys of heavy metals in aquatic organisms (by Pasminco) since 1972 at 25 sites. There has been bimonthly monitoring of physical parameters, nutrients, chlorophyll-*a*, algae (by E&P/DELM), during 1994–98 at 20–25 sites.

Nutrient concentrations in the Derwent Estuary were monitored over a one-year period, commencing in March 1993. Water samples were collected fortnightly at 51 stations, both at the surface (0.1 m) and at depth (5–20 m). This program was extended in 1996 to 36 sites for nutrients and for various other parameters such as temperature, salinity and dissolved oxygen concentrations at approximately six-week intervals over two days, for a total of nine surveys in 1996.

In 1999, the Derwent Estuary Program (DEP) was established — a joint state, local government and Commonwealth initiative to restore and protect the Derwent Estuary. The primary objective of the first two years of the DEP is to develop a coordinated environmental management plan for the Derwent Estuary, together with agreements for the implementation of specific projects. The intention is to integrate, streamline and standardise monitoring activities in the Derwent Estuary, and to establish a regular reporting and review process. It is also intended that the DEP will draft Protected Environmental Values for the Derwent Estuary.

**Table A4.3.** List of measurement parameters

| Measurement Parameters | | Industrial & municipal discharges | Derwent River | Estuary water quality | Present studies (1999– ) |
|---|---|---|---|---|---|
| Physical | Turbidity | | ✓ | ✓ | ✓ |
| | Colour | | ✓ | ✓ | |
| | Temperature | ✓ | ✓ | ✓ | ✓ |
| | Total suspended solids | ✓ | ✓ | ✓ | ✓ |
| | Electrical conductivity | ✓ | ✓ | ✓ | ✓ |
| Chemical | pH | ✓ | ✓ | ✓ | ✓ |
| | Dissolved oxygen | ✓ | ✓ | ✓ | ✓ |
| | Biological oxygen demand | ✓ | | ✓ | |
| | Chemical oxygen demand | ✓ | | ✓ | |
| | Ammonia | ✓ | ✓ | ✓ | |
| | Nitrate + nitrite | ✓ | ✓ | ✓ | ✓ |
| | Total nitrogen | ✓ | ✓ | ✓ | ✓ |
| | Orthophosphate | ✓ | ✓ | ✓ | ✓ |
| | Total phosphorus | ✓ | ✓ | ✓ | ✓ |
| | Zinc | ✓ | ✓ | ✓ | ✓ |
| | Cadmium | ✓ | | ✓ | ✓ |
| | Copper | ✓ | | ✓ | ✓ |
| | Lead | ✓ | | ✓ | ✓ |
| | Iron | ✓ | ✓ | ✓ | |
| | Manganese | ✓ | ✓ | ✓ | |
| | Mercury | ✓ | | ✓ | ✓ |
| | Selenium | ✓ | | ✓ | |
| | Arsenic | ✓ | | ✓ | |
| | Fluoride | ✓ | | ✓ | |
| | Sulfate | ✓ | | ✓ | |
| Others | Oil & grease | ✓ | | ✓ | |
| | Resin acids | ✓ | | ✓ | |
| | Phenols | ✓ | | ✓ | |
| | Polycyclic aromatic hydrocarbons (PAHs) | ✓ | | ✓ | |
| | Hydrocarbons | ✓ | | ✓ | |
| | Chlorophyll-*a* | | | ✓ | ✓ |
| Biological | Faecal bacteria | ✓ | ✓ | ✓ | ✓ |
| | Algal biomass & composition | | | ✓ | |

Currently (1999–2000), there is quarterly monitoring of physical parameters, suspended solids, nutrients, chlorophyll-*a* and heavy metals at 25 sites throughout the estuary. Physical parameters are measured through the water column and water samples are collected at the surface and at depth. Recreational water quality is also monitored weekly during summer at 30 sites, for faecal coliforms and enterococci.

Other recent monitoring initiatives in the Derwent include the first full survey of estuarine habitat — macroalgae, seagrasses and wetlands — carried out by the Tasmanian Aquaculture and Fisheries Institute (University of Tasmania), and an associated surface sediment survey.

### A4.3.4. Data Analysis and Interpretation

Analysis has been limited to simple statistical analysis of medians, ranges and trends (time and distance downstream). Financial constraints have limited the use of models in analysis. Data from the present monitoring programs are being entered into the E&P/DELM database.

### A4.3.5. Reporting

Reports have been prepared by the Department of Environment and Land Management (Coughanowr 1995), the Inland Fisheries Commission (e.g. Davies et al. 1988, 1989) and Pasminco EZ. Information from these studies has been presented at workshops and conferences, published in scientific journals, and incorporated in reports by Commonwealth agencies. In 1997, all available environmental monitoring data for the Derwent Estuary were reviewed, compiled and synthesised in the *State of the Derwent Estuary Report* (Coughanowr 1997). The report, which can be accessed at www.derwentriver.tas.gov.au, was an important catalyst for improved management, including monitoring. A Stage 2 discussion paper (Existing Situation) has also been prepared to establish: Uses and Values, Protected Environmental Values, Management Systems and Structures, Environmental Conditions and Key Environmental Issues.

A number of Priority Environmental Issues have been identified and briefing sheets have been prepared for each of these issues for consideration in the next stage of the Derwent Estuary Program. These issues are: sewage discharges, industrial discharges, urban runoff, boat wastes, seafood safety, recreational water quality, heavy metal contamination, organic enrichment/low dissolved oxygen, introduced marine pests, estuarine habitat loss, threatened species, foreshore management, nutrients, upper catchment flows. These briefing sheets provide a good example of the use of existing information to identify and develop objectives and monitoring strategies that meet the information requirements for those objectives.

This review has resulted in the re-establishment of a quarterly monitoring program for heavy metals in the Derwent Estuary and a recognition of the need for a better understanding of the sediments in the estuary, particularly the conditions that may stimulate the mobilisation of heavy metals from the sediments, and how the sediments affect dissolved oxygen concentrations. It has also been recognised that there is a need for continuous monitoring of dissolved oxygen; previously the monitoring had been confined to individual readings during daylight hours, when dissolved oxygen levels tend to be higher.

## A4.4. Case Study 4: Long-term Chlorophyll Monitoring in the Great Barrier Reef World Heritage Area

### A4.4.1. Objectives and Information Requirements

In 1992, the Great Barrier Reef Marine Park Authority (GBRMPA) established a long-term monitoring program of water within the Great Barrier Reef. The major objective of this program was to investigate the long-term trends and regional differences in nutrient status of the waters that comprise the world's largest reef ecosystem.

This investigation relates to the increased sediment loads that have resulted since European settlement, some 200 years ago. In the last 140 years total nutrient input has increased by about 30%. This excess of nutrients has the long-term potential to damage the fragile ecosystem that exists within the Great Barrier Reef.

The information requirements identified at the outset of the study were these:

- What is the current nutrient status and sediment loading of the Great Barrier Reef system?
- What are the likely effects of increased nutrients and sediment on the reef system; are there specific sites within the reef where water quality guidelines are being exceeded?
- What is the nature and extent of excessive chlorophyll concentrations within the reef environment?
- What are the important sources of the nutrients that are contributing to increased concentrations of chlorophyll, and what would be considered an acceptable level?
- What is the current status of eutrophication within the Great Barrier Reef environment?
- Are there relationships between specific catchment activities and excessive chlorophyll concentrations?
- What is the relationship between chlorophyll concentration and phytoplankton biomass?
- What land management practices are being employed at present within the catchments associated with the Great Barrier Reef?
- *Trichodesmium* exist in the Great Barrier Reef; what is their response to nutrient availability?
- What are the temporal and spatial variations associated with river plumes within the reef?

### A4.4.2. Study Design

#### *Conceptual Model*

These were the initial assumptions or conceptual models interrelating pressure and state conditions:

- that chlorophyll concentrations within the Great Barrier Reef are a function of nutrient input which is directly related to sediment loading;
- that there is a relationship between catchment-based activities and sediment loading output from that catchment;
- that excessive concentrations of chlorophyll are associated with eutrophication problems, which will lead to the breakdown of reef ecosystems;
- that aquatic grazing has no major influence on phytoplankton abundance and distribution.

More recently, some consideration has been given to event-based sedimentation and nutrient inputs into the Great Barrier Reef. Stevens et al. (1996) studied the spatial influence and composition of river plumes in the central Great Barrier Reef. They concluded that flood plumes can introduce large quantities of nutrients and sediment, resulting in levels that far exceed non-flood conditions. It has also been established that plumes of this nature can travel large distances from the river mouth (Brodie & Furnas 1996), and persist as recognisably distinct water masses for several weeks. It was also stated that these river plumes, within inshore fringing reefs, may persist for longer periods and in a more concentrated form with effects that may be both more acute and longer lasting. Brodie (1996) attempted to relate the catchment conditions, based on climatic zonation within the Great Barrier Reef, to plume characteristics. He concluded that although larger dryland catchments have extreme flow patterns compared to the more even discharge patterns of the ‘wet tropics’, the extent of their river plumes is often contained to near-shore environments. Geostrophic forces and wind appear to be the major determinants of the directions of the plume travel and extent of dispersion.

#### *Study Boundaries*

The monitoring program covers an area of approximately 350 000 km$^2$ with an archipelagic complex of over 3000 reefs. Almost all the catchments that drain into the near-shore environments of the Great Barrier Reef are used for agricultural purposes and have been extensively modified.

**Table A4.4.** Weather and hydrographic parameters measured at each station

| Parameter | Unit | Method of determination |
|---|---|---|
| **Weather** | | |
| Wind speed | kph | Anemometer |
| Wind direction | 360 degrees | Ribbon and compass |
| Wave height | m | Visual estimation: trough to peak |
| Wave direction | 360 degrees | Compass |
| Cloud cover | octets (*/8) | Visual estimation |
| Rainfall | mm | Gauge |
| **Hydrographic** | | |
| Depth | m | Vessel depth sounder |
| Salinity | % | Salinometer or refractometer in field |
| Temperature | degrees C | Field meter or thermometer |
| Secchi depth clarity | m | Secchi disc |
| *Trichodesmium* | I/O | Visual: present or absent |
| Chlorophyll-*a* | | Fluorimeter |

### *Measurement Parameters*

The parameters to be monitored to respond to the identified questions were:

- the mass of sediment discharged from catchments during event-based discharges, expressed as a function of depth of runoff and land use and management practices;
- the mass of nutrients discharged from catchments during event-based discharges, expressed as a function of depth of runoff and land use and management practices;
- the concentrations of chlorophyll-*a* at inner shore areas and outer shore areas, documenting the season in which samples were taken, water temperature, etc. Specific measurements included chlorophyll-*a*, salinity, temperature, phosphorus, nitrate, nitrite, ammonia, dissolved organic carbon and free amino acids together with supporting general water quality parameters.

**Table A4.5.** Long-term monitoring transect summary

| Marine Park | Sampling transect | Date begun | Shelf range | No. of stations |
|---|---|---|---|---|
| Far Northern | Cape Weymouth | October 1996 | Inshore to offshore | 5 |
| Far Northern | Cape Melville | October 1996 | Inshore to offshore | 4 |
| Cairns | Lizard Island | January 1993 | Offshore | 5 |
| Cairns | Port Douglas | December 1992 | Inshore to offshore | 5 |
| Cairns | Cairns | December 1992 | Inshore to offshore | 7 |
| Central | Townsville | October 1996 | Inshore to offshore | 4 |
| Central | Whitsundays | October 1996 | Inshore to offshore | 8 |
| Mackay/Capricorn | Keppels | January 1993 | Inshore | 5 |
| Mackay/Capricorn | Heron Island | January 1993 | Offshore | 5 |

### *Sampling Sites and Frequency*

The design of the monitoring sites, sampling frequency and selection of analytes were guided by the following principles:

- the need to monitor concentration and loads at near-shore locations (<20 km) and offshore locations, with sampling areas being determined by the availability of personnel equipped to undertake sampling;

- the need for event-based monitoring in conjunction with routine monthly sampling;
- the need to quantify regional and cross-shelf patterns of phytoplankton biomass within the Great Barrier Reef lagoon which may be related to regional differences in nutrient inputs;
- the need to determine how much temporal variability (seasonal, event-related) in phytoplankton biomass may reflect changing nutrient inputs to Great Barrier Reef waters;
- the need to monitor ambient concentrations of chlorophyll which would represent relative nutrient concentrations, i.e. the use of chlorophyll as a bioindicator of ambient nutrient concentrations;
- the need to monitor salinity because this is a function of the proximity of the river plume;
- the need for Secchi disc measurements that determine water clarity because this also relates to the proximity and intensity of the plume;
- the need for special studies to better describe in-reef physical, chemical and biological processes, such as:
  - phytoplankton in the Great Barrier Reef and their response to nutrient availability,
  - the effect of excessive nutrient input on reef communities: a physical, biological and chemical perspective,
  - an investigation into physical characteristics and nutrient dynamics of the river plumes and correlations between benthic composition and water nutrient concentrations,
  - nutrient spiking to assess the effects of varying concentrations on phytoplankton biomass, assessment of the duration and proximity of effects in relation to plume intensity,
  - an investigation into the dynamics of phytoplankton grazing within the reef.

Sampling at monthly intervals would be sufficient, giving results that represented seasonal variation. The Great Barrier Reef is spatially immense, so the sampling locations were dictated by the proximity of available personnel. The sampling regime was broken into six main components:

- over 100 stations were monitored once or several times per year; these sites corresponded to previous research conducted on the reef in the late 1970s; the stations were arranged in cross-shelf transects that spanned the broad latitudinal range between 14°S and 23°S extending from the coast to the shelf break;
- at monthly intervals, 38 stations lying along 10 cross-reef transects were sampled; hydrographic parameters, chlorophyll and clarity were measured;
- the weekly and monthly sampling of cross-shelf transects took duplicate surface and near bottom samples with statistical parameters being evaluated in each case;
- provisions for event monitoring, for example, during flood plumes, cyclonic resuspension events and *Trichodesmium* blooms, were built into the sample design;
- built into the sampling design was a smaller-scale study located at Port Douglas (16°S). This involved five sites that were monitored at weekly intervals for dissolved organic matter, dissolved free amino acids, nutrients, phytoplankton biomass and composition, and *Trichodesmium* abundance.
- river nutrient and sediment flux monitoring studies were continued, building on previous research done on the reef (by the Australian Institute of Marine Science (AIMS)). Further refinement of nutrient budget models, both in the Great Barrier Reef lagoon (by AIMS) and for catchment processes (by Queensland Department of Primary Industry), were continued.

It was anticipated that there would be problems of high variability of phytoplankton abundance that would result in numerous problems in the statistical analysis. Trend analysis methods that allow for missing values, non-normal distributions, censored data, autocorrelation in space and time and seasonal trends were used. There was some coordination of the program with other monitoring occurring in the area. This involved long-term monitoring of temperature (by GBRMPA), photographic benthic monitoring (by GBRMPA and Queensland Department of Environment and Heritage (QDEH)), inshore and estuarine water quality monitoring (by QDEH) and sediment monitoring (by AIMS).

### A4.4.3. Sampling and Analysis

During this study all the data were collected at the site locations. Among other steps taken for quality assurance, the fluorimeter for chlorophyll-*a* analysis was calibrated regularly against diluted chlorophyll extracts prepared from log-phase diatom cultures.

***Data Archive***

There was early recognition of the importance of establishing an archive of water quality data, with checking and validation protocols for the entry and management of data, and documentation of sampling and analytical techniques and methods. In view of the volume of the data and the range of groups participating in sampling and analysis, only by this means could there be:

- systematic logging, validation and entry of data;
- secure storage;
- consistent nomenclature, procedures and analytical methods;
- ease of data access.

Entries into the data archive comprised information on the sample data, field observations or comments, sampling method, and site descriptions of reef condition at the time of sampling. User-specified reports were based on site description (number), date and determinands required.

Throughout the study the main principles that guided data management were as follows:

- validation checks were standard for various fields in the database to minimise data entry errors;
- data analysis and interpretation were peer reviewed.

### A4.4.4. Data Analysis and Interpretation

The concentrations of chlorophyll recorded at the reef stations were often skewed and it was necessary to transform the data. Typically, $\log_{10}(x)$ transformations were applied which conformed with parametric assumptions of normality and heterogeneity. Extreme values make the choice of summary statistics important. The means are greatly influenced by the outliers (extreme values), whereas median values are more conservative but use only 50% of the data. Techniques such as trimmed mean and M statistics have the advantage of retaining most of the information, yet are obviously more robust to the presence of outliers.

The analyses of long-term temporal trends in chlorophyll concentrations predominantly used non-parametric techniques. This was due to the non-normal nature of the data produced when monitoring chlorophyll concentrations; other factors such as extreme values, serial correlation and seasonality contribute to this issue. One technique that can be employed to analyse such data sets is the seasonal Mann–Kendall tau test. This test involves decoupling monotonic trends in water quality parameters from seasonality. The test sums the number of positive differences between an observation and all later observations, minus the sum of all negative differences. The trend slope is estimated from the seasonal Kendall slope estimator, which can be characterised as the median annual change adjusted for seasonality. This estimator is resistant to extreme values and seasonality. All tests are two-sided, since both the upward and downward trends are possible.

### A4.4.5. Reporting

Reporting has comprised Project Reports, annual reviews of water quality, and web-based information. Access to the water quality database is available through the Web.

A range of techniques has been used to present the data analyses, including:

- time-based trend lines of water quality;
- box and whisker plots (1 standard error of mean) for a range of sites and determinands;

- analysis of temporal and spatial variation in chlorophyll concentrations (all data being $\log_{10}$ transformed);
- graphs of phytoplankton nitrogen vs. time, in response to a constant load exceeding the threshold load by 20%;
- monthly surface temperature, salinity and chlorophyll graphs from the stations, produced for both inshore and offshore stations;
- summary statistics of regional chlorophyll-*a* concentrations grouped by season (summer and winter) and cross-shelf position (inshore and offshore);
- frequency observations of *Trichodesmium* slicks during sampling events in each cluster;
- summary of paired *t*-tests between near-shore and near-bottom chlorophyll-*a* concentrations within each regional cluster and grouped by season (summer and winter) and cross-shelf position (inshore and offshore);
- mean (SE±) variability of chlorophyll-*a* concentrations from replicate casts from surface waters, and between duplicates derived from the same cast;
- results of the seasonal Mann–Kendall test for trends in regional and cross-shelf clusters.