# A guide to managing and restoring wetlands in Western Australia

## Monitoring wetlands

In Chapter 4: **Monitoring wetlands**

Version 1

Australian Government

Department of Environment and Conservation

Our environment, our future

# Introduction to the guide

Western Australia's unique and diverse wetlands are rich in ecological and cultural values and form an integral part of the natural environment of the state. *A guide to managing and restoring wetlands in Western Australia* (the guide) provides information about the nature of WA's wetlands, and practical guidance on how to manage and restore them for nature conservation.

The focus of the guide is natural 'standing' wetlands that retain conservation value. Wetlands not addressed in this guide include waterways, estuaries, tidal and artificial wetlands.

The guide consists of multiple topics within five chapters. These topics are available in PDF format free of charge from the Western Australian Department of Environment and Conservation (DEC) website at www.dec.wa.gov.au/wetlandsguide.

The guide is a DEC initiative. Topics of the guide have predominantly been prepared by the department's Wetlands Section with input from reviewers and contributors from a wide range of fields and sectors. Through the guide and other initiatives, DEC seeks to assist individuals, groups and organisations to manage the state's wetlands for nature conservation.

The development of the guide has received funding from the Australian Government, the Government of Western Australia, DEC and the Department of Planning. It has received the support of the Western Australian Wetlands Coordinating Committee, the state's peak wetland conservation policy coordinating body.

For more information about the guide, including scope, purpose and target audience, please refer to the topic 'Introduction to the guide'.

DEC welcomes your feedback and suggestions on the guide. A publication feedback form is available from the DEC website at www.dec.wa.gov.au/wetlandsguide.

# Contents of the guide



These topics are available in PDF format free of charge from the DEC website at www.dec.wa.gov.au/wetlandsguide.

# 'Monitoring wetlands' topic


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## Recommended reference

When referring to the guide in its entirety, the recommended reference is: Department of Environment and Conservation (2012). *A guide to managing and restoring wetlands in Western Australia*. Department of Environment and Conservation, Perth, Western Australia.

When specific reference is made to this topic, the recommended reference is: Department of Environment and Conservation (2012). 'Monitoring wetlands', in *A guide to managing and restoring wetlands in Western Australia,* Prepared by G Daniel, Department of Environment and Conservation, Western Australia.

# Contents

## Before you begin

Before embarking on management and restoration investigations and activities, you must consider and address the legal requirements, safety considerations, cultural issues and the complexity of the ecological processes which occur in wetlands to ensure that any proposed actions are legal, safe and appropriate. For more guidance, see the topic 'Introduction to the guide'.

# Introduction

This topic is intended to assist people involved in wetland management and restoration to develop and implement monitoring programs. In particular, the requirements of land managers, landowners, community groups and technical officers in local and state government and non-government organisations have been considered. Consultants, planners and secondary and tertiary students may also find the information useful.

The topic aims to provide guidance on wetland monitoring in a simple and user-friendly manner. That said, some of the concepts presented are complex and readers may require expert assistance to apply them to their own monitoring.

There are many different ways to design a monitoring program and to measure **indicators** of wetland condition.

The method that is most appropriate will depend upon the objectives of the monitoring program, the characteristics of the site being studied and the available resources. As such, the information presented in this topic is not prescriptive; it does not provide a ready made monitoring program. Rather, this topic describes the principles of monitoring, some suitable techniques for monitoring commonly used indicators of wetland health and where to get additional help and information.

## Monitoring defined

Monitoring is the systematic collection of data, over time, in order to test a **hypothesis**.

In the context of biodiversity conservation, the hypothesis will usually relate to the effect of management strategies on the **condition** of a natural area.

Put simply, monitoring determines whether management of an ecosystem is having the desired effect on its condition. Monitoring is an essential component of every wetland management program as it is the only way to ensure that management activities actually improve (or maintain) the condition of the ecosystem.

**Indicators:** the specific components and processes of a wetland that are measured in a monitoring program in order to assess changes in the conditions at a site

**Hypothesis:** a concept that is not yet verified but that, if true, would explain certain facts or phenomena

**Condition:** the relative integrity of an ecosystem compared to a reference state. It includes being able to maintain key ecological and physical processes, ecosystem services, and communities of organisms. (Note: health is taken to have the same meaning as condition)

## Strategies for managing biological diversity

There are six broad strategies for managing the biological diversity of a natural area[1]:

1. Take no positive management action
2. Ensure that current threats to biodiversity are not accelerated
3. Slow the rate at which biodiversity assets are lost from the landscape
4. Take positive steps to conserve specific elements of the biota
5. Take positive steps to conserve all natural populations in an area
6. Reconstruct landscapes and their natural biota

Monitoring may be undertaken to assess the effectiveness of any of these strategies. In the case of the first strategy, the hypothesis may be that the condition of the area is stable in the absence of management intervention and a monitoring program may be designed to assess this.

**Replication:** repeating an experiment several times and collating all the results. It allows the error margin of the measurements and natural variations in the subjects to be discounted from consideration

**Control:** a subject that is identical to the experimental subject in every way, except that the experimental subject receives the treatment and the control does not. This means that if a change is observed in the experimental subject after the treatment, but not observed in the control, that change could only have occurred due to the treatment

**Treatment:** subjection to some agent or action. In the case of a monitoring program, the treatment will be the management regime that is expected to cause some change in the condition of the site

The terms *monitoring* and *survey* are frequently confused and, because both are used in this topic, it is necessary to clearly define the difference between them. A survey is an exercise in which a set of observations are made about some components of an ecosystem. Monitoring is a series of surveys, repeated over time, that are designed to test a specific hypothesis. For example, a survey might involve counting the number of waterbirds at a wetland. This is not monitoring, unless the count is repeated over time in order to test a theory about the effect of management of the site on the bird population.

### Monitoring outputs and outcomes

It is important to distinguish between monitoring *outputs* and monitoring *outcomes*. Outputs are activities undertaken, or products produced, by a particular project. An outcome, on the other hand, is a measurable consequence of the project's activities. For example, a project may *output* 20 kilometres of livestock exclusion fencing around a wetland. The *outcome* of this may be a 10 per cent increase in native vegetation biomass within the fenced area, due to reduced grazing pressure. Outputs are steps along the way to achieving the desired outcome. Although output monitoring is required in some situations, this topic discusses only outcomes monitoring in the context of wetlands biodiversity conservation.

➤ More information on output monitoring is available in the Australian Government's *Natural Resource Management Monitoring, Evaluation, Reporting and Improvement Framework.*[2] It is available from the Caring for Our Country website: www.nrm.gov.au.

## Planning a monitoring program

A monitoring program is the series of actions that will be taken to gather the information required to test the monitoring hypothesis. Monitoring programs can vary greatly in complexity and rigour. At one extreme, anecdotal evidence and a simple 'mental tick' that things are progressing as expected. At the other, a research project involving pre and post management surveys, significant **replication** of both **control** and **treatment** plots and comprehensive statistical analyses.

There is no single correct approach to monitoring and no one program of actions that will suit all situations. A monitoring program must be developed to suit the requirements of each individual project. Regardless of the approach adopted, however, the following four questions must be answered when planning a monitoring program:

- What is the hypothesis to be tested?
- How much confidence is required in the answer?
- Which indicators will be measured?
- How will the collected data be analysed?

Depending on the nature of the work or project being undertaken, it may be necessary to formally document the answers to these questions in a monitoring plan.

➤ More information on writing a formal monitoring plan is available from the website of the Department of Environment and Conservation: www.dec.wa.gov.au.[3]

## The monitoring hypothesis

Defining the hypothesis is probably the most important step in the design of a monitoring program. Without a meaningful question to answer, it will be difficult to know what to measure or how to measure it. Any data that are collected will lack context and may not inform management of the site.

Usually, the reason that a monitoring program has been proposed will guide the formulation of the hypothesis to test. Monitoring will have been proposed in response to a particular issue, such as a change to the way a wetland is managed or to the surrounding land use or because a water quality issue or some other impact is becoming apparent. The issue under consideration is expected to have some impact on the health of the wetland and the results of that impact are to be monitored. The monitoring hypothesis will clearly identify the issue being investigated, the change that is expected and the period of time over which it should be observed. In stipulating these factors, the hypothesis guides the design of the monitoring program.

Framing the hypothesis may require some background information to be gathered. Ideally, monitoring will seek to demonstrate some cause and effect relationship between the management of a wetland and changes in its condition. This will require an understanding of the components of the wetland ecosystem and the processes that connect them. It will also be important to understand the nature of the management regime that is affecting the site.

➤ Additional detail on the components and processes of wetland ecosystems can be found in Chapter 2 Understanding Wetlands.

### The relationship between management and the monitoring hypothesis

Many Western Australian wetlands are degraded from the impacts of livestock grazing vegetation, disturbing soils and defecating in, or near, the water. The most common management response to this threat is to fence the wetland, excluding stock. A wetland manager might wish to assess the effectiveness of stock exclusion fencing at a particular wetland, before committing to fencing other sites on the property. In this example, assume the manager is particularly concerned with the status of native vegetation at the wetland. Monitoring is proposed to assess the effect that fencing the site has on the native grasses that grow there.

A suitable hypothesis to be tested by the monitoring program at the wetland might be:

*That excluding stock from the wetland will result in a 20 per cent increase in the cover of native grass at the site by 2011, compared to 2009 cover.*

This hypothesis states the management action that is being assessed, the expected change in the condition of the wetland component and the period of time over which the change should occur.

## Characteristics of a monitoring program

Having formulated a hypothesis to be tested in a monitoring program, it is next necessary to decide how much certainty is required in the answer. Being certain of the answer to the hypothesis means being able to state, with confidence, whether a change occurred in the system being studied and, if it did, whether the change was caused by a specific management action. The degree of certainty required will determine what kind of monitoring program is undertaken and how it will be designed.

The most rigorous and robust monitoring programs will use replication of treatment and control sites to establish cause and effect relationships between wetland components, processes and threats. This is done to provide strong evidence that a particular management action caused an observed change in the wetland ecosystem, or resulted in no change to the system. The data that are collected will allow sophisticated statistical analyses of elements of the ecosystem. Documentation will be comprehensive, allowing critical appraisal of the techniques that were employed to collect and analyse data and the conclusions that are drawn from them.

At low levels of rigour, a monitoring program may suggest that a change is occurring at a site, but will provide little evidence of what the cause of the change is. It will not be possible to distinguish between 'natural' variation in the system and the effects of a particular management regime. The techniques that are used to measure indicators of wetland condition will often be relatively simple and prone to inaccuracy and imprecision. Methods may include opportunistic sampling and qualitative approaches and documentation of the program will be informal.

➤ For definitions of the terms inaccuracy, imprecision and qualitative, see the section 'Data Quality' in this topic.

These two examples are extremes on a continuum of approaches to monitoring. The less rigorous end of the spectrum is readily achieved by people with little previous experience in monitoring, but will probably not provide a full answer to the hypothesis. The most rigorous of programs will comprehensively address the monitoring hypothesis, but require significant experience, particularly in relation to the statistical design of the monitoring program. The advice provided in this topic aims to guide readers toward a middle path, with practicalities and logistical constraints balanced against the need to collect robust data.

➤ More information on data confidence is available in the *Queensland Community Waterway Monitoring Manual*.[4] www.qld.waterwatch.org.au.

### Sources of errors in a dataset

There are a number of ways that errors may enter a monitoring program. Firstly, errors may relate to the design of the program. This results in the wrong indicators being measured, indicators being measured at the wrong time, too few measurements being taken or the use of instruments that are not suited to the task. A well planned survey may record poor data if members of the survey team are not adequately trained in the techniques being used, inconsistently apply methods, misread instruments, record or copy data incorrectly, contaminate samples or fail to properly calibrate equipment. The inconsistent application of methods is particularly likely when a number of different people collect data, but can result from a single person changing their approach over time. Such inconsistency can be minimised by implementing processes that ensure each person applies methods and interprets conditions in the same manner.

Finally, losing the collected data is an error. It may occur if recording sheets are misplaced or computer records incorrectly transcribed or corrupted. An 'institutional' data loss is when insufficient documentation of methods and procedures prevents data from being interpreted correctly.

There are a number of general principles that will help to avoid errors and achieve high quality data:

- Understand the system being studied, particularly sources of natural variation. This will allow spatial and **temporal** variation to be properly accounted.
- Ensure all participants in the monitoring program have the necessary training and competencies.
- Apply methods that are appropriate to the system being monitored and the objectives of the program.
- Comprehensively document the methods that are used.
- Use the correct equipment for a task and ensure that it is maintained and calibrated carefully.
- Treat samples with care to avoid contamination.
- Manage the data well.
- Analyse and report on data appropriately.

**Temporal:** of or pertaining to time. Temporal variations are changes that occur over time

**Accuracy:** closeness to the 'true' value of the parameter being measured

**Precision:** minimal variability between measurements

## Data quality

High quality data are achieved by eliminating errors, so that the dataset truthfully represents the conditions at the study site. High data quality are required if a monitoring program is to show that a change in an indicator is significant and is not an anomaly of the data.

High quality data are accurate, precise, sensitive and representative. **Accuracy** and **precision** refer to the potential for error in each measurement taken. Accurate measurements are very close to the 'true' value of the parameter being measured. Precise measurements have minimal variability between measurements (Figure 1). Both accuracy and precision are achieved by the use of appropriate, well calibrated equipment and the careful implementation of suitable, consistent methods.

Sensitivity refers to the ability to distinguish between different values in the parameter being measured. Sensitivity is a product of the equipment used, data handling techniques and experimental design.

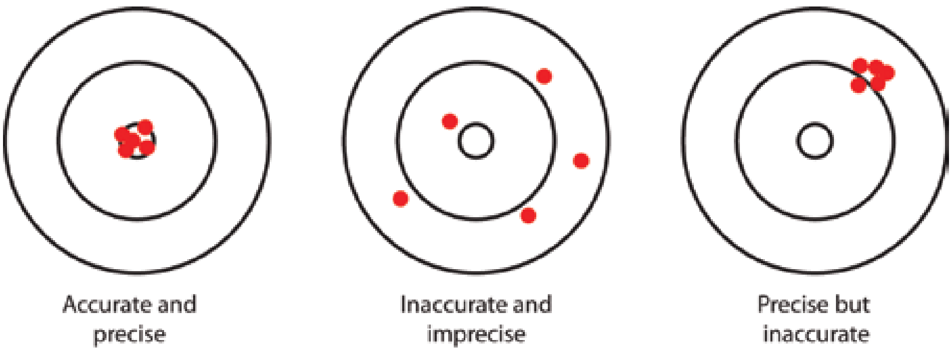


**Figure 1.** Accuracy and precision. Figure adapted from Department of Natural Resources and Water, 2007.[4]

Representativeness is how well a series of measurements reflect the full range of values in the system being measured. In order to be representative of conditions at the site, monitoring data must be comprehensive of spatial and temporal variation. For example, a salinity measurement taken at the point where a drain enters a wetland might not be representative of conditions at the site as a whole. That measurement may accurately reflect the salinity at the point it was taken, but it does not represent the range of salinity that is encountered across the water body. Similarly, a single salinity measurement taken at the wetland mid-summer will not be representative of the variation that occurs at the site throughout the year.

**Qualitative data:** descriptive data; they are collected using techniques such as estimation, categorisation, statements of type or condition, diagrams, photographs and maps

## Causation

Showing causation, or lack of it, is a common requirement of monitoring programs. It means showing a relationship exists between two variables such that a change in one (the cause) causes a change in the other (the effect). To be sure of the relationship between cause and effect, it is also necessary to show that the effect will not occur if the cause does not. Demonstrating this requires the use of a control.

A control is a subject that is identical to the experimental subject in every way, except that the experimental subject receives a treatment and the control does not. If a change is observed in the experimental subject after the treatment, but not observed in the control, that change could only have occurred due to the treatment. It is also necessary to replicate the treatments and controls to ensure that the observed effect is not a chance occurrence.

Replication involves repeating an experiment several times and collating the results. It allows the error margin of the measurements and natural variations in the subjects to be discounted from consideration. In natural settings, replication is very difficult to achieve, because no two natural areas are identical. Showing causation in natural ecosystems, therefore, requires the use of specialised techniques. These are beyond the scope of this topic; more information is available from text books that deal with ecology or statistics in a biological context.

## Quantitative and qualitative data

A monitoring program may collect quantitative or qualitative data, or a combination of both. **Qualitative data** are descriptive; they are collected using techniques such as estimation, categorisation, statements of type or condition, diagrams, photographs and maps. Quantitative data have been measured or counted in some way, for example, the number of plants in a plot or the pH of a water sample.

Collecting qualitative data usually requires less technical expertise and can be achieved more quickly than applying quantitative methods. The drawback of a qualitative approach is that it is subjective and so prone to inter-operator error. Also, if data are grouped into classes it is more difficult for other people to interpret.

Quantitative methods rely on the measurement of parameters. This means that, assuming methods are faithfully recorded, future workers can be sure they are obtaining comparable measurements. Recording the actual measurements, as opposed to grouping them into classes, also allows the data to be reanalysed at a later date. This may be important if, for example, a future project wishes to use the data differently or change the categorisation of a parameter. Quantitative measures are usually more time consuming and, in some instances, may require technical skills or training. Also, if the entire population is not measured, then some statistical analyses will be required to extrapolate from the data gathered from the sample.

## Spatial and temporal scale

The spatial and temporal scale at which a monitoring program operates will influence the sensitivity of the data that are collected and the resources required to collect them. Operating at appropriate scales will ensure that meaningful data are collected in an efficient manner.

Spatial scale refers to the minimum size of an area about which data are collected. A program operating at a small spatial scale, for example, may conduct surveys in each micro-habitat within a wetland, while a larger scale program may survey only one location at each wetland.

When setting the spatial scale, consider whether it is important to detect variation within a wetland or if a single measure that is representative of the site will suffice. The first scenario will provide more data, but that may not translate to a better understanding of the system. It will, however, require more effort and so, entail higher costs.

Temporal scale refers to the timing of surveys, the frequency with which they are repeated and the period of time over which they are continued. Temporal scale needs to be tailored to suit the availability of resources, purposes of the monitoring program and attributes of the system being studied.

The various components and processes of a wetland ecosystem will respond to changes in the environment at different rates. The temporal scale of monitoring must be such that changes in the parameter of interest can be detected and monitored. For example, clearing in the catchment of a wetland might cause a relatively rapid change in extent and duration of inundation at the site. It might be several years before this is reflected in the extent and composition of plant communities. The monitoring program in this example, therefore, might measure the inundation of the site seasonally, but only assess the vegetation annually. More frequent monitoring will collect a greater quantity of data, and so use more resources, but this may not better address the monitoring hypothesis.

The timing of monitoring activities is also important. The elements of the system that are being observed must be 'active', measurable and interpretable at the time of survey. For instance, it is difficult to conduct a vegetation survey when plants are not flowering or to sample aquatic invertebrates when no water is present.

Another aspect of the timing of monitoring is determining how long to continue with a monitoring program that is not detecting the predicted changes in indicators. Some changes can be slow to occur, but this should not be a reason to continue an ineffective management regime or an insensitive monitoring program. The monitoring plan should stipulate within what period of time changes should be detected. If the identified milestones are not met, either the monitoring program or the management regime may need to be re-evaluated.

## Sampling

The vernacular usage of the term 'sampling' is to take a measurement from a water body, collect a specimen or record a reading from an instrument. Sometimes its usage is even broader, being applied to describe the entire survey process. For the purposes of designing a monitoring program, however, it is important to be familiar with the strict definition of the term 'sampling'.

Sampling is the process of selecting a set of individuals that will be analysed to yield some information about the entire **population** from which they were drawn.

**Population:** in statistics, the term population refers to the entire aggregation of components that are the subject of a study. This may be all the individuals in a biological population, but it may equally relate to a non-biological entity such as quadrats.

For example, a sample of ten plants may be selected from the population of all of the plants at the wetland. The measurements taken of these ten plants will be extrapolated to make assumptions about all of the vegetation at the wetland. Similarly, measurements of groundwater salinity taken at ten bores within a catchment are a sample of the entire population of the aquifer.

Monitoring does not always require sampling. Sometimes it may be possible to count or measure every individual in a population. This is termed a census or inventory. More often, however, it will be necessary to select a sample that will represent the whole population.

Most ecological studies rely on random sampling, that is, randomly selecting a subset of the population to measure. Random sampling aims to avoid bias in the measurements. For example, say the condition of vegetation at a wetland is to be assessed by measuring the health of ten individual plants. Clearly, selecting ten dead plants, or the ten most vigorous plants, will bias the results. To be unbiased, it is necessary to select ten plants entirely at random.

There are situations in which measurements might be intentionally biased to a certain sample of the population. For instance, if investigating point source pollution of a water body, specimens will probably be taken from near water inlets rather than from random areas. If a biased sampling technique is applied, specialised types of analysis may be required to draw meaningful information from the data.

A thorough explanation of sampling and its effects on the interpretation of data is beyond the scope of this topic. The reader is advised to seek guidance from a dedicated textbook, statistician or ecologist when developing a monitoring program. A few basic principles are provided:

- Sample randomly unless there is good reason not to. If sampling is not random, be sure to document the approach that was taken and why it was adopted.
- A larger sample size usually makes the data more representative, although this must be balanced against logistical constraints.
- Be careful about extrapolating from small samples.
- Always present information about the sampling method and size of the sample with the results. This will allow users of the information to understand the data's statistical power, or reliability.

## Quality assurance

Quality assurance is the process of documenting data quality and data confidence by describing how the dataset was collected, analysed and stored. Without proper documentation, other users cannot trust the data to be free from errors.

All datasets should have an accompanying quality assurance statement (also known as metadata) that tells other users about the group that collected them and the methods that were employed. In particular, it is important to record the following information:

### Why monitoring was conducted

It is helpful for other users of the data to understand the background to the monitoring program. This is because the reasons that a monitoring program was conducted will have a bearing on the type of measurements that are taken and the methods that are used. For example, a program that monitors a population of rare plants may only record specimens of that rare species. If it is not clear that a specific taxon was targeted, it may seem that no other taxa were present at the site.

### Who conducted the monitoring program

To help predict the potential for errors in the data, other users need to know the identity of the group that was responsible for designing and implementing the program. Although it is not necessary to identify the individuals involved, it is important to list their competencies, experience and training in relevant fields.

### What equipment and methods were used

Every instrument, piece of equipment and method has a limit of sensitivity and an inherent margin of error. Other users of the data need to know what equipment and methods were used so that they can appreciate the potential errors in, and sensitivity of, the measurements. It is also important to record how the equipment was calibrated. The description of methods applies not just to field methods, but also to how samples were stored, transported and analysed in the laboratory.

### What quality controls were in place

Quality control is the process of detecting errors and determining their magnitude. The quality assurance statement should describe what methods were used to control the quality of the data. There are specific quality control techniques for different methods, but some of the important general principles are:

*Calibrating meters and performing a calibration check against a known standard*

Calibration of electronic meters and equipment is necessary to ensure that their accuracy does not deteriorate over time. After calibration, the meter should be tested against a standard; a solution that is prepared in a laboratory and has precisely known properties (such as pH or salinity). Any deviation between the meter's reading and known properties of the standard should be recorded. If the deviation is significant, the meter may not be calibrated correctly.

*Use of blanks to test for contamination*

Blanks are solutions (usually deionised water) that have a value of zero for the parameter being assessed. The blank is treated the same way as a sample throughout the analysis process and then analysed. If they return a detectable measurement of the parameter being tested, some contamination has occurred which may also affect other samples.

*Use of replicates to test precision*

Taking multiple measurements of a parameter allows statistical analysis of the error margin inherent in the technique or equipment used. For more information on this, see the section 'Analysis of data' in this topic.

*Referring subsamples to experts*

A subsample of a biological sample, such as aquatic invertebrates, can be re-identified by a person with relevant expertise, to check the accuracy of the original identifications.

## Data management procedures and custodianship arrangements

Errors can enter the dataset when field sheets are entered to an electronic database or due to corruption of that database. Any steps taken to reduce the error margin, such as having the data entry checked by a second operator, should be recorded. Also, the quality assurance statement should state which individual or organisation will be responsible for maintaining the dataset and ensuring it is kept current.

➤ More information about quality assurance information, including a template for a monitoring metadata statement can be found in *The Volunteer Monitor's Guide to Quality Assurance Project Plans.*[5] It is available from the website of the United States Environmental Protection Agency: www.epa.gov.

## Selecting indicators to measure

Indicators are the specific characteristics of a wetland that are measured in a monitoring program in order to assess changes in the conditions at a site. Any component or process of an ecosystem may be used as an indicator, but they are broadly grouped into biotic and abiotic types. Biotic indicators that are commonly used in wetland monitoring include vegetation composition and vigour and the diversity and composition of invertebrate or waterbird communities. Abiotic indicators include characteristics of the water chemistry, soils and hydrology.

It will usually be necessary to select a suite of indicators to accurately gauge the effects of management on a site. However, an effective monitoring program will be able to take a relatively small number of indicators and draw conclusions about the condition of the entire system. The indicators that are selected for use in a monitoring program should be informative in the context of the wetland's ecology, address the monitoring hypothesis, be measurable with sufficient sensitivity and show changes at an appropriate temporal scale.

Selecting the most appropriate indicators to measure will require a good understanding of the system being managed. This will be facilitated by considering the broad 'type' of wetland being studied and by developing a conceptual model of its components and processes.

### National indicators of wetland extent, distribution and condition.

The National Indicators of Wetland Extent, Distribution and Condition (National Indicators) project is an attempt to implement a consistent approach to monitoring and reporting on wetlands nation-wide. The National Indicators project proposed standard condition indicators that were derived from conceptual models of typical Australian wetland types. Benchmarks were recommended to allow each indicator to be assessed against a reference condition.

The indicators recommended by the National Indicators project are shown in Table 1. Compliance with these will ensure that monitoring projects measure and report on biologically relevant and nationally consistent variables. As such, it is recommended that these indicators be used in all wetland monitoring programs. Unfortunately, standard measures of some of the indicators have not yet been stipulated. More information is available from the website of the National Land and Water Resources Audit: www.nlwra.gov.au.[6]

**Table 1** – The national indicators of wetland extent and condition, as defined by the National Land and Water Audit.

| Indicator | Measure |
|---|---|
| **EXTENT AND DISTRIBUTION** | |
| Extent and distribution of wetlands | Extent of wetlands in bioregion |
| Extent and distribution of significant wetlands | Extent of significant wetlands in bioregion |
| **CONDITION** | |
| Catchment Disturbance | Land use category |
| | Infrastructure |
| | Land cover change |
| **PHYSICAL FORM AND PROCESSES** | |
| Area of wetland | Percentage change in wetland area |
| | Loss in area of original wetland |
| Wetland topography | Percentage of wetland where activities have resulted in a change in bathymetry |
| | Degree of sedimentation / erosion |
| | Percentage change in bathymetry |
| Soil Disturbance | Percentage and severity of wetland soil disturbance |
| | Substrate disturbance |
| **HYDROLOGICAL DISTURBANCE** | |
| Local physical modifications to hydrology inflow, drainage and extraction | Severity of activities that change the water regime |
| | Impact of man made structures |
| Changes to water regime | Not yet developed |
| **WATER AND SOIL QUALITY** | |
| Turbidity regime | Not yet developed |
| Salinity regime | |
| Change in pH | |
| Soil properties – change in salinity, acidity | |
| **FRINGING ZONE** | |
| Change in fringing zone (measured by change in vegetation condition) | Percentage of fringing vegetation that is intact |
| | Percentage of natural and exotic vegetation |
| **BIOTA** | |
| Change in wetland vegetation | Not yet developed |
| Change in invertebrate diversity and community composition | |
| Change in wetland dependant vertebrates presence, breeding and abundance | |
| Change in introduced species presence and abundance | |
| Change in algae | |

## Wetland type

Every wetland is the result of a unique combination of hydrological, morphological, chemical and biological factors. Predicting how a wetland will respond to management intervention, and therefore selecting appropriate indicators to measure, will require an understanding of these various components.

A good starting point for understanding a wetland is to consider it as a representative of a broad wetland 'type'. An effective **wetland typology** will allow a relatively small number of readily discernable characteristics to be used to categorise a site.

Many different methods have been developed to divide wetlands into types. In WA, the 'geomorphic classification system' is used to identify wetland types for the purpose of wetland mapping. A national system is being introduced to enable consistent reporting nationally. This is the Australian national aquatic ecosystem (ANAE) classification framework. If these approaches are outside the scope of a monitoring project, a vernacular description can be applied to sites. This description should draw on the elements of the system that are most important to its character and ecological functioning. Examples of vernacular descriptors are *naturally saline lake* and *intermittently filled freshwater swamp*. Even such broad descriptors will help to communicate the nature of the site and guide decisions about which benchmarks and indicators should be used in the monitoring program.

➤ More information on wetland typologies is available at www.dec.wa.gov.au/wetlands.

## Conceptual models

A wetland conceptual model is a simplified diagram that expresses ideas about components and processes that are important to the ecosystem. A model assists in the development of a monitoring program by demonstrating the relationships between elements of the ecosystem and the points at which the effects of a disturbance will become evident. Understanding these relationships will assist in developing a hypothesis by highlighting the points that a monitoring program should target.

Formal wetland studies should include conceptual models as part of the definition of the ecological character of the site. For instance, the Ramsar Convention recommends that a conceptual model of a wetland be developed prior to implementing management and monitoring.[8] Less formal studies, such as landholder monitoring, don't require conceptual models. It will still be necessary, however, to think about the relationships between elements of the wetland ecosystem when developing a monitoring program. Constructing a basic, generic conceptual model for the wetland type may help to identify important elements to monitor.

➤ The Queensland Department of Environment and Resource Management currently leads the nation in the use of wetland conceptual models. Their *WetlandInfo* website is an excellent resource: www.epa.qld.gov.au.[7]

**Wetland typology:** the process of classifying wetlands according to characteristics of their hydrological, morphological, chemical and biological factors

**Ecological character:** the sum of a wetland's biotic and abiotic components, functions, drivers and processes, as well as the threatening processes occurring in the wetland, catchment and region [4,9]

**Wetland components:** include the physical, chemical and biological parts of a wetland (from large scale to very small scale, e.g. habitat, species and genes)[10]

**Wetland processes:** the forces within a wetland and include those processes that occur between organisms and within and between populations and communities including interactions with the non-living environment and include sedimentation, nutrient cycling and reproduction[10]

### Monitoring wetlands of international significance

When a wetland is nominated under the Ramsar Convention, the nominating party is required to complete an **ecological character** description of the site.[8]

The characteristics of the site at the time of nomination then become the benchmark against which any change in condition is measured.

In particular, the primary determinants of ecological character must be monitored. These are the features of the wetland that make it special or unique. In the case of a Ramsar listed site, these will be the **wetland components** and **wetland processes** that support the relevant nomination criteria.

For example, if a site is internationally significant because it supports large numbers of waterbirds, it is important to protect these birds and the habitat that they utilise. This may include maintaining the water level and the water quality to ensure that the birds' food source persists, as well as maintaining vegetation that is used for nesting.

At a minimum, monitoring must determine if the site continues to meet the Ramsar criteria under which it was nominated. Ideally, a monitoring program will include elements of the ecosystem that will provide early warning of any pending deterioration in ecological character.

## Surrogate measures

There are times when it is not practical to measure a required indicator. This may be because the indicator is cryptic, slow to respond to environmental change, expensive to assess or poorly understood. In such cases a surrogate measure may be used. This is another component of the system that shows a correlated response to the management issue being evaluated. An example of a surrogate measure is the use of aquatic invertebrate community composition to draw conclusions about water quality. Some taxa of invertebrates persist only within a narrow range of environmental conditions (particularly salinity and pH). The presence of such taxa may be used as a surrogate for the direct measurement of water quality.

A surrogate measure must show a strong correlation with the response of the original indicator. Even so, a problem inherent in the use of surrogates is a loss of specificity. Although surrogate measures may alert us to trends in the condition of the indicator, they are unlikely to provide quantifiable data about the indicator. Also, surrogates may be affected by factors that do not relate to the original indicator.

## Assessing condition

A common aim of monitoring is to assess changes in the overall 'condition' of a wetland. Although this can be a valid endeavour, it does require a very careful definition of condition.

In general terms, condition refers to the capacity of an entity to fulfil a particular function. It is a nebulous concept because of the requirement to link condition to a specific purpose. In the context of wetlands conservation, a wetland could simultaneously be in excellent condition for supporting salt tolerant invertebrates, but in very poor condition for the persistence of fish. It can be useful to compare the integrity of a wetland to a reference state. This may be the known or inferrred natural state of the wetland prior to alteration.

There have been many attempts to develop a broadly applicable method for categorising overall wetland condition. These have usually involved combining weighted measures of indicators of wetland function to provide a score or ranking. There is no universally accepted method for achieving this and most proposed methods stir controversy in some way. It is generally agreed, however, that a condition assessment scheme should include considerations of hydrology, geomorphology, water chemistry and biology and that both components and processes are important.

A project that aims to monitor wetland condition should develop a project-specific definition of condition. This should be guided by the type of wetland being studied and should incorporate a conceptual model to demonstrate the importance of the selected indicators. The weighting applied to different indicators will need to be carefully considered to ensure they accurately represent the way in which the ecosystem functions.

Of course, providing an overall score of condition is not necessary. It is often sufficient, and may be more accurate, to measure indicators without attempting to combine or scale them. Such an approach is more flexible as it allows more scope for the interpretation of data.

# Implementing a monitoring program

This section provides information about practical elements of monitoring programs, including the methods recommended to measure commonly used indicators of condition. There are many different ways to measure most indicators and to combine them to build a picture of wetland health and function. Those presented here are examples that have been tested and found to be appropriate in the Western Australian environment.

Most of the recommended methods are within the capabilities of a private landholder or community group and, if executed properly, will provide high quality data. Some, however, do require specialised equipment and will require expert assistance.

## Positioning monitoring actions

The correct positioning of the activities of a monitoring program is crucial to its success. There are three scales of positioning to consider:

- Study site: the wetland that is being monitored.
- Survey location: the area of the wetland where a survey is completed.
- Sampling point: the precise place at which a sample is taken.

When choosing where to undertake monitoring, the factors outlined below should be considered:

### Available resources

More sites, locations and points mean more time and money are required to collect data. It may also mean that data can be collected less frequently or that hurried collection causes data quality to deteriorate. It is important to strike the right balance between developing a comprehensive dataset and having the time required to collect complete information in each survey. This balance will depend on the resources available to complete the program.

### Objectives and design of the monitoring program

In some circumstances, it is appropriate to deliberately bias the positioning of monitoring activities. However, if the program relies on random sampling, consider using a random siting technique. One way to achieve this is to assign numbers to all potential sites, locations or points and then use a random number generator to select the final list.

### Spatial scale of the project

A monitoring program should set the minimum size of a reporting unit at the outset. Detail that is collected at a finer scale than the reporting unit will be lost if values are averaged or combined. This may mean it is inefficient to collect fine scale data, unless greater statistical power is required.

### Spatial heterogeneity of the indicator

Some indicators are only likely to vary significantly over fairly large distances, while others will be much more changeable. For example, air temperature and rainfall are likely to be quite stable across a wetland suite, while pH and salinity may be different in each wetland and vegetation composition may change several times at a single site. Likely sources of heterogeneity include variation in the type of habitat, soils, geology, aspect, hydrology and elevation. A monitoring program may need to account for any spatial heterogeneity in the parameter being measured in order to gather a representative sample.

### External interference

Many monitoring programs will require a monitoring location to be representative of an entire wetland. A location may not be representative if it is subject to an obvious external influence. For instance, causeways are a popular place to take water quality measurements due to ease of access. However, causeways often disrupt the hydrology of the system and roads may be a source of pollutants. This means that the measurements taken at a causeway might not be representative of the wetland as a whole.

### Constraints on access

Sampling points must be accessible at times that are appropriate and convenient. There is little point in planning to place a point in an area that is inaccessible due to tenure, hygiene or topography.

## Recording the site location

It is very important that the positions of monitoring locations are accurately recorded. The best monitoring data are long term data so researchers might want to return to the exact position of the monitoring location in years to come. Here are some guidelines for accurately, and lastingly, recording the position of monitoring locations:

### Assign a site name and code

Each site and location requires a unique identifier. Using a short alphanumeric code will help when storing monitoring data in a database or recording information on a sample bottle. It's also a good idea to include a project identifier in the site code. For instance the Department of Environment and Conservation's Resource Condition Monitoring Project study sites were coded RCM001 to RCM044. This identifies both the site and the project to associated personnel.

Site and location names are optional, but can be very helpful when discussing the monitoring program. People usually remember names better than numbers. Wherever possible, use an existing geographic identifier. If multiple locations are located within a single site, use cardinal points or topographic features.

### Mark the location

A marker should be left in position to allow future workers to confirm the location. If the situation allows, leave a permanent marker, such as a star picket or fence dropper, in place. If the soil or water is saline, a plastic star picket should be used, as metal pickets will corrode. Attach an aluminium tag to the picket, by means of a sturdy piece of wire, with the project name and site code embossed on it. A cap on the picket or dropper will protect people and animals from sharp edges. It may also be helpful to attach a length of flagging tape or paint the top of the picket a bright colour. This will make it more visible, particularly if vegetation grows up around the marker.

If a star picket or dropper is not appropriate, usually because of concerns about potential impacts on people or domestic animals, a marker may be attached to a tree. Select a sturdy, long-lived species and drive a nail into the trunk. Hang the site identification tag from the nail by a short length of wire.

If no trees are available and a star picket is not appropriate, it may not be possible to permanently mark the monitoring location. This will increase the importance of recording very accurate positional information.

## Recording the location using a geographical positioning system

A GPS is essential for accurately recording the position of a monitoring location or a sampling point. Modern GPS units are very reliable and even basic units are usually accurate to within a few metres. That said, if the wrong settings are used, or the full details of the readout not recorded, the position information will be useless. The important points when using a GPS are:

### Use the correct datum

A datum is an established point on the globe that is used as the reference from which other locations are calculated. Australia uses the Geographic Datum of Australia 1994 (GDA94). If the GPS being used does not support that datum, then WGS84 is almost equivalent and will suffice for most purposes. The datum that was used must be recorded on the data sheet to allow other users to plot it accurately.

### Record the zone

The entire planet is divided into zones to maximise the accuracy of GPS measurements. Western Australia lies across zones 48 to 52 south. The zone that a measurement is taken in will appear next to the location display on the GPS and it must be recorded on the data sheet. Without the zone number, the point cannot be mapped.

### Record the error margin

GPS units are usually accurate to within a few metres. On occasions, however, poor reception or deliberate signal interference could result in much lower precision. Recording the error margin that is displayed on the GPS screen allows future users of the information to see its spatial accuracy.

### Check that the reading makes sense

Quick consultation of a topographic map will show if the GPS reading is nonsensical. This will be a warning that the datum, or some other variable, is set incorrectly or that the unit is faulty.

## Access details

Future site visits will be facilitated by recording information such as the name and contact details of the land manager and any specific instructions on gaining access to the monitoring location. A mud map of the access route and sampling points may also be helpful. Annotating an aerial photo is also a good way to record access details. Remember that the person who conducts the next site visit may not be familiar with the area. In particular, any potential hazards should be clearly identified.

## Site and location overview

It is always useful to provide some contextual information about the site at the time that the survey was conducted. This is not monitoring data in the strictest sense, but will help others to interpret the survey findings. Here are some examples of contextual information that should be recorded during a site visit:

### Time and date

Some indicators show variation throughout a day, for instance, pH varies in a diurnal cycle and waterbirds are most active at dawn and dusk. Recording the time that a measurement was taken will be important when the data are interpreted later. Recording the date is essential to allow the data to be included as part of a time series or compared to surveys at other sites.

### Weather and climate

Weather conditions at the time of the visit, and in the time leading up to it, can be important. Weather at the time of the visit can directly influence measurements or increase the margin of error. For example, rain or fog will make it much more difficult to see waterbirds and a bird count done under such conditions is likely to underestimate their numbers. Weather patterns in the lead up to a survey may also affect measurements. For instance, rainfall may alter water chemistry by diluting salts in a waterbody or introducing pollutants to it.

### Evidence of recent disturbance

Disturbance to a site may be a result of natural phenomena, land management practices, an accidental spill or illegal activities. A monitoring program should capture information about any evidence of disturbance at sites, including the source of the impact, extent of the area affected and severity of the impact. This will allow temporally discrete impacts to be accounted for in the monitoring dataset.

Table 2 shows the most common threats to wetland ecosystems. For some of these, it is possible to quantify the extent and severity of the impact. For example, it is possible to measure the area of the fringing vegetation that is infested with weeds and to calculate the percentage of the total cover contributed by weed species. Other categories of threat may require a more qualitative approach, because the area affected is difficult to assess, an area statement is irrelevant or the severity of the impact cannot be quantified. Whichever approach is adopted, it is important to take notes and photographs that will allow future surveyors to determine if the extent or severity of any impacts have changed. Notes should also indicate if the impact will affect the measurements taken of any indicators, for example a recent fire reducing the vegetation cover at a site.

**Substrate:** a generic term denoting the material forming the floor of a wetland and its surrounds. It is used here because the term 'soil' is not inclusive of organic substrates.

**Table 2.** Threats that may have a detrimental impact in wetland ecosystems.

| Threat Category | Threat |
|---|---|
| Altered biogeochemical processes | Waterlogging and salinisation |
| | Eutrophication |
| | Erosion and sedimentation |
| | Drainage into / from site |
| | Groundwater abstraction |
| Introduced plants and animals | Weeds |
| | Feral animals |
| | Livestock grazing and wallowing |
| Problem native species | Usually overgrazing |
| Impacts of disease | |
| Detrimental regimes of physical disturbance and climate change | Fire |
| | Drought |
| | Flood |
| | Storm damage |
| Impacts of pollution | Herbicide, pesticide, fertilisers |
| | Spills |
| | Runoff |
| Competing land uses | Urban and industrial development |
| | Recreation |
| | Agriculture |
| | Consumptive and productive use |
| | Mines and quarries |
| | Illegal activities |

## Substrate composition

The **substrate** of a wetland is an important contributor to biological and chemical processes, such as nutrient cycling and the occurrence of vegetation.

Although an important part of the ecosystem, the substrate at a study site is unlikely to change, except over very long periods of time. As such, monitoring programs will not usually include repeated assessment of substrate composition. It is, however, very useful to record the characteristics of the substrate at the commencement of monitoring.

Many wetland substrates show classic soil structure, with a combination of mineral particles and organic matter. Some wetlands, however, lack true soils, and instead are underlain by deep deposits of organic matter. Little analysis is required of organic substrates, except to record their presence. The following information, therefore, relates to wetlands with a true soil profile.

The uppermost layer of a wetland soil is the P (peat) horizon, composed of organic materials in varying states of decomposition. This layer is termed the O (organic) horizon if it forms under dry conditions. Beneath the peat or organic horizon is the uppermost layer of mineral soil, known as the A horizon. The A horizon will often contain some organic material that has been incorporated from the O or P layers but will be predominantly mineral.

Various other layers of soil occur between the A horizon and the underlying bedrock. Unless soil composition is a particular focus of the project, however, it will probably only be necessary to record the nature of the O/P and A horizons. The documentation of deeper soil horizons will require a soil pit to be dug or soil cores to be taken.

### Soil depth

The depth of the O / P horizon can be an important indicator of ecosystem health as organic material plays a role in nutrient cycling and habitat provision. The depth of the A horizon may also be a useful measure, as it is indicative of the suitability of the area for different types of vegetation.

### Soil colour

The colour of soil reflects the minerals that compose it and the processes that are occurring within it. As such, it is indicative of the physical and chemical conditions in the soil. The colour of the O/P horizon is not usually important as decomposing organic matter is usually grey or black in colour. The colour of the A horizon of the soil profile may be a useful parameter to collect.

Soil colour is measured by comparing a soil sample to colour swatches in a Munsell Soil Colour Chart until a match is found. Colour is expressed as alphanumeric code that represents **hue**, **value** and **chroma** (Figure 2).

**Hue:** the property of colours by which they can be perceived as ranging from red through yellow, green, and blue, as determined by the dominant wavelength of the light

**Value:** the property of a colour by which it is distinguished as bright or dark; also known as luminosity

**Chroma:** the purity of a colour, or its freedom from white or grey

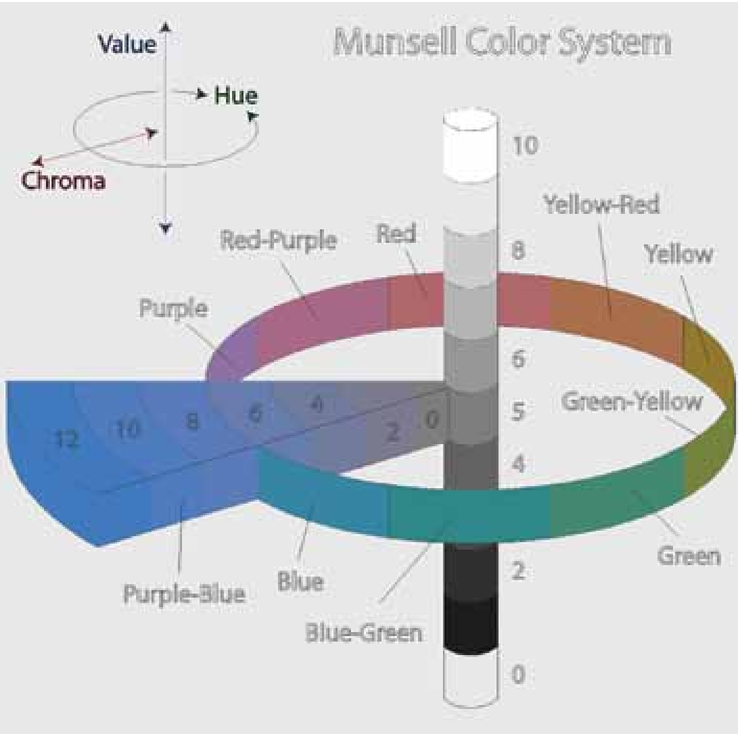


**Figure 2.** A diagrammatic representation of the combination of hue, value and chroma to give a unique colour identifier in the Munsell Colour System. From en.wikipedia.org.[11]

Colour is usually recorded when the soil is damp, but dry colour can be used. Annotate the recorded colour with 'M' for a moist recording or 'D' for a dry one.

If a Munsell chart is not available an attempt may be made to provide a vernacular descriptor of the soil. Most soils will be some mixture of grey, yellow, red and brown.

## Soil texture

Texture refers to the distribution of grain sizes of the mineral particles in a soil. Soil texture strongly influences the physical and chemical properties of soil.

Soil particles are grouped into classes of clay, silt and sand according to size (Table 3). The texture of a soil is defined by the relative abundance of particles of these different sizes. A texture category is assigned by plotting, on a texture triangle diagram (Figure 3), the percentage of a soil sample that is in these different size classes.

**Table 3.** Soil size fractions. Adapted from McDonald (1998)[12]

| Soil Particle Group | Maximum Particle Size (mm) |
|---|---|
| Clay | 0.002 |
| Silt | 0.02 |
| Fine sand | 0.2 |
| Coarse sand | 2.0 |
| Fine gravel | 6.0 |

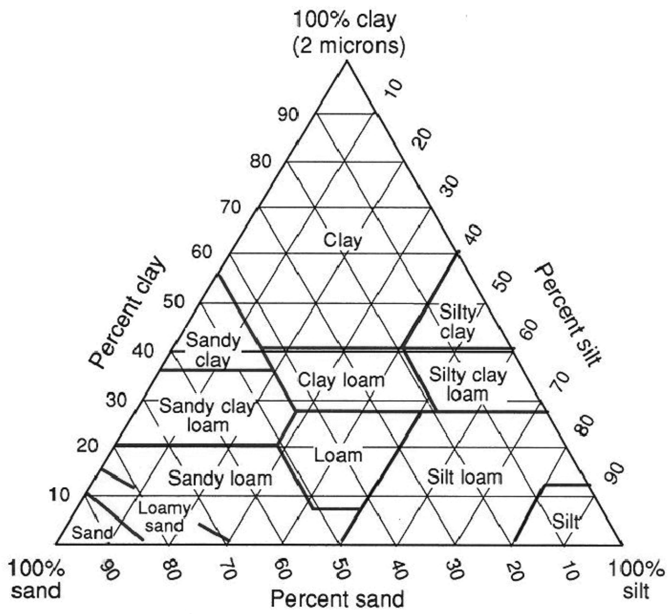


**Figure 3.** Triangular soil texture diagram. Texture is determined by plotting the percentage of particles in a soil sample that are in the size category of clay (<0.002 mm), silt (<0.02 mm) and sand (<2 mm). From Wikipedia en.wikipedia.org.[13]

Soil texture can be accurately measured by passing a dried soil sample through a set of nested sieves. The weight of soil collected by 0.002 millimetre, 0.02 millimetre and 2.0 millimetre sieves is weighed and converted to a percentage of the total soil weight. However, texture is more commonly assessed in the field using a ribbon test.

To assess soil texture in the field, begin by moistening a small handful of the soil while kneading and rolling it in the hand. Continue slowly adding water until the soil ball (or bolus) just fails to stick to the fingers. Once this point is reached, squeeze the bolus between the thumb and forefinger such that a ribbon of soil is squeezed away from the hand. Continue squeezing the ribbon until it breaks under its own weight. The behaviour of the bolus during its formation, and the length of the ribbon that can be formed from it, provide a good indication of soil texture (Table 4).

**Table 4.** Guidelines for the assessment of soil texture in the field. From the website of the New South Wales Department of Planning and Infrastructure www.dpi.nsw.gov.au.[14]

| Field Texture Group | Texture Grade | Coherence | Feel | Ribbon Length (mm) | % Clay |
|---|---|---|---|---|---|
| Sands | Sand | Nil | Sandy | Nil | <5 |
| Loamy sand | Slight | Sandy | 5 | 5 | |
| Clayey sand | Slight | Sticky | 5–15 | 5–15 | |
| Sandy loams | Sandy loam | Just coherent | Sandy | 15–25 | 10–25 |
| Fine sandy loam | Just coherent | Sandy | 15–25 | 10–25 | |
| Loams | Loam | Coherent | Spongy greasy | 25 | 25 |
| Silt loam | Coherent | Smooth | 25 | 25 | |
| Clay loams | Sandy clay loam | Strong | Sandy | 25–40 | 20–30 |
| Fine sandy clay loam | Coherent | Smooth, sandy | 40–50 | 20–30 | |
| Clay loam | Strong | Smooth | 40–50 | 30–35 | |
| Silty clay loam | Coherent | Smooth | 40–50 | 30–40 | |
| Light clays | Sandy clay | Coherent | Plastic | 50–75 | 30–40 |
| Silty clay | Coherent | Plastic | 50–75 | 35–40 | |
| Light clay | Coherent | Plastic | 50–75 | 35–40 | |
| Clays | Medium clay | Coherent | Plastic | 75+ | 45–55 |
| Heavy clay | Coherent | Plastic | 75+ | 50+ | |

### Soil pH

The pH of soil is an important determinant of the ecological character of a wetland. It will influence the chemical properties of the water body and the biology of the system. Soil pH may undergo rapid changes if environmental conditions are altered, and so, is one element of the sediment that may be measured regularly in a monitoring program. It is measured using a soil pH test kit, available from nurseries, or with a pH probe.

## Hydrology

There are two components of hydrology that are of interest to wetland managers: water budget and water regime. The water budget of a wetland is the balance of all of the inflows and outflows of water. The water regime of a wetland is the specific pattern of when, where and to what extent water is present in a wetland.

➤ For additional detail on wetland hydrology, see the topic 'Wetland hydrology' in Chapter 2.

### Water budget

The water budget of a wetland is calculated by summing all of the inputs of water to the system and subtracting all of the outputs. The main inputs of water to a wetland are from direct rainfall, surface water inflow via channels and overland flow and groundwater inflow. The main outputs of water from a wetland are evaporation, evapotranspiration, surface water outflows and groundwater outflows.

Determining and monitoring the water budget of a wetland is one of the most difficult monitoring activities to attempt. Establishing a water budget monitoring program is likely to require expert assistance and professional equipment. However, recording some basic information, such as rainfall and channel flows at the site, may be useful even if a full water budget is not calculated.

### Rainfall

Precipitation falling directly on the wetland is the easiest component of the water budget to measure. The quantity of rain received at the site is measured in a rain gauge. A gauge should be sited so that it is no closer to any obstruction than three times the height of that obstruction. For example, a gauge should be no closer than 30 metres from a tree that is 10 metres in height. A gauge should also be about 1.5 metres above the ground, as this helps to standardise the influence of wind on rainfall measurements.

The following formula will convert the rain gauge reading to a volume of water entering a wetland via direct rainfall:

$$V_W = V_G A_W / A_G$$

Where

$V_W$ = Volume of rainfall on wetland
$V_G$ = Volume of water in gauge
$A_W$ = Area of wetland
$A_G$ = Area of gauge opening

If the volume and area measurements are expressed in cubic metres and metres respectively, the output of the equation will be in cubic metres of water. This can be converted to litres by multiplying by 1000.

### Channel inflow and outflow

Channel flows are ideally measured using a V-notch weir or similar in-stream device. A V-notch weir is a channel engineered to known proportions such that the volume of water passing through can be calculated. These require quite precise engineering to install and, because of the need to modify the channel, will not be appropriate in some settings.

➤ More information on V-notch weirs is available from this website: www.lmnoeng.com.[15]

An alternative to establishing a weir is to use measurements from the extensive network of water gauging stations maintained by the Western Australian Department of Water (DoW). If one of these is located in near the study site, it may be able to provide the flow rates required to calculate the water budget.

➤ The location of, and data produced by, these stations are available from the DoW website: www.water.wa.gov.au.[16]

If a permanent monitoring station is not available, a handheld flow metre may be used to measure the flow velocity. The metre should be used mid-stream, where the velocity is highest. The flow volume can then be estimated by multiplying the flow velocity (in metres per second) by the channel cross sectional area (in square metres).

The cross sectional area of the channel is calculated by taking water depth measurements at regular intervals across the width of the waterway. Minimising the distance between measurements will improve the accuracy of the calculation.

These measurements can then be graphed to construct a channel cross section. On a sheet of graph paper, draw horizontal and vertical axes that are appropriate to contain the cross section of the waterway being assessed. Mark a dot on the graph to represent the depth of water at the point where the measurement was taken. Repeat this for all the points at which depth measurements are taken. Finally, connect the dots to form a diagram of the channel's cross-section. The area can then be calculated by counting the graph squares that are within the waterway. The area of any incomplete squares should be estimated (Figure 4).

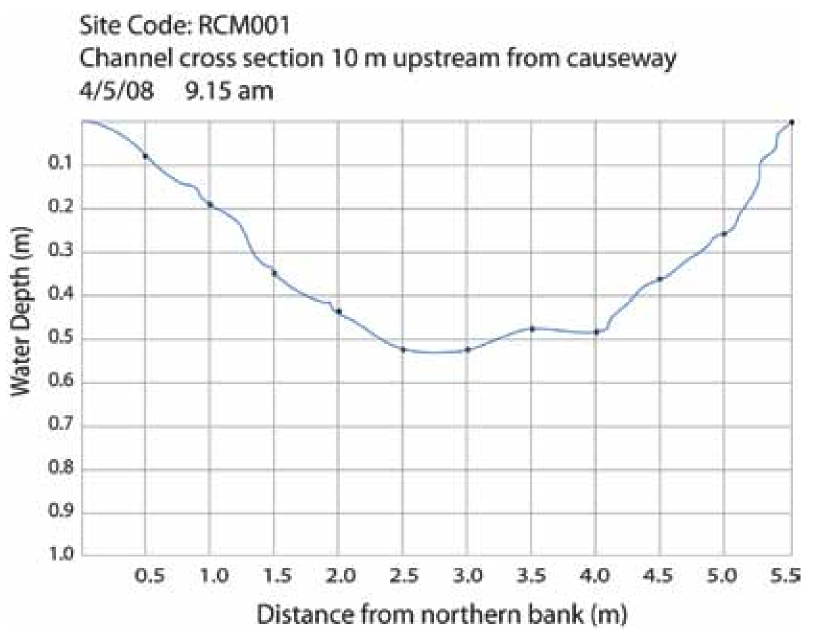


**Figure 4.** An example of a channel cross-section diagram. Depth measurements were taken every 0.5 metres across the channel width and plotted onto graph paper. The area of the channel can now be calculated by counting the number of squares within the depth profile. In this example, each square has an area of 0.05 square metres.

### Overland flow

Overland inflow occurs when surface water runoff enters wetlands after heavy or persistent rainfall exceeds the infiltration capacity of soils in the catchment. Water may exit a wetland via overland flows if water tops the banks and floods surrounding land.

Overland flow is very difficult to measure in the field. If it is important that overland inflow is included in a water balance equation, it will be necessary to use modelling software to calculate the runoff from surrounding land. This will be affected by many factors including rainfall duration, quantity and intensity, topography, soils and geology, land use in the catchment and the nature of surrounding vegetation. Such modelling will require assistance from a professional hydrologist.

Measuring flood outflows will not be necessary for most monitoring programs, as it will be possible to calculate the quantity of water remaining in the system after a flood event. At the cessation of flooding, the wetland will be at maximum capacity.

➤ For additional detail on calculating the capacity of a wetland, see the 'Water regime' section of this topic.

### Groundwater inflow and outflow

Groundwater is an important element of the water balance of most wetlands. Measuring groundwater fluxes is, however, a difficult task that requires both expertise and specialised equipment. In brief, piezometers (monitoring bores) are sunk into the groundwater across the landscape. Regular measurement of the height of groundwater in these bores allows a hydrogeologist to calculate the position of the water table and its direction and rate of flow.

Once a network of piezometers is established, the depth to groundwater is measured by lowering a weighted string, known as a 'plopper', down the bore. When the weight can be heard to hit the water, a reading of the depth below surface is taken from the string. Although this aspect of the operation is straightforward, establishing a suitable piezometer network and analysing the data require specialised knowledge. A hydrogeologist must be employed to assist if groundwater monitoring is required by a project.

### Evaporation

The loss of water via evaporation is a major factor in the water balance of Western Australian wetlands. Evaporation rate is influenced by the amount of solar radiation received, ambient temperature, wind speed, atmospheric humidity and water chemistry. It is measured using a class A evaporation pan.

An evaporation pan is a water tight, circular pan, 121 centimetres in diameter and 25 centimetres deep, made of 20 gauge galvanized iron. It is mounted on an open wooden platform and protected with a wire bird-guard to prevent animals drinking the water (Figure 5). The pan is filled to a fixed mark 19 centimetres above the base. Twenty-four hours later, the volume of water required to refill the pan to that mark is measured. Every 1.14 litres of water required to refill the pan represents 1 millimetre of evaporation. Any rainfall that has occurred during the 24 hour period must be deducted from the evaporation measurement.

**Figure 5.** Class A evaporation pan. Image from Pickering (2007).[17]

Water will evaporate more rapidly from an evaporation pan than from a wetland. This is mainly due to a layer of water vapour that sits above large water bodies and insulates them against further evaporation. The chemical composition of the water and the extent to which a wetland is shielded from the wind are also important factors.
A correction factor is required to determine lake evaporation from pan evaporation:

Evaporation = Lake Factor x Salinity Factor x (Pan Evaporation – Rainfall)

Evaporation, Pan Evaporation and Rainfall have the same units and are normally expressed in millimetres per day.

Lake Factor is normally assumed to be 0.7, although it may be lower in the case of sunken wetlands or sites that are otherwise shielded from the wind. If the site is highly shielded from the wind, use a lake factor of 0.65.

Salinity Factor is 0.7 for saturated brines. The following formula allows the salinity factor to be calculated for other solutions.

Salinity Factor = 1-salinity (%) x 0.00086[18]

### Evapotranspiration

Vegetation within and around a wetland will influence the water balance by transpiring water. Measuring the rate at which plants transpire requires specialised equipment, and is very difficult to achieve in a natural setting. This is because the rate of evapotranspiration will be different for each plant and will also be affected by the type of soil, the availability of water and the ambient climatic conditions.

The number of variables affecting evapotranspiration rate makes it impractical to measure in a wetland monitoring program. Two alternatives approaches are mathematical modelling and remote sensing. Both of these approaches are beyond the scope of the current document and will require expert assistance if they are to be applied.

## Water regime

The water regime of a wetland is the timing, duration, frequency, extent, depth and variability of water presence at the site. The water regimes of Western Australian wetlands typically show a high degree of variability. For example, it is common in arid parts of the state, for wetlands to be dry for long periods of time before rapidly filling in the aftermath of a storm. The variability of wetland water regimes means that relatively long term data (probably in the order of decades) will be required in order to identify trends amidst natural variation.

**Australian Height Datum (AHD):** is a fixed survey point from which the elevation of any point in Australia may be measured

Documenting the water regime of a wetland will require a surveyed depth gauge and some knowledge of the bathymetry of the system. A depth gauge should be positioned at the deepest point of a wetland and should be surveyed to **Australian Height Datum** (AHD) or a suitable local height datum.

The water level on the depth gauge is recorded regularly to monitor seasonal changes. A bathymetric survey of the wetland will allow a correlation between the depth of water measured on the gauge and the total volume in the basin.

Bathymetric survey involves constructing a three dimensional model of a wetland's floor by taking depth measurements along a number of transects. The measurements must be calibrated to AHD or a suitable local height datum, so that they are relative to a fixed datum, rather than to water level at the time of survey.

The extent of a wetland is best delineated by determining the maximum area that is waterlogged over several wetting / drying cycles. This may be problematic, however, at sites that are only 'wet' occasionally and at sites that flood over broad areas.

## Water conditions

Water in natural settings is never pure; it always contains dissolved ions and molecules that give it particular chemical properties. These properties of the water body are very important to a wetland's condition as they dramatically affect many of the components and processes in the system.

Some of the chemical properties of the water column may be measured in-situ, while others will require water samples to be analysed in a laboratory (Table 5). Techniques are provided here for taking in-situ measurements and for collecting water samples for laboratory analysis. The actual methods required to complete laboratory analyses are not included as they are beyond the scope of this document. If such analyses are required, it is recommended that a commercial laboratory be contracted to provide them.

**Table 5.** A summary of standard equipment and where measurements may be conducted for various water quality parameters.

| Parameter | Equipment Required | In-situ Measurement | Laboratory Measurement |
|---|---|---|---|
| Conductivity | Meter with probe | ✔ | |
| pH | Meter with probe | ✔ | |
| Transparency | Secchi disc | ✔ | |
| Turbidity | Meter with probe or water sample for lab | ✔ | ✔ |
| Dissolved Oxygen | Meter with probe | ✔ | |
| Total dissolved solids | Meter with probe or water sample for lab | ✔ | ✔ |
| Ionic composition | Water sample for lab | | ✔ |
| Nutrients | Filtered water sample for lab | | ✔ |
| Colour | Water sample for lab | | ✔ |
| Chlorophyll a | Frozen filter paper for lab | | ✔ |

Water chemistry is monitored to confirm that the parameters of interest remain within an appropriate range to maintain ecosystem health. This requires predetermination of the range of values that are acceptable for each water chemistry parameter. It is difficult to generalise about these values because the many different types of wetland ecosystems across Western Australia each give rise to unique environmental conditions.

The *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC guidelines)[19] describes 'trigger values' for various water quality parameters (Table 6). These describe the acceptable range of measurements in different types of wetlands in various parts of Australia. Although it provides some context for water quality measurements, the ANZECC guidelines do not fully reflect the potential range of 'natural' wetland conditions in WA.

Rather than relying on a prescribed acceptable range, monitoring programs should set trigger values or limits of acceptable change for the study site. This will require an understanding of the natural variability of the system. Such understanding may be developed from a review of relevant literature, but is best achieved through surveillance of the site through several wetting and drying cycles.

➤ More advice on developing site specific trigger values is available in Chapter 2 of the ANZECC guidelines [20] and the topic of the guide 'Conditions in wetland waters'.

**Table 6.** Default trigger values for chemical stressors for slightly disturbed ecosystems in Western Australia.[19]

| Water Quality Parameter | Trigger Value Northern Australia | Trigger Value Southwest Australia |
|---|---|---|
| Chlorophyll a (µgL-1) | 10 | 30 |
| Total Phosphorous (µgL-1) | 50 | 60 |
| Filterable Reactive Phosphate (µgL-1) | 25 | 30 |
| Total Nitrogen (µgL-1) | 1200 | 1500 |
| Oxides of Nitrogen (NOx µgL-1) | 10 | 100 |
| Ammonium (NH4+ µgL-1) | 10 | 40 |
| Dissolved Oxygen (% saturation) | <90 and >120 | <90 and >110 |
| pH | <6.0 and >8.0 | <7.0 and >8.5 |

➤ More information on measuring water quality parameters is available in Module 4 of the *Waterwatch Australia National Technical Manual*: www.waterwatch.org.au.[21]

## In-situ measurement of electrical conductivity

Pure water is a poor conductor of electricity, as it contains few of the free ions required to transfer an electrical charge. The electrical conductivity of a water body is, therefore, determined by the concentration of dissolved ions in the water. Because of this, electrical conductivity (EC) can be measured as a surrogate for the total dissolved solids (TDS) in a water body. The greatest contribution to the solids dissolved in a wetland will be the ions of various salts, unless the water is very turbid, in which case the suspended particles can make up more of TDS than the salts. In turbid wetlands, TDS is not a good indicator of salinity; a more accurate measure is the summed concentration of the major ions.

EC is measured in preference to TDS because the former is easily measured in the field using an inexpensive handheld meter. However, EC only provides an approximation of TDS. There are many factors that affect the conversion of EC to TDS, including the type of salt dissolved and the pH and temperature of the water. For most purposes, it will be sufficient to simply multiply the EC reading in millisiemens per metre (mS/m) by 5.5 to get an approximation of the milligrams of salt per litre of water (note that relatively fresh water may return a value measured in microsiemens per centimetre (µS/cm); this must be divided by 10 to convert it mS/m). If a precise measurement of TDS is required, it is necessary to use the laboratory method provided later in this section.

The natural concentration of salts in wetlands varies markedly, both through time and between wetlands. The geology, hydrology and soils of a wetland play an important role in determining the salinity regime and many WA wetlands are naturally saline.

Also, even in relatively fresh wetlands, salt concentration is directly related to the volume of water in the system. Salts will be diluted when water levels are high and become more concentrated as wetlands dry. This is part of the natural cycle of a wetland. Although freshwater generally supports a greater richness and diversity of biota, naturally saline sites also provide valuable habitat for flora and fauna that are adapted to such conditions. It is not possible, therefore, to provide any range of EC values that are acceptable or ideal in wetlands. Rather, monitoring should aim to detect any unnatural change in the pattern of EC measurements at a site. To provide some context, the maximum EC of water that is fit for human consumption is approximately 250 millisiemens per metre, while adult sheep may tolerate up to 2200 millisiemens per metre. Seawater has an EC of approximately 60 000 millisiemens per metre.

When monitoring EC, it will be necessary to take measurements regularly (at least seasonally) through a number of wetting and drying cycles. This will allow the natural variation in the system to be documented, and so, any unnatural trend in conditions to be identified. It is also important to record the volume of water in the wetland when each EC measurement is taken. This will allow the total salt load in the system to be monitored rather than the concentration of salt in the water, which will vary through a wetland's seasonal cycle.

Before using a handheld EC meter, it must be calibrated according to the manufacturers instructions. This will involve placing the probes into solutions of a known concentration of salts. It is also necessary to clean the probes after use, as per the manufacturers instructions, to ensure their longevity.

Conductivity meters have a maximum detection threshold, and so, cannot measure highly saline solutions. If the detection threshold of the meter is exceeded, it is possible to dilute a sample with fresh water of known conductivity, in order to obtain a reading. If this approach is used, the volume of the water sample and the volume of fresh water added must be measured very accurately. Alternatively, a water sample could be taken for laboratory analysis.

### In-situ measurement of pH

pH is a measure of the concentration of hydrogen ions in a solution; dissolved hydrogen ions being responsible for giving a solution the properties of an acid. The pH of a solution will influence the solubility of compounds and the behaviour of ions in it. This makes pH a strong determinant of the biota that can persist in a wetland.

pH is measured on a logarithmic scale typically ranging between 1 and 14. Lower pH values denote a greater concentration of hydrogen ions, making the solution acidic. Many wetlands have near-neutral pH (approximately 7), but considerable variation in either direction occurs naturally. Very low pH in wetlands is a cause for concern, as it may cause the mobilisation of toxic metals or other contaminants.

pH is measured in the field using a handheld meter. The meter should be calibrated prior to use, according to the manufacturers instructions. Calibration will involve immersing the probe into solutions of known pH.

pH varies in a diurnal cycle, so measurements in a monitoring program should ideally be taken at the same time every day. If this is not possible, ensure the time of day that the reading was taken is recorded. A water temperature measurement should be recorded at the same time that a pH measurement is taken, as temperature also affects pH.

### In-situ measurement of transparency

Transparency is a measure of the degree to which light is able to penetrate the water column. Light penetration is important to the survival of the aquatic plants and algae which are at the base of the wetland food chain. The transparency of wetlands varies according to a number of factors including the nature of the sediments in the wetland and in the catchment, water chemistry, rainfall and wind. Transparency is reduced by high concentrations of dissolved and suspended material in the water column, such as clay, algae or tannins. It can naturally be very low, such as in turbid claypans. Any significant, ongoing reduction in transparency should be investigated as it may be indicative of increased algal activity, erosion in the catchment or changed chemical conditions in the water.

A secchi disc is used for measuring water transparency. This is a 15–20 centimetre diameter, round, metal plate that is divided into quadrants that are alternately painted black and white (Figure 6).

The secchi depth of a water body is found by lowering the disc into the water until the black and white quadrants are no longer discernable. The depth at which this occurs is the secchi depth and the transparency of the water column is double the secchi depth.

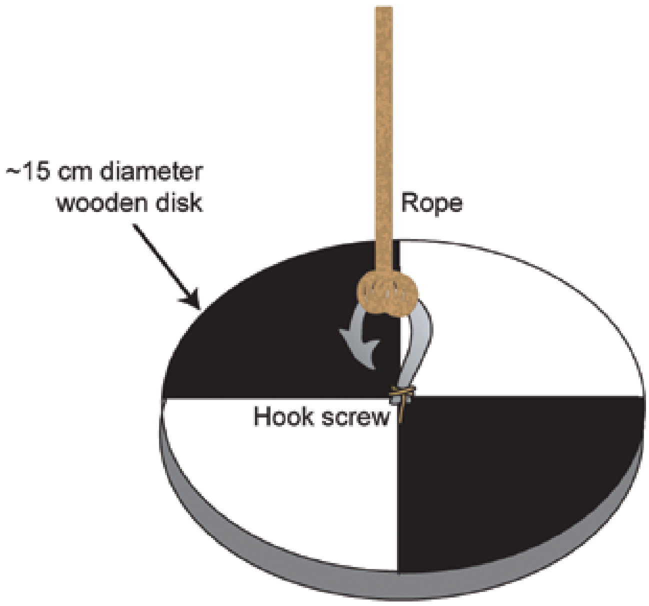


**Figure 6.** Recommended width, colouration and weighting of a secchi disc.
Images taken from website www.globe.gov.[22]

## In-situ measurement of turbidity

Turbidity is, essentially, the inverse of transparency. It is the extent to which light is scattered and reflected by particles suspended or dissolved in the water column (turbid water appears cloudy due to suspended material). It is measured with a handheld, electronic probe. If turbidity is to be measured, it must be done before the substrate is disturbed by other monitoring activities. Turbidity can also be measured in the laboratory using a water sample from the wetland.

## In-situ measurement of dissolved oxygen

Oxygen in the water column is essential to many of the natural chemical processes that occur in a wetland and to the persistence of aquatic fauna. The concentration of oxygen dissolved in the water of a wetland reflects equilibrium between atmospheric exchange, oxygen-producing processes, such as photosynthesis, and oxygen-consuming processes, such as respiration and chemical oxidation.

Dissolved oxygen (DO) concentration is measured using a handheld, electronic meter. It is important to follow manufacturers instructions to calibrate the unit prior to use. This will involve placing the probe into an oxygen-saturated solution, followed by a solution from which all oxygen has been chemically removed. It is also necessary to clean the probe after use, to ensure its longevity.

DO will show diurnal variation caused by photosynthetic activity during daylight. It is good practice, therefore, to take measurements at dawn and midday to track this natural variation. At a minimum, a monitoring program must take DO measurements at the same time of day in every round of surveys.

The solubility of oxygen in water is influenced by atmospheric pressure, water temperature and the concentration of dissolved salts in the water column. To take these factors into account, it is usual to express DO as a percentage of the saturation value. Most meters will complete this calculation automatically. It is good practice, however, to also record the actual concentration of oxygen, in milligrams of oxygen per litre of water (mg/L).

DO meters are most accurate when oxygen levels are moderate or high. At low oxygen concentrations, meters may be slow to register a reading and the reading may change continually. In such cases, it will be necessary to estimate a mean value over a period of up to two minutes. Note also, that oxygen levels can exceed 100 per cent saturation, particularly on hot sunny days or when algal growth is prolific.

## Collecting water samples

Water samples are collected for laboratory analysis of water chemistry attributes that cannot be measured in the field with sufficient accuracy or precision. It is very important to avoid contamination of water samples, as the equipment that will be used to analyse samples is very sensitive and will detect trace amounts of contaminants.

Water samples should be collected and stored in high density polyethylene or polypropylene bottles. These bottles should be washed with a phosphorous free, laboratory grade detergent prior to use and handled with care to avoid any potential for contamination.

When taking a water sample, gloves should be worn to avoid contamination of the water body with oils from the sampler's hands. Whenever possible, a sampling pole should be used to avoid the need to enter the water body. This is a 1 to 2 metre long polycarbonate pole with acrylic jaws that hold a bottle. If it is necessary to enter the water, disturbance of the substrate should be minimised and a sampling pole used to ensure that the sample is taken some distance from the disturbed area. If the water is flowing, samples should be taken upstream from any people that are in the water, with the bottle mouth upstream of the collector's hands and the body of the bottle.

The cap of the sample bottle should not be removed until immediately prior to collecting the sample and the inside of the bottle or cap should never be touched. Before collecting the sample, rinse the bottle and lid several times in the water body to remove any rinse-water left over from washing the container. The sample bottle should be filled by holding it near the base and plunging it below the water surface with the opening downward. The bottle should be held about 20 centimetres below the water surface, or mid-way between the water surface and bottom if the water is shallow, until it is full. Once full, the bottle is recapped without the sampler having any contact with the inside of the bottle or the cap. Table 7 shows the volume of water required for laboratory analysis of various chemical parameters.

The details of the sample are recorded on the datasheet form and the sample bottle labelled with the same details. Standard details to record are the site and location codes, date, water quality parameter, type and quantity of any preservative used and any hazard warnings.

Water samples that will be used for measuring chlorophyll and nutrients must be passed through filter papers and the filter papers frozen until they are analysed. This requires samples to be transported in an insulated carrier box (esky) with ice or in a portable refrigerator. Note that carrier boxes can be a source of sample contamination and must be cleaned thoroughly before use.

**Table 7.** The volume of water required for laboratory analysis of various parameters.

| Parameter | mL required | Notes |
|---|---|---|
| Total filterable phosphorus and nitrogen | 100 | Filtered through 0.45 micron filter paper that is then frozen until analysis |
| Acidity, Colour, Conductivity, pH, Turbidity, Total dissolved solids, Suspended solids | 250 | |
| Calcium, Magnesium, Sulphate, Potassium, Chloride, Sodium, Hardness, Alkalinity, Bicarbonate, Carbonate | 500 | Hardness and Alkalinity are calculated from these ions |
| Total Nitrogen, Total Kjeldahl Nitrogen, Total Phosphorus, nitrate and nitrite | 250 | Store frozen until analysis |
| Chlorophylls* | 1000 | Container is used to collect a sample for filtration. Filter paper is analysed. Filtered water can be used for further filtering the dissolved nutrient fractions. |

### Laboratory analysis of total dissolved solids

The total dissolved solids (TDS) in a wetland are all the molecules, ions and microgranules present in the water column. It also includes suspended material that is smaller than 2 microns in diameter. TDS is the most accurate measure of the salts that are present in a water sample, although organic chemicals and other pollutants may contribute to the TDS. TDS is determined by passing water through a 2 micron filter and then evaporating a known mass of the filtered water. The weight of the remaining residue is expressed as a weight per volume of the water sample.

### Laboratory analysis of ionic composition

The complete chemical composition of a water sample is determined in the laboratory by ion chromatography. This is a process that allows the separation of ions and polar molecules based on the charge properties of the molecules. It provides a complete analysis of the concentration of every ion in a sample. The sum of the concentrations of these ions is the most accurate measure of salinity but is also the most expensive.

### Laboratory analysis of nutrients

Nitrogen and phosphorous are the two most important elements for the growth of plants and algae. These elements are also common pollutants, with elevated concentrations leading to dangerous and/or cyanbacterial algal blooms.

Both nitrogen and phosphorous can exist in several forms within a wetland ecosystem; categorised as dissolved and organic components. The dissolved component; consisting of nitrate, nitrite, ammonia and orthophosphate; can be readily used by plants.
The organic component is bound to carbon, for instance within bacteria or algae, and is not available for use by plants. A measure of total nutrients includes both the dissolved and organic components. A more useful measure is total dissolved nutrients or measures of the individual 'species' of each element.

Water samples taken for the purpose of determining dissolved nutrients should be passed through a filter paper of pore size 0.45 micron (μm) and frozen in the field. The exception is highly turbid samples, which should be frozen unfiltered and centrifuged prior to analysis.

### Laboratory analysis of turbidity

When analysed in the laboratory, turbidity is measured with a nephelometer. A beam of light is passed through the sample and onto the nephelometer's detector. The detector registers the scattering of the light beam by particles in the sample. The units of turbidity from a calibrated nephelometer are called Nephelometric Turbidity Units (NTU).

### Laboratory analysis of colour

Colour can be precisely measured in the laboratory using a spectrophotometer. The absorbance of light of particular wavelengths by the water sample provides its colour in True Colour Units (TCU).

Highly coloured water will limit light penetration, and so, can mitigate the effect of elevated nutrient concentrations on plant and algal productivity. This means that damaging algal blooms are less likely to occur in highly coloured water.

### Collecting and analysing a sample for chlorophyll a

Chlorophyll a is the pigment required for photosynthesis in plants and algae. Its concentration in a water sample is the best indicator of the algal biomass in the water column. Very high chlorophyll a levels may indicate an algal bloom due to nutrient enrichment of the wetland.

To measure chlorophyll a concentration, a water sample is first passed through a glass fibre filter paper. The quantity of water required is somewhat dependant on the nature of the water, as highly turbid samples will rapidly block the filter pores. In general, aim to filter at least 500 milliletres (mL) of water. The filter paper is then removed and frozen for transportation to the laboratory. The content of chlorophyll a in the water is determined by using a spectrophotometer.

## Wetland vegetation

Vegetation is an integral part of a wetland ecosystem and, as such, will usually be included when monitoring a site. There are many different ways to monitor vegetation, but most aim to collect a similar set of data: the **composition** of the **plant communities** that are present, their **structure**, condition and extent.

Note that no distinction is drawn here between vegetation that grows on the floor of a wetland, including aquatic plants, and that which fringes it. This is because the recommended survey methods are suitable for both.

**Community composition:** the plant taxa that occur in a given community

**Plant community:** a discernable grouping of plant populations within a shared habitat. A community develops due to a unique combination of geologic, topographic and climatic factors and will be recognisable where those factors co-occur

**Community structure:** the three-dimensional distribution (height and width of foliage) and abundance of plant taxa and growth forms within a community

### Plant community survey for the community

The method of vegetation assessment recommended here is designed to provide a high level of data confidence. It requires some botanical knowledge and can be relatively time consuming to implement. Monitoring programs that do not require this level of rigour may prefer a more rapid assessment. The book *Bushland plant survey: a guide to plant community survey for the community*[23] is a well respected publication that provides such a method.

To accurately assess these factors, a monitoring program will require a detailed assessment of vegetation based on quantitative measures. The assessment will define the composition and structure of each plant community and measure its extent. It will also measure the percentage **crown cover** for each stratum in each community.

The method that is recommended here relies on the collection of quantitative data using standardised techniques. This approach will minimise inter-operator errors and make the resultant information more robust. It will also require some botanical expertise and may be more time consuming than qualitative methods.

Data should also be collected on the impacts of threats to vegetation. At lower levels of data confidence, this may require assessors to broadly categorise evidence of the impacts of threatening processes. If more confidence is required, it may be desirable to record additional information about the health of individual plants and the reproductive success of the community. This detail will show if changes are occurring within communities and if communities are likely to persist in their current form.

**Canopy cover:** the proportion of ground surface covered by the leaves and branches of plants when projected vertically downwards

**Crown cover:** the vertical projection of the outer extent of the crown of a plant. A line around the outer edge defines the limits of an individual canopy, and all the area within is treated as 'canopy' irrespective of gaps and overlaps

**Stratum:** (plural strata) a visibly conspicuous layer of photosynthetic tissue within a plant community

## NVIS - the National Vegetation Information System

The National Vegetation Information System (NVIS) was developed to resolve differences in the way that vegetation data are interpreted and managed across Australia. This includes a method for writing a standardised description of a plant community. NVIS was produced by the National Land and Water Resources Audit (NLWRA) as part of a nation-wide assessment of vegetation extent.

The guidelines for capturing, interpreting and managing vegetation survey data for NVIS are provided in *The Australian Vegetation Attributes Manual*.[24] The manual describes the attributes that should be measured in the field and how these are used to build a description of the vegetation. It also stipulates the requirements for metadata and the process of collating vegetation information into a relational database.

An NVIS community description concisely communicates a great deal of information about the vegetation at a survey location. There are six levels of detail in NVIS; higher levels require more data to be collected and give a more detailed description of the vegetation (Table 8). At the higher levels of detail, the community description states the **strata** that are present, their height, canopy cover and growth form and the plants that are dominant in each.

A complete NVIS level VI vegetation description may look like the example in Figure 7 (note that colouration has been added to assist the reader in distinguishing between parts of the description):

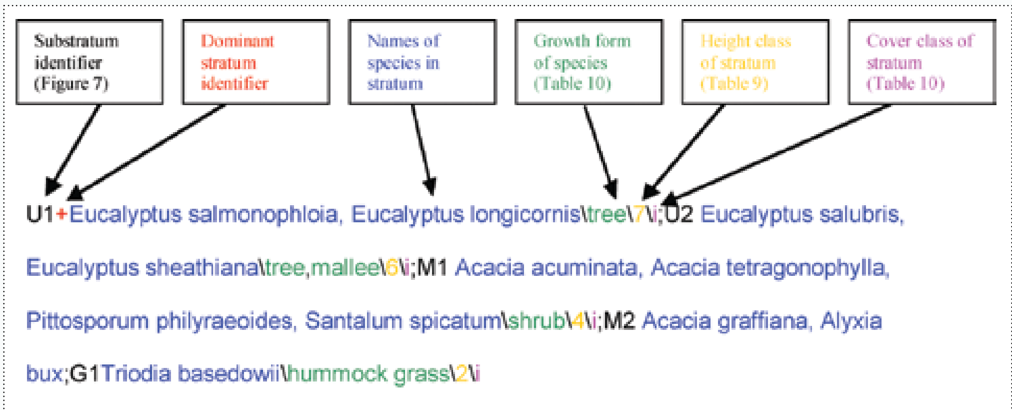


**Figure 7.** An example of an NVIS vegetation association description.

NVIS is required to be flexible to allow for regional environmental differences. As such, it does not require the application of a particular vegetation survey technique. However, the manual recommends the approaches described by Hnatiuk et al. (2008).[25] The point intercept and zig-zag methods described in this section are based on the methods of Hnatiuk et al. with some minor adjustments deemed necessary to ensure suitability for application in a wetland setting.

## Describing a plant community

This section explains the process of developing an NVIS association (Level 5) or sub-association (Level 6) vegetation description (see Table 8 for an explanation of these terms). The same basic approach can also be used to describe vegetation at lower NVIS levels. Data should be collected that allows a community description to be developed that is appropriate to the purposes of the monitoring program. It is recommended, however, that monitoring programs describe vegetation to at least association level.

There are a number of reasons why it will be useful to define the plant communities that occur at a wetland. Firstly, community names are an effective way to communicate the nature of the vegetation. Also, vegetation will naturally undergo continuous minor changes in composition and structure. A monitoring program will need to decide if these changes are significant, and one measure of this will be if they cause a change in the definition of the community. Finally, defining communities will allow them to be mapped, and the position of community boundaries to be used as an indicator of changes in conditions at the site.

The minimum data required to describe a community are the height, dominant species and percentage cover of each stratum in the plant community. These parameters are recorded along a transect established within the community being described. The transect should be 50 metres in length, run in a straight line and remain within a single vegetation community. The requirement to remain within the selected vegetation community will mean that, at wetland sites, the transect will run approximately parallel to the shoreline. If it is not possible to fulfil the requirements above, a shorter transect may be established, but this should be noted on the data sheet.

Photographs should be taken every 10 metres along the transect. They should be aligned in such a way that they show the nature and condition of the vegetation that is present. These photos will provide photo monitoring data, assisting in the detection of changes in site conditions over time. Take care not to trample understorey vegetation when moving along the transect, as doing so may affect the results of the survey.

**Table 8.** Description of the information used to develop vegetation descriptions at NVIS levels I – VI. Italicised text denotes the new information added at each successive level.

| NVIS Level | Name of Level | Data Required | Example |
|---|---|---|---|
| I | Class | Growth form of the dominant stratum. | Mallee. |
| II | Structural formation | Growth form, height class and cover class of the dominant stratum. | Sparse mallee shrubland. |
| III | Broad floristic | Growth form, height class, cover class and dominant genus of the dominant stratum. | Eucalyptus sparse mallee shrubland. |
| IV | Sub-formation | Growth form, height class, cover class and dominant genus of the three traditional strata (upper, middle, lower). | Eucalyptus sparse mallee shrubland / Acacia sparse shrubland / Triodia sparse hummock grassland. |
| V | Association | Growth form, height class, cover class and 3 dominant species of the three traditional strata (upper, middle, lower). | U^Eucalyptus oleosa, Eucalyptus transcontinentalis, Eucalyptus platycorys\mallee\6\r etc.* |
| VI | Sub-association | Growth form, height class, cover class and 5 dominant species of all strata. | U1+Eucalyptus oleosa, Eucalyptus transcontinentalis, Eucalyptus platycorys, Eucalyptus sp. aff. concinna, Eucalyptus sp. aff. comitae-vallis\mallee\6\r etc.* |

* Note that, for brevity, the examples given for NVIS levels V and VI provide only a description of the uppermost sub-stratum. Other sub-stratum would follow with a similar format. Species should be listed in order of dominance.

### Strata in the community

A stratum is a measurable, visibly conspicuous layer of photosynthetic tissue in a plant community (Figure 8). The plants in the community being surveyed should be separated into strata (and sub-strata if appropriate) based on the height of their canopy or foliage.

There are no defined height brackets for upper, mid or lower strata; they are named in relation to the height of other plants in the community. The approximate mean height of the top and bottom of each stratum must be recorded to allow future workers to replicate the strata descriptors that are used. At most locations, there will be plants that intergrade between strata. A decision should be made as to which stratum these really belong to (i.e. is it an unusually tall example of the mid-storey or is it a juvenile member of the upper storey). If there is no identifiable, discrete break in the range of canopy heights, all plants may belong to a single stratum.

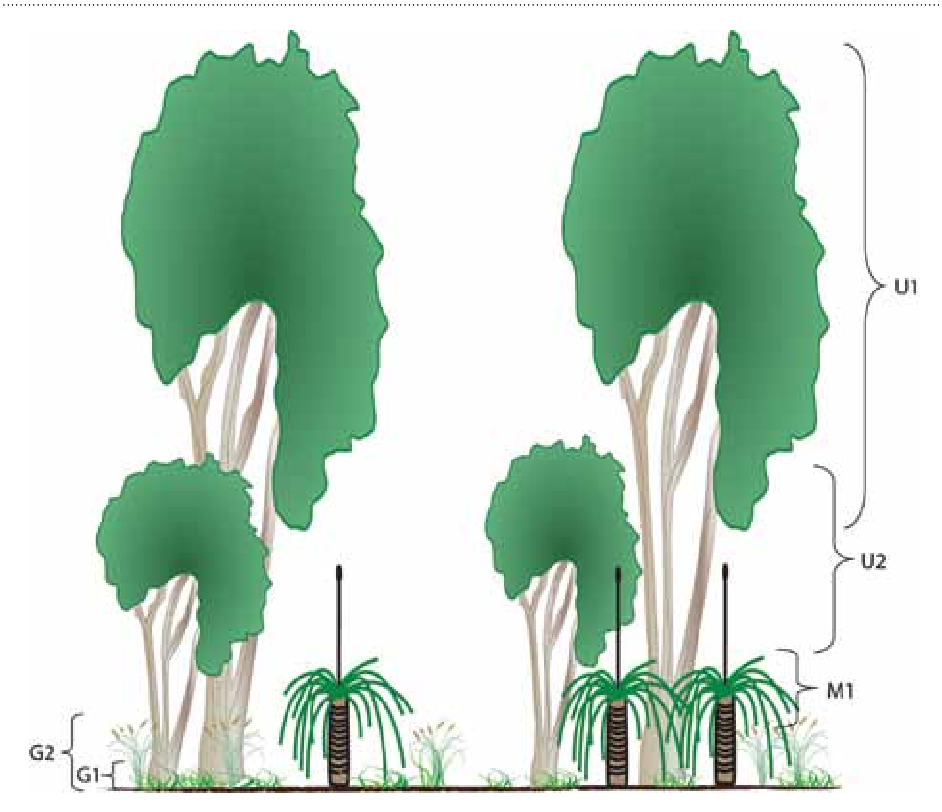


**Figure 8.** Identification of sub-strata in the upper strata (U1 and U2) and ground cover (G1 and G2).

In an NVIS description, the letter 'U' is used to denote the upper storey, 'M' the mid storey and 'G' the under storey (ground cover). These letters can be followed by numerals to denote substrata. For example, U1 is the tallest substrata of the upper storey, U2 the next tallest etc. (Figure 8).

### Dominants and emergents

An NVIS community description names the dominant strata and dominant taxa in each strata. Dominance is conferred on the strata and taxa that have the greatest biomass (note that this is not necessarily the tallest stratum or taxon). Dominants will usually be identifiable with the naked eye, however, in some instances, measurements of canopy cover may assist the decision.

The dominant stratum or substratum in a vegetation association or sub-association is indicated with a '+' symbol e.g. U1+Eucalyptus oleosa, indicates that U1 is the dominant substrata in the vegetation unit and that it is composed of *E. oleosa*.

The dominant taxa in a vegetation description are preceded by the symbol '^', described as a 'hat'. A 'hat' preceding one species name will identify it as the dominant; 'hats' preceding two species names indicates co-dominance. A 'double hat' (^^) indicates that more than two species are co-dominant and the broad floristic will be described as 'mixed'. e.g  U^Corymbia calophylla,^Eucalyptus rudis, Melaleuca preissiana\tree\7\i; indicates that *Corymbia calophylla* and *Eucalyptus rudis* are co-dominant species in the upper stratum.

Emergents are individuals that are taller than the highest stratum, but are not present in sufficient numbers to form a stratum in their own right. Emergents may be ecologically important, even if they are widely dispersed, and their presence should be recorded. Emergents are not identified in the community description.

### Growth form and height classes

In an NVIS description, strata are given a height descriptor, based on the median height of the top of the canopy of that stratum. Table 9 shows the range of actual heights that comprise each height class and which growth forms may occur in each height class. The growth form and height class code are given for each stratum and substratum at the end of the species list e.g. U1+Eucalyptus oleosa \mallee\6 indicates that the U1 substrata is dominated by low (less than 10 metres high) mallees.

**Table 9.** **NVIS height class bracket descriptors for different growth forms. Empty boxes represent an unacceptable combination of growth form and height. Table from ESCAVI (2003)[24].**

| **Height** | | **Growth Form** | | | | |
|---|---|---|---|---|---|---|
| Height Class | Height Range (m) | Tree, vine, single stemmed palm | Shrub. Heath shrub, chenopod shrub, fern.  Samphire shrub, cycad, tree fern.  Grass tree, multi-stemmed palm | Tree mallee. Mallee.  Shrub | Tussock grass, hummock grass, other grass, sedge, rush, forb, vine | Bryophyte, lichen, seagrass, aquatic |
| 8 | >30 | Tall | | | | |
| 7 | 10-30 | Mid | | Tall | | |
| 6 | <10 | Low | | Mid | | |
| 5 | <3 | | | Low | | |
| 4 | >2 | | Tall | | Tall | |
| 3 | 1-2 | | Mid | | Tall | |
| 2 | 0.5-1 | | Low | | Mid | Tall |
| 1 | <0.5 | | Low | | Low | Low |

### Species in the community

A list of plant species occurring at the survey location should be compiled, along with the relative abundance of each taxon. Although the community description only uses the most dominant species, it may be prudent to record all of the species at the survey location.

A plant specimen should be collected for submission to the WA herbarium if there is any doubt over its identity, it is considered to be rare, unique or unusual or it has not previously been collected from the general area. The specimen should include as many features of the plant as possible (roots, bark, leaves, flowers, buds, fruit etc.) and be kept in a sealed plastic bag until it is pressed. More information about collecting voucher specimens can be found in Bean (2006).[26]

Remember that a permit is required from the Department of Environment and Conservation to collect native flora. A flora collecting permit does not authorise the holder to collect rare or endangered flora. It is important to be familiar with any rare flora that might occur at a survey location to prevent accidental collections.

Each specimen should be labelled with a unique identifier that matches it to a field collecting sheet. The collecting sheet will record where the sample was collected, when and by whom, as well as characteristics of the plant, soil and topography. Without this sheet, the collection cannot be submitted to the herbarium. The information captured on the field data sheet can also be very important for successful identification of unknown specimens.

### Estimating canopy cover

The degree to which the canopy forms a continuous layer determines the penetration of light to the ground, and so influences the habitat available to flora and fauna. As such, canopy cover is an important element of a community description. Monitoring canopy cover can also provide early indication of changes in the vegetation, particularly of deteriorating plant health.

The easiest way to assess canopy cover is to estimate its continuity at several points at the monitoring location. The objective is to estimate how much of the sky is obscured by the canopy. This can also be thought of as the proportion of the ground that would be shaded if the sun was directly overhead. The number of points at which estimates should be taken will depend on the size of the area being assessed, the degree of heterogeneity of the vegetation and the available time and resources.

Estimations of canopy cover may be made more accurate by referring to a visual aid. While the exact appearance of various cover densities will be influenced by the type and height of vegetation, photographs of known canopy cover classes will provide some guidance.

Estimates of canopy cover are prone to a high degree of inter-operator error. They can also be affected by light conditions and wind. Although estimation is an efficient technique, the results should be treated with caution as they may be inaccurate.

### Measuring crown cover

The purpose of measuring cover is to quantify the relative contribution made by different species or structural components to the biomass at a location. There are many different ways of expressing the cover characteristics of a plant community; two of these are recommended here.

Foliage cover should be measured when assessing ground cover and plants up to around 50 centimetres in height. The point intercept method is recommended to calculate foliage cover. For taller plants, the per cent crown cover should be calculated using the zigzag method.

The point intercept and zigzag methods require transects to be established within the plant community being studied. The point intercept method requires a 30 metre transect, while the zigzag method requires a 50 metre transect. Transects should be positioned in areas that appear representative of the plant community.

The accuracy of these cover measurements can be improved by surveying multiple transects within a community. More transects will decrease the potential error margin in the dataset, but will also be more labour intensive. Establishing three transects in any one community should be adequate to ensure high quality data.

### The point intercept method and percentage foliage cover

Foliage cover is a measure of the direct projection of foliage on a tape measure on the ground. Looking down on the tape measure, record the length of tape that is covered by any part of a plant (Figure 9). Also record the total length of the transect.

Foliage cover is the percentage of the total length of the tape that is covered by plants (cover / total length x 100). Usually, around 30 metres of the transect will be sufficient to get a good measure of cover, although this may vary depending on the density of vegetation at the site.

One issue that commonly arises is a difficulty in determining the cover of thin leafed grasses on the transect. The suggested approach here is to gently bunch the grass and take a measurement of the total area the bunch covers. This is more accurate than trying to measure the width of several very thin leaves.

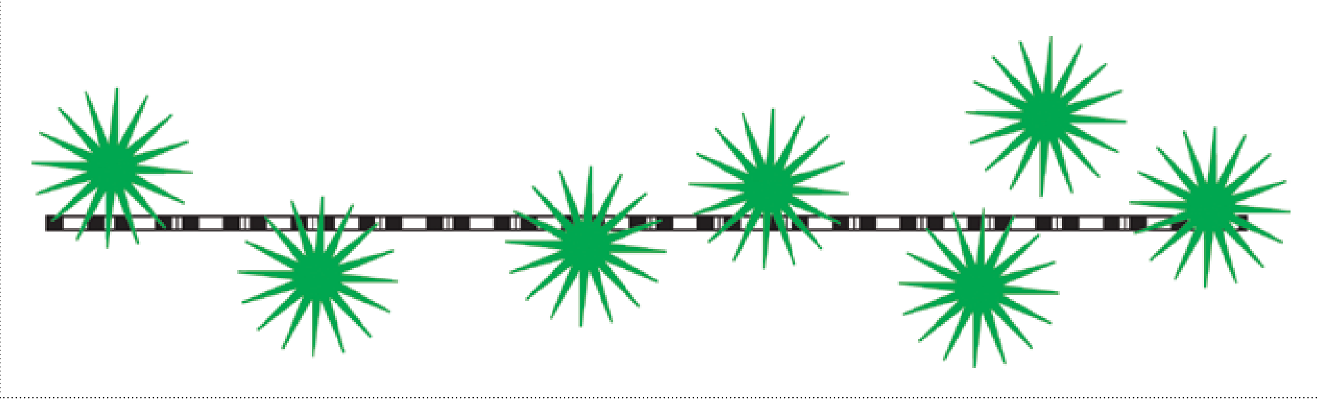

**Figure 9.** The point intercept method for measuring percentage foliage cover of understorey vegetation. The measurement taken is the length of the tape (dashed line) that is covered by vegetation (green shapes). Only tape that is directly beneath the foliage of the vegetation is measured as an intercept. Figure adapted from Hnatiuk (2008)[27].

### The zigzag method and crown cover percentage

In order to calculate percentage crown cover, it is first necessary to determine the crown separation ratio. This is the simple ratio of the mean distance between the crowns of plants along the transect relative to the mean size of those crowns. It is measured in the field using the 'zigzag method' (Figure 10). Crown separation ratio can then be converted to crown cover percentage, using a simple formula. The following steps refer to Figure 10 and describe the process for calculating crown cover. A template for recording the required measurements is provided in the 'Data collection' section, later in this topic.

1. Measure and record the distance from the beginning of the transect (P) to the nearest crown (A).
2. Measure the width of crown A (perpendicular to transect) and the length (parallel to transect). Record the arithmetic mean of these measurements.
3. Measure and record the shortest distance between crown A and the nearest crown that is towards or across the transect and closer to the end of the transect (crown 1). If the two crowns are overlapping, measure the width of the overlap as a negative gap. If the crowns are touching, record a gap of zero.
4. Repeat steps 2 and 3 until the end of the transect is reached (point Q).
5. Calculate the crown separation ratio (C) by dividing the mean gap between crowns along the transect by the mean width of crowns along the transect.
   C = mean gap / mean width
6. Calculate the percentage crown cover
   Crown cover % = 80.6 / (1+C)2

The most common issue encountered when applying this method is determining which plants to include as part of the transect and which to exclude. Firstly, as this method is designed to give a mean measure of cover over the length of the transect, the selection of plants used is not critically important. Apply the general rule of moving to the next plant that is further along the transect and either towards or across the transect line. Also, the important feature of the plant is the crown. A tree with a stem near the transect that leans such that its crown is several metres from the transect probably should not be included. Conversely, a stem several metres from the transect with a crown over the transect should be included. Finally, if the crown of a plant is in two or more distinct and separated clumps, it may be appropriate to treat those clumps as separate crowns.

Table 10 shows how increasing canopy 'connectedness' alters the description of a vegetation unit. The 'cover code' attribute is provided in a written NVIS description to identify the vegetation structure e.g. U1+Eucalyptus oleosa\mallee\6\r indicates that the U1 stratum has less than 10 per cent foliage cover and is, therefore, an open mallee woodland.

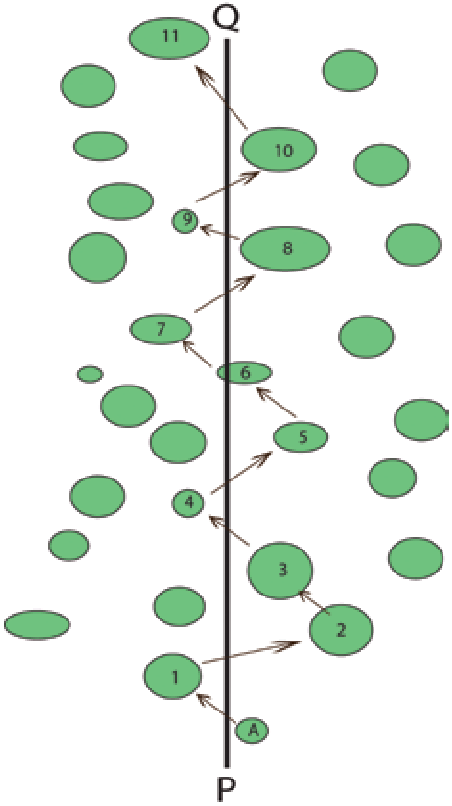


**Figure 10.** The 'zigzag' method for measuring crown separation ratio. (Figure on the left from Hnatiuk, 2008[27]).

**Table 10.** Selected structural formation classes defined by crown cover and growth form under National Vegetation Information System.[24] The full table can be found in ESCAVI (2003).

| Crown Cover | >80 | 50-80 | 20-50 | 0.25-20 | <0.25 |
|---|---|---|---|---|---|
| Cover Code | d | c | i | r | bc |
| Growth Form | Structural Formation Class | | | | |
| Tree | closed forest | open forest | woodland | open woodland | isolated trees |
| Mallee | closed mallee forest | open mallee forest | mallee woodland | open mallee woodland | isolated mallee trees |
| Shrub | closed shrubland | shrubland | open shrubland | sparse shrubland | isolated shrubs |
| Grass | closed grassland | grassland | open grassland | sparse grassland | isolated grasses |
| Sedge | closed sedgeland | sedgeland | open sedgeland | sparse sedgeland | isolated sedges |
| Rush | closed rushland | rushland | open rushland | sparse rushland | isolated rushes |
| Forb | closed forbland | forbland | open forbland | sparse forbland | isolated forbs |
| Aquatic | closed aquatic bed | aquatic bed | open aquatic bed | sparse aquatic bed | isolated aquatics |

## Measuring the extent of native vegetation

The native vegetation surrounding a wetland acts as a buffer between the wetland and many threatening processes that are occurring in the catchment. It also provides habitat for fauna, assists in groundwater regulation, prevents erosion and sedimentation and provides a multitude of other roles. The greater the extent of vegetation, the more effectively it will fulfil these functions. The total extent of dryland vegetation surrounding a wetland can, therefore, be an important variable to monitor. Note that monitoring total vegetation extent is only required when a wetland is situated within remnant vegetation in a cleared landscape. If the wetland is within extensive unmodified vegetation, it may be desirable to monitor the extent of the wetland vegetation, but monitoring total vegetation extent will probably not be required.

The extent of vegetation surrounding a wetland is best measured and recorded on a current aerial photograph or satellite image. Regularly updated imagery will be required to determine if changes in vegetation extent are occurring. Often, the density of vegetation will gradually decrease as the remnant transitions to agricultural or urban land. It will be necessary to decide what density of native plants constitutes 'remnant vegetation' as opposed to, for example, a paddock with scattered trees. This decision will depend on the nature of the landscape, the objectives of the monitoring program and the spatial scale of the mapping.

Determining the extent of the vegetation that is 'wetland dependant' is more difficult to achieve. The delineation between wetland and terrestrial vegetation is complex, and no standardised method has been published.

One approach to defining the extent of wetland vegetation is to undertake on-ground surveys to define the plant communities, determine which of these are more commonly associated with wetland areas and then map the extent of each. Communities may be mapped by walking their boundaries with a GPS unit. It is common for plant communities to transition gradually, so some interpretation will be required to decide where a community boundary lies. The precision with which boundaries should be defined will be influenced by the required scale of the resultant map. For this reason, the working scale should be defined before commencing mapping.

### Monitoring the condition of vegetation

The condition of vegetation at a wetland is an important indicator of the health of the ecosystem. Wetland plants are adapted to flourish in relatively narrow environmental niches. Any deterioration in vegetation condition may, therefore, be indicative of some significant change in the system. This makes the ability to quantitatively assess and compare the condition of vegetation an essential component of a wetland monitoring program.

The condition of a plant community is determined by comparing its composition, structure and regenerative capacity to those of a reference site. The reference site, known as a benchmark, is an example of the same plant community that is pristine, or free from evidence of degradation. Good condition sites will have very similar composition, structure and regenerative capacity to the reference site.

Benchmarks may be actual areas of vegetation or they may be theoretical, constructed from historical data and expert opinion. Benchmarks are difficult to define because plant communities change in structure and composition through time. Communities can develop in different ways, and exist in different states, depending on the prevailing conditions and the time elapsed since the last significant disturbance. This means it can be difficult to judge what the 'ideal' nature of the community is.

An example of a vegetation condition assessment process is the Vegetation Assets States and Transitions model (VAST), proposed by Thackway and Leslie.[28] In the VAST model, vegetation communities are assigned to a condition category dependant upon consideration of regenerative capacity, composition and structure. The diagnostic criteria are defined for each class but it is left to the surveyor to determine the appropriate method to evaluate those criteria at the monitoring site.

VAST recognises that vegetation communities can exist in different states and can make transitions between states. A shortcoming of the VAST approach is the very broad nature of the condition categories. There are only three categories of native vegetation condition: residual, modified and transformed. VAST does, however, guide the user toward a rapid and defensible appraisal of vegetation condition at monitoring sites.

Methods for quantifying vegetation composition and structure have been recommended in the previous section. The application of the VAST framework, therefore, requires only a method for determining the regenerative capacity of the community.

### Regenerative capacity

The regenerative capacity of a plant community is the ability of its constituent taxa to successfully produce new generations of plants. It is a critical consideration of community condition because it determines whether the community will remain viable in the long term. Successful recruitment is also an indicator of ecosystem health as it shows that processes such as pollination have not been disrupted, that soil conditions are suitable for vulnerable juvenile plants and that grazing pressure is within acceptable limits.

The regenerative capacity of a vegetation unit is difficult to assess because many Australian taxa reproduce only in response to disturbance. If an appropriate disturbance, such as a fire, has not occurred, no recruitment will occur. There are some approaches that will assist an assessment of regenerative capacity, but the data obtained will usually be qualitative for all but annual taxa.

The first step is an appraisal of evidence of historical recruitment. Examine the vegetation for evidence of different age classes within taxa. The presence of plants of different ages shows that successful recruitment has occurred in the past. Look also for any recent recruitment or evidence that a disturbance (such as a fire) has occurred without stimulating recruitment. Make note of any taxa that have recruited or that have not, despite apparently conducive conditions.

If a recruitment event has occurred, it may be desirable to quantify its magnitude. Doing so will allow comparison of future recruitment events and may also allow an assessment of the survival rate of germinants.

Due to the small size of newly recruited plants, a **quadrat** is a more appropriate sampling technique than a transect. A quadrat is a square plot that is marked, either temporarily or permanently, to facilitate counts of plants in a given area. The most appropriate size for a quadrat will depend on the density of the vegetation and germinants. A larger quadrat will obtain a more representative sample, but will be more labour intensive to analyse.

Once a quadrat is marked, count the number of germinants within it. If the taxa being counted are perennial, it may also be useful to record the height and/or width or each individual. Note that this quadrat technique may also be applied to monitor weed populations.

It is also good practice to record any evidence of stress or ill health affecting individual plants at a study site. Doing so will assist in the interpretation of changes that occur over time. Due to the difficulty in assessing the condition of plants, this measure will tend to be qualitative. Simply estimate the percentage of plants in the surveyed area that are showing evidence of stress. It is also helpful to note any likely causes of that stress, such as disease, grazing, salinity, waterlogging, fire, agricultural chemical impacts and drought.

**Table 11.** The Vegetation Assets States and Transitions (VAST) model

| | | **NATIVE VEGETATION COVER**<br>**Dominant structuring plant species indigenous to the locality and spontaneous in occurrence** | | | | **NON-NATIVE VEGETATION COVER**<br>**Dominant structuring plant species alien to the locality or indigenous to the locality but cultivated.** | | |
|---|---|---|---|---|---|---|---|---|
| Vegetation cover classes | | Type 0: RESIDUAL BARE<br>Areas where native vegetation does not naturally persist | Type 1: RESIDUAL<br>Community structure, composition and regenerative capacity intact with no significant perturbation from land management practices. | Type 2: MODIFIED<br>Community structure, composition and regenerative capacity intact but perturbed by land management practices. | Type 3: TRANSFORMED<br>Community structure, composition and regenerative capacity significantly altered by land management practices. | Type 4: REPLACED ADVENTIVE<br>Native vegetation replaced by species alien to the locality and spontaneous in occurrence | Type 5: REPLACED MANAGED<br>Native vegetation replaced with cultivated vegetation | Type 6: REMOVED<br>Native vegetation removed |
| Diagnostic criteria | Regenerative capacity | Unmodified – ephemerals and lower plants | Unmodified | Enduring under past and / or current land management practices | Limited and at risk. Rehabilitation possible with changes to land management | Suppressed by ongoing disturbance with limited potential for restoration | Lost or suppressed by intensive land management with limited potential for restoration | Nil or minimal |
| | Vegetative structure | Nil or minimal | Very high | Altered but intact e.g. a stratum, growth form or age class is missing in places | Dominant structuring species significantly altered e.g. strata removed | Dominant structuring species removed or extremely degraded | Dominant structuring species removed | Vegetation absent or ornamental |
| | Vegetative composition | Nil or minimal | Very high | Altered but intact e.g. particular taxa reduced in abundance | Species dominance relationships significantly altered | All dominant species removed. | All dominant species removed. | Vegetation absent or ornamental |
| Examples | | Bare mud, rock, river and beach sand, salt and freshwater lakes | Old growth forest, with a natural fire regime native grasslands that are not grazed | Vegetation under sustainable grazing systems, forests with altered fire regime | Heavily grazed grassland, weedy native remnants, degraded road reserves | Isolated native tress within severely weed infested area | Improved pastures with isolated trees, plantations, tree cropping | Urban and industrial landscapes, salt scalded areas |

### Monitoring the impacts of threatening processes

Some studies may opt to avoid the difficulty of defining condition by recording the impacts of threatening processes instead. This is an easier approach, as it requires less knowledge of the vegetation being assessed. The assessor records, usually qualitatively, the extent and severity of disturbance caused by events such as: waterlogging and salinisation, erosion, drainage, groundwater abstraction, weeds, feral animals, stock, problem native animals, disease, fire, drought, flood, storm damage, spray drift, recreational usage of the site, consumptive and productive uses of the site, mines and illegal activities. Monitoring then consists of regular re-assessment of the extent and severity of these impacts. Establishing photo points might assist in this. A proforma for recording the impacts of threatening processes is provided in the 'Data analysis' section of this topic.

**Macroinvertebrate:** invertebrate taxa that, when fully grown, are visible with the naked eye. It usually includes all of the insects, worms, molluscs, water mites and larger crustacea such as shrimps and crayfish

**Microinvertebrate:** invertebrate taxa that are too small to see with the naked eye, also referred to as plankton, specifically ostracods, copepods, cladocerans, rotifers and protozoans

## Algae

Algae is an important component of wetland ecosystems, and so, a valuable indicator of wetland condition. Although some algae is required as a food source for wetland fauna, excessive algal biomass is detrimental to wetland function. Such 'blooms' occur as a result of artificial nutrient inputs. Blooms can reduce light penetration of the water column, be toxic to fauna and, when they break down, dramatically reduce the dissolved oxygen content of the water column. All of these effects are detrimental to the ecosystem.

The biomass of algae in the water column is commonly determined by recording the chlorophyll a concentration in the water. More information on this can be found in the section 'Collecting and analysing a sample for chlorophyll a' of this topic titled. Identifying the species of algae present may require the assistance of an experienced algologist.

➤ A user-friendly guide to the algae and aquatic plants found in WA water bodies is provided in *Scum book: a guide to common algae and aquatic plants in wetlands and estuaries of south western Australia.*[29]

## Aquatic invertebrates

Aquatic invertebrates are a popular target for wetland monitoring programs because they are found in almost all wetlands, are sedentary for at least part of their lifecycle and are relatively easy to survey. Also, they can be an effective indicator of environmental conditions because many invertebrate taxa have quite specific ecological requirements.

A survey of aquatic invertebrates has three stages: collecting a sample, picking specimens and identifying specimens. The first two stages can be undertaken by inexperienced workers with some basic training. The identification of specimens, however, requires considerable expertise. Lay-people can roughly group specimens to broad morphological types, which may suffice for some purposes. More rigorous monitoring programs, however, will require at least family level identification. This will not usually be achievable without expert assistance.

### Collecting a sample of the aquatic invertebrate community

A sample of the aquatic invertebrate community is collected from a wetland by sweeping a mesh net through the water column. A monitoring program may choose to collect only **macroinvertebrates**, but more rigorous programs will also collect **microinvertebrates**.

A sample is collected using a D—frame pondnet constructed with 250 micron mesh for macroinvertebrates or 50 micron mesh for microinvertebrates. Figure 11 shows the recommended dimensions for a net. The net should be checked for holes prior to each survey. It should be washed thoroughly after surveying each habitat to remove any animals remaining from the previous location and to avoid potential transfer of contaminants between locations.

**Figure 11**. D-framed pondnet. The net opening is approximately 35 cm wide and 25 cm deep. The attached net is approximately 75 cm long.
Photo - A Nowicki/DEC.

**Habitat type:** 'habitat' is a species specific term, with every taxon having its own environmental requirements. 'Habitat type' is used here to refer to areas where environmental conditions are appreciably different from their surroundings. These differences increase the likelihood that the area may support a distinctive flora or fauna assemblage

### Timing of sample collection

Most wetlands experience constant change in the composition of the aquatic invertebrate community. This means the suite of species collected will be influenced by the timing of the survey in relation to the season and water regime of the site. The best time to survey aquatic invertebrates will usually be several weeks after the main wet period at the study site. This allows time for flood flows to recede, habitat conditions to stabilise and invertebrate communities to mature after hatching or colonizing. In wetlands that have strongly seasonal water regimes, conditions usually become less conducive to invertebrates as the wetland dries.

Surveying too soon after a wetland fills will increase the likelihood of collecting immature specimens that will lack identifying features. It may also mean that taxa that have not yet hatched in response to the change in conditions are not collected. Surveying too far into the site's drying phase will mean that little water is present and habitat availability is reduced. Water quality is also usually poorer during the drying phase of a wetland, due to the concentration of nutrients and salts in the remaining water. These factors are likely to reduce the richness and diversity of invertebrates present as the wetland dries. There is also a risk that taxa that develop into aerial forms will have left the wetland.

In the south-west of Western Australia, mid spring (around October) is normally the best time for an aquatic invertebrate survey, although this depends on the timing of rainfall. In the Pilbara and Kimberley, the seasonality of surveys is less important than the water regime of the site. Surveys may be timed to coincide with consistent water levels rather than the being conducted at the same time each year. Surveying weeks to months after summer rainfall is ideal. In arid regions, sampling is usually opportunistic, ideally within two to three weeks of rain. If a site is not inundated during the life of a monitoring program, it may be necessary to collect sediments and incubate invertebrates in the laboratory (see 'Collecting a sample of invertebrates from a dry wetland' later in this section for more information). This will usually only capture a small proportion of the species that are present when the site is inundated.

### Selecting sampling points

A survey of aquatic invertebrates should collect samples from all potential habitats at the survey location. If this is not possible, a monitoring program should, at a minimum, collect a sample from the same **habitat type** in each survey event.

Some aquatic invertebrates will be present in the water column, but many seek shelter within the sediments, or on and under plants, rocks, leaf litter, logs, sticks and any other materials that are in the water. These materials must be agitated and moved in order to flush invertebrates into the water, where they can be collected in a net. The diversity of available habitat is usually greater near the edge of the water body and the greatest sampling effort will probably be required there.

### Sampling method

To collect a sample of macroinvertebrates the surveyor should move through the area being sampled, disturbing the substrate with their feet or the net. Care should be taken not to agitate the substrate too violently, as doing so may crush animals. Also, if using the net to disturb the substrate, do not allow the net to fill with sediment and organic material. After allowing a few seconds for the larger sediments to settle, the net is swept vigorously through the water column. This will capture invertebrates that were disturbed from the substrate, as well as those that were in the water column.

The net should also be swept through any plants that are present, and large plants agitated to shake invertebrates loose. Large rocks and twigs should be washed in the net to dislodge animals from them. In flowing water, rocks should be disturbed upstream of the surveyor to dislodge animals.

If the net becomes too full of litter and sediment, it will be difficult to handle. In this event, empty the contents of the net into a bucket and resume sampling. The two subsamples are combined at the conclusion of all the required sweeps. As a general rule, the net should not be allowed to become more than one third full.

If using a 50 micron net, aim to collect a very clean sample by sweeping only through open water and very gently against some of the submerged plants. Do not agitate the sediment as this will cause suspended material to clog the net. If both net sizes are to be used, sample with the fine mesh net before agitating the environment and collecting a sample with the coarser mesh net.

Samples should be collected over the same distance in every survey of the monitoring program. A sample collected over 50 metres of variable habitat (not necessarily contiguously) should capture approximately 60 to 75 per cent of taxa at a site. Sampling over this distance is excessive for single habitat sampling, where a sample taken over 10 to 20 metres will suffice (Halse, et al. 2000 and Pinder et al. unpublished data)

In some circumstances, it may be desirable to separate the fauna of each habitat type. If this is the case, a sweep should be conducted of the water column prior to disturbing the substrate, another after the substrate is agitated and individual sweeps conducted through any other habitat types that are present, such as vegetated areas. The net should be emptied and washed after each sweep and each sample stored separately.

## Sorting invertebrate specimens from the sample

In most instances, too many invertebrates will be collected for it to be practical to identify all individuals. A sub-set of the sample is identified instead. The term 'sorting' refers to picking individual organisms from the sample to form a sub-sample. Sorting may be undertaken in the field, immediately after sampling, or the sample may be returned to the laboratory for sorting.

Laboratory sorting should be undertaken when accurate determination of species diversity is required, such as when conducting a biodiversity audit. The time required for laboratory work is dependant on the nature of the sample and the skill of the taxonomist, but is usually greater than that required for field sorting.

Sorting in the field will save time but accurate identification of specimens will be more difficult and some taxa may be overlooked altogether. If applied consistently, field sorting can be used to compare relative diversity across sites and over time. However, it is an imprecise method and is not suitable for a detailed audit of biodiversity. Field sorting is only appropriate for macroinvertebrate taxa, as a microscope will be required to see microinvertebrates.

The sorter should always be familiar with the taxa that might be expected to occur in the wetland before beginning sorting. This will help them to 'get their eye in' as well as alerting them to remain vigilant for cryptic taxa.

➤ Information about the invertebrates found in wetlands of south west WA can be found in *A guide to wetland invertebrates of south west WA.*[30] This includes taxonomic keys that will aid in specimen identification.

### Sorting in the field

Field sorting is the rapid selection of a subsample of invertebrates at the conclusion of sampling at a survey location. The subsample might also be identified in the field, but is often returned to the laboratory for more detailed study. Samples collected with a 50 micron plankton net cannot be identified in the field as it will include microscopic zooplankton.

**Box-subsampler:** watertight box that is divided into a number of cells. A box-subsampler is used when sorting aquatic invertebrates to eliminate observer bias. Dividing the sample into a number of cells which are sorted individually, and in their entirety, reduces the likelihood of preferential selection of larger or more conspicuous taxa

Begin by emptying the sample from the net into a large bucket that contains several litres of water. Swirl the bucket to dislodge invertebrates that are clinging to detritus and decant the sample back through the net into a second bucket. Aim to leave heavy inorganic matter in the original bucket while the lighter organic matter is caught in the net. Check the inorganic matter for heavy animals such as molluscs, or small animals that may be clinging to rocks, then discard it. Repeat this process until all conspicuous inorganic matter has been removed from the sample.

Empty the organic matter from the net into a bucket containing clean water. Wash any vegetation, leaf litter or sticks in the water, check for animals that are within, or on, it and then discard. Be particularly alert for any pieces of detritus that move in the water, as they may contain caddisflies. What remains should be a bucket of relatively clean water, containing the aquatic invertebrate sample.

Separate the sample into three size fractions by pouring the contents of the bucket through a 2 millimetres and then a 250 micron sieve, catching in another bucket the material that passes through the finest sieve. The three fractions are sorted separately because it is easier to look for animals within a limited size range. If a sieve size contains very little material, the whole fraction can be placed into the sorting tray without subsampling. Otherwise, separate the sieves and place the contents of one into a box-subsampler.

Figure 12. A box subsampler, shown with the lid removed. This one is constructed from perspex and measures 355 by 355 by 160 millimetres high. It contains 8 by 8 compartments, each 40 by 40 millimetres.[31]

Securely close the subsampler before agitating and rotating it. Transfer the contents of one randomly selected cell into a white sorting tray using a hand vacuum pump and conical flask.

An alternative randomised subsampling method is to stir each sieve size in a bucket of clean water and remove subsamples using a cup. This is especially useful if the available water is limited and the box-subsampler cannot be washed between samples.

Remove animals from the sorting tray using a pipette and/or tweezers and preserve in a small vial of 100 per cent ethanol (this assumes that identification will be performed in the laboratory). Start by picking out common, abundant taxa while avoiding a bias toward large or highly conspicuous taxa. The most effort, however, should be directed at finding less common and inconspicuous taxa. Particular care should be taken to search for the groups that are easily missed when sorting such as larvae, Oligochaeta, Empididae, Hydroptilidae, and Ceratopogonidae. A sample will normally contain many species that look superficially similar. Look for different sizes, colours and movement patterns (swimming, crawling, squirming etc.) to separate superficially similar taxa.

Count the number of animals removed using a hand-held counter. The rule of diminishing returns applies to sample sorting: as the number of individuals picked increases, the likelihood of finding new taxa decreases. A subsample of 200 individuals has been shown to adequately represent family richness and diversity in most wetlands.[32]

Approximately 50 of the 200 individuals should come from the largest fraction, 100 from the medium fraction and 50 from the fine fraction. If insufficient individuals have been found after the finest sieve size has been picked, return to the coarsest sieve size and start again. In some cases, a second sample may be required to obtain the 200 animals.

In order to maintain consistency, it is essential that the same number of individuals are picked at each site, although the proportion taken from each sieve size may vary according to site characteristics.

Some texts recommend that sorting continues for a set period of time, rather than until a certain number of individuals are subsampled. This 'fixed time' approach is highly susceptible to inter-operator errors as more experienced workers will tend to find many more individuals within the time limit. Other variables, such as light conditions and water colour can also affect results. For these reasons, the fixed time approach is not recommended.

### Sorting in the laboratory

Laboratory sorting and specimen identification requires considerable expertise and should be only be undertaken by suitable experienced workers. If it is to be undertaken, wash and sieve the sample as per the field sorting method then preserve it in 100 per cent ethanol for transportation to the laboratory.

In the laboratory, the sample will be examined under a dissecting microscope with 10–50x magnification. Animals are picked out, placed into groups and identified using a taxonomic key and comparison to reference material.

## Collecting a sample of invertebrates from a dry wetland

Most wetlands in arid and semi-arid areas of Western Australia only contain free water intermittently. This can make it difficult to survey these sites during their wet phase. An alternative approach is to collect dry sediments, containing resting eggs of invertebrates from the bed of the wetland, incubate them in the laboratory and identify the taxa upon maturation. Although this approach will provide some indication of the diversity of invertebrates that occupy the site, it will never allow determination of the full suite of invertebrate taxa.

Begin by marking a series of 1 metre by 1 metre quadrats across the floor of the dry wetland, from which surface sediments will be collected. The distribution of quadrats should be such that they capture the diversity of habitat types that would be present when the wetland is inundated and as it dries. A greater density of quadrats may be required near the maximum extent of inundation as eggs will tend to be concentrated there by wind and wave action. Taxa dependant on fresh water conditions will deposit eggs near the high water mark, when the system is fresh after filling. Species tolerant of more saline conditions will usually deposit eggs nearer the centre of the wetland, as the water recedes and becomes more saline through evapoconcentration.

Eggs are collected by using a piece of PVC pipe, split lengthways, to scrape and gather the upper layer of sediment from the quadrat. Approximately 3 centimetres of the sediment profile should be collected, although this may prove difficult if the substrate is very hard. A total of approximately one kilogram of sediment should be collected and stored in a calico bag (B Timms 2009, pers. comm.).

In the laboratory, oven dry the sediment sample for 2–3 days at 50 degrees celcius. After drying, mix the sample thoroughly to distribute eggs evenly through it. Spread a thin layer of sediment across the bottom of several rectangular plastic containers (takeaway food containers are ideal). To each container add 200 millilitres of deionised, distilled water or rain water. Tap water is not suitable as the chemicals in it will prevent eggs from hatching.

Place the containers where they will receive natural light from a north facing window. They can also be incubated in a growth cabinet that provides at least 8 hours of light per day. Ensure the containers receive constant air flow and are at room temperature.

If no hatching occurs after 14 days, dry the sediment, then rewet 4 weeks later. This wetting and drying cycle may need to be repeated several times before the eggs are induced to hatch. After hatching, allow at least two weeks for individuals to reach maturity, then proceed with sorting as per the laboratory sorting method.

**Identifying specimens**

The identification of aquatic invertebrates should be completed by a person with relevant expertise. The taxonomic level to which specimens are identified depends on the aims of the project and time and funds available. A substantial proportion of the state's aquatic invertebrate fauna is undescribed, so formal scientific names cannot always be applied.

## Fish

Fish are not present in all WA wetlands but, where they are, can be a good indicator of wetland condition. Fishes' survival depends on good quality water that is oxygenated and disease free; food, which has its own habitat requirements; shelter from currents and predators and, in some cases, shade. Finally, water regime is important to fish survival as particular types of flows are required for different lifecycle stages. If these factors are all adequate to support healthy populations of native fish, it is likely that the wetland ecosystem is not significantly degraded.

The methods available to survey fish populations are: electrofishing, netting and visual survey. All but the last of these carry some risk of harming the fish, require permits and must be undertaken in a manner consistent with animal ethics policies. Limited information is presented here about these methods, as it is not recommended that fish monitoring be undertaken without the assistance of a suitably qualified and experienced researcher.

> Fish should not be taken from a wetland without approval from the Department of Fisheries and the relevant animal ethics committee. Contact your local Fisheries office for more information.

### Electrofishing

Electrofishing is a technique in which an electric current is applied to the water. Fish, like many aquatic animals, will become motionless if their body exceeds a certain voltage. If the current is carefully controlled, this effect will be temporary. Fish will initially be involuntarily attracted to the electrode before going into a state of narcosis. The stunned fish can be collected and identified before being returned to the water to recover. Electrofishing is only effective in waters shallower than approximately 2.5 metres.

The voltages used when electrofishing are sufficient to cause serious injury or death to humans. As such, there are considerable health and safety risks for the operators. Under the *Australian Code of Electrofishing Practice*[33], electrofishing surveys must be supervised by an operator who has participated in at least twenty previous sessions, holds a current senior first aid certificate and has a current medical certificate stating freedom from major heart or respiratory complaint. All other team members must also hold a senior first aid certificate and current medical clearance.

The equipment required for electrofishing is highly specialised and not readily available to the public. It must be constructed for the purpose by a qualified electrical engineer. Electrofishing is only regularly undertaken by research organisations.

### Netting

Netting is safer for the survey team, but carries significant risks for the fish that are caught. There are three main types of net that are used to conduct surveys: fyke nets, seine nets and gill nets. Fyke nets are large hoop nets that act as funnels to trap swimming fish. They are often placed together in an array that captures all fish using a waterway. A seine net is a large fishing net that hangs vertically in the water due to weights attached along the bottom edge and floats along the top. Seine nets are used like long fences to encircle fish and are then drawn closed to complete the trap. Gillnets are long rectangular panels of netting. They are held vertically in the water column by floats and anchored by weights. Fish swim into the net but are unable to fit through the mesh. They are entangled by the gills, fins and spines and so are unable to back out of the net.

All three approaches to netting carry a risk of harming the trapped fish. As such, netting should not be conducted unless fish abundance is a critical consideration in a monitoring program. If fish are netted, they must be freed from the net as soon as possible, handled as little as possible and returned to the water as soon as possible after capture. Nets should be checked and emptied regularly to minimise impacts on caught fish.

### Visual survey

The most benign way to survey a fish population is by a visual assessment of the wetland. This can be achieved by using a glass bottomed boat or snorkelling or diving in the water body and counting fish numbers. This type of survey relies on good visibility in the target wetland.

A visual survey simply involves one or more people diving, snorkelling or traversing transects in a boat and recording the number and identity of any fish that are seen. Methods similar to those for bird surveys may be employed to ensure adequate coverage of the site and avoid double counting (see the section 'Waterbirds', later in this topic).

### Frogs

Frogs are often used as condition indicators at wetlands because of their sensitivity to changes in the local ecosystem. Also, because frogs are amphibious, their presence provides information about both the aquatic and terrestrial environments. Frogs are particularly good indicators of changes to water chemistry because their skin is semi-permeable and their eggs lack a protective shell. Both of these factors make them highly susceptible to pollutants in the water and to changes in water chemistry.

The easiest way to conduct a frog survey is to listen for calling frogs. Each species has a distinctive call, used by breeding males to attract females. The calls that are heard can, therefore, be used to identify the species of frog that are present at a site and the intensity of calls can be used to estimate of the size of the population.

Frog surveys are best conducted at night, as this is when frogs are most active. The first couple of hours after sunset is a particularly good time to hear frogs calling. Surveys must also be timed to coincide with the breeding season of the frogs at the study site and may need to be repeated as not all species of frog breed at the same time. In arid regions, frogs breed whenever water becomes available. In the south west of the state, many frogs breed in spring, when water is plentiful and the weather becomes warmer. A comprehensive frog audit, however, may require several surveys throughout the year to include the breeding season of all species that might be present.

When planning a frog survey, it will be necessary to determine what species are likely to be present at the site and what time of year they breed. Surveys are best done following rain, as calling activity is greatest in wet conditions.

➤ The website of the Frogs Australia Network frogsaustralia.net.au[34] is a valuable resource for anyone wishing to monitor frogs. The site includes lists of the species that are known to occur in various regions of Australia. It also provides a host of information about these taxa, including the breeding period of each and a recording of the breeding call.

➤ A CD of frog species calls is also available from the WA Museum, see their website for more information: frogwatch.museum.wa.gov.au.[35]

Frog surveys should not be conducted in windy conditions or when it is raining heavily as both of these conditions will affect the ability to hear frogs calling. A good rule of thumb is that a frog survey should not be attempted if the wind strength exceeds 3 on the Beaufort scale (Table 12) or if precipitation is heavier than a light drizzle. Background noise, such as passing traffic, can also reduce the effectiveness of a survey, but this is more difficult to avoid.

**Table 12.** The first five divisions of the Beaufort wind scale.

| Beaufort Wind Scale | Wind Speed (km/h) | Description | |
|---|---|---|---|
| 0 | <2 | Calm | smoke rises vertically |
| 1 | 2–5 | Light air | rising smoke drifts, weather vane inactive |
| 2 | 6–11 | Light breeze | leaves rustle, can feel wind on face |
| 3 | 12–19 | Gentle breeze | leaves and twigs in constant motion, small flags extend |
| 4 | 20–28 | Moderate breeze | small branches begin to move, dust and loose paper raised (too windy to monitor) |
| 5 | 29–38 | Fresh breeze | small trees begin to sway (far too windy to monitor) |

Begin a frog survey by becoming familiar with the calls of frogs that are expected to be present at the study site. This can be achieved by visiting the website of The Australian Frog Network.

Next, select the ‘observation’ locations that will be used in the survey. This is best done during daylight hours. A small wetland may be surveyed from a single location, while larger sites may require multiple observation locations.

The observation locations should be accessible without causing disturbance to vegetation or frog habitat. This is particularly important if monitoring is to extend over several nights or several seasons. If not managed carefully, the cumulative impact of surveys can cause degradation of the site. It may be appropriate to lay out a temporary elevated boardwalk if the vegetation or substrate is particularly fragile.

After nightfall, the surveyor should establish themselves at the observation point. It is important that the surveyor remains still and quiet throughout the observation period, as disturbance may discourage frogs from calling. On a data sheet, record the prevailing weather conditions, including air temperature and any recent rainfall. Also, record any other factors that may affect the results, such as background traffic noise. After spending several minutes quietly at the location, begin recording the identity of any frogs that are heard calling. Also record the intensity of calls (Table 13), as this is indicative of the size of the population. It may also be helpful to record frog calls on a portable tape recorder. This will allow them to be checked against reference material at a later time.

Continue identifying frog calls for a set period of time. The time over which calls are recorded must be the same at every observation point to ensure that data are comparable. Fifteen minutes of listening should be sufficient to hear all calling frogs at a location.[36] If disturbed, for example by an aeroplane passing overhead, begin the listening period again.

**Table 13.** Call intensity rating system used during frog surveys.

| Rating | Call Intensity Definition |
|---|---|
| 0 | No frogs can be heard calling. |
| 1 | Individual calls can be counted; there is space between calls. |
| 2 | Some calls are overlapping; but individuals are still distinguishable. |
| 3 | Chorus is constant, continuous and overlapping; impossible to count individuals. |
| 4 | A species was seen but not heard during the survey. |

If a more comprehensive census of frogs is required than what is achievable using the calling intensity scale, it is necessary to capture and mark each calling frog. This ensures that individuals are not double counted. A licence from the Department of Environment and Conservation is required if native fauna is to be caught. A catch and release survey should not be undertaken without instruction from that department.

An alternative survey method is to record the number of tadpoles that are present in the wetland. Tadpoles may be caught in the same manner as aquatic invertebrates (see the preceding section: Aquatic invertebrates) or in a tadpole trap. The advantage of surveying tadpoles is that they demonstrate that successful breeding has occurred. They do, however, require some expertise for species identification (A Storey 2009, pers. comm.)

## Waterbirds and shorebirds

**Waterbirds** and **shorebirds** are common targets for wetland monitoring programs because they are highly visible, they are relatively easy to survey and many people feel an affinity for them.

There is also a school of thought that birds can be used as indicator species because their position near the top of the food chain means that impacts on taxa lower in the food chain will be reflected in bird populations.

The accuracy of birds as an indicator of condition at wetlands, however, is subject to a number of limitations. Firstly, birds' mobility means there is often a large degree of variability in species occurrence and population sizes at individual sites. The movements of birds are influenced by climatic conditions, seasonality, diurnal cycles and population size is also subject to natural fluctuations in breeding success. Populations of migratory birds may also be affected by factors far removed from the wetland being monitored. Finally, birds may be slow to respond to deterioration in environmental conditions. For example, the collapse of a bird population due to a shortage of their aquatic invertebrate food source may not occur until some time after the environmental change that triggered the shortage. A further time lag will then occur before the change in bird numbers can be confirmed. These limitations aside, birds are an important component of wetland ecosystems and their abundance and diversity is likely to be of interest when monitoring a site.

There are two main methods for conducting a bird count; aerial survey and ground survey. Aerial surveys, undertaken from light aircraft, are usually required at very large or isolated sites. The techniques for aerial bird counts are not covered in this topic as they are highly specialised and will require expert assistance.

**Waterbirds:** birds that have specialised beaks and feet that allow them to swim, dive and feed in water. Examples include egrets, crakes, herons, ducks, swans and grebes

**Shorebirds:** those birds commonly found wading near the shores of wetlands, beaches, mudflats and lagoons in search of food. They include plovers, sandpipers, stone-curlews, snipes, pratincoles, oystercatchers, stilts and avocets

A ground survey is an inexpensive, non-intrusive and relatively easy alternative. It involves observing a wetland over a period of time and recording any birds that are present at the site. Ground survey is the most appropriate method for conducting counts at small wetlands and is required to detect cryptic species and to count shorebirds.

extra information

## Shorebirds 2020

Shorebirds 2020 is a program designed to reinvigorate and coordinate national shorebird monitoring in Australia. It is a collaborative enterprise between Birds Australia, The Australasian Wader Studies Group, the WWF-Australia and the Australian Government's Natural Heritage Trust.

The primary objective of the program is to collect data on long and short-term trends in shorebird populations, and to explore what may be causing any changes. The project also seeks to understand the effect of habitat quality and threats on the distribution and abundance of shorebirds.

Shorebirds 2020 maintains a website that contains many resources to assist with conducting bird counts. These include data sheets that may be used in the field and information about shorebird conservation. The website address is www.shorebirds.org.au.[37]

## Observation point

The observation point, from which the count will be conducted, should be situated where the observer can see the entire wetland. If this is not possible, the wetland should be divided into sectors and counters situated at an observation point in each sector, such that the entire wetland is covered. The delineation of sectors will be determined by the topography of the site, the number of counters available, considerations of access and safety and the number of birds present. All sectors should be counted concurrently, with observers recording the birds within their assigned sector only. Observers should identify any flocks that enter, leave or pass over the sector and the time at which this occurs. This will prevent mobile birds being counted in multiple sectors. On the data sheet, record if the site was divided into sectors and, if so, how this was done. It is important that surveys are standardised, with the same area of the wetland being counted on each occasion.

## Number of observers

A minimum of two observers at each observation point is recommended, in order for species identification and flock counts to be confirmed. The number of observers involved in the count, and the experience of each, should be recorded on the data sheet, to allow future users of the data to evaluate its probable accuracy.

### Seasonality of survey

A survey during summer is essential for recording migratory birds, as these species usually spend October to March in Australia. In the south of the state, January and early February is the ideal time to conduct surveys for migratory birds. In northern Australia, surveys should be conducted before the beginning of the wet season. After this, migratory birds are likely to disperse in response to rainfall and access to sites will become difficult. Resident waterbirds are ideally surveyed in late spring in the southern part of the state. In the north of the state, resident birds concentrate at water sources during the dry season, providing the best opportunity for counting their numbers.

It may be necessary to conduct several surveys over the course of the year to develop a comprehensive species list. Although the spring / summer surveys described above are required as a minimum, additional surveys throughout the year will provide more comprehensive data. The size and composition of the bird population at a site will vary throughout the year in response to many external variables. Any additional surveys through the year will help provide information about these natural variations.

On the field data sheet, record the date on which the count was conducted, as well as the water regime of the wetland at that time. If possible, record the actual depth or extent of inundation, or if this is not known, use a general description, such as 'filling' or 'full'.

## Time of survey

Bird surveys are best conducted in the morning as a heat haze that may occur later in the day will affect visibility. If possible, conduct counts with the sun behind the observer as this improves visibility by avoiding glare. In areas with a tidal influence, the ideal time for conducting bird surveys is at high tide. The inundation of the inter-tidal habitat zone tends to force birds to congregate along the shoreline, making them easier to observe.

If regional populations are being assessed, sites that are near to one another should be surveyed on the same day. This will minimise the opportunity for birds to move between sites, thereby avoiding duplicate counting. The time of day that the count was conducted should be recorded on the data sheet.

## Weather

Bird surveys should not be conducted during significant rainfall events or in windy conditions. These may cause birds to seek shelter or take flight, thus affecting the count. Rain may also affect visibility, obscuring birds from the sight of observers. Very hot days should also be avoided, as the heat haze that forms over water bodies can distort viewing and make counting and identification difficult. On the data sheet, record details of the weather on the day of the survey, including temperature, wind speed and wind direction.

## Counting techniques

The appropriate counting technique is determined by the size of the waterbird population at a site. Small populations may simply be tallied, while larger populations will require a component count to be undertaken.

### Total count

Small bird populations can be surveyed with a total count. The survey team should begin by quietly watching from the observation point and tallying the number of birds of each species that are seen. Once they are confident that the majority of birds have been sighted, they should walk the shoreline (or parts of the shoreline at larger wetlands) looking for small wader species. The number of birds of each species should be recorded on a datasheet, audio recorder or notebook.

Birds will fly and swim around the site during the survey, potentially confusing the count. It is important to remain aware of bird movements and avoid double counting individuals or flocks.

### Component count

Counting individual birds is impractical when very large flocks are encountered. A component count may be used to estimate and record the number of individuals in large flocks. Pairs of workers conducted the count, with one person acting as the observer and the other as the scribe.

The observer estimates bird numbers by grouping individuals into sets of approximately ten or 100 birds, depending on the size of the flock. The ability to do this accurately is crucial and will only be developed through practice. Some experience in counting birds is, therefore, essential for the observers in the component count team.

The scribe uses a form of shorthand annotation to record the data called out by the observer. A letter code is assigned to each flock of birds at the site and that letter precedes the number of individuals counted in the flock. For example, if flock A has 100 red-necked stints and flock B has fifty, the population of stints will be recorded as: A100 / B50. An X follows any count that was estimated or counted in multiples.

As with total counts, it is important to make note of any birds that move during the count. Birds that fly through a sector are annotated with an 'f' suffix and the time and direction of movement are recorded. If any disturbances cause birds to take flight during the count, a note of this should be made on the field data sheet. It may also be helpful to use abbreviations for species names. The complete list of shorthand annotation is provided in Table 14.

**Table 14.** Summary of standard shorthand annotation used in bird counts.

| Code | Position | Meaning |
|---|---|---|
| X | suffix | birds counted in multiples or estimated. |
| (f) | suffix | birds flying through sector but not landing ( include time of transit and direction of flight) |
| (b) | suffix | breeding |
| A, B, C etc. | prefix | flock identifier (note capitalisation to distinguish from codes for breeding etc.) |
| / | separator | separates flocks in a species tally. |

## An example of a component bird count:

The following is recorded on a field data sheet:

**Red-necked stint 11 / 35 / A444 X / 325 / B77 / 10**

**Bar-tailed godwit 40 / A 12,000 X / 781 (f) / B 848 / 7 / 39**

**Curlew sandpiper A 57 / 5 / 2 / 5,000 X / 99 / 878**

This shows that the site had:

- Approximately 902 red-necked separated into 6 flocks.
- Approximately 13 715 bar-tailed godwits separated into 6 flocks, one of which flew over the site.
- Approximately 6041 curlew sandpipers separated into 6 flocks.
- 444 red-necked stint, 12,000 bar-tailed godwit, and 57 curlew sandpiper in flock A and that the number of red-necked stint and bar-tailed godwits in that flock were estimated.
- 77 red-necked stint and 848 bar-tailed godwit in flock B.

### Finalising counts

The participation of multiple observers in a survey creates the potential for duplication in counts. All observers should, therefore, come together to collate their data at the conclusion of survey. Each observer will have recorded the time that flocks of birds entered or left their sector and the direction they came from, or departed to. This will allow a moving flock to be tracked, and any duplicate counts of it to be discounted from consideration.

# Data analysis

Measuring indicators in a series of surveys will not provide an answer to the monitoring hypothesis, unless the collected data are analysed appropriately. Data analysis is the process of extracting information from the data collected in the field in order to address the monitoring hypothesis.

The data, information, knowledge, wisdom pyramid is an anecdote that is commonly used to explain the progression from data collection to understanding an ecosystem (Figure 13). The pyramid has a broad base of *data*; unorganized and unprocessed facts that, in this case, have been collected about a wetland by a monitoring program. Those data are aggregated and analysed to provide a lesser quantity of information, which means it is now useful to the decision making process. In the current context, this will mean that it indicates to the land manager whether the land management regime is having the desired effect on the health of the wetland ecosystem. Once the land manager has complete information, they may claim to have *knowledge* of the system, meaning understanding of a subject matter that has been acquired through proper study and experience. The pyramid anecdote shows that a large quantity of information is required to develop a relatively small store of knowledge. Finally, if this knowledge leads to good decisions about land management practices, the land manager may claim *wisdom*. Climbing the steps of the pyramid will require that data are well collected, stored, analysed and reported on.

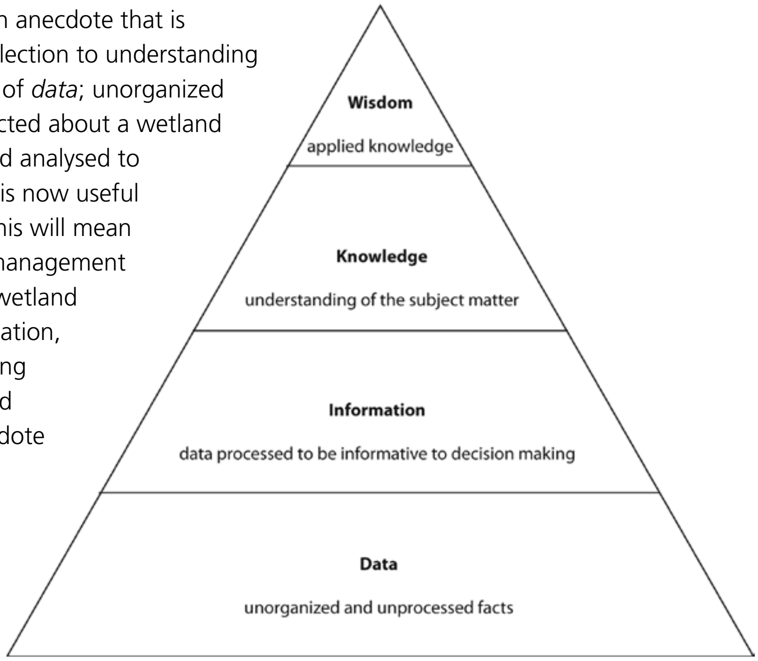


**Figure 13.** The data, information, knowledge, wisdom pyramid.

## Data collection

The use of a standard template is essential to collecting good data. A template, such as a field data sheet, acts as a checklist of the parameters to be measured and assists in the standardisation of units and methods.

An example of a data recording sheet is provided in Appendix A. It was developed by the Department of Environment and Conservation's Inland Aquatic Integrity Resource Condition Monitoring project. A monitoring program will need to develop its own field data sheets with spaces to record all of the required parameters. The provided example may be tailored to suit the requirements of a monitoring program.

The provided data sheet is divided into four sections. The first section is for recording general information about the monitoring site and survey locations. This includes a map of the site showing where any survey locations and monitoring points are situated and how to access them; site scale notes on the hydrology, geomorphology and vegetation of the system; the number of photos that were taken and any other general information that helps to provide context. The second section of the data sheet is used for recording water chemistry readings, waterbird counts and information about the aquatic invertebrate survey. The third section relates specifically to the vegetation of the survey locations.

It provides space to record the data required to develop an NVIS community description and also some more qualitative fields. The final section of the sheet is used for recording the nature and magnitude of, and area affected by, various threatening processes.

## Data storage

It is important to retain raw data, as well as any intermediate datasets produced during the process of analysis and reporting. Doing so will allow the source of any errors to be identified. Retaining raw data also allows reanalysis of the dataset if new information about a site comes to light. Hard copies of the field data sheets should, therefore, be filed for future reference.

Usually, data sheets will also be entered into an electronic database. Data entry is a common source of errors and the entered data should be checked by a second person to ensure it accurately reflects the field sheets.

The database should be stored in a place and format where it will remain safe, accessible and understandable for future users. It should be accompanied by metadata that explains how the database was created, by whom and when. Metadata should also provide an explanation of all headings or classes that are used in the database.

## Analysis of data

Having collected good data, the next step is to use them to test the monitoring hypothesis. The way this is achieved will depend on the nature of the monitoring program and the type of data collected. Probably the most readily applied technique is data visualisation, which can be used to display trends in the measurements taken at a site. This is a basic form of statistical analysis, but can be quite powerful if it is used appropriately and its limitations respected.

More sophisticated monitoring programs may employ statistical tests to show that a significant change has, or has not, occurred in the system and to allow cause and effect relationships to be explored. If the demonstration of statistically significant cause and effect is required, it is advisable to seek the advice of a statistician before developing a monitoring program. A statistician will be able to assist in the program design to ensure that sufficient and suitable data are collected during surveys.

### Summary statistics

There are several statistical measures that are commonly used to provide a summary of a dataset (summary statistics). These measures aim to express the central tendency and variability of the data. In biological monitoring programs, the most useful measure of central tendency is usually the mean, but median and mode measurements may also be used in some circumstances. Measures of variability include the range of values obtained, the standard deviation of the dataset and the percentile distribution (Table 15).

**Table 15.** Overview of statistical summary techniques.

| Summary Statistic | Definition | Calculation Method |
|---|---|---|
| Mean | Representative of the values being summarised due to being intermediate between the extremes of the dataset. | Divide the sum of the values by the number of values.<br>$\mu = \sum xi / N$<br>μ is the mean<br>xI is each of the values in the set<br>N is the population size |
| Median | The value for which one-half (50%) of the observations (when ranked) will lie above that value and one-half will lie below that value. | List all values in ascending order and select the middle point of the list. If the dataset has an even number of values, sum the two middle values and divide by 2. |
| Mode | The most commonly occurring value in a dataset. | Count the frequency with which each value occurs in the dataset. |
| Range | The difference between the maximum and minimum value in a dataset. | Subtract the smallest value from the largest value in the dataset. |
| Standard deviation | A measure of how closely the values in a dataset are clustered around the mean. | $= [\sum (x_i - \mu)^2 / N]^{1/2}$<br>where<br>is the standard deviation<br>xI is each of the values in the set<br>μ is the population mean.<br>N is the population size. |
| Standard error | A measure of how close the sample mean is likely to be to the population mean. | $s = ( / N)^{0.5}$<br>where<br>s is the standard error<br>is the standard deviation<br>n is the sample size |
| Percentile | The value below which a given percentage of the data values lie. The pth percentile is the value in the dataset which p% of values is less than. The 25th, 50th and 75th percentile are called quartiles. The 50th percentile is the median. | List all values in ascending order and select the value that is ranked p% of the way through the list. |

## Data visualisation

Data visualisation is the technique of summarising a dataset graphically. It is an approach with limited statistical power, but it is a highly effective way to communicate results. Some of the most commonly used methods are bar graphs, line graphs, box and whisker plots and scatter plots. All of these can be easily prepared with a spreadsheet application such as Microsoft Excel.

When creating a graph, remember that the primary purpose is to assist the reader to understand the dataset. To achieve this, the graph must be clear – do not try to convey too much information on a single chart. To avoid skewing data, graph axes must be scaled and labelled appropriately, including a statement of the unit of measurement that has been used. Using inappropriate units or scale can dramatically change the readers interpretation of the data that are presented. A legend may also be important, in order to differentiate between classes or attributes. Finally, a graph must have a caption that explains what information is being presented and any analyses that have been undertaken prior to graphing the data. If the graph shows error bars (see the following subsection), the caption must state whether a standard error or a standard deviation is shown. A good caption should allow a reader to understand the figure without referring to the main body of the report.

### Error bars

It is always a good idea to add error bars to graphs, as these allow the reader to judge the reliability of the data displayed. Large error bars indicate that the data have a high degree of variability, while small error bars show that the data are tightly clustered around the mean.

Excel provides several options for the type of error bar to be displayed. Two of these are most useful for monitoring applications, an error bar of:

- a set number of standard deviations or
- one standard error.

Standard deviation error bars should be used if the graph is intended to show the extent to which individual measurements deviate from the population mean. For example, when determining if a management action has caused an indicator to move away from its long term mean value. If the error bar overlaps the data point, any perceived difference between the value and the mean may be due to chance. If the error bar and the data bar do not overlap, there is a likelihood that the measurement is truly different from the population mean. Using an error bar that is two standard deviations in length will provide 95% confidence that non-overlapping bars represent truly different values.

An error bar of one standard error should be used when a graph is comparing the means of two samples or sites. This is the case when determining, for example, if two wetlands have different salinity levels. In this example, it will be necessary to measure salinity at the two sites on a number of occasions. These measurements can then be graphed in pairs, according to the day they were taken and a standard error bar for each wetland added (Figure 15). If the error bars for the two sites overlap, it is likely that no statistically significant difference exists between the two measures on that day. Non-overlapping error bars, such as in the provided example, do not guarantee that the difference is statistically significant, but do make it much more likely.

### Bar graphs

A bar graph is a simple, two dimensional chart that shows the magnitude of a measurement, or the frequency with which it was recorded as a bar or column (Figure 14). It allows a rapid comparison between sites or between survey events. Usually, bar graphs will only be used when there are a small number of measures to be displayed, as displaying too much information will make the chart messy and difficult to interpret.

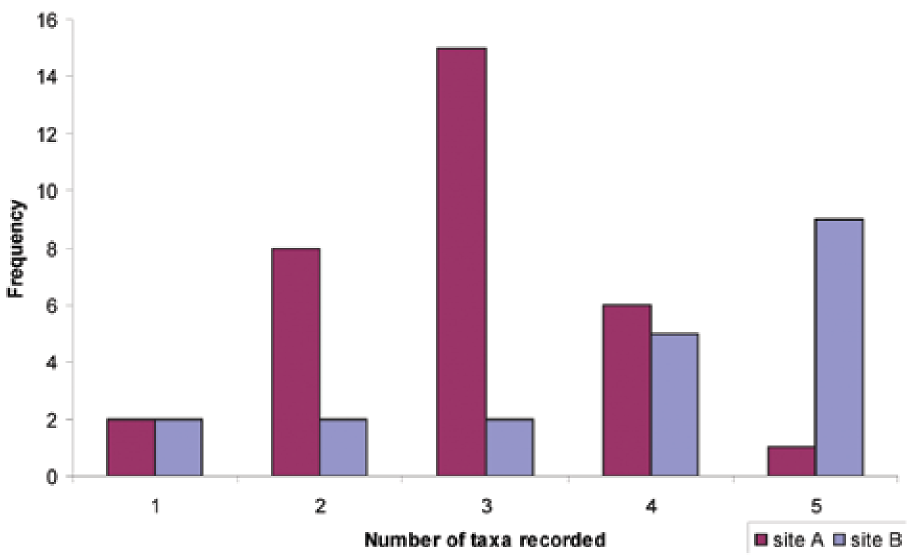


**Figure 14.** An example of a bar graph showing the frequency with which a given number of taxa were collected at two different sites in a long term monitoring program.

### Line graphs

Line graphs are commonly used to show time series data. They are similar to a bar graph, except that the measurement value is displayed as a point and adjacent points are connected. Figure 15 shows the water salinity measured at two sites over four days, presented as a line graph.

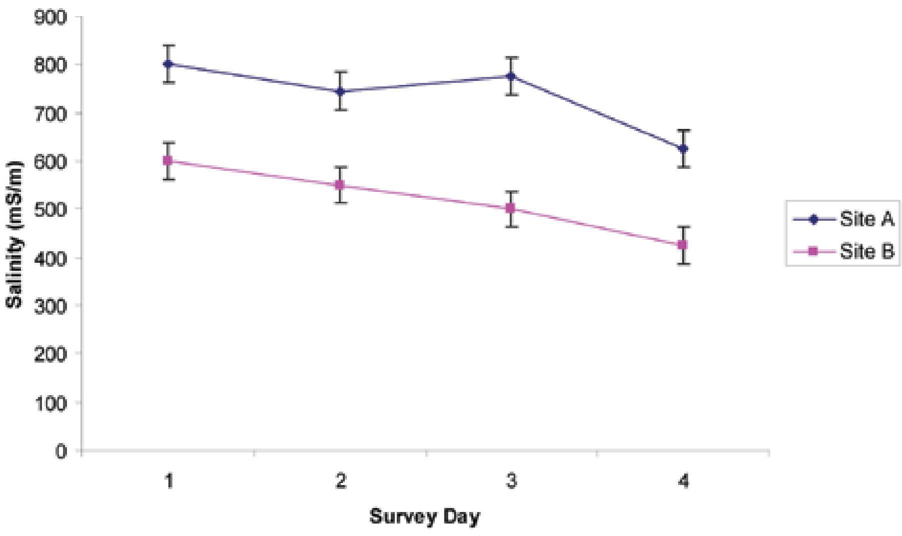


**Figure 15.** A line graph showing changes in salinity over four survey days at a hypothetical wetlands. Standard error bars are shown for each data point.

### Scatter plots

A scatter plot is used when looking for a relationship between two variables. It allows a lot of data to be displayed and trends to be readily identified. Figure 16 is an example of a scatter plot in which the salinity of a hypothetical wetland has been plotted against the total rainfall for the month. A table showing all of these data would be large and difficult to interpret, but a scatter plot allows the reader to see a strong trend. Trends may be further highlighted by adding a trend line. Error bars may also be added to the data points to illustrate the variability of the data, although this is already indicated by the distribution of dots.

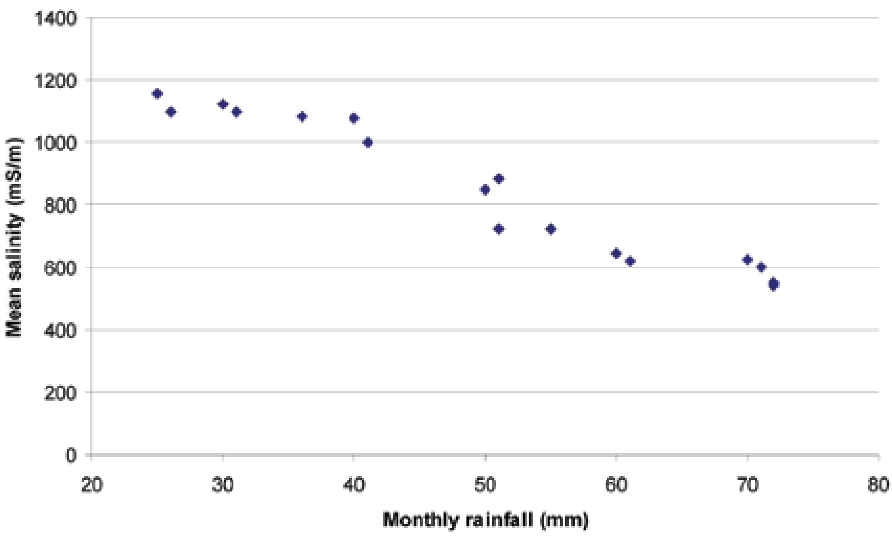


**Figure 16.** A scatter plot showing the relationship between rainfall and salinity in a hypothetical wetland.

### Box and whisker plot

A box and whisker plot is a good way to graphically display the most important summary statistics. The 'box' is bounded by the 25th percentile and the 75th percentile with a horizontal line through it at the median. The 'whiskers' extend from either end of the box to the last data point that is within 1.5x the interquartile range (Figure 17).

**Interquartile range:** the distance between the 25th and 75th percentile

Values greater than the whiskers (outliers) may be plotted to show the full range of variability in the dataset. Sometimes, a format is used whereby the whiskers extend to the maximum and minimum values in the dataset.

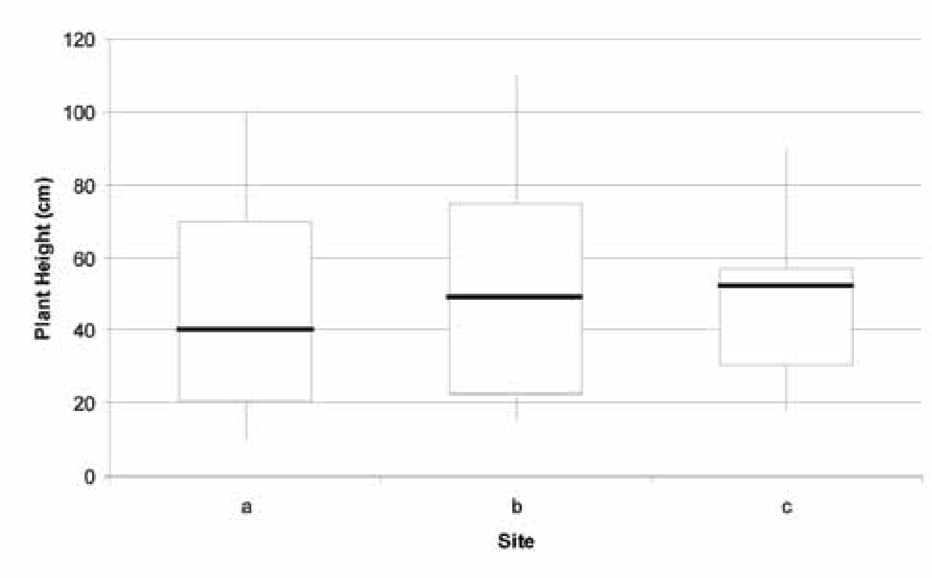


**Figure 17.** An example of a box and whisker plot. In this example, the height of all plants in three different quadrats have been measured. The 25th and 75th percentile heights are denoted by the ends of the box, while the heavy mark within the box is the median height. The whiskers extend to the last data point that is within a height of 1.5x the interquartile range.

Box and whisker is not a standard chart type in Microsoft Excel, but it is possible to construct them by modifying a stock chart. See support.microsoft.com for details.[38]

## Statistical analysis

The objective of undertaking a statistical analysis of a dataset is to determine if a trend, or an observed difference, is statistically significant. In a monitoring context this means determining if any observed difference between the treatment and control site occurred by chance, or because those sites really are different. If a monitoring program is required to demonstrate statistical significance, it is recommended that a statistician be consulted before commencing the design of the program. Tests of statistical significance are beyond the scope the current document.

# Appendix A: Example field data sheet

**Section 1a: Site Information**

| | | | | | |
|---|---|---|---|---|---|
| Project: | | | | Assessor name: | |
| Site name: | | | | Site code: | Date: |
| Hydro regime at time of survey (circle): | Filling / Full | Drying / Dry | Recent rainfall: | Photographs (number, location, facing): | |
| Location and access description: | | | | Site map: | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| Site description (wetland type, size, habitats sampled etc.): | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| Site scale notes on vegetation, fauna, condition, land use etc.: | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

**Section 1b: Monitoring Location Information**

| Code or name | Zone | Easting | Northing | Reason for Location |
|---|---|---|---|---|
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

Notes on monitoring locations:

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## Section 2a: Water Chemistry and Aquatic Invertebrates

| Site name or code: | | | | Assessor name: | |
|---|---|---|---|---|---|
| Location name: | | | | Location code: | Time: |
| Sample checklist (record #): | | | | Habitats sampled for invertebrates: | Description |
| 125 mL filtered water | | Chlorophyll | | | |
| 125 mL unfiltered water | | Volume filtered | | | |
| 250 mL unfiltered water | | # filter papers | | | |
| 500 mL unfiltered water | | | | | |
| Substrate samples | | | | | |

| Water property measured | Habitats sampled | | | | Notes on measures |
|---|---|---|---|---|---|
| | | | | | |
| Conductivity below surface | | | | | |
| Conductivity above sediment | | | | | |
| pH below surface | | | | | |
| pH above sediment | | | | | |
| Temperature below surface | | | | | |
| Temperature above sediment | | | | | |
| Turbidity below surface | | | | | |
| Turbidity above sediment | | | | | |
| Maximum flow | | | | | |
| Minimum flow | | | | | |

## Section 2b: Waterbirds

| Species | Count | Notes | Time: |
|---|---|---|---|
| | | | Observer names: |
| | | | |
| | | | |
| | | | |
| | | | Area surveyed: |
| | | | |
| | | | Weather obs: |
| | | | |
| | | | |
| | | | Method used: |
| | | | |
| | | | Page ____ / ____ |

## Section 3a: Vegetation Monitoring Location

| | | |
|---|---|---|
| Site name or code: | Assessor name: | |
| Location name: | Location code: | Date: |

| Transect or quadrat location | | | Substrate composition | | | | | | Soil % |
|---|---|---|---|---|---|---|---|---|---|
| Datum | Easting | Bearing | Bare% | Rock% | Crypto% | Litter% | Trash% | Logs% | Dry |
| | | | | | | | | | |
| Zone | Northing | Length or size | A horizon | | | | | | Wet |
| | | | depth: | | | | | | |
| Reason for transect location | | Transect photos | colour: | | | | | | |
| | | | texture: | | | | | | Inundated |
| | | | pH: | | | | | | |

## Section 3b: Qualitative Vegetation Assessment

| Growth form | Trees | | | Shrubs | | |
|---|---|---|---|---|---|---|
| | >30m | 10-30m | <10m | >2m | 1-2m | <1m |
| Cover % | | | | | | |
| Dominant Species | | | | | | |
| Recruitment | | | | | | |
| Stress | | | | | | |

| Growth form | Grasses | Herbs | Sedges | Other | Overall Vegetation Condition | | |
|---|---|---|---|---|---|---|---|
| | | | | | Pristine | | see Keighery, B. 1994. *Bushland Plant Survey*. Wildflower Society of WA. Perth. |
| Cover % | | | | | Excellent | | |
| | | | | | Very good | | |
| Dominant Species | | | | | Good | | |
| | | | | | Degraded | | |
| | | | | | Notes: | | |
| Recruitment | | | | | | | |
| Stress | | | | | | | |

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## Section 3c: Quantitative Vegetation Assessment

| | |
|---|---|
| Site ID: | Assessor name: |
| Location ID: | Transect ID: |
| Dominant Stratum: | Emergents: |

| Stratum | % cover | Height | | Stratum | % cover | Height | |
|---|---|---|---|---|---|---|---|
| Species (in order of dominance) | | Form | Voucher # | Species (in order of dominance) | | Form | Voucher # |
| 1 | | | | 1 | | | |
| 2 | | | | 2 | | | |
| 3 | | | | 3 | | | |
| 4 | | | | 4 | | | |
| 5 | | | | 5 | | | |
| 6 | | | | 6 | | | |
| Stratum | % cover | Height | | Stratum | % cover | Height | |
| Species (in order of dominance) | | Form | Voucher # | Species (in order of dominance) | | Form | Voucher # |
| 1 | | | | 1 | | | |
| 2 | | | | 2 | | | |
| 3 | | | | 3 | | | |
| 4 | | | | 4 | | | |
| 5 | | | | 5 | | | |
| 6 | | | | 6 | | | |
| Stratum | % cover | Height | | Stratum | % cover | Height | |
| Species (in order of dominance) | | Form | Voucher # | Species (in order of dominance) | | Form | Voucher # |
| 1 | | | | 1 | | | |
| 2 | | | | 2 | | | |
| 3 | | | | 3 | | | |
| 4 | | | | 4 | | | |
| 5 | | | | 5 | | | |
| 6 | | | | 6 | | | |

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## Section 3c: Quantitative Vegetation Assessment

| | |
|---|---|
| Site ID: | Assessor name: |
| Location ID: | Transect ID: |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Stratum | | | | | | | | | | | | | |
| Crown gaps or tape intercepts | | | | | | | Crown widths or tape intercepts | | | | | | |
| | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| Stratum | | | | | | | | | | | | | |
| Crown gaps or tape intercepts | | | | | | | Crown widths or tape intercepts | | | | | | |
| | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| Stratum | | | | | | | | | | | | | |
| Crown gaps or tape intercepts | | | | | | | Crown widths or tape intercepts | | | | | | |
| | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| Stratum | | | | | | | | | | | | | |
| Crown gaps or tape intercepts | | | | | | | Crown widths or tape intercepts | | | | | | |
| | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| Stratum | | | | | | | | | | | | | |
| Crown gaps or tape intercepts | | | | | | | Crown widths or tape intercepts | | | | | | |
| | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| Stratum | | | | | | | | | | | | | |
| Crown gaps or tape intercepts | | | | | | | Crown widths or tape intercepts | | | | | | |
| | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
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## Section 4: Impacts of threatening processes

| | |
|---|---|
| Site ID: | Assessor name: |
| Location ID: | Transect ID: |

| Threat Category | Threat | % area affected | Severity of impact | Notes |
|---|---|---|---|---|
| Altered biogeochemical processes | waterlogging and salinisation | | | |
| | eutrophication (aquatic only) | | | |
| | erosion | | | |
| | drainage into site | | | |
| | groundwater abstraction | | | |
| Introduced plants and animals | weeds | | | |
| | feral animals | | | |
| | stock grazing | | | |
| Problem native species (list) | | | | |
| | | | | |
| | | | | |
| Disease (list) | | | | |
| | | | | |
| | | | | |
| Detrimental regimes of physical disturbance | fire | | | |
| | drought | | | |
| | flood | | | |
| | storm damage | | | |
| Impacts of pollution | spray use | | | |
| | spills | | | |
| | runoff | | | |
| Competing land uses | recreation | | | |
| | agriculture (other than above) | | | |
| | consumptive, productive use | | | |
| | mines and quarries | | | |
| | illegal activities | | | |

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## Topic summary

- Monitoring is the systematic collection of data, over time, in order to determine the effect of a management regime on the condition of a wetland.
- Planning a monitoring program requires four questions to be addressed:
  1. What is the hypothesis to be tested?
  2. How much confidence is required in the answer?
  3. Which indicators will be measured?
  4. How will the collected data be analysed?
- The hypothesis should state which elements of the ecosystem are expected to change, the magnitude and direction of the change and what period of time changes are expected to occur over.
- Data confidence is achieved by using replication and controls to be sure that a significant change has occurred in an ecosystem and to be able to state what the cause of the change was.
- The indicators to be measured in a monitoring program should address the monitoring hypothesis, be informative in the context of the wetland's ecology, show changes at an appropriate temporal scale and be measurable within the budget and technical expertise available to the program.
- The methods used to analyse the data should be determined when planning the program to ensure that appropriate data are collected.

## Sources of more information on monitoring wetlands

**Aquatic biodiversity assessment and mapping method – AquaBAMM**
www.epa.qld.gov.au
A decision support tool that utilises existing information and expert input to assess conservation value in aquatic ecosystems in Queensland.

**Index of Wetland Condition Methods Manual**
www.dse.vic.gov.au
Provides a methodology used by Victoria's Department of Sustainability and the Environment to assess the condition of wetland ecosystems.

**Matter For Target Inland Aquatic Ecosystem Integrity – Wetlands**
nlwra.gov.au
Describes the national indicators for wetland extent, distribution and condition and progress toward developing nationally consistent measures for them.

**Natural Resource Management Monitoring, Evaluation, Reporting and Improvement Framework**
www.nrm.gov.au
Information about output monitoring for NRM projects funded by the Australian Government.

**The Volunteer Monitor's Guide to Quality Assurance Project Plans**
www.epa.gov
The website of the United States Environmental Protection Agency provides information about quality assurance, including a template for a monitoring metadata statement

**Queensland Community Waterwatch Monitoring Manual**
www.qld.waterwatch.org.au
Promotes a strategic approach to community waterway monitoring that supports local and regional natural resource management, and improved understanding and awareness of waterway and catchment issues.

**Water Quality Monitoring Program Design**
water.wa.gov.au
Assists agencies and groups involved in surface water quality monitoring to develop programs that use standard operating procedures for sample collection and analysis.

**Waterwatch Australia National Technical Manual**
www.waterwatch.org.au
Provides information to help Waterwatch coordinators, environmental staff, teachers and experienced Waterwatchers to understand the health of Australia's waterways and the tools to monitor their condition.

**WetlandInfo**
www.epa.qld.gov.au.
The Queensland Department of Environment and Resource Management's wetlands website. It includes information about wetland typology and conceptual models.

# Glossary

**Accuracy:** closeness to the 'true' value of the parameter being measured

**Australian Height Datum:** a fixed survey point from which the elevation of any point in Australia may be measured.

**Blank:** a solution (usually deionised water) that has a value of zero for the parameter being assessed. Used to calibrate meters.

**Box-subsampler:** watertight box that is divided into a number of cells. A box-subsampler is used when sorting aquatic invertebrates to eliminate observer bias. Dividing the sample into a number of cells which are sorted individually, and in their entirety, reduces the likelihood of preferential selection of larger or more conspicuous taxa.

**Canopy cover:** the proportion of ground surface covered by the leaves and branches of plants when projected vertically downwards.

**Causation:** showing a relationship exists between two variables such that a change in one (the cause) causes a change in the other (the effect). To be sure of the relationship between cause and effect, it is also necessary to show that the effect will not occur if the cause does not.

**Chroma:** the purity of a colour, or its freedom from white or grey.

**Community composition:** the plant taxa that occur in a given community.

**Community structure:** the three-dimensional distribution (height and width of foliage) and abundance of plant taxa and growth forms within a community.

**Control:** a subject that is identical to the experimental subject in every way, except that the experimental subject receives the treatment and the control does not. This means that if a change is observed in the experimental subject after the treatment, but not observed in the control, that change could only have occurred due to the treatment.

**Crown cover:** the vertical projection of the outer extent of the crown of a plant. A line around the outer edge defines the limits of an individual canopy, and all the area within is treated as 'canopy' irrespective of gaps and overlaps.

**Data confidence:** the degree of certainty with which it is possible to state that a change has (or has not) occurred in a system and what the cause of the change is.

**Data quality:** the degree to which the data set truthfully represents conditions at the monitoring site. High quality data are achieved by eliminating errors from the dataset.

**Data visualisation:** the technique of summarising a dataset graphically

**Datum:** an established point on the globe that is used as the reference from which other locations are calculated. Australia uses the Geographic Datum of Australia 1994 (GDA94).

**Ecological character:** the sum of a wetland's biotic and abiotic components, functions, drivers and processes, as well as the threatening processes occurring in the wetland, catchment and region.

**Electrofishing:** a technique in which an electric current is applied to the water in order to temporarily stun fish.

**Habitat type:** 'habitat' is a species specific term, with every taxon having its own environmental requirements. 'Habitat type' is used here to refer to areas where environmental conditions are appreciably different from their surroundings. These differences increase the likelihood that the area may support a distinctive flora or fauna assemblage.

**Hue:** the property of colours by which they can be perceived as ranging from red through yellow, green, and blue, as determined by the dominant wavelength of the light.

**Hypothesis:** a concept that is not yet verified but that, if true, would explain certain facts or phenomena.

**Indicators:** the specific components and processes of a wetland that are measured in a monitoring program in order to assess changes in the conditions at a site.

**Interquartile range:** the distance between the 25th and 75th percentile.

**Macroinvertebrate:** invertebrate taxa that, when fully grown, are visible with the naked eye. It usually includes all of the insects, worms, molluscs, water mites and larger crustacea such as shrimps and crayfish.

**Mean:** representative of the values being summarised due to being intermediate between the extremes of the dataset.

**Median:** the value for which one-half (50%) of the observations (when ranked) will lie above that value and one-half will lie below that value.

**Microinvertebrate:** invertebrate taxa that are too small to see with the naked eye, also referred to as plankton, specifically ostracods, copepods, cladocerans, rotifers and protozoans.

**Mode:** the most commonly occurring value in a dataset.

**Monitoring:** the systematic collection of data, over time, in order to test a hypothesis.

**Outcome:** a measurable consequence of the project's activities.

**Outputs:** activities undertaken, or products produced, by a particular project.

**Percentile:** the value below which a given percentage of the data values lie. The pth percentile is the value in the dataset which p% of values is less than. The 25th, 50th and 75th percentile are called quartiles. The 50th percentile is the median

**pH:** a measure of the concentration of hydrogen ions in a solution; dissolved hydrogen ions being responsible for giving a solution the properties of an acid.

**Plant community:** a discernable grouping of plant populations within a shared habitat. A community develops due to a unique combination of geologic, topographic and climatic factors and will be recognisable where those factors co-occur.

**Population:** in statistics, the term population refers to the entire aggregation of components that are the subject of a study. This may be all the individuals in a biological population, but it may equally relate to a non-biological entity such as quadrats.

**Precision:** minimal variability between measurements

**Qualitative data:** descriptive data; they are collected using techniques such as estimation, categorisation, statements of type or condition, diagrams, photographs and maps.

**Quality assurance:** the process of documenting data quality and data confidence by describing how the dataset was collected, analysed and stored.

**Quality control:** the process of detecting errors and determining their magnitude.

**Quantitative data:** data that are measured or counted in some way, for example, the number of plants in a plot or the pH of a water sample.

**Range:** the difference between the maximum and minimum value in a dataset.

**Replication:** repeating an experiment several times and collating all the results. It allows the error margin of the measurements and natural variations in the subjects to be discounted from consideration.

**Representativeness:** how well a series of measurements reflect the full range of values in the system being measured.

**Sampling:** the process of selecting a set of individuals that will be analysed to yield some information about the entire population from which they were drawn.

**Sampling point:** the precise place at which a sample is taken.

**Sensitivity:** the ability to distinguish between different values in the parameter being measured.

**Shorebirds:** those birds commonly found wading near the shores of wetlands, beaches, mudflats and lagoons in search of food. They include plovers, sandpipers, stone-curlews, snipes, pratincoles, oystercatchers, stilts and avocets.

**Soil texture:** the distribution of grain sizes of the mineral particles in a soil.

**Sorting (aquatic invertebrates):** picking individual organisms from a sample to form a sub-sample.

**Spatial scale:** the minimum size of an area about which data are collected.

**Standard deviation:** a measure of how closely the values in a dataset are clustered around the mean.

**Standard error:** a measure of how close the sample mean is likely to be to the population mean.

**Stratum:** (plural strata) a visibly conspicuous layer of photosynthetic tissue within a plant community.

**Study site:** the wetland that is being monitored.

**Substrate:** a generic term denoting the material forming the floor of a wetland and its surrounds. It is used here because the term 'soil' is not inclusive of organic substrates.

**Summary statistics:** measures that express the central tendency and variability of a dataset; most commonly mean, median, mode, range, standard deviation, standard error and percentile.

**Surrogate measure:** another component of the system that shows a correlated response to the management issue being evaluated.

**Survey:** an exercise in which a set of observations are made about some components of an ecosystem

**Survey location:** the area of the wetland where a survey is completed.

**Temporal:** of or pertaining to time. Temporal variations are changes that occur over time.

**Transparency:** a measure of the degree to which light is able to penetrate the water column.

**Treatment:** subjection to some agent or action. In the case of a monitoring program, the treatment will be the management regime that is expected to cause some change in the condition of the site.

**Turbid:** the cloudy appearance of water due to suspended material.

**Turbidity:** the extent to which light is scattered and reflected by particles suspended or dissolved in the water column.

**Value:** the property of a colour by which it is distinguished as bright or dark; also known as luminosity.

**Waterbirds:** birds that have specialised beaks and feet that allow them to swim, dive and feed in water. Examples include egrets, crakes, herons, ducks, swans and grebes.

**Wetland components:** include the physical, chemical and biological parts of a wetland (from large scale to very small scale, e.g. habitat, species and genes).

**Wetland conceptual model:** a simplified diagram that expresses ideas about components and processes that are important to the ecosystem.

**Wetland processes:** the forces within a wetland and include those processes that occur between organisms and within and between populations and communities including interactions with the non-living environment and include sedimentation, nutrient cycling and reproduction.

**Wetland typology:** the process of classifying wetlands according to characteristics of their hydrological, morphological, chemical and biological factors.

# Personal communications

| Name | Date | Position | Organisation |
|---|---|---|---|
| Professor Brian Timms | 27/01/2009 | Conjoint Academic in Environmental Science. | University of Newcastle |
| Doctor Andrew Storey | 09/07/2009 | Principal Consultant with Wetland Research and Management. | University of Western Australia |

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