Technical Fact Sheet: Water Quality

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Overview

The purpose of this Fact Sheet is to provide assistance to members of the public in determining the adequacy of water quality assessments and monitoring programs undertaken as part of environmental impact assessments.

This Fact Sheet has been prepared by Scientific Advisory Service at EDO NSW. It has been reviewed by a member of EDO NSW's Expert Register.

This Fact Sheet is a guide only. If you have specific questions regarding water quality assessments, please contact EDO NSW via the Environmental Law Advice Line.

Aspects of water quality

Water quality is described by:

- the physical properties of water (e.g. temperature, flow);
- the chemical constituents of water (e.g. nutrients, toxicants);
- biological indicators; and
- sediment quality

Good quality water is water that can support the human uses and environmental values that the community deems important for each waterway.

[1] http://www.edonsw.org.au/legal_advice

Physical and Chemical Stressors

Physical and chemical stressors include nutrients, low dissolved oxygen, turbidity, suspended particulate matter, changes in temperature, salinity, pH and changes in flow regime. Physical and chemical stressors can cause changes in aquatic ecosystems such as nuisance growth of aquatic plants, smothering of organisms living in aquatic environments, and stress to or death of native fish. They may also modify the effects of toxicants. Typical sources and potential impacts of physical and chemical stressors in aquatic ecosystems are provided in Appendix A.[2]

Toxicants

Toxicants are chemical contaminants such as metals, aromatic hydrocarbons, pesticides and herbicides that can have potentially toxic effects at concentrations that might be encountered in the environment. Typical sources and the fate of toxicants in aquatic ecosystems are provided in Appendix A.[3]

Biological Indicators

Biological assessment and biological indicators are used because physical and chemical guidelines are too simple to be meaningful for biological communities and processes. Biological assessment provides information on changes in biology that may result from changes in water quality, changes in physical habitat (e.g. increased sediment deposition, changes in hydrology) or changes in biological interactions (e.g. the introduction of exotic species or diseases). It is used to detect important departures from a relatively natural, unpolluted or undisturbed state. An important departure is deemed to be one in which the ecosystem shows substantial effects, including:

- Changes in species richness, community composition and/or structure;
- Changes in abundance and distribution of species of high conservation value or species important to the integrity of ecosystems; and
- Physical, chemical or biological changes to ecosystem processes.

Sediment Quality

Many contaminants which enter aquatic systems will bind to **particulate matter** and end up in the sediments. Initially these contaminated sediments will be deposited at the surface of the bed, however through time they will be buried as sediments erode from the surrounding landscape.

Sediments, particularly the upper 10 cm, are habitats and food sources for many biological communities such as molluscs and worms. If sediments are contaminated, they can be an ongoing source of contaminants to the **water column**. Benthic

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[2] Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand (2000) *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*. [Date accessed 7/12/07]

[3] Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand (2000) *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*. [Date accessed 7/12/07]

organisms (those that live on or in the sediments of aquatic habitats) can take up contaminants from the sediments and this may affect the aquatic food chain through the processes of **bioaccumulation** and **biomagnification**.

When are assessments required?

Water pollution is prohibited under NSW law.[4] The definition of water pollution includes but is not limited to:

placing in or on, or otherwise introducing into waters, any matter, so that the physical, chemical or biological condition of the water is changed.[5]

This means that water quality assessments should be undertaken prior to development in order to ensure that water pollution will not occur in the construction or operation of that development.

Water quality assessments are required for developments or activities where there is likely to be an impact on water quality.[6] For Part 3A developments, water quality assessments are sometimes required by the Director-General's requirements.

Relevant legislation

***Protection of the Environment Operations Act 1997* (NSW)**

Prohibits the pollution of waters, except with an Environmental Protection Licence.

***Catchment Management Authorities Act 2003* (NSW)**

Establishes the functions for Catchment Management Authorities (CMAs), including their role in undertaking or funding catchment activities which may improve water quality e.g. riparian re-vegetation.

***Environmental Planning and Assessment Act 1979* (NSW)**

The need to consider the impact of a proposed development on water quality depends on what part of the Act the development is being assessed under.

Under Part 4-Section 79C outlines the matters that must be considered when granting development consent, including environmental impacts. These include impacts of the development on water quality.

Under Part 3A-, impacts on water quality may need to be addressed as part of the Director-General's requirements, but this is at the discretion of the Director-General

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[4] *Protection of the Environment Operations Act 1997* (NSW), s. 120.
[5] *Protection of the Environment Operations Act 1997* (NSW), Dictionary.
[6] The *Environmental Planning and Assessment Regulation 2000* (NSW), Schedule 2.

Under Part 5- the determining authority should consider impacts on water quality under s111.

National Parks and Wildlife Act 1974 (NSW)

Contains provisions relating to the declaration of Wild Rivers, which are rivers of high conservation significance. A Wild Rivers declaration will change the **trigger values** used for assessing the water quality of that river.

Rivers and Foreshores Improvement Act 1948 (NSW)

Regulates excavation within 40m of waterways and the construction of works in navigable waterways.

Water Management Act 2000 (NSW)

Manages water volumes and flows, including access entitlements for licence holders and environmental flows. Flows affect water quality.

Water Act 1912 (NSW)

The old regime for water management. As water sharing plans are approved for river systems, the Water Management Act 2000 comes into force.

Environmental Planning and Assessment Regulation 2000 (NSW)

Schedule 2 establishes what must be covered in an environmental impact statement for development applications, including any part of the environment that will be affected by the development.

SEPP 14 - Coastal Wetlands

For coastal wetlands identified by this SEPP, the impact on water quality must be considered when development consent concurrence is granted by the Director of the Department of Planning and Environment.

SEPP 71 - Coastal Protection

For land where this SEPP applies, the consent authority must not consent to a development which proposes to dispose of effluent in a non-reticulated system, where this will or may have water quality impacts.

Relevant policy/guidelines

Australian Drinking Water Guidelines (ADWG)[7]

[7] National Health and Medical Research Council (2004) *Australian Drinking Water Guidelines* [Date accessed 7/12/07]

Provide a framework to ensure that drinking water is of good quality for human consumption. The ADWG are not mandatory standards, however, they provide a basis for determining the quality of water to be supplied to consumers in all parts of Australia.

Australian Guidelines for Water Quality Monitoring and Reporting[8]

Provide guidance on suitable methods to design and implement water quality monitoring programs.

Interim Sediment Quality Guidelines (ISQG)[9]

Used to assess the impacts of contaminated sediments on aquatic ecosystems and to identify the need for sediment remediation. They are largely based on biological-effects-based guidelines, where sediment contaminant concentrations exceeding an interim guideline value leads to additional studies to confirm or deny the possibility of biological impacts.

National Ocean Disposal Guidelines for Dredged Material (NODG)[10]

Used to assess the acceptability of dredged sediments for ocean disposal. The NODG values are identical to those in the ISQG document. Sediment contaminant concentrations are compared to numerical guideline values in the initial assessment, and where the screening levels are exceeded, biological assessment is undertaken to determine whether the material is suitable for ocean disposal.

Water Quality Guidelines[11]

Establish environmental values (including human uses) for different types of waterways and then provide trigger values and a methodology to ensure that the water quality of the waterway can support these values.

NSW Water Quality Objectives[12]

The agreed environmental values and long-term goals for NSW's surface waters. They set out the community's values and uses for our rivers, creeks, estuaries and lakes (i.e. healthy aquatic life, water suitable for recreational activities like swimming and boating, and drinking water); and then use the ANZECC water quality guidelines

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[8] Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand (2000) *Australian Guidelines for Water Quality Monitoring and Reporting* [Date accessed 7/12/07]

[9] Part of Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand (2000) *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*. [Date accessed 7/12/07]

[10] Environment Australia (2002) *National Ocean Disposal Guidelines for Dredged Material* [Date accessed 7/12/07]

[11] Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand (2000) *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*. [Date accessed 7/12/07]

[12] NSW DEC (2000) NSW Water quality and river flow objectives. Available online at http://www.environment.nsw.gov.au/ieo/ [Date accessed 6/12/07]

to ensure that water quality is suitable for these purposes, or is supporting the agreed values.

Water quality guidelines

The most important of the guidelines is the Water Quality Guidelines (ANZECC Water Quality Guidelines).[13] These establish generic environmental values for **ambient waters** and then set out technical methods to determine if the waterway will support this value.[14] The Water Quality Guidelines link the management of water quality to the environmental values of each waterway. Environmental values are the human uses, or ecosystems that the community wishes to maintain for a given waterway, and may include;

- Protection of aquatic ecosystems;
- Primary industries (e.g. irrigation, stock watering, aquaculture);
- Recreation and aesthetics; and
- Drinking water

For each environmental value, the guidelines identify particular water quality characteristics or 'indicators' that are used to assess whether the condition of the water supports that value.[15] Those to be monitored should be chosen by identifying key issues that influence water quality in the catchment, and then choosing appropriate indicators.[16] A flow chart outlining the steps to be taken to determine the health of a waterway is included in the NSW DEC Guide to Using the ANZECC Guidelines and Water Quality Objectives in NSW.[17]

Environmental values, called Water Quality Objectives (WQOs), have been established for every waterway in NSW.[18] These were developed in consultation with the community and are the environmental values and long-term goals taken into consideration by decision-makers when making decisions on activities that may have an impact on the water quality of a waterway. The WQOs provide a guide as to which trigger values to use from the Water Quality Guidelines. For example if the water objective identified for a particular waterway is irrigation, then the trigger values used will be those that apply to primary industries.

The Guidelines also offer different values depending on the conservation value, and therefore the relevant protection level of the waterway. Most waterways in NSW

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[13] Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand (2000) *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*. [Date accessed 7/12/07]
[14] NSW DEC (2006) *Local planning for healthy waterways using NSW Water Quality Objectives* Available online [Date accessed - 6/12/07]
[15] NSW DEC (2006) *Using the ANZECC water quality guidelines and the water quality objectives in NSW* Available online [Date accessed - 4/12/07]
[16] See Appendix A for a list of common issues and appropriate indicators.
[17] NSW DEC (2006) *Using the ANZECC water quality guidelines and the water quality objectives in NSW* Available online [Date accessed - 4/12/07] at pg 2
[18] These can be found at http://www.environment.nsw.gov.au/ieo/

would be 'slightly to moderately disturbed', however those of outstanding ecological significance e.g. Wild Rivers, would be of 'high conservation value'.[19]

If the default trigger value for a certain parameter is not exceeded in ambient waters, there is low risk to the environmental value. However, when the trigger value is exceeded, there is a risk that the environmental value is not being protected or achieved.[20] Exceeding the trigger values means that there is a higher risk of the environmental value being compromised, and suggests the need for further investigation or management action. It is important to understand that the guideline values have no formal legal status and are not threshold levels of pollution above which significant impacts will occur as might be required for prosecution in a court of law.

What is a good water quality assessment?

Assessment and monitoring of aquatic ecosystems will generally take place in relation to a definable event, called a disturbance. Examples of disturbances include the construction of a new outfall, a change in land use, or development in the catchment.

Environmental impact assessment and monitoring should be undertaken by a suitably qualified environmental consultant, with analysis of samples undertaken by a **NATA accredited laboratory**. The environmental consultant should adopt an integrated approach to the assessment and monitoring of impacts on aquatic ecosystems using a mix of physico-chemical and biological indicators which are appropriate to the type of impact being investigated. Many testing laboratories will have a testing suite that includes all relevant water quality testing. This will usually be cheaper than asking for individual tests.

The Water Quality Guidelines establish the principle that the intensity of any given assessment and monitoring program should reflect the level and risk of potential impacts on water quality and the achievement and protection of environmental values.[21]

What should be measured?

When deciding which indicators are necessary to measure, the key issues in the local ambient waterway should be considered, as well as the key pollutants generated by the type of activity occurring, and any pollutants or potential pollutants of concern.

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[19] Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand (2000) *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*. At page 3.1-9. [Date accessed 7/12/07]
[20] NSW DEC (2006) *Considering environmental values of water when issuing prevention notices* Available online http://www.environment.nsw.gov.au/mao/envwater.htm [Date accessed 7/12/07]
[21] NSW DEC (2006) *Considering environmental values of water when issuing prevention notices* Available online http://www.environment.nsw.gov.au/mao/envwater.htm [Date accessed 7/12/07]

The initial step in most investigations is to compare data for the physical and chemical stressors and toxicants in the water and sediment to the appropriate guideline trigger values in the national Water Quality Guidelines.

It is important that the physical and chemical stressors selected for measurement are appropriate (see Appendix A for a guide). For example, if the impact of a petrol station on an aquatic ecosystem is being investigated, monoaromatic hydrocarbons, polycyclic aromatic hydrocarbons and phenols should be assessed, as these chemicals are specific to this type of facility. It would be ineffective to assess the aquatic ecosystem for cyanide or dioxins, as it is highly unlikely that these chemicals would be associated with a petrol station. The selection of appropriate physical and chemical stressors and toxicants is essential to ensure potential impacts associated with the disturbance can be detected.

How to measure water quality

Physical and chemical components of water quality

There are strict protocols on collecting samples, including the types of bottles each sample should be collected in, and ensuring that no air is left in the top of each bottle. Samples should be sent to a certified laboratory for analysis within the recommended holding time in order to ensure accurate results.

More information on sampling protocols and procedures for water and sediments is available in Chapter 4 of the Monitoring Guidelines[22] and the Handbook for sediment quality assessment.[23]

Biological Assessment

Ecological assessment is generally undertaken using tools for rapid biological assessment such as the Australian River Assessment System (AUSRIVAS). The AUSRIVAS models assess the ecological health of freshwater streams by predicting the **macroinvertebrate** community structure expected to occur at a site in the absence of environmental stress, and compares this to the macroinvertebrate community structure actually at the site or in the area of interest.

AUSRIVAS macroinvertabrate predictive models have been developed for each state and territory for the main habitat types found in Australian river systems, including **riffle, edge, pool and bed habitats**. For further information on biological assessment techniques refer to the AUSRIVAS website.[24]

Ecotoxicological testing is another type of biological assessment that consists of laboratory testing of the acute and chronic toxic effects of contaminants in water and

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[22] Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand (2000) *Australian Guidelines for Water Quality Monitoring and Reporting* [Date accessed 7/12/07]

[23] Simpson, S.L., Batley, G.E., Chariton, A.A., Stauber, J.L., King, C.K., Chapman, J.C., Hyne, R.V., Gale, S.A., Roach, A.C and Maher, W.A. (2005) *Handbook for Sediment Quality Assessment* , CSIRO, Bangow, NSW.

[24] http://ausrivas.canberra.edu.au/

sediments on biota. Acute toxic effects are effects resulting from exposure over a small part of the organism's life span, e.g. mortality, enzyme inhibition. Chronic toxic effects are effects resulting from exposure over a significant portion of the organism's life span, e.g. effects on growth and reproduction. These tests include **bioassays** and the measurement of **biomarkers** or **bioindicators**, focusing on effects at a species level.

Where and when to measure?

Selection of Sampling Locations

Sampling locations may be selected in a random, **stratified** or targeted manner.

Random selection provides an unbiased assessment of the condition of the water body, however there is the potential for areas of impact to be missed.

If the source of contamination is known, it is better to use a random stratified sampling design. This is where sampling locations are selected at increasing distance from the source.

Targeted sampling designs use prior knowledge of factors such as contaminant sources, **substrate** types and anthropogenic activities to select sampling locations. Targeted sampling is useful to provide a comprehensive understanding of where the contamination is located.

If using the **BACI** approach (see Table below), the independence of control and impact sites should be maintained by ensuring sampling locations are placed a sufficient distance apart. Information on water movements to understand the likely dispersion of contamination is essential to plan the extent and separation of control and impact sites.

Number of Samples

The appropriate number of samples for an investigation will depend on numerous factors including:

- the area of impact;
- the nature of impact;
- the approach used to select sampling locations; and
- the objectives of the investigation.

Because the composition of water and sediment in an aquatic ecosystem will vary with location and time due to the effects of rainfall, flow, catchment activity and seasonal variations, it is preferable for multiple water samples to be collected from multiple locations at multiple times. This will allow the range of concentrations in the water body to be determined and a more representative picture of actual conditions in the water body to be obtained.

The frequency and depth of sampling undertaken in monitoring studies may also be dictated by the rate of sedimentation, which may vary from 1 to 20 mm/year. The frequency and depth of sampling should also consider the distribution of biological activity in the sediments. Most biological activity occurs in the upper 10 cm, however some organisms can burrow to greater depths. Sediment sampling should be undertaken where the potential for threats to benthic organisms exist.

Spatial Variation

Water, sediments and biota can exhibit spatial variability at a range of scales, from centimetres, to metres, to kilometres. To understand whether the differences being observed are due to natural variability or due to a disturbance, it is important that the sampling design investigates the variability at these different spatial scales. This is called a hierarchical sampling design.

An example of a hierarchical sampling design to investigate spatial variability would be collecting half of the samples in **duplicate** or **triplicate** to understand small scale spatial variability, and collecting five samples in a 10 m 2 area to understand the larger scale spatial variability.

The sampling program should take into account the fact that sediments are chemically and physically **heterogeneous** . Contaminant distribution is likely to be grain-size dependent, with the highest concentrations of contaminants associated with the fine fraction of the sediment (muds), and the lowest concentrations of contaminants associated with the sandy or coarse fraction of the sediment. Sampling should be designed to account for this sediment heterogeneity. For example, replicate samples should be collected to assess localised heterogeneity, core samples should be collected in preference to surface grab samples so that vertical heterogeneity can be assessed and the different types of materials present should be sampled.

Temporal Variation

The timing of sample collection is important. If the objective of the sampling is to assess the impact of a **point source** on water quality, such as from a facility which discharges waste, then samples should be collected immediately after the discharge event as well as before the event. If the objective of sampling is to assess the impact of a **diffuse source** on water quality, such as broad scale application of pesticides, then samples should be collected immediately after a spray event and also after heavy rain, when the chemical sprayed could runoff into the water body under investigation.

Design of monitoring programs

Baseline Studies

Baseline studies are investigations undertaken before a disturbance has occurred to obtain a detailed understanding of the environment in the vicinity of the proposed development and to detect unanticipated changes or trends.

Baseline data is an important component of any environmental impact assessment to predict and/or model potential impacts due to the development. It can also be used to compare post development monitoring data to determine the accuracy of the predictions and the significance of impacts due to the development.

Baseline data should be collected for at least one year to enable seasonal variations in different parameters to be identified. The greater the length of time that baseline data is collected for, the greater the understanding of the natural fluctuations in water quality will be.

The Queensland Department of Environment and Resource Management has developed a suite of chemicals that should be tested for in baseline studies of areas where coal seam gas exploration is underway. A list of these chemicals is provided in Appendix B.

Comparison of Sampling Designs

The sampling design specifies the number, type and location of data to be collected and the duration and frequency of sampling. The sampling design will be influenced by the nature of the disturbance being investigated and the objectives of the assessment and monitoring program.

Statistical procedures are often used to determine the significance of the impacts predicted or detected. There are several classes of assessment and monitoring design, summarised in the following table.

Comparison of sampling designs

Sampling design	Features	Data required	Effectiveness
Before-After Control-Impact (BACI)	Enables differences before and after the development at control and impacted sites to be compared.	Sampling undertaken at a control location and at the location of impact before and after the development	High
MBACI	Enables greater certainty of the integrity of the control values.	Same as BACI, but multiple control sites used	Highest
After development at control and impact sites	Sampling undertaken at the same time at control and impacted sites so other influences on water quality can be taken into account e.g.	Sampling undertaken at a control site and impacted site, after the development has occurred.	Medium

	rainfall events, seasonal variation		
Before and after development at impact site	The control (monitoring undertaken before the development) is measured at a different time to the impacted site, therefore it is more difficult to prove that any changes are due to the development and not other factors that differ temporally e.g. water flow, seasonal variations etc.	Sampling undertaken at the impacted site before and after development	Medium/Low
A posteriori	May be appropriate where the toxicant under investigation is unusual and could only have come from the human activity under investigation (e.g. specialised pesticides). Lack of control site makes it more difficult to prove the link between the development and any changes to water quality.	Sampling only at the impact location after the disturbance	Low

In addition to sampling before and after the development, sampling should be conducted during construction of the development, with the type and frequency of sampling tailored to the nature of the construction process, rather than the nature of the development.

Conclusion

A good water quality assessment will have the following characteristics:

- The level and amount of assessment reflects the level of risk of potential impacts;
- All the potential pollutants and stressors associated with the activity are identified and measured;

- Biological, physical and chemical monitoring is undertaken;
- A sampling design is used that allows detection of spatial and temporal variability and compares control and impacted sites before and after impact; and
- Water sampling protocol and procedures, including analysis at an accredited laboratory, are followed to ensure accuracy of results.

Glossary

Ambient waters- Surrounding waters

BACI- Before, After, Control, Impact. Sampling design where samples are taken before and after the impact at both a control and an impact site.

Bed habitat- the sediments or rocks at the bottom of the river or lake where benthic organisms live.

Benthic organisms- organisms that live on the bottom of the waterbody i.e. in the sediment or on the rock that makes up the bed habitat.

Bioaccumulation- Bioaccumulation is when contaminants are accumulated by aquatic organisms either directly from the water or sediments, or through consumption of other organisms containing the contaminant.

Bioassay- Bioassays are experiments which introduce bioindicator substances to water samples in order to observe changes in their behaviour, physiology or chemistry e.g. exposure of microorganisms to a particular environment and observation of any changes in the organism related to toxin exposure, such as the presence of stress proteins produced when cells are exposed to harmful environmental conditions.

Bioindicator- Bioindicators are a species, or a group of species, whose function, population or status can be measured to indicate environmental or ecosystem integrity.

Biomagnification- Biomagnification is when concentrations of contaminants in tissue increase up through the food chain

Biomarker- A biomarker is a substance used to indicate a particular biological state. It may be any kind of substance indicating the existence of living organisms. It may be used to indicate a healthy organism, or a stressed or unhealthy organism or ecosystem.

Biota- living things. The flora and fauna of an area.

Diffuse source pollution- where there is no clear, identifiable source of pollution e.g. agricultural runoff after rainfall, urban stormwater runoff. Individually each source may not cause a significant impact on water quality, however cumulative impacts may create water quality problems.

Duplicate- 2 samples from the same sampling site

Ecological assessment- determining the health of the waterway by sampling plants and animals, including macroinvertebrates, fish and algae. The numbers and types of species found can give an indication of water quality.

Edge habitat- the areas on the edge of the river or lake which have different characteristics to areas in the middle e.g. water flows more slowly, more aquatic plants may grow, shallower water.

Heterogeneous- W hen a mixture is comprised of many different components which cannot be easily separated.

Macroinvertebrate- Macroinvertebrates are aquatic animals without backbones. They are large enough to be seen with the naked eye and include insects, crustaceans, snails, worms, mites and sponges. The insects include the larvae of flying insects (e.g. midges, two-winged flies, dragonflies, mayflies, stoneflies and caddisflies) as well as the adults of some groups (e.g. waterbugs, beetles, springtails). Other, perhaps more familiar crustaceans include yabbies and freshwater shrimps and prawns. Macroinvertebrates are often used in biological monitoring because they are common, widely distributed, and easily sampled. Most can be readily identified by experienced biologists.

NATA accredited laboratory- National Association of Testing Authorities accreditation assures competence of the facility's testing, measurement, inspection and calibration of samples and equipment.

Particulate matter- particles of solid material suspended in water e.g. soil, organic matter

Point source pollution- where there is a single, identifiable source of pollution into the waterway e.g. discharge from a factory

Pool habitat- calm, deeper water between riffles.

Riffle habitat- A stretch of choppy water. These habitats have more dissolved oxygen than pool habitats.

Spatial variability- variations in a measured parameter over space. Where measurements for one attribute of water quality e.g. pH, vary in different areas.

Stratified sampling- the area to be sampled is divided into subareas and then random samples are taken of each subarea.

Substrate- the surface on or in which plants, algae and certain animals e.g. barnacles, live and grow. The substrate may serve as a source of food for the organism, or simply as an attachment point.

Trigger values- Guideline values for chemical and physical components of water quality, found in the Water Quality Guidelines. If water quality measurements are outside the trigger values, there is a risk that water quality in that area is not fit for uses established in the water quality objectives.

Triplicate- Three samples from the same sampling site.

Water column- A hypothetical "cylinder" of water from the surface of a water body to the bottom and within which physical and chemical properties can be measured.

References

Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand (2000) *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*. [Date accessed 7/12/07]

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NSW DEC (2006) *Using the ANZECC water quality guidelines and the water quality objectives in NSW* Available online http://www.environment.nsw.gov.au/water/usinganzeccandwqos.htm [Date accessed - 4/12/07]

NSW DEC (2000) NSW Water quality and river flow objectives. Available online at http://www.environment.nsw.gov.au/ieo/ [Date accessed 6/12/07]

Appendix A

Sources and Potential Impacts of Physical and Chemical Stressors in Aquatic Ecosystems[25]

Physical/Chemical Stressor	Potential Anthropogenic Sources/ Causes	Potential Impacts
Nutrients (nitrogen and phosphorous)	Sewage outfalls Leaching from cleared land Fertiliser runoff Industrial effluents Agricultural effluents	Nutrients can stimulate the growth of nuisance plants which can dominate and change the dynamics of an aquatic ecosystem and lead to eutrophication. Impacts include displacement of endemic species, obstruction of fish migration, reduction in light available to species below, depletion of oxygen concentrations and reduction in habitat quality. Nutrients may also act as toxicants to aquatic organisms.
Low dissolved oxygen	Decomposition of sewage by microorganisms Decomposition of dead plant material by microorganisms	Low dissolved oxygen concentrations can result in adverse effects on aquatic organisms which depend on oxygen for efficient functioning, including fish, invertebrates and microorganisms. At reduced dissolved oxygen concentrations, many compounds become increasingly toxic, including zinc, lead, pentachlorophenol, cyanide, hydrogen sulphide and ammonia.

[25] Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand (2000) *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*. [Date accessed 7/12/07]

Suspended solids (turbidity)	Soil erosion Sewage outfalls Industrial waste Stormwater discharge Stream bank erosion Carp disturbing bottom sediments	Suspended particulate matter can affect aquatic systems while in suspension and once settled out. In suspension, the main impact is to reduce light penetration and adversely impact on the photosynthetic capability of aquatic plants. Suspended particulate matter has been shown to directly affect fish by clogging or coating gills. It may also impair feeding behaviour for species that use visual cues for foraging and for filter feeders. When it settles out, suspended particulate matter can smother benthic organisms, habitats and fish eggs.
Temperature	Heat pollution Discharge of cooling water from power plants Loss of riparian vegetation Global warming/ climate change Cold pollution Discharge of bottom waters from reservoirs	An aquatic organism's growth, metabolism, reproduction, mobility and migration patterns may all be altered by changes in ambient water temperature. Impacts on aquatic ecosystems due to thermal pollution include bleaching of coral reefs, changes in species diversity and changes in species abundance.
Salinity (electrical conductivity)	Increased salinity Runoff from areas affected by dryland salinity Runoff from areas affected by irrigated land salinity	Australia has freshwater, brackish and marine aquatic systems. Most aquatic organisms are only able to adapt to a narrow range of salinity. Changes in salinity can result in changes to physiological functions such as osmoregulation (the control of water and mineral salts

	Mine water discharge (coal seam dewater) Power station discharge Desalination plant discharge Reduced salinity Sewage outfalls Stormwater discharge	levels in the blood). Salinity can indirectly affect aquatic organisms by modifying the species composition of the ecosystem and affecting species that provide food or refuge. Freshwater biota are most vulnerable to increased salinity, whilst marine and estuarine biota are most susceptible to decreased salinity.
Low pH (acidity)	Acid mine drainage Acid sulphate soils exposed during clearing, excavation, dredging or lowering of the groundwater table Acid deposition (wet and dry) due to metal smelters, coal fired power stations, industrial plants and vehicle exhaust Surface runoff and groundwater discharged from soils acidified by agriculture	Most natural freshwaters have pH in the range 6.5-8.0, whilst the pH of most marine waters is closer to 8.2. Most waters have some capacity to buffer (or resist) changes in pH due to the presence of bicarbonate ions (HCO3-), but in poorly buffered waters, pH can change dramatically. Changes in pH may affect physiological functions of biota such as enzyme and membrane processes. pH changes can also increase the toxicity of some chemical compounds. For example, reduced pH can increase the toxicity of metals, ammonia and cyanide.
Flow regime (magnitude, timing, duration and frequency of flows)	Reduction in flows and flooding River regulation (weirs and dams) Excessive consumptive use of water by agriculture, mining, power stations and industry Levee banks to protect	Australia's extreme rainfall variability produces unpredictable variations in flow in riverine and estuarine systems. Aquatic ecosystems have adapted to these periods of drought and flood over millions of years and these cycles are critical in maintaining the biodiversity and productivity of rivers, estuaries, floodplains and

	floodplain development Increase in flows during storm events Urbanisation Land clearing	wetlands. A reduction in flows can result in the desiccation of habitat for aquatic biota and the loss of groundwater recharge. A reduction in flooding can reduce the biological productivity of floodplains, which is a major source of food and biological recruitment for the river. The loss of natural flow variability can reduce biodiversity.

Sources and Fate of Toxicants in Aquatic Ecosystems[26]

Toxicant	Potential Anthropogenic Sources/ Causes	Fate in Aquatic Ecosystems
Metals	Acid mine drainage Industrial wastewater discharge Municipal wastewater (sewage) discharge Urban runoff/ stormwater Waste incineration Dust deposition	The bioavailability and toxicity of metals to aquatic organisms is generally greatest in acidic solutions and at higher temperature. The toxicity of some metals is dependent upon valency state (e.g. arsenic, chromium). Metals are generally strongly bound by dissolved organic matter and/or adsorbed by suspended particulate material before being deposited in the sediments. Some metals can bioaccumulate (e.g. copper, lead). Mercury can form organomecurial complexes which are toxic and have the potential to bioconcentrate.
C6-C9 Aromatic Hydrocarbons -Benzene,	Marinas and boating activities Ports and shipping activities, including oil tanker spills	The high volatility and relatively low water solubility of these chemicals indicates that they would be rapidly lost to the

[26] Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand (2000) *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*.[Date accessed 7/12/07]

Toluene, Ethylbenzene, Xylene (BTEX)	Contamination of groundwater by underground storage tanks at petrol stations and airports Urban runoff/ stormwater Industrial wastewater discharge Municipal wastewater (sewage) discharge Contamination of groundwater by landfills or gasworks sites	atmosphere from a water body. Biodegradation and photodegradation are rapid and these chemicals are not expected to adsorb strongly to sediments or bioaccumulate.
Polycyclic Aromatic Hydrocarbons (PAHs)	Marinas and boating activities Ports and shipping activities, including oil tanker spills Contamination of groundwater by underground storage tanks at petrol stations and airports Urban runoff/ stormwater Combustion processes and atmospheric deposition Industrial wastewater discharge Municipal wastewater (sewage) discharge Contamination of groundwater by landfills or gasworks sites	Concentrations of PAHs in aquatic ecosystems are generally highest in sediments, intermediate in aquatic biota and lowest in the water column. Suspended particles and bed sediments are the primary mechanisms for the removal of high molecular weight PAHs from the water column, whereas volatilisation and transport are the primary removal mechanisms for low molecular weight PAHs. Microbes living in sediment water systems may degrade some PAHs, with degradation progressively decreasing with increasing molecular weight.
Pesticides and Herbicides	Agricultural activities Urban runoff/ stormwater Contamination of groundwater by landfills	Pesticides and herbicides can be toxic at low concentrations. They tend to adsorb strongly to the sediments and are persistent (i.e. do not degrade easily). Some pesticides and herbicides have the potential to bioaccumulate.
Cyanide	Industrial wastewater discharge Gold and silver mines Gasworks sites Agricultural activities	Different forms of cyanide have different toxicities to aquatic organisms. HCN and CN- (free cyanide) are the principal toxic forms. The form of cyanide in water is affected by pH, temperature, dissolved oxygen, salinity, other ions, complexing

		agents and sunlight.

Appendix B

DERM minimum water quality analytes for baseline assessments in coal seam gas areas[27]

Category	Parameters	
Physical parameters	pH (field and laboratory) temperature (field only) electrical conductivity (field and laboratory) total dissolved solids (laboratory only)	
Ions	calcium chloride fluoride magnesium	potassium sodium sulphate
Metals (dissolved & total)	Aluminium arsenic barium beryllium boron cadmium chromium cobalt copper iron	lead manganese mercury molybdenum nickel selenium uranium vanadium zinc
Alkalinity and hardness	alkalinity - bicarbonate, carbonate, hydroxide and total as CaCO3 (field and laboratory) total hardness as CaCO3	
Dissolved gases	carbon dioxide (field) methane hydrogen sulphide	

DERM suggested additional water quality analytes for baseline assessment in coal seam gas areas[26]

Category	Parameters
Physical parameters	benzene toluene ethyl-benzene xylene (Total) naphthalene phenanthrene benzo (a) pyrene

[27] Department of Environment and Resource Management (2011) *Baseline Assessment Guideline* Coal Seam Gas Regulatory Project, Queensland Department of Environment and Resource Management, pp 10-11.

	sodium hypochlorate sodium hydroxide formaldehyde ethanol gross alpha radiation
Nutrients	ammonia nitrate as N nitrite as N nitrate + nitrite as N total nitrogen as N total phosphorus
Microbiological	total heterotrophic plate count sulphate-reducing bacteria
Miscellaneous	ionic balance sodium adsorption ratio (calculated)

According to the DERM guidelines:
"All samples for baseline assessments are to be analysed at National Association of Testing Authorities (NATA) accredited laboratories. The limit of detection must be sufficient for assessment against current and relevant guidelines, including but not limited to:

- ANZECC & ARMCANZ, 2000. Australian and New Zealand Guidelines for Fresh and Marine Water Quality, National Water Quality Management Strategy Paper No. 4, Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, Canberra.
- NHMRC & NRMMC 2004, Australian Drinking Water Guidelines, National Water Quality Management Strategy Paper No. 6, National Health and Medical Research Council and Natural Resource Management Ministerial Council."