6 Monitoring change in ecological character

Framework for designing a monitoring program

CM Finlayson

Environmental Research Institute of the Supervising Scientist
Locked bag 2, Jabiru, NT 0886

Abstract

A framework for assisting with the design of ideal and effective monitoring programs is presented. The framework is placed within the context of a management system that provides the means of responding to the results of the monitoring program. It is noted that monitoring is not the same as surveillance, which is generally undertaken without a particular reason for collecting the data or information. The framework is not a prescriptive recipe for any particular monitoring program. It is a series of steps in a logical sequence. The general headings for these steps are listed below:

- Identify the problem or issue
- Set the objective
- Establish the hypothesis
- Choose the methods and variables
- Assess the feasibility and cost effectiveness
- Conduct a pilot study
- Collect the samples
- Sample analysis
- Analyse the samples
- Report the results
- Evaluate the project

These steps are presented pictorially and described in the text. Feedback loops within the framework provide the means of reassessing the effectiveness of the preferred method in achieving the objective.

1 Introduction

Environmental monitoring has received more and more attention in recent years. At a global level this has arisen as awareness of the extent of environmental degradation and habitat loss has increased. Wetlands, including those of northern Australia, have not been exempt from this general and widescale degradation (Finlayson & von Oertzen 1993, Storrs & Finlayson 1997, Finlayson et al 1998). Such is the concern at the extent of wetland degradation that increased effort is being directed towards developing effective management processes and responses to problems. In many instances this effort is being held back by a lack of relevant information on the nature of the problem, the cause of the problem and the effectiveness of management procedures and actions. Effective monitoring programs can help overcome such problems.

In a general sense monitoring addresses the general issue of change or lack of change through time and at particular places. Monitoring is built upon survey and surveillance but is more precise and oriented to specific targets or goals (Hellawell 1991).

> **Survey** *is an exercise in which a set of qualitative observations are made but without any preconception of what the findings ought to be*.
>
> **Surveillance** *is a time series of surveys to ascertain the extent of variability and/or range of values for particular parameters.*
>
> **Monitoring** *is based on surveillance and is the systematic collection of data or information over time in order to ascertain the extent of compliance with a predetermined standard or position*.

Thus, monitoring is built on a time series of surveys and differs from surveillance by assuming that there is a specific reason for collecting the data or information (Spellerberg 1991, Hellawell 1991, Furness et al 1994).

A framework for assisting with the design of a monitoring program is presented, largely based on that developed for the MedWet Mediterranean wetland program (Finlayson 1996a) and the Ramsar International Wetland Convention (Finlayson 1996b). The framework applies to all forms of monitoring (eg changes in the area of a wetland, the ecological health of a wetland, or the underlying reasons behind the loss of wetlands). It is not prescriptive and it is not a recipe for a particular type of problem or a particular type of wetland. It presents a series of steps that will assist those charged with designing a monitoring program to make decisions suitable for their own situation. A person using the framework will make these decisions based on some degree of knowledge and/or expertise. The framework is not a substitute for knowledge or expertise.

Where monitoring programs already exist the framework can be used to ensure that the monitoring is being done in a logical and well-structured manner. All monitoring programs should be regularly reassessed and, where necessary, modified or even terminated.

2 Management and monitoring

Even a well-designed monitoring program could have little value if the information that is collected is not utilised or does not influence the management process for that locality or site. Ideally, the locality or site will be subject to an interactive and holistic management plan that provides the means of responding to the information obtained from the monitoring program. If a formal or official management plan does not exist or is not being effectively implemented it is critical that mechanisms to make use of the information collected from a monitoring program are identified and developed.

Constable (1991) outlines the connection between a formal management procedure and an environmental monitoring program. Essentially, monitoring provides the means of measuring the output of the management procedure – that is, it provides the means of measuring the (observed) state of the environment and the extent to which it may have been altered. If the management objectives are not being met the existing legislation or regulations that affect the site (or location) are used to adjust the management activities. Importantly, a monitoring program can be established either before or after a particular management activity is implemented.

3 A framework for monitoring

Monitoring programs that are data rich and information poor are not effective management tools. Effectiveness is further reduced if the program provides misleading information. Frameworks for designing monitoring programs are tools to assist managers and planners. It is important to reiterate that the framework does not provide the answers – those responsible for the design provide the answers.

In an ideal situation the development of a monitoring program should be a straightforward and cooperative process between managers (who make decisions) and scientists (who provide expert advice and interpret data). In a simple sense, the managers would outline the need for a monitoring program and the scientists recommend the most appropriate techniques and, by an iterative process, an approach that has both scientific rigour and meets the management objectives will be developed. Adherence to a logical framework for designing monitoring programs cannot eliminate situations where this does not occur, but it can provide the means to identify the limits of a program and thereby potentially reduce the incidence of such cases.

The framework presented by Finlayson (1996a,b) is shown in figure 1. Key aspects of the various components of the framework are described below, based on material presented in a number of published sources (Green 1984, Maher & Norris 1990, Goldsmith 1991, Spellerberg 1991, Finlayson 1994, Maher et al 1994). A summary of the points to consider when using the framework is given in table 1.

The framework illustrates an ideal and perhaps even a hypothetical situation. The amount of time spent considering each step in the framework will be dependent on time and resources. As the framework is not prescriptive there is no expectation that every step should be given equal attention. Managers and designers will make their own decisions based on local circumstances – the framework provides a guide to assist them in making these decisions.

3.1 Identify the problem or issue

Identification of the issue that leads to a change in the ecological character of a wetland is an important first step. This needs to be done clearly and unambiguously. It is also linked with setting the objective. Once this has been done it is possible to formulate management activities, including further investigations, to shed light on the issue/problem and to provide the justification for monitoring.

Where possible, the extent or scale of the problem (or likely problem) should also be identified (eg will the entire wetland or a number of different wetlands be affected?). Knowing the likely extent of the problem could be made difficult unless the ecological character of the wetland has been adequately described (eg how large is the wetland and how much water does it contain?). Thus, baseline or reference data are needed.

The cause (or most likely cause) of the problem should also be identified (eg nutrients added to an inflowing stream, or over-exploitation of a fish species). If the cause is not known an investigative program should be implemented, but it is noted that it can be difficult to establish cause-and-effect relationships between an activity and observed features of the environment. Often such information is not available and given the urgency of many situations little effort is made to obtain it. However, without such information it can be difficult to determine what should be monitored.

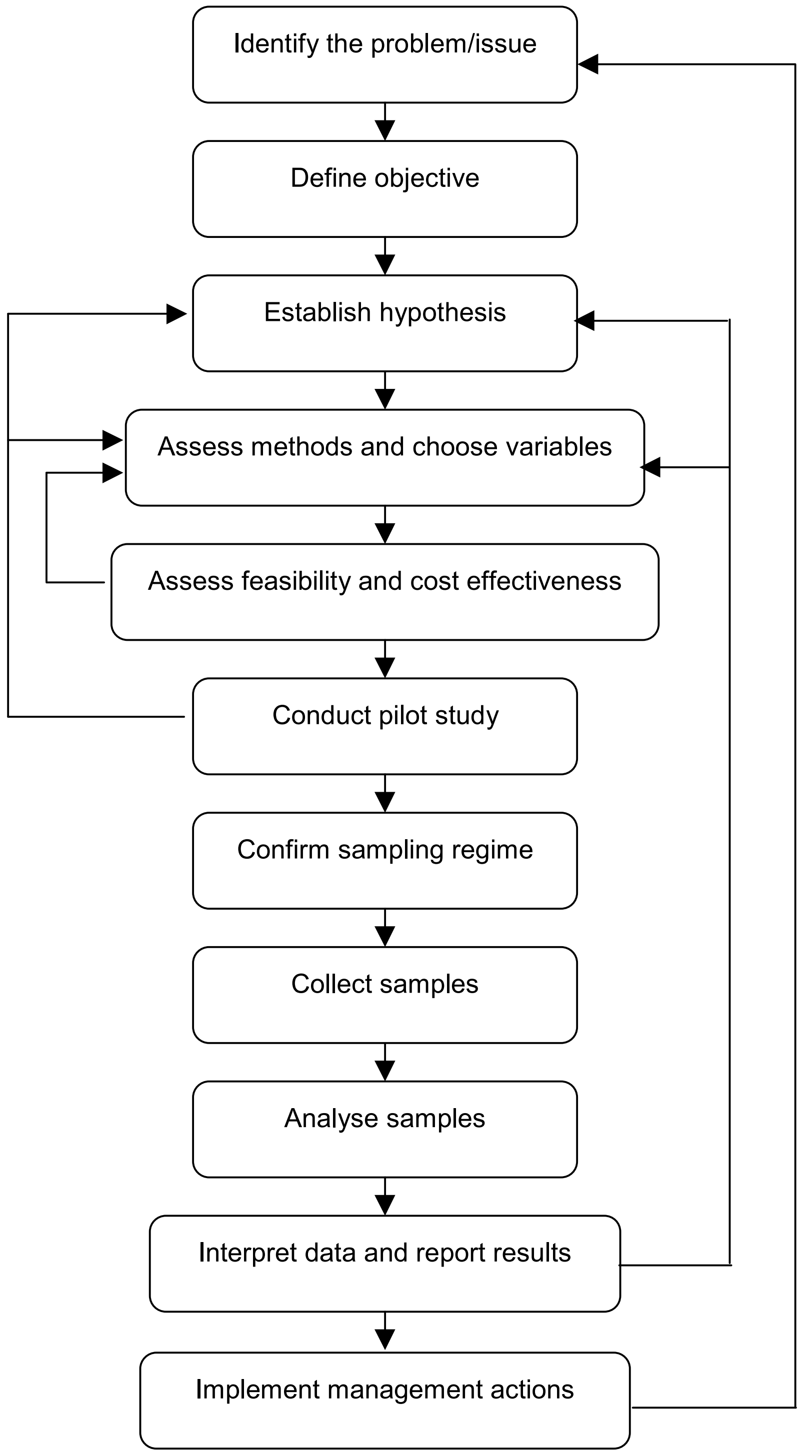

Figure 1 A framework for designing a wetland monitoring program (from Finlayson 1996a,b)

Table1 Summary of key points to consider when using a framework for designing a wetland monitoring program (from Finlayson 1996a,b)

Identify the problem or issue	State clearly and unambiguously State the known extent and most likely cause Identify the baseline or reference situation
Set the objective	Provides the basis for collecting the information Must be attainable and achievable within a reasonable time period
Establish an hypothesis	Supports the objective and can be tested
Choose the methods & variables	Specific for the problem and provides the information to test the hypothesis Able to detect the presence of and assess the significance of any change Identifies or clarifies the cause of the change
Assess the feasibility & cost effectiveness	Determine whether or not it can be done regularly and continually Assess factors that influence the sampling program: availability of trained staff; access to sampling sites; availability and reliability of specialist equipment; means of analysing and interpreting the data; usefulness of the data and information; means of reporting in a timely manner Determine if the costs of data acquisition and analysis are within the budget
Conduct a pilot study	Time to test and fine-tune the method and specialist equipment Assess the training needs for staff involved Confirm the means of analysing and interpreting the data
Collect the samples	Staff should be trained in all sampling methods All samples should be documented: date and location; names of staff; sampling methods; equipment used; means of storage or transport; all changes to the methods Samples should be processed within a timely period and all data documented: date and location; names of staff; processing methods; equipment used; and all changes to the protocols
Analyse the samples	Sample and data analysis should be done by rigorous and tested methods The analyses should be documented: date and location; names of analytical staff; methods used; equipment used; data storage methods
Interpret the data and report the results	Interpret and report all results in a timely and cost effective manner The report should be succinct and concise and indicate whether or not the hypothesis has been supported and contain recommendations for management action, including further monitoring
Evaluate the project	Review the effectiveness of all procedures and where necessary adjust or even terminate the program

3.2 Set the objective

The objective provides the basis for collecting the information. Imprecise or inadequate objectives negate the usefulness of a monitoring program. Simply stating that an excessive level of water extraction should not occur is insufficient. The objective must be precise and specific. A surveillance program can occur without a specific objective, but a monitoring program cannot; the objective is the starting point of a monitoring program. When more than one objective is identified they should be prioritised in order to make the best use of time and resources.

Explicit statements not only assist in defining the sampling program, but in a long-term program also enable new staff to continue the work in a consistent manner. The objective provides the basis for obtaining the required information over a specified time period.

3.3 Establish the hypothesis

The objective is supported by an explicit hypothesis. A hypothesis that asserts to simply 'assess significant change' is not explicit and should be altered to indicate the required level of change (ie it exceeds a preset level or standard or differs from the long-term mean value by more than a specified level of statistical significance). In other words, a hypothesis that can be tested on the basis of the collected data or information is required. If this is not done it is not possible to know whether the objective has been attained. When determining whether or not a hypothesis has been supported by the data/information the sources and extent of variability in the data/information must also be recorded. This is particularly important when the natural fluctuations (eg in water depth or population levels) are highly variable or even unknown. The hypothesis should be based on sound information.

Hypotheses are often not formulated. Hypothesis-free monitoring has rarely been successful or cost-effective. Surveillance is generally done without formulating a hypothesis and can be useful, but may not provide evidence of the vital linkage between cause and effect that is necessary for management purposes. The significance of the results must be assessed if the program is to be useful for management actions.

3.4 Choose the methods and variables

Many monitoring methods are available. When assessing which method (or methods) are appropriate for monitoring a specific problem or site it is necessary to be aware of the advantages and disadvantages of the alternatives in relation to the level of protection that is required. A literature review and expert advice are essential. Above all, the monitoring objective and hypothesis need to be kept in mind; can the method detect change at the required level and over the chosen time period?

In choosing methods and/or variables it is necessary to know what level of change is acceptable (the hypothesis) and whether the preferred method can account for potential sources of variability in the data or information being collected. The following parameters need to be considered when deciding which method to use:

- existence and adequacy of baseline information
- general approaches for collecting data/information
- number and location of sampling sites
- sampling frequency
- sample replication
- specific techniques for collecting the samples
- techniques for processing and/or storing samples
- protocols and means of storing the data or information
- methods of statistically analysing the data
- processes for interpreting the data and information

In a general sense, the method needs to be able to detect the presence of any change, provide a basis for assessing the significance of the change and identify or clarify the cause.

Where an adequate method does not exist, well-directed research is needed to develop or identify a specific technique. Methods that do not allow the hypothesis to be assessed should not be used.

3.5 Assess the feasibility and cost effectiveness

Once a method has been chosen and a sampling regime identified it is necessary to determine whether or not it is actually feasible to undertake the program on a regular and continual basis. Thus, factors that influence the sampling process and continuity of the program need to be considered, for example:

- availability of trained personnel to collect and process the samples
- access to sampling sites
- availability and reliability of specialist equipment for sample collection or analysis of samples
- means of analysing and interpreting the data
- usefulness of the data and information derived from it
- means of reporting in a timely manner
- financial and material support for continuing the program

If the monitoring program is contained within a structured management plan these factors should be easily assessed. If it is not contained within such a plan the assessment may be more difficult; great care should therefore be exercised.

In undertaking the feasibility assessment the cost effectiveness needs to be considered. The aim of a sampling program is to collect useful data or information with the least cost. The costs of data acquisition and analysis should be determined and considered in terms of the budget and the objective of the program. This assessment could benefit from independent and expert advice. Ideally, the cost effectiveness assessment would influence the budget allocation for the program. If an adequate budget is not available the program may need to be reduced or even abandoned. Inadequate funding should not be used as a reason to reduce the scientific rigour of a program. The goal is to obtain valid data for management purposes or to influence management decisions.

3.6 Conduct a pilot study

Before launching a large-scale program a pilot study is essential in order to save time and resources in the future. This is the time to fine-tune the method and individual protocols and test the basic assumptions behind the method and sampling regime. Some idea of the rigour of the method and the need to make changes in the design or particular techniques for collecting or analysing the data can be obtained at this stage. This is the time to make changes to the procedures that have been chosen. It can be very expensive and even nullify a program if changes are made at a later date. Specialist field equipment should be tested in the pilot study and, if necessary, modified based on practical experience. It is also the opportunity to assess the training needs for staff involved.

The means of analysing the data also require testing. If statistical analyses are being used they should be tested with data from the pilot study. For example, possible violations of statistical assumptions such as non-normally distributed data, non-independent data, and insufficient replication should be established and compensatory action taken. It may not be important that all statistical assumptions are met exactly, but the importance and consequences of any violations should be understood.

The amount of time and effort required to conduct the pilot study will vary considerably depending on the hypothesis to be tested and the methods. In some instances the information collected during the pilot study can also be used as part of the monitoring information. Based on the assessment of the monitoring method in the pilot study the sampling regime should be confirmed and clearly articulated. Individual sampling protocols need to be finalised and a detailed procedure made available to all personnel involved. Standardisation between individuals can be critical. Information gained from the pilot study could be used to change both the hypothesis and the methods.

3.7 Collect the samples

Sampling should not commence before the method has been established and staff trained or instructed accordingly. The rigour with which sampling is undertaken can influence the success or otherwise of the monitoring program. Sampling details (eg replication, dimensions) should be based on statistical premises and checked during the pilot study. The agreed sampling protocols should be adhered to. Where this is not possible all variations should be carefully documented and this documentation kept with the data. The following documentation should accompany all samples:

- date and location
- names of sampling staff
- method used to collect the samples
- number of samples required
- equipment used to collect the samples
- methods used for sample storage or transport
- all changes to the established methods or protocols

Sampling and data collection should be done in a manner to ensure the results can be used with confidence (ie were adequately replicated). Documentation of all practices is a vital part of demonstrating this confidence.

The effectiveness of a monitoring program is also dependent on the timely processing of samples collected for further analysis (eg dissecting fish for chemical analysis of specific biological tissue). However, the need for rapid results should not compromise the processing of samples. If the processing is not sufficiently rapid the program may need reassessment. Delays in processing the samples could also negate the usefulness of the program. When the samples are processed the following should be documented:

- date and location
- names of processing staff
- method used to process the samples
- equipment used to process the samples
- all changes to the established methods or protocols.

3.8 Analyse the samples

Many samples require analysis after they have been collected and processed. Whether this involves chemical analysis or biological identification the means of having this done should be determined in the pilot study.

Statistical analysis is regularly used to analyse data and ascertain the extent of any change or variation. These techniques should also be well and truly tested in the pilot study. There seems to be little point in collecting and processing samples if the means of interpreting the data are not available. Collecting samples in the hope of finding the means to analyse them is not an effective strategy for a monitoring program (it may be appropriate for a surveillance project). Achieving the objective of a monitoring program is not possible unless the data from the samples is made available for interpretation. Valid statistical analysis is critical where complicated or contentious issues are being addressed (see Hewett 1986, Bishop 1983). Sample and data analysis should be done by rigorous and valid processes.

As with sample collection a basic set of information should be documented when the samples are analysed:

- date and location
- names of analytical staff
- methods used for analysis
- equipment used for analysis
- means and location of storing data
- all changes to the established methods
- statistical tests and significance levels

3.9 Interpret data and report the results

All monitoring information and results need to be interpreted and reported in a timely and cost effective manner. If this is not done the program can be considered to have failed – monitoring is designed to provide results to assist further management. The interpretation should take place within the framework provided by the program objective. Making the reporting schedule and the reports themselves publicly available is one way of ensuring that this critical aspect of the monitoring program is given due attention.

Reporting can take many forms and it is not always necessary or even desirable to include all the results and detail, although these should be readily accessible. The form of the report will, in part, be determined by the nature of the problem and the monitoring objectives. Its express purpose is to ensure the monitoring data becomes part of the management planning process. In many instances it will also be useful to comment on the need for further monitoring of the same nature or even of a different nature. The size and style of a report will vary according to the objective, the method used and the audience. Despite this variation in style the report should be succinct and concise and supported by statistical analyses.

The report should indicate whether or not the hypothesis has been supported and whether management action is required. It should also be used to assess the effectiveness of the sampling methods.

3.10 Evaluate the project

The framework given in table 1 and figure 1 provide a series of steps that feedback into the planning process. Throughout the planning and implementation process for a monitoring program these feedback steps should be used to ensure that the required rigour is being obtained and that the hypothesis can be tested by the data being collected. At the end of the program, or after a predetermined time period the entire process should be re-examined and necessary modifications made and recorded. Where the objectives have been met the program can be terminated.

4 Concluding comment

Monitoring is an integral component of the management process. Poorly designed monitoring programs are a liability and should be terminated and replaced as they can produce misleading and erroneous data or information. Given the difficulties of finding resources for management we do not need these to be wasted on ineffective monitoring.

The framework given above does not attempt to provide a recipe for any particular monitoring program. Rather, it provides a series of steps to assist people planning monitoring programs to make informed decisions about their particular needs. The feedback links in the framework are a means of ensuring that the adequacy of any program is regularly reassessed.

5 References

Bishop DN 1983. *Statistics for biology*. Longman, Harlow, United Kingdom.

Constable AJ 1991. The role of science in environmental protection. *Australian Journal of Marine and Freshwater Research* 42, 527–538.

Finlayson CM 1994. Monitoring ecological change in wetlands. In *Monitoring ecological change in wetlands of Middle Europe*, eds G Aubrecht, G Dick & RC Prentice, Stapfia 31, Linz, Austria and IWRB Special Publication No 30, Slimbridge, UK, 163–180.

Finlayson CM 1996a. Framework for designing a monitoring programme. In *Monitoring Mediterranean wetlands: A methodological guide*, ed P Tomas Vives, MedWet Publication, Wetlands International, Slimbridge, UK & ICN, Lisbon, 25–34.

Finlayson CM 1996b. The Montreux Record: A mechanism for supporting the wise use of wetlands. In *Ramsar Convention, Proceedings of 6th Conference of the Contracting Parties of the Convention on Wetlands, Technical Sessions: Reports and Presentations*, Ramsar Convention Bureau, Gland, Switzerland, 32–38.

Finlayson CM & von Oertzen I 1993. Wetlands of northern Australia. In *Wetlands of the world I: Inventory, ecology and management*, eds DJ Whigham, D Dykyova & S Heijny, Kluwer Academic Publishers, Dordrecht, The Netherlands, 195–243.

Finlayson CM, Hall R & Bayliss B 1998. *Regional review of wetland management issues: Wet-Dry tropics of northern Australia*. LWRRDC National Wetlands R&D Program, LWRRDC Occasional Paper 03/97, Land and Water Resources Research and Development Corporation, Canberra.

Furness RW, Greenwood JJD & Jarvis PJ 1994. Can birds be used to monitor the environment? In *Birds as monitors of environmental change*, eds RW Furness & JJD Greenwood, Chapman & Hall, London, 1–14.

Goldsmith FB (ed) 1991. *Monitoring for conservation and ecology*. Chapman & Hall, London.

Green RH 1984. Statistical and nonstatistical considerations for environmental monitoring studies. *Environmental Monitoring and Assessment* 4, 293–301.

Hellawell JM 1991. Development of a rationale for monitoring. In *Monitoring for conservation and ecology*, ed FB Goldsmith, Chapman & Hall, London, 1–14.

Hewett CN 1986. *Methods of environmental data analysis*. Chapman & Hall, London.

Maher WA & Norris RH 1990. Water quality assessment programs in Australia: Deciding what to measure, and how and where to use bioindicators. *Environmental Monitoring and Assessment* 14, 115–130.

Maher WA, Cullen PW & Norris RH 1994. Framework for designing sampling programs. *Environmental Monitoring and Assessment* 30, 139–162.

Spellerberg IF 1991. *Monitoring ecological change*. Cambridge University Press, Cambridge.

Storrs MJ & Finlayson CM 1997. *Overview of the conservation status of wetlands of the Northern Territory*. Supervising Scientist Report 123, Supervising Scientist, Canberra.

Biological monitoring

R O'Connor

Environmental Research Institute of the Supervising Scientist,
Locked bag 2, Jabiru, NT 0886

Abstract

The range of biological monitoring programs developed at ***eriss*** are described. The approach adopted encompasses a range of indicators to allow for early detection of short term impacts and detection of longer term impacts. Practical requirements for producing consistent, reproducible results in biological monitoring are also discussed, as are considerations for data management using the ***eriss*** macroinvertebrate relational database as an example.

1 Introduction

Biological monitoring involves the systematic collection of data or information about biological responses over time, in order to evaluate environmental changes and thus ascertain the extent of compliance with a predetermined standard or position (adapted from Finlayson 1996). At ***eriss*** biological monitoring techniques have been developed to detect possible impacts arising from mining activities in the Alligator Rivers Region. Monitoring to date has focused on aquatic systems after a review of literature determined that fully aquatic organisms (or life stage of organisms) were most at risk from the release of mine waste-waters to the environment (Humphrey & Dostine 1994). Biological monitoring using benthic macroinvertebrates commenced in the late 1980s in the South Alligator River in response to a proposal to mine gold and uranium at Coronation Hill. Though mining did not go ahead at Coronation Hill, research by ***eriss*** has nevertheless resulted in a valuable baseline data set. Conversely, a biological monitoring program has been developed for the Magela Creek system where uranium mining on the Ranger lease has taken place since the late 1970s (Humphrey et al 1990).

The implementation of biological monitoring programs requires a high degree of protocol development and documentation to ensure consistent reproducible results. Thought also needs to be given to how data derived from biological monitoring can best be stored to ensure effective use of resources and data integrity. A relational database has been developed at ***eriss*** to store and manage macroinvertebrate data collected from the region.

2 Biological monitoring at *eriss*

It has been recognised that no 'ideal' indicator organism exists. The selection of complementary indicators (ie those that integrate somewhat different aspects of environmental stress) is particularly useful. For example, measurements of populations, communities and ecosystems tend to be more appropriate compliance indicators for judging achievement of ecosystem objectives, while measurements performed on individuals will tend to be better diagnostic and early warning indicators (Cairns et al 1993). Using these principles, ***eriss*** has developed a comprehensive and sensitive biological monitoring program to provide 'early warning' of short-term (acute) effects of waste-water releases and detection of longer-term effects (delayed in expression or chronic) of mining generally (Humphrey & Dostine 1994, Humphrey et al 1990, 1995).

2.1 Early detection of short-term effects

An early detection type of biological monitoring was judged to be necessary to detect any unexpected, harmful responses occurring during releases of waste waters from the mine. Thus, if necessary, releases could be quickly adjusted or terminated, so reducing the risk of any adverse effects occurring in the stream itself (Humphrey & Dostine 1994). A creekside monitoring system has been developed to this end.

The creekside monitoring system uses organisms in containers located on the creek bank which are exposed to a flow of appropriately diluted waste water pumped from the creek. Tests so far have been developed for two species of freshwater snail (*Amerianna cumingii* and *A. carinata*) and two species of fish (*Mogurnda mogurnda* – Purple-spotted gudgeon; and *Melanotaenia nigrans* – Black-striped rainbow fish). Snails are monitored for changes in reproduction, early development and juvenile mortality, while fish are monitored for larval mortality and growth (Humphrey & Dostine 1994).

Organisms for use in the tests were selected according to the following criteria:

1 Sensitivity to mine waste waters comparable to those used in lab toxicity testing

2 Low (natural) mortality when exposed to creek waters

3 At least one organism to provide early feed-back of adverse effects in a readily identifiable way

4 Responses should be varied (sub-lethal to acute)

5 Organisms from different phyla and/or trophic levels represented to cover the broadest possible range of potential impacts on biota

6 Easy to culture

7 Biology should be understood so results can be interpreted.

2.2 Detection of longer term effects

Biological monitoring by ***eriss*** to detect longer term effects of mining on the aquatic environment have been of two main types: 1) investigation of natural communities and populations; and 2) chemical monitoring of biota (bioaccumulation).

2.2.1 Natural communities and populations

Community based approaches to monitoring are robust because they incorporate a variety of species responses, however community responses to environmental stressors are complex and, in most cases, not well understood. This means that community level monitoring programs have a good chance of detecting changes in the environment but the precise mechanisms responsible for that change may not be understood. Studies at ***eriss*** have focused on 1) benthic macroinvertebrate communities and populations; 2) daily counts of fish migrating upstream past the mine; and 3) fish communities in billabongs. Observations of communities are made at the end of the Wet season to detect any effects of waste-water releases during that time and to assess the success of Wet season breeding. Detection of impact relies on statistical comparisons of post-release data with historical baselines.

Benthic macroinvertebrate communities are sampled at the end of the Wet season from two lotic habitats (macrophyte in flowing water and sand beds) at sites upstream and downstream of the mine and in nearby catchments with similar types of streams ('controls'). The design is based on the BACIP approach (Faith et al 1995, Humphrey et al 1995). Fish migration aims to quantify the number of fish moving from spawning and feeding habitats on the floodplain to Dry season refuges upstream of the mine. This migration is an essential survival strategy and released waste waters should not impair recruitment and subsequent movement of fish. Fish communities are monitored in billabongs of Magela Creek at the same time of year as macroinvertebrate sampling. Billabongs can represent Dry season refuges (Bishop et al 1995) and depositional zones in the creek system (Wasson 1992). Billabongs may thus be of ecological significance due to long-term accumulation of contaminants and future invertebrate monitoring may be extended to these habitats.

2.2.2 Bioaccumulation studies

Bioaccumulation studies focus on organisms that accumulate substances in their tissues in a way that reflects environmental levels of those substances or the extent to which the organism has been exposed to them. They may also be used to detect what may otherwise be very low, undetectable environmental levels of substances (Hellawell 1986). At ***eriss***, baseline concentrations of chemical elements in body organs of fish (Martin et al 1995) and soft parts of freshwater mussels (Allison & Simpson 1989) have been determined so that future concentrations might be compared. These taxa were chosen because they are long-lived and, in the case of fish, at the top of the aquatic food-chain.

3 Implementation of biological monitoring programs

Well-designed studies do not necessarily yield data that can be used in addressing project objectives. The additive effects of failure to implement laboratory protocols, equipment malfunction unnoticed by inexperienced staff, poorly designed data sheets that promote transcription errors, inappropriate analysis etc may result in poor quality data (Norris & Georges 1993). In monitoring programs the need for consistent and reproducible techniques and results is of the utmost importance given that data is collected repeatedly over time, often with the aim of detecting temporal trends. Undocumented changes in methods will confound any real temporal changes that may have taken place.

Some of the requirements for ensuring consistency and reproducibility are:

1 Clear documentation of all aspects of the sampling design and regime eg the locality of sampling sites (including map references, GPS references and descriptions of access routes), all field and laboratory procedures, and standardised field and data sheets

2 Training of field staff in sampling protocols and sampling theory to ensure consistency in collection techniques ie results should be independent of who does the collection

3 Documentation of required quality assurance procedures.

4 Data management and the *eriss* relational database for macroinvertebrate data

The planning phase of biological monitoring programs should include consideration of how data arising from the program will be stored and managed. This section does not aim to cover data management theory in detail but to point out practical considerations relevant to biological monitoring programs. A database is an organised collection of information or data (eg an address book is a database as it organises people into specific categories: names, phone numbers and addresses). Databases should not be confused with other types of files that contain data. Spreadsheets, for example, are designed for data manipulation not for data storage. Some of the properties that distinguish databases from other forms of data files are (from Beynon-Davies 1989):

1 Data integration – implies that a database should be a collection of data which has no redundancy, that is, no unnecessarily duplicated or unused data.

2 Data integrity – implies that when maintaining data we can be sure that no inconsistencies are likely to arise in the database eg if the name of a macroinvertebrate taxon were to change, all previous records including the original name would need to be changed.

3 Separate logical and physical views of data. The major idea behind the database concept is the attempt to model the natural or logical structure of data and separate this from the exigencies of any particular implementation of the data.

Databases can have in-built integrity rules to ensure the accuracy and correctness of data (eg in the COUNTS table of the ***eriss*** macroinvertebrate database only invertebrate codes listed in the look-up table FULLCODES will be accepted during data entry). Despite these in-built checks it is inevitable that most data sets will contain some errors. Even gross errors may go undetected, profoundly affecting the outcome of analysis (Norris & Georges 1993). Data validation is one practice that can reduce the level of error in databases. Validation consists of checking for transcription errors when data from field and laboratory data sheets is entered on to the database. Data verification and procedures designed to minimise errors can also be performed at each step in the implementation of a monitoring program. Verification can range from calibration of field equipment to verification of data after it has been entered onto a database. Data verification can take a number of forms including scanning for outliers, and checking for known ranges, if appropriate (Norris & Georges 1993).

Relational databases are one type of database that organise data into a series of linked tables (or files). A relational database can be a useful tool in biological monitoring programs as it can store the range of information relevant to the program in an efficient way. For example, the ***eriss*** macroinvertebrate database contains information ranging from the location of sampling sites through to the date on which sample specimens were identified and by whom (figs 1 & 2). In relational databases all data are organised into 2-dimensional tables which are constrained in the following ways:

- All entries in a column (or field) must be of the same kind eg for invertebrate counts you would only have whole counts, not fractions or presence/absence records.
- All columns must be assigned distinct names eg 'Date' would be an inappropriate field name in a table as it could refer to the date a sample was collected, the date it was processed, the date specimens were identified or the date the data was entered into the table.
- The ordering of columns is not significant ie the value of one column is not a function of a preceding one.
- Each row must be distinct ie duplicate rows are not allowed in any one table. This means that each table must have a so-called primary key (an attribute or combination of attributes whose value(s) uniquely identify the rows). These primary keys are also used to link the tables together.
- Each column/row intersection (cell) in a relation should contain a single value.

Sample Number :	1	# Rings :	
Site :	MAGELA CK SITE 1	Method :	1HR LIVE PICK
Habitat :	MACRORIFFLE	Collection Date :	3/05/95
Replicate :	1.00	Field Mesh Size :	500.00

# Vials	Mesh Size (um)	% Subsampled	ID Date	Operator
1	500.00	100.00	10/04/96	Catel
2	500.00	100.00	28/03/96	Rutho

Species Code	Count
ATYIUUUX	1
BAETZZZN	2
BEROS01L	1
CERAS02L	3
DYTIS13A	1
HELLFORL	9
HPTIUUUL	11
HYPHZZZX	2
LESIZZZX	11

Figure 1 An example of information contained in the ***eriss*** macroinvertebrate database

Relational systems are designed to operate on whole files (tables) rather than columns or rows. Tables are structured so that every item can have a value assigned eg in the SAMPLES table of the ***eriss*** database every sample (represented by sample number) has information about the site and habitat of collection, the collection date, replicate number etc. This structure provides the most efficient structure for data storage. When reporting is required, copies of the relevant data can be copied into the appropriate software packages (such as statistical and graphical packages).

6 Conclusion

Biological monitoring is an essential part of ensuring highly valued aquatic ecosystems such as those found in the Alligator Rivers Region are not altered through activities such as mining. The use of a range of indicators gives the greatest guarantee that any potential impacts are detected. The implementation of biological monitoring programs requires a high degree of detailed documentation of protocols to ensure consistency and reproducibility of results. Results and associated information can be stored effectively in relational databases.

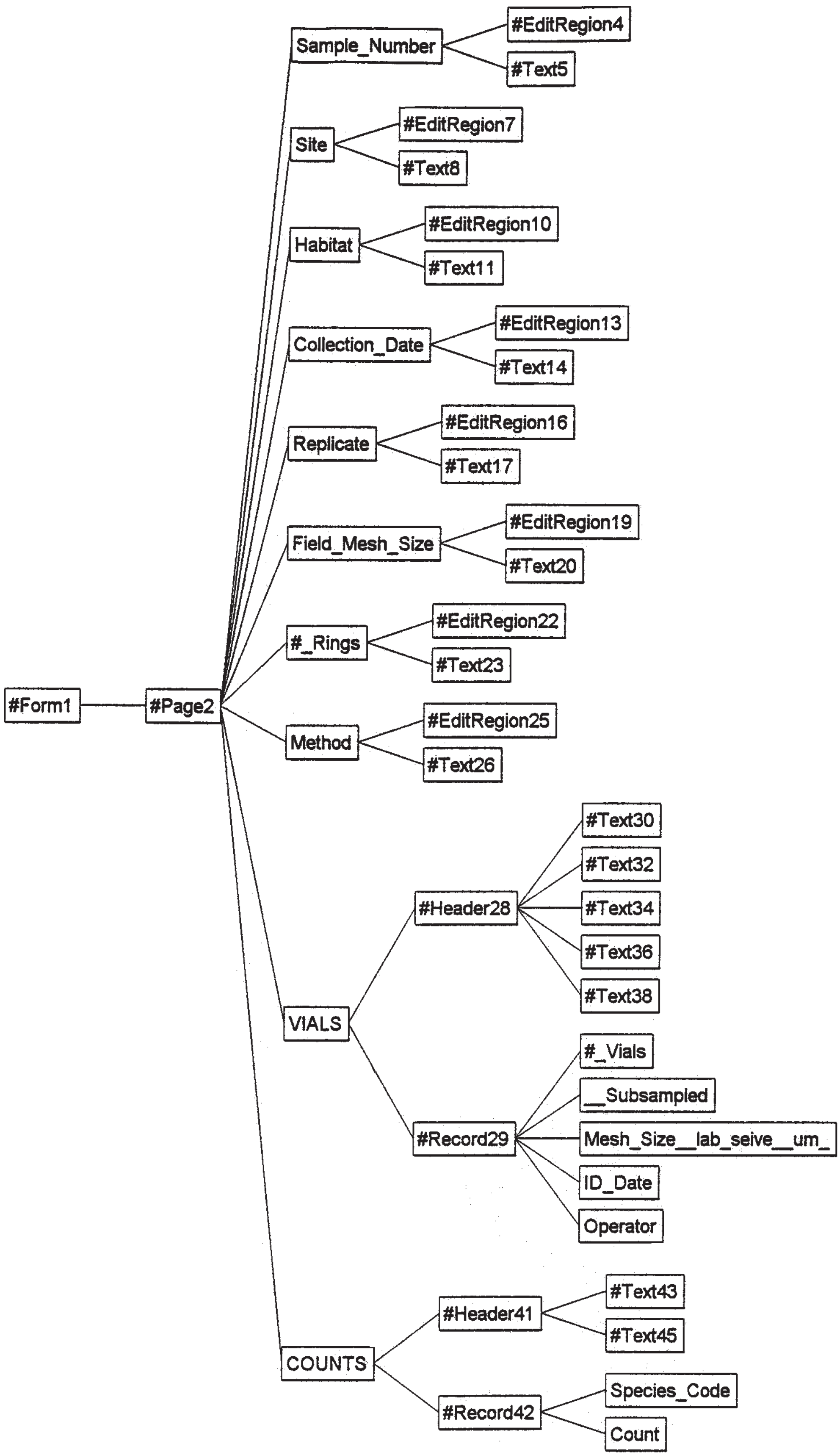

Figure 2 Structure of the *eriss* macroinvertebrate database

References

Allison HE & Simpson RD 1989. *Element concentrations in the freshwater mussel,* Velesunio angasi*, in the Alligator Rivers Region*. Technical Memorandum 25, Supervising Scientist for the Alligator Rivers Region, Canberra.

Beynon-Davies P 1989. *Information systems development*. Macmillan, London.

Bishop KA, Pidgeon RWJ & Walden DJ 1995. Studies of fish movement dynamics in a tropical floodplain river: Prerequisites for a procedure to monitor the impacts of mining. *Australian Journal of Ecology* 20 (1), 81–107.

Cairns Jr J, McCormick PV & Niederlehner BR 1993. A proposed framework for developing indicators of ecosystem health. *Hydrobiologia* 263, 1–44.

Faith DP, Dostine PL & Humphrey CL 1995. Detection of mining impacts on aquatic macroinvertebrate communities: Results of a disturbance experiment and the design of a multivariate BACIP monitoring programme at Coronation Hill, Northern Territory. *Australian Journal of Ecology* 20, 167–180.

Finlayson CM 1996. Framework for designing a monitoring programme. In *Monitoring Mediterranean wetlands: A methodological guide*, ed P Tomas Vives. MedWet Publication, Wetlands International, Slimbridge, UK & ICN, Lisbon, 25–34.

Hellawell JM 1986. *Biological indicators of freshwater pollution and environmental management.* Elsevier, London.

Humphrey CL, Bishop KA & Brown VM 1990. Use of biological monitoring in the assessment of effects of mining wastes on aquatic ecosystems of the Alligator Rivers Region, tropical northern Australia. *Environmental Monitoring and Assessment* 14, 139–181.

Humphrey CL & Dostine P 1994. Development of biological monitoring programs to detect mining waste impacts upon aquatic ecosystems of the Alligator Rivers Region, Northern Territory, Australia. *Mitteilungen Internationalis Vereinigung Limnologiae* 24, 293–314.

Humphrey CL, Faith DP & Dostine PL 1995. Baseline requirements for assessment of mining impact using biological monitoring. *Australian Journal of Ecology* 20, 150–166.

Martin P, Hancock GJ, Johnston A & Murray AS 1995. *Bioaccumulation of radionuclides in traditional Aboriginal foods from the Magela and Cooper Creek systems*. Research Report 11, Supervising Scientist for the Alligator Rivers Region, Canberra.

Norris RH & Georges A 1993. Analysis and interpretation of benthic macroinvertebrate surveys. In *Freshwater biomonitoring and benthic macroinvertebrates*, eds DM Rosenberg & VH Resh, Chapman & Hall, New York & London, 234–286.

Wasson RJ (ed) 1992. *Modern sedimentation and late quaternary evolution of the Magela Creek Plain*. Research Report 6, Supervising Scientist for the Alligator Rivers Region, Canberra.

Ecotoxicology in the Wet-Dry tropics

C Camilleri

Environmental Research Institute of the Supervising Scientist,
Locked bag 2, Jabiru, NT 0886

Abstract

Ecotoxicology is a relatively new field, and is still evolving. It seeks to understand how toxic chemicals affect the environment and ecosystems. Representative organisms are used in toxicity testing to investigate the fate of pollution, especially where there may be chemical contamination. It is crucial that toxicity of chemicals or substances be prioritised and the relevance of effects be addressed. In order to protect diversity, certain decisions are made regarding toxicity testing protocols. To date, single species tests are widely used, but are not without criticism. Single species tests have been developed at ***eriss*** for whole effluent testing of the waste waters from a uranium mine in the Wet-Dry tropics. The protocols have been handed over to the regulatory bodies, and these protocols have since been utilised in a range of environmental protection and risk assessment issues in the Wet-Dry tropics.

1 Introduction

Ecotoxicology seeks to understand how toxic chemicals affect the structure and function of natural ecological systems (populations, species assemblages, communities and ecosystems) (D Baird pers comm).

Representative organisms have been used extensively in toxicity testing to investigate the fate and effect of pollutants in natural systems. Pollution itself arises from many diverse human activities, and has the potential to cause effects directly in the area of use, or can disperse widely around the world eg organochlorins, being highly volatile, disperse widely from the point of use (Forbes & Forbes 1994).

2 Chemical contamination

There is increasing pressure to find better ways of protecting crops from insects or disease, and hence better yields of production, and generally it is chemical compounds such as pesticides and herbicides that are used. Developing countries especially utilise large amounts of pesticides, and hence areas of high biodiversity, eg Brazilian rainforests, are under increasing threat.

2.1 Global fractionation of pollutants

There is nowhere on the planet that is not subject to pollutants, due to global fractionation. The fate of compounds can be highly variable, as they can be transported over vast distances depending on their chemical properties. Consideration must be given to the problems chemicals such as chlorinated compounds will cause globally, ie CFCs do not become deposited; instead they are found in polar regions and in the ozone layer.

2.2 Problems of chemical analysis

Many substances or chemical compounds that are in use today are extremely toxic. There has been a trend towards using smaller amounts of certain chemicals but at higher concentrations. It is also possible that toxic effects may be present in a natural system, but in quantities too low to be analysed by current methods. If the trend of using more complex toxic compounds persists, it is possible that they will be more difficult to identify, and subsequently analyse, in a particular environment.

2.3 Problems of ignorance

If detection of a toxicant is difficult/expensive etc there is a tendency to ignore it. Toxicity testing is expensive, and is usually a regulatory requirement eg ERA Ranger Mine whole effluent testing of mine waste waters.

2.4 Problems of priority

Identifiable catastrophic events, eg oil spills, more often receive wide media attention. However, there are the low-level 'silent' compounds which may go unnoticed (eg effect of DDT on the alligator population in Lake Apopka, Florida, where abnormalities of gonadal tissue resulted in feminisation of male alligators), but are as pervasive as events on a much larger scale. How we prioritise toxicity of compounds or chemicals is often based on the publicity they receive.

2.5 Problems of relevance

Addressing what effects are relevant is crucial in determining and prioritising importance of a toxicant or possible effect. Ecologically relevant endpoints need to be determined that are also relevant at population/community levels, to ensure protection of a natural system.

3 Protecting biodiversity

Biodiversity is the number, variety, and variability of living organisms. It is not possible to test every single species from an ecosystem and determine which species would be adversely affected more than others from a particular toxicant. Instead, representative organisms are selected based on several criteria.

Environmental quality standards are designed to protect 95% of the organisms, based on a minimal number of selected species. The underlying assumption is that the selected species are representative of a random sample from within the system. The questions which should be addressed are 1) whether 5% is too much to lose eg if the ecosystem is highly valued for certain species and habitat; and 2) is what is measured in a laboratory a true random sample of the distribution.

One ideal approach that can be taken is the following:

1 Design tests for making predictions about a particular kind of community or habitat eg tropical wetland, and try to incorporate field studies

2 Try to select 'indicator' or key species from the community which may be threatened

3 Address the effects upon the end points of such factors as seasonal or behavioural variations

4 Address the ecological consequences of pollutant-induced mortalities.

To enable such an approach a large database would be required of the ecosystem in question, and more often than not in the tropics, that level of information is not available.

4 Single species laboratory tests

As mentioned previously, economic, societal and political pressures will ultimately determine what is achievable in protecting an ecosystem. To date, single species tests are used due to several reasons, and certainly are not without criticism. More importantly, we need to look at the single species test and address options of improvement.

For example, water flea tests have a vast database available on how they respond to a wide range of different toxicants. Water fleas also reproduce asexually (parthenogenetic females) and therefore the genotype can be manipulated. They are relatively easy to maintain in laboratory cultures, have an optimum body size for experiments (ie they are large enough to measure various responses), yet are still small enough such that sufficient numbers for replication can be obtained for testing. Water fleas also have a non-selective method of feeding, and are representative of the trophic level of herbivores/grazers. Being non-selective feeders, they are unable to avoid exposure to contaminated food.

Standard tests using water fleas are used in OECD Guidelines, and it is from these guidelines that site specific tests may be modified or derived eg the test used by ***eriss***.

5 Protection of wetlands in the Wet-Dry tropics

The toxicity testing protocols at ***eriss*** were developed to ensure adequate protection of the waterways of the Alligator Rivers Region from the activities of mining, particularly the management of mine waste waters (Hyne et al 1996). Initially, a broad survey was conducted to collect and identify potentially suitable species from the local creeks and billabongs, and being located within a national park, certain restrictions prevent the importation of exotic species into the area. The criteria used were based on the above mentioned points, and from a starting list of approximately 20 species, three species were eventually selected as suitable. The species chosen were *Moinodaphnia macleayi* (water flea), *Hydra viridissima* (green hydra), and *Mogurnda mogurnda* (purple-spotted gudgeon). Endpoints for determining an effect are based on reproduction, population growth and sac fry survival respectively.

Whole effluent tests using the three species concurrently were carried out using mine retention pond waters and natural receiving waters from Magela Creek. Test treatments or concentrations were established by preparing serial dilutions of the toxicant and receiving waters, from 0 to 32%. The most sensitive response of the NOEC (No-observed-effect-concentration) and LOEC (Lowest-observed-effect-concentration) from the three species was taken, and a nominal safety factor applied. Results were then used in conjunction with pure chemical analyses, and a dilution rate established for the release of mine waste water that would ensure no adverse effects on aquatic life downstream of the release.

These protocols have been successfully applied to several areas other than mining eg effects of herbicides on non-target aquatic organisms, tourism impacts on a plunge pool, ANZECC Water Quality Guidelines for U and CU.

6 Types of toxicity tests

In addressing the potential threats to wetlands it is necessary to ascertain the mode of transport and the fate of the toxicant eg application of herbicide in pellet form is potentially more toxic to sediments. The type of test and test conditions should reflect the nature of the toxicant, and target as well as non-target organisms. For effects in the aquatic environment, there are several tests available including the cladoceran reproduction, hydra population growth, sac fry survival, algal and lemna growth. Sediments can be assessed for toxicity using chironomids or cladocera. Actual running of the tests can be done by static renewal of test solutions every 24 or 48 hours, or by using flow-through systems, depending on available resources. The decision to use site specific tests and local species versus existing standard tests also needs consideration.

Acute or chronic toxicity tests can be utilised for different purposes. Acute tests assess part of the life cycle of an organism and generally provide a less sensitive endpoint eg EC_{50}, as compared with chronic tests which expose a significant part of the lifecycle of the organism to the toxicant eg water flea reproduction test using NOEC and LOEC responses.

References

Forbes VE & Forbes TL 1994. *Ecotoxicology in theory and practice*. Chapman & Hall Publishers, London, UK.

Hyne RV, Rippon GD, Hunt SM & Brown GH 1996. *Procedures for the biological toxicity testing of mine waste waters using freshwater organisms*. Supervising Scientist Report 110, Supervising Scientist, Canberra.