NSW GOVERNMENT
Department of Planning

Aquatic Ecology in Environmental Impact Assessment

EIA Guideline Series

May 2003

ACKNOWLEDGMENTS

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These Guidelines were sent for review to a broad range of consultants, managers and scientists from government and aquatic ecologists from several universities. Those who were able to provide a response have greatly enriched this document and their efforts are acknowledged most gratefully. They are listed in alphabetical order as follows.

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Department of Planning welcomes feedback on the Guidelines.

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1. Introduction and summary of guidelines

(a) Why are guidelines needed?

These Guidelines have been prepared to assist in improving the quality of assessment of potential impacts of proposed projects on aquatic ecosystems[1]. They will assist proponents of projects and their consultants, the community and decision-makers in the identification, prediction and assessment of impacts and suggest approaches to the management of impacts that have either been predicted or observed through monitoring. The Guidelines also aim to facilitate improvement of the environmental impact process in general by:

- encouraging a standardised, rigorous approach to aquatic investigations in environmental impact assessment; and
- providing information which can be used to understand and manage changes to the aquatic environment in NSW.

In NSW, the environmental impact assessment (EIA) process requires the proponent of a project to describe the environment that may be affected by the development, assess the likely effects of the proposal on that environment and justify the sustainability of the proposal. However, there is often inconsistency in the methodology used and the level of detail provided in the assessment of impacts of development on aquatic ecology. These Guidelines set out a comprehensive methodology to provide a consistent approach as well as providing guidance on the appropriate level of detail.

(b) When do these guidelines apply?

The Guidelines apply in the assessment of impacts on aquatic habitats including coastal waters, estuaries, rivers and streams, natural and artificial lakes and reservoirs and permanent and ephemeral wetlands.

The Guidelines may be applied whenever aquatic ecological assessment is required under the *Environmental Planning and Assessment Act, 1979*. The information presented here will be useful when preparing an Environmental Impact Statement (EIS), Statement of Environmental Effects (SEE) or Review of Environmental Factors (REF). Also, the Guidelines may be of use in preparing Local Environmental Plans (LEPs), Regional Environmental Plans (REPs) and Plans of Management (eg. Estuary Management Plans).

(c) Other guidelines and sources of information

In New South Wales, local councils and many government departments have a statutory interest in the aquatic ecology of the waterbodies. In many cases, there are legislative requirements that must be addressed prior to affecting the aquatic environment. For example, under the Fisheries Management Act 1994, permits are required for any alteration of aquatic vegetation, such as seagrasses or mangroves.

[1] An aquatic ecosystem is defined here as an assemblage of aquatic organisms, interacting with one another, plus the aquatic environment in which they live and with which they interact – after Abercrombie *et al.* 1985.

Relevant departments and local council(s) should be consulted with respect to any potential for changes to the aquatic environment including:

- Department of Planning
- Department of Environment and Climate Change (DECC)
- Department of Primary Industries
- NSW Maritime

There are some matters for which consultation with the Commonwealth Government is required. For example, disposal of material at sea is administered by the Commonwealth via the *Environment Protection Act (Sea Dumping) 1981,* based on the London Dumping Convention.

Finally, there are often special interest groups that should be consulted in relation to activities that could affect aquatic ecology. These include commercial and recreational fishing groups, oyster farmers, diving and conservation groups, catchment and estuary management committees and Aboriginal Land Councils.

Apart from these Guidelines, a number of other guidelines published by Government departments focus on specific matters related to their areas of responsibility. Examples of these are provided in Appendix 5. Of particular relevance are the EIS Guidelines prepared by Department of Planning. These guidelines complement the EIS guidelines which cover all issues related to an EIS, not just those related to aquatic ecology. The Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC 2000) including the Volume 2 on Aquatic Ecosystems and the Australian Guidelines for Water Quality Monitoring and Reporting (ANZECC 2000) and Department of Primary Industries habitat management policy and guidelines present particular perspectives on issues related to management of aquatic ecosystems.

(d) How to use these guidelines

The Guidelines focus the efforts of aquatic scientists, especially ecologists, so that appropriate information required for decision-making. They provide a reference for:

- the extent to which the existing environment needs to be described;
- the extent to which a proposal is likely to affect aquatic ecology;
- the minimal acceptable standard for assessing potential impacts on aquatic ecology;
- predicting cumulative impacts within a body of water;
- when monitoring should be done and what components of aquatic ecology (biotic and abiotic – ie. non-living) should be monitored; and
- requirements for adequate information to manage potential impacts and initiate feedback from monitoring to management.

The guidelines do not provide intensive detail on the design of ecological surveys, but suggest basic approaches that may be applied and provide references with more detailed information.

The Guidelines present an approach to the study of aquatic ecology in approximate chronological order of the preparation and follow up investigations for an EIS.

- They begin with preliminary or scoping studies (Part 2), including defining the study area, developing the consultative process (eg. initiating planning focus meetings) and provisionally identifying issues that will need to be addressed.
- The next stage (Part 3) is the design and implementation of studies of aquatic ecology for an EIS and covers matters related to the actual investigations required. These should be based on the types of study identified from scoping.
- The following stage (Part 4) is predicting the effects of a project and assessing their importance. It addresses the prediction of the effects of a proposed project, mitigation of impacts and the design of ways in which effects can be measured (monitoring).
- Then final phase includes the identification of any ongoing studies involving monitoring and audit.

Some of the guidelines are a little repetitive, reflecting the need to address the same issues at different stages of the EIA process. The overall process is shown in Figures 1 and 2. These figures recommend inputs of information or expertise at various stages of the process and outputs that are valuable for:

- proceeding to subsequent stages of investigation and
- communicating findings to other stakeholders.

Note that Figure 1 includes a feedback loop from the planning focus meetings to scoping studies, as these meetings will often be important in defining the scope of work to be done and, as such, several meetings may be required.

1.2 Assessment appraisal tables

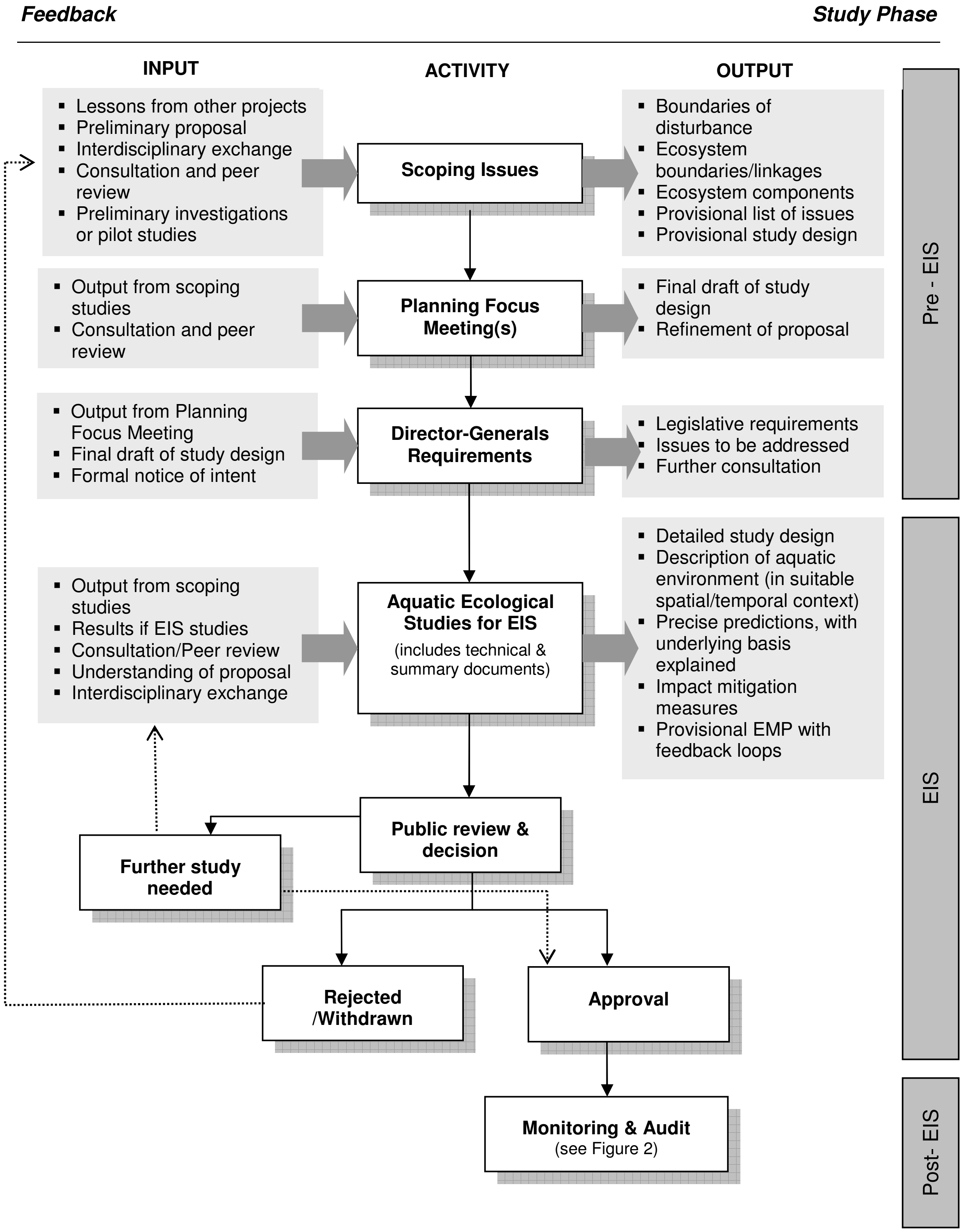
A summary of each step is provided in **Appendix 1, 2 and 3** to assist in appraising the adequacy of work proposed or done for an EIS. There are boxes beside each issue for stakeholders to nominate the level of importance of the issue and/or the adequacy with which the issue was dealt with where it was relevant. Space is provided to list further action that may be required.

The tables relate to:

- Scoping appraisal – Appendix 1
- Investigation appraisal for assessment - Appendix 2
- Assessment appraisal for prediction, mitigation, monitoring and adit - Appendix 3.

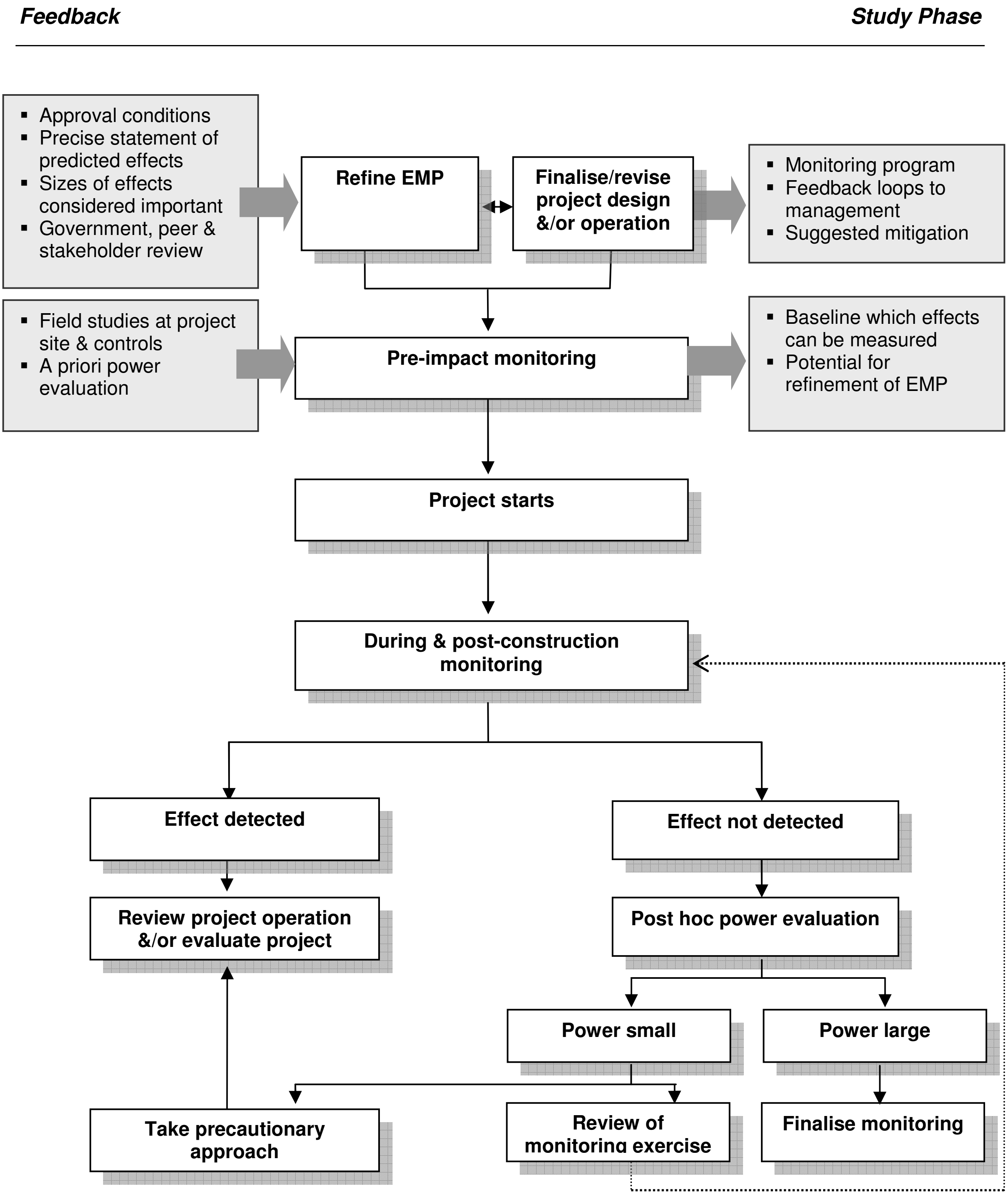
The appraisal tables may be used throughout the preparation and review of the EIS. For example, using the appraisal tables for scoping may be useful during the planning focus meeting(s) to evaluate the level of detail required for the various issues identified. The appendixes can be photocopied, fill-in the level of detail and planned action for each project and distribute to relevant stakeholders. From a different perspective, the approval authorities or representative of the local community may choose to photocopy the appraisal tables and use them to identify adequacy or further action whilst reviewing the EIS document.

Figure 1: Flow chart of inputs and outputs for aquatic ecological studies for an EIS



Note: *EMP = Environmental Management Plan*

Figure 2: **Flow chart of inputs and outputs of activities for aquatic ecological studies for work done following approval of a project**



Note: *EMP = Environmental Management Plan*

2. SCOPING THE AQUATIC ECOLOGY STUDIES

2.1 Why scoping of ecological assessments is so important

A strong emphasis should be placed on preliminary investigation (ie. scoping) at the earliest stages of the preparation of an EIS. If issues are properly identified and studies properly designed, the EIS process for each proposed project[1] is likely to be much more efficient, timely and much less likely to be subject to additional requirements for information.

It is important to distinguish between

- preliminary work done prior to initiation of an EIS,
- the EIS studies themselves and
- follow-up work done as part of environmental management of the project (including monitoring and audit).

Whilst it may be straightforward to define these stages, studies on aquatic ecology may evolve in an iterative manner with information obtained during preliminary studies being incorporated in the EIS, and studies done as part of the EIS can becoming the baseline for the monitoring of the operational phase of the project (Figures 1 & 2).

Prior to preparing an EISs for proposed projects in or near aquatic ecosystems, four matters must be considered to properly assess the effects of the proposal. Proponents and their consultants must:

- Decide what types of disturbance are likely to occur
- Define what effects may result and their likely magnitude.
- Define the boundaries of the aquatic ecosystem that could be affected and identify aquatic resources and their importance within those boundaries. This may be complicated where potential cumulative effects from other projects result in overlapping boundaries.
- Decide on the appropriate level of investigation of the aquatic ecology that should be done to ensure that stakeholders could be confident that the aquatic environment has been adequately examined in relation to the proposed project.

In Part 2, guidance is provided to assist with scoping studies which examine the effects of human activities on aquatic ecology, with examples of the types of impacts on aquatic habitats in NSW.

A **"Scoping Appraisal Form"** is presented in Appendix 1 to facilitate scoping process. This form should be of value for Planning Focus Meetings and other discussions with stakeholders in determining the scope of studies for an EIS.

[1] The guideline refers to the "proposed project" or “proposal” (either the development or activity prior to approval) and the "approved project" or "project", referring to the construction and operational phases.

2.2 The nature of disturbance and response

To predict and measure the effects of any project in an aquatic ecology, it is important to identify the nature of the disturbance and how the components of the aquatic ecosystem may respond. It is important to recognise, however, that a particular disturbance may not cause a detectable response (ie. have a "significant effect"). Scientists often distinguish between a "disturbance" which is some change in the environment, and a "perturbation" which is the disturbance plus some measurable response. These issues have been given considerable attention by ecologists, in relation to natural and human-induced perturbations. Discussion of these issues, with examples, may be found in papers by Bender *et al*. (1984), Underwood (1989, 1994), Skilleter (1995) and Glasby and Underwood (1996).

Types of disturbance

Because they are very important in predicting and measuring the effects of projects, the three types of disturbance commonly identified:

- A **pulse disturbance** is an acute, short-term episode of disturbance, which may cause a temporary response in a population. One example of this may be the short-term impacts associated with construction of a building near a waterway (eg. rain runoff with turbid water).

- A **press disturbance** is a sustained or chronic disturbance to the environment, which may cause a long-term response. An example of a press disturbance may be long-term discharge of thermal effluent from a power plant, which may cause change in the distribution of seagrasses close to the outlet (eg. Robinson 1987).

- A **catastrophic disturbance** is a major destruction of habitat from which populations are unlikely to recover in that area because the habitat has been removed or irreparably changed in some way. Examples of this type are construction of reservoirs, dumping of dredge spoil on a rocky reef or filling a mangrove forest.

In practice there may be several combinations of these types of disturbance associated with any one project. Moreover, these disturbances may vary in relation to the organisms being considered and the response they cause (Glasby and Underwood 1996). Thus, a pulse disturbance to a population of very long-lived organisms may be a press disturbance to a population of organisms with a short life span. Similarly, some organisms may show a long-term (press) response to a short-term perturbation and *vice versa*.

Response to disturbance

The response of a population or an assemblage of organisms to disturbances is often considered in terms of its inertia, resilience and stability.

- **Inertia** is the ability of a population to withstand change to environmental perturbation. Thus, the case of decreased water quality associated with a project, some populations may show a response while others - which are relatively more inert - may not. In coastal freshwater ecosystems, Australian bass, eels and grayling are fishes with a low inertia to the creation of barriers between freshwater and estuaries because they need to migrate between these two ecosystems to spawn. Thus, if a barrier is created, these species will become locally extinct upstream of the barrier. On the other hand, freshwater smelt and the introduced mosquito fish can spawn on either side of barriers, so they have a higher inertia with respect to barriers.

- **Resilience** is the ability of a population to recover, once it has responded to a disturbance. A species with a poor resilience may be eliminated from an area, whereas another with high resilience may rapidly increase its population or recolonise from nearby, unaffected populations. The fish described in the above example would have a low resilience to recovery because, with the possible exception of eels, they would be unable to recover in areas where they were excluded by barriers (the eels may be able to ascend over some barriers). The seagrass Posidonia australis has a low resilience to disturbances where it is removed from an area, because it is very unlikely to recolonise that area. On the other hand, the seagrasses Halophila spp. and Zostera capricorni have a higher resilience, because they can recolonise some habitats after removal. Note, however, that none of these seagrasses is resilient to removal of the sediments in which they grow, or to a large increase in depth such as resulting from dredging, so the resilience of a species depends both on the species and the type of disturbance.

- **Stability** is the rate of recovery from disturbance. A species that is highly mobile, produces lots of offspring and has a high growth rate may be much more capable of recovering from disturbance than one that has the opposite characteristics. A good example of the latter is the grey nurse shark, which produces only one or two offspring and is slowing growing, whereas many of the bony fishes produce many offspring that are widely broadcast as eggs or larvae in the plankton. Stability may be affected by the type of disturbance, by its timing and by the occurrence of random, natural events (often called stochastic processes). For example, if oysters are removed from a rocky shore, they may colonise the bare space rapidly if there are oyster spat in plankton that are available to settle from the plankton and utilise the bare space. If there are few or no spat available, but there are many larvae of barnacles available, they may “claim” the available space and it may take many years before oysters become re-established on that shore.

In scoping the studies required for aquatic ecological assessment, it should be possible to assess provisionally the types of disturbance from a proposed project that the aquatic environment may need to respond to. The provisional assessment provides the basis for designing studies to examine aquatic ecosystems for an EIS. It will be more difficult, however, to assess how populations may respond, due to the potential for complex physical, chemical and biological interactions and our limited understanding of how particular species respond to disturbance.

***Scoping Guidance 1:** Define the types of physical, chemical and/or biological disturbance in an aquatic environment that may be associated with, or caused by, the proposed project.*

2.3 Identifying the potential impacts associated with a proposed project

To some extent, the effects of each project on the environment will be unique, due to its construction, operation and location. There are, however, these effects on aquatic ecology can be categorised in terms of its potential physical, chemical and biological effects which helps to focus on the nature of impacts and their likely magnitude.

(a) Physical effects

Physical alteration of the aquatic environment can include the creation of barriers to movement of aquatic species and changes to the physical properties of the water and the floor of the waterbody (usually sediments, reef or natural and artificial substrata). Physical effects may be gross and highly self-evident, very subtle or barely detectable.

In scoping the extent of impacts on the aquatic environment, the types of physical effects associated with the proposal should be considered as well as the potential for occasional events such as major storms to change or increase those effects.

Direct alteration of habitat

Putting physical structures on or near to a waterway can alter the size of aquatic habitats by causing their removal or creation. Four examples of alteration of habitat are discussed here. (**Case Study 1**).

- **Dredging and reclamation —** These activities are often associated with foreshore development, including marinas and navigation within waterways. Within estuaries of NSW, concerns are often raised that dredging and reclamation will remove significant habitat, such as seagrass beds, mangroves and saltmarshes for example with the dredging and reclamation for the construction of Third Runway at Sydney Airport

- **Disposal of spoil —** Waste materials are often dumped in coastal waters. This activity can have a variety of effects, but amongst the most obvious is smothering of the seafloor. Effects are usually considered to be greatest where the material being disposed of is very different to the seafloor, for example, where sediments are deposited on reef habitat, or fine mud is dumped on sandy substrata. In recent years, the NSW DECC has published several reports on the effects of spoil disposal on rocky reefs off the NSW coast. These impacts can be changed by major storm events.

- **Construction of impoundments —** These structures are usually associated with water supply, irrigation and flood mitigation proposals. The inundation of valleys to create impoundments creates a large amount of aquatic habitat, but it can also alter important existing habitat. For example, inundation of the original streambed and banks can remove spawning habitat for fish such as Macquarie perch and can affect amphibians and aquatic mammals such as platypus. Changes to patterns of flow below a dam can affect the amount and type of riparian and aquatic habitat available. The effects of impoundments on freshwater ecosystems are a major area of interest for the Department of Primary Industries and DECC. Impoundments also have the potential to alter the salinity regime and hydrology downstream in estuaries (Burchmore (1993)).

- **Channelisation and removal of snags —** These activities are often done to improve navigation or, in flood mitigation programs, to improve flow during flooding. The presence of snags is of major significance for many freshwater organisms, which use snags for shelter. At least two native species of fish, Murray cod and river blackfish, lay their eggs among snags. See Department of Primary Industries *Fisheries Habitat Management Plan No. 1* and also Koehn and O'Connor 1990, Burchmore 1993 and Turak and Bickel 1994 for further details.

Scoping Guidance 2: *Assess the extent to which the proposed project may physically alter any waterbodies.*

Creation of barriers

Apart from relatively localised effects associated with physical alteration of habitats, there may be other, more far-reaching effects associated with physical alteration of the aquatic environment. In particular, the creation of barriers in rivers and estuaries may affect the movements of numerous species of aquatic organisms, including spawning migrations crucial for the maintenance of some populations.

Within the Murray Darling river system, several species of fish undergo long spawning migrations, the most notable being the silver perch and golden perch. Within coastal river systems, the migratory species that are best known include Australian bass, freshwater eels, common galaxias, lampreys and prawns. Some of these migrations are related to natural physical events, particularly flooding and changes in water temperature. Among the "alien" species introduced into our waterways, trout living in lakes undergo annual spawning migrations into feeder streams.

Many animals migrate along our open coastline, both north/south and between shallow and deep waters. Sea mullet migrate from estuaries along the NSW coast in response to seasonal changes and gemfish migrate annually along the continental slope off NSW to spawn. Well-known examples are the movements of southern right and humpback whales along the NSW coast each winter and spring. It has been suggested that disposal of dredge spoil, discharge of effluent and noise associated with shipping could create barriers to the movement of these whales.

Scoping Guidance 3: *determine if there are aquatic species present whose migratory patterns could be directly affected by creation of barriers and assess if unnecessary impacts could be avoided by timing components of the proposal (eg. Construction activities) to coincide with periods when migrations are not likely to occur.*

Case Studies 1: Physical alteration of habitat

Physical alteration of habitat has the potential to cause catastrophic disturbance to aquatic organisms, for example by direct mortality (e.g. smothering, removal by dredging, etc) or by making conditions unsuitable for the original aquatic inhabitants. Two examples illustrate this.

1. Construction of Sydney's Third Airport Runway

The EIS prepared for the Third Runway predicted that there would be a direct loss of approximately 22 ha of seagrass (predominantly **Zostera capricorni***) due to reclamation of seafloor in the northern portion of Botany Bay (Kinhill Engineers 1990). Ecological studies were designed to test this prediction and monitor seagrasses adjacent to the area that would be lost, so that any unforeseen changes could be addressed by management. Aerial photographs were used to map accurately the extent of seagrasses in relation to the proposed works. It was found that the area that would be directly lost due to the works covered less than predicted, namely 18.8 ha (Inglis et al. 1994). Field studies were implemented to determine if there were changes at several spatial scales of percentage cover of seagrass and density of shoots, leaf length and width and cover of leaves by epiphytes. These studies detected a reduction in percentage cover of seagrass following commencement of dredging which did not occur concurrently at control locations (Inglis and Lincoln Smith 1994). The seagrass bed lost under the runway reclamation was found previously to be one of the most productive beds in NSW, in terms of fisheries per unit of area sampled (McNeill et al. 1992). One impact of the loss of habitat that is very difficult to predict and monitor is the consequential loss, if any, of fisheries resources within Botany Bay.*

2. Disposal of dredge spoil

Disposal of dredge spoil into the ocean is undertaken in coastal waters around Australia. In NSW, there are designated disposal sites on the continental shelf off the major population centres of Sydney, Newcastle and Port Kembla/Wollongong. NSW DECC have commissioned several studies to evaluate the impacts of this activity.

One operation monitored was the disposal of about 1 million m^3 *of spoil from Port Kembla Harbour onto a designated dump ground of 84 ha, in water depths of 40-50 m, off the Five Islands (Roach 1992). The spoil consisted mostly of silt, clay and sand and was dumped over a one year period. Bathometric surveys showed that the spoil migrated from the site in a northerly direction, due largely to mobilisation during storms. Given the volume of spoil and the different nature of the dumped material compared to the natural substratum, it is likely that large mortality of sediment-dwelling invertebrates would have occurred at the dump site (Roach 1992). The greatest concern, however, was about migration of spoil (either as a surface plume during disposal or mobilisation from the seabed) onto the nearby reefs at the Five Islands. Monitoring involved tracking the plumes, bathometric surveys of the seabed and surveys of fish and attached flora and fauna of the reefs and at control locations. The studies showed that some of the spoil had migrated from the dump site, but there was little evidence to suggest that the reefs at the Five Islands were affected. In this example, no alteration of habitat and consequential effects were found at the area judged to be most ecologically sensitive, but there were large physical changes at the dump site, probably with consequential biological effects.*

In another example, spoil consisting of sandstone and siltstone excavated from the tunnel used to carry effluent to Bondi's deepwater ocean outfall, was disposed of directly onto rocky reefs at the base of the Sydney cliff line. Predictions that the spoil would be quickly dispersed by wave action were not confirmed by monitoring. In fact, changes to the reef were relatively long term (>10 yrs), with a shift in the ecology of the (localised) area from a "barrens" habitat to a kelp bed, probably as a consequence of the removal of sea urchins (which are algal grazers) at the time of disposal (Lincoln Smith et al. 1993).

Changes to physical properties, including salinity

Changes to the physical properties of water and sediments can have profound effects on plants and animals. Three of the most obvious examples are changes to light penetration, temperature and salinity.

The physical and chemical attributes of waterbodies are often termed "water quality" and, by implication, a waterbody with levels outside the normal range of these attributes is considered as having poor water quality. Water quality guidelines prepared by the Australian & New Zealand Environment & Conservation Council (ANZECC 2000) provide a framework for assessing and monitoring the effects of changes in water quality.

Penetration of light through the water is critical for many ecological processes, particularly the growth of aquatic plants, including algae such as kelp and flowering plants such as seagrasses. Dredging, effluent discharge, construction of solid platforms or pontoons can affect penetration of light. Studies indicate that changes to the light regime may affect the depth distribution of seagrasses and the morphological characteristics of seagrass beds, including length of leaves and density of shoots (Larkum *et al.* 1989, Fitzpatrick and Kirkman 1995).

Changes to water temperature can cause large changes to the ecology of waterways. One example of this is the construction of impoundments, where a layer of cold water may form in the deeper waters, particularly during summer. These colder waters can exhibit different chemical parameters to the surface waters and they may provide a thermal barrier for warm-water species or a refuge for cold-water species, such as trout. Moreover, release of bottom waters into streams can significantly reduce the temperature streams, affecting local ecology. Another example is the release of cooling water from industrial sites and power stations. Power stations releasing warm water can affect aquatic ecosystems by increasing water the temperature (and introducing biocides such as chlorine) at the outlet.

Salinity is a critical variable influencing the ecology of many plants and animals, particularly within estuaries and increasingly in inland waterways. Studies in the Hawkesbury and Shoalhaven Rivers suggest that the distributions of benthic organisms (ie. invertebrates living on or in the sediments of the estuary floor) are structured by changes in salinity (Jones *et al.* 1986). As with many variables, changes to salinity can affect aquatic ecology at several spatial and temporal scales. At a large scale, reduction of freshwater input to an estuary may lead to an increase in saline penetration up into the estuary. At a smaller scale, increased runoff from hard surfaces, or discharge of sewage effluent or freshwater used in industrial processes may cause a local reduction in salinity.

Scoping Guidance 4: *Evaluate the extent to which the proposed project may affect the physical properties of any waterbodies in relation to factors such as water clarity, temperature, salinity and sediment characteristics. Consider the potential for unexpected events, such as runoff from unbunded areas during construction.*

Case Study 2: Acid sulfate soils and coastal ecology

A good overview of the problem of acid sulfate soils (ASS) can be obtained from papers within Bush (1993) and in government publications available from the NSW Acid Sulfate Soils Management Advisory Committee (ASSMAC, Stone et al 1998). The brief overview here is drawn from these publications. ASSs develop in sediments containing sufficient iron pyrite which, when oxidised to form sulphuric acid, cannot be neutralised by the inherent buffering capacity of the sediment, for example by buffering due to clays and shells. The iron pyrite remains inert and innocuous while in a reduced state (e.g. in anaerobic sediments below the water table). The formation of sulphuric acid occurs when ASS become exposed to the air and pH can drop to less than 3.5 units. The exposure of ASS to air occurs by several processes, but there are numerous human activities that can lead to acidification, including farming practices, flood mitigation, construction of canals, ponding for aquaculture, dredging and reclamation, etc. There are numerous signs of the presence of ASS in the environment, including the presence of stunted vegetation, deposits of jarosite (a yellowish mineral) within or on the surface of the soil, red or brown discoloration of water and corrosion of concrete, iron and steel structures.

One consequence of the formation of acid is that elements, such as aluminium, iron and potentially heavy metals such as cadmium, which are normally inert within the soils, become dissolved at low pH. These elements, which may be highly toxic to aquatic life, can then leach from the soil into adjacent waterways. It has been observed in some cases that acid leachate, upon entering a waterway, causes flocculation of suspended sediments which then sink. This is due to the precipitation of aluminium as the pH rises when acid is diluted or, to some extent neutralised, in brackish water. A spectacular example of this was reported in the Tweed River in March 1987, when the normally turbid river became gin-clear overnight.

Within acid-affected waterways there can be several types of effects on aquatic animals (Sammut et al. 1993):

- Acid may be lethal at pH 3 - 4 units;
- Aluminium and iron may be lethal, and aluminium is considered to be the primary cause of injury and death in fish; and
- Chemical reactions involving iron may cause de-oxygenation of the water.

Sammut et al. (1993) reported that there may be several impacts at the species, population and ecosystem level. These include:

- Mortality of fish and aquatic invertebrates, although there is variability among species in their susceptibility and there may also be some variability among age classes within species. For example, gudgeons (Eleotridae) a group of small fishes common in NSW estuaries have been observed to be unaffected in extremely acidic water.
- Physiological effects. Numerous physiological effects have been reported, including reduced growth rates, visual and olfactory impairment and bone disorders.
- Increased susceptibility to disease. Acid waters have been implicated in the occurrence of epizootic ulcerative syndrome (EUS) - also known as red spot disease - in fish. EUS, which has significant consequences for fisheries, has been reported following release of acid waters.
- Avoidance responses. Sammut et al. (1993) noted that avoidance behaviour by fish has been reported in waterways and in controlled tank experiments. Crabs and eels have also been observed to avoid acid water by climbing out of the water.

In the past five or so years, research on the effects of ASS on aquatic organisms in Australia has intensified, but there still remain many questions, particularly regarding the effects on a wide variety of species (including fish and invertebrates), the exact causes of mortality (especially under different pH conditions) and the time scales over which affected water bodies are likely to become recolonised.

(b) Chemical effects

Chemical effects on aquatic organisms are often considered in groups, including changes to pH and dissolved oxygen, nutrients and a variety of contaminants such as heavy metals and organochlorine pesticides. An important part of evaluating the potential effects of chemicals on aquatic ecosystems is anticipating the potential for unexpected events, such as accidental spillage, associated with a proposed project.

pH Marine and estuarine waters are generally slightly alkaline and freshwater can range naturally from acidic to alkaline. pH can also change due to natural environmental conditions; for example acidity may increase (ie. low pH) due to the production of acids caused by decomposition of vegetation following flooding.

Changes in pH can have direct effects on aquatic organisms, but can also lead to secondary impacts caused by chemical reactions. One of the major causes of acidification in waterways is the disturbance (ie. oxygenation) of acidic soils, known popularly as acid sulfate soils (ASS). Maps of the location of ASS have been produced by the Department of Planning and these have been incorporated into Local Environmental Plans by many coastal councils.

Dissolved oxygen Changes in levels of dissolved oxygen can profoundly affect the ecology of water and sediments. Reductions in oxygen can be associated with numerous natural and human-derived processes, including eutrophication due to excess nutrients, stratification of water, dredging and creation of deep holes in which water becomes trapped and oxygen exchange reduced (Chapman 1996).

Nutrients Nutrients (eg. nitrogen and phosphorus) play a vital role in the ecology of fresh and marine waters, being a requirement for primary production. When nutrients occur in large concentrations, it is possible for there to be excessive primary production, which can lead to problems such as toxic algal blooms and deoxygenation of water. Excessive nutrients can be introduced into a waterbody by natural events or by human activities. For example, flooding may lead to large-scale decomposition of terrestrial vegetation that is then transported into adjacent waterways as the floodwaters recede.

Human activities that can lead to excessive nutrients include discharge of sewage effluent and intensification of land use leading to changes in runoff characteristics. Also, dredging that may disturb sediments with large amounts of nutrients. Some activities accentuate the effects of natural events, for example, flood mitigation works may affect the frequency of flooding, while flooding of modified heavily grazed pastures may lead to runoff of large amounts of nutrient-rich animal wastes.

Inorganic and organic contaminants Some of the most common contaminants that humans introduce into the aquatic environment are heavy metals (eg. copper, lead and mercury), hydrocarbons, including polycyclic aromatic hydrocarbons (PAHs) and a variety of insecticides and herbicides. Some contaminants, such as heavy metals, occur naturally in the environment while others, such as organochlorine pesticides are exclusively anthropogenic.

The approach used to examine the effects of heavy metals can often be very different to that used for organochlorines, particularly in pristine areas, where it is often necessary to distinguish background levels of heavy metals from those associated with a proposed development (eg. a marina, outfall or industrial site). This may not always be necessary for organochlorines and other organic contaminants if there are no sources within the area of interest.

In a relatively developed area, there may be a need to distinguish levels of heavy metals from both the natural background levels and the levels associated with other activities in the are, and to distinguish concentrations of organochlorines from those associated with other activities in the area. It should be noted that many contaminants finding their way into a waterbody might ultimately settle into the sediments. Thus, sampling of both water quality and sediments should be considered.

Scoping Guidance 5: *Evaluate the extent to which the proposed project may affect the chemical properties of water and sediments in waterbodies in relation to factors such as pH, nutrients and contaminants. Consider the potential for unexpected events, such as accidental spillages.*

(c) Biological effects

Direct biological effects may occur by introducing new species into waterways. NSW freshwater systems already have a large number of water plants (eg. water hyacinth) and species of fish introduced from overseas (termed "alien" species"), including carp, goldfish, trout, mosquito fish, redfin, weather loach and cichlids (Farahger and Lintermans 1997). Our estuaries and coastal waters also have several alien species, including Japanese goby, Asian goby, and triplefin. These species may compete with native species and even alter habitats. In addition to alien species, several native inland fishes (eg. golden perch) have been introduced into some coastal streams.

There is also a potential for introducing species into new areas or altering the genetic structure of local stocks as a result of aquaculture activities, stocking ponds with ornamental species, etc. (Bartley and Minchin 1996). It is important to recognise that, in many cases, the source of the introduction may not be immediately apparent. For example, introductions may occur via microscopic larvae or eggs present in water, attached to boat hulls, or parasitic on other organisms. The consequences of introductions must be part of the scoping for any project that could lead to introduction of species that 1) did not occur previously in an area; or 2) or that have a different genetic structure to existing populations.

Scoping Guidance 6: *Identify any species (or stocks genetically distinct from existing stocks) that may be introduced into an area - either intentionally or by accident - as a result of the proposed project.*

2.4 Defining the aquatic ecosystems likely to be affected by the proposed project

The third matter that the proponent should consider in relation to scoping studies for an EIS is the extent of the aquatic ecosystem that could be affected by the project. Related to this are questions about the spatial and temporal scales of variability that need to be considered, which components of the ecosystem need to be studied to provide a suitable description of the aquatic environment and provide a basis for predicting impacts and, the level of detail required to describe the biological constituents of the habitats within the ecosystem.

(a) Defining boundaries in space and time

For these Guidelines, aquatic ecosystems are considered as relatively distinct geographic units, including oceanic, coastal, estuarine, wetland, riverine and lacustrine ecosystems. Within each of these, there may be sub-units, often called habitats (eg. seagrass beds within an estuarine ecosystem) and microhabitats (eg. the leaf structure of seagrasses and associated plants and animals). Irrespective of the terminology used, it is important to consider the "landscape units" which may need to be assessed in relation to a particular proposal. In defining these units, two factors must be considered.

First, no unit of the landscape is completely isolated from all others, thus, the effects of a project may not be contained within the unit(s) selected for assessment. This is particularly the case in the aquatic environment because the water medium is critical for transport of oxygen, food, wastes and dispersal of eggs, seeds and larvae. Thus, changes caused by a project in one location or ecosystem may lead to changes in another.

Second, there may be significant variation through time, which affects the boundary of an ecosystem. For example, a wetland ecosystem may alter its boundaries in response to flooding and drought and therefore the variation in the boundary of that ecosystem needs to be considered in scoping the studies required for an EIS for a project that may have an effect on the wetland.

> ***Scoping Guidance 7:*** *Clearly define the extent of the aquatic ecosystem, habitats and communities, etc that may be affected by a proposed project, specify how the area may change through time and identify potential linkages to other locations or ecosystems.*

(b) Scales of variability in space and time

A project may cause impacts to the aquatic environment at different spatial and temporal scales. The scoping of studies for an EIS should focus either on the scale at which effects are most likely to occur, or, if this is not known, several scales should be incorporated into the sampling design of field studies (see Andrew and Mapstone 1987, Underwood 1993, Keough and Mapstone 1995 and Part 3 of these Guidelines), as a precautionary measure.

Recent studies by Morrisey *et al.* (1992a & b) and James *et al*. (1995) provided good reasons why sampling at several spatial and temporal scales is important in studying the ecology of invertebrates in soft sediments of coastal waters and estuaries. A brief overview of this issue is given in **Case Study 3** and the implications are discussed further in Part 3 of these Guidelines.

Scoping Guidance 8: *Define the appropriate spatial and temporal variability that should be considered to provide a proper assessment of effects; if these are not known, incorporate two or more scales for consideration.*

Case Study 3: Investigations of variability of macroinvertebrates in soft sediments at different spatial scales

It is extremely important that field studies for assessment of the effects of proposed projects be done at appropriate spatial and temporal scales. This applies to the scales at which populations may vary within the boundaries being considered; the scale of different types of disturbance associated with a proposed project and the scale at which organisms may respond to a disturbance. Much of the quantitative sampling done for EIA is spatially constrained by the units of sampling (e.g. transects or quadrats) selected by the investigator.

The use, however, of quadrats or other sampling units imposes an order on the populations being sampled that may mask true spatial relations among organisms (Andrew and Mapstone 1987, p.75). Therefore, the selection of a sampling unit of appropriate size and the allocation of those units within study areas is crucial to the outcome of field studies. In NSW, the assemblages and populations of benthic macroinvertebrates living in soft sediments is often used as an indicator of environmental conditions (see Keough and Mapstone 1995 for further discussion).

Recently, Morrissey and coworkers studied variation in macroinvertebrates at several spatial and temporal scales and their findings have important implications for the design and interpretation of EIA studies. Their approach uses a multi-stage sampling design, also called hierarchical or nested (Underwood 1981a, Andrew and Mapstone 1987), which provides a simultaneous comparison of data collected at several spatial and/or temporal scales. Morrissey et al. (1992, 1994) used this approach to investigate spatial variability in macroinvertebrates in Botany Bay at spatial scales ranging from 3.5 km to <10 m (see Figure at left). Significant variability occurred at all spatial scales: some families varied among several scales; others varied at either large or small scales.

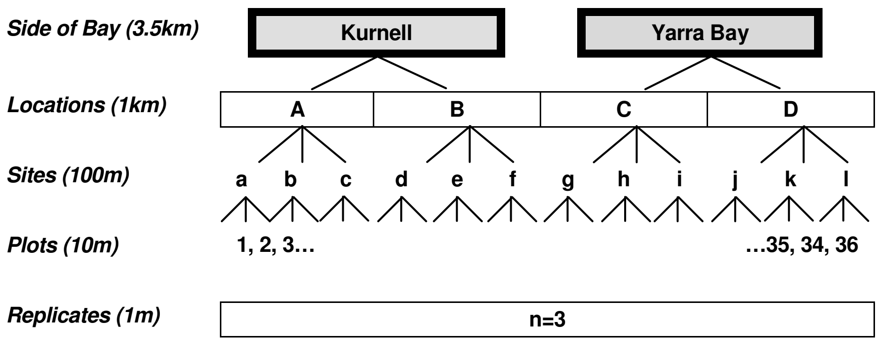
A consequence of this for other studies is that comparisons of macroinvertebrates over large scales could, in fact, be confounded with variability at smaller scales. Morrissey et al.(1994) also provided examples of factors likely to influence the structure of these macroinvertebrates at different spatial scales (see Table below).

Table 1.Examples of factors likely to influence structure of macroinvertebrate assemblages at different spatial scales

Factor	Scale					
	>100 km	1-10km	100's of m	10's of m	m's	<1 m
Latitude	■	■				
Climate	■	■	■			
Depth	■	■	■			
Topography (incl. biogenic features)	■	■	■	■		
Water Movement:						
larval supply	■	■	■	■	■	■
food/oxygen	■	■	■	■	■	■
mechanical stress		■	■	■	■	■
sediment type		■	■	■	■	■
Disturbances:						
feeding activity (eg. rays)					■	■
Adult larval interactions				■	■	■
Tube builders:						
refuge/structure				■	■	■
alter sediment						■
stabilise sediment				■	■	■
disturbance/interference					■	■
Competition					■	■
Predation					■	■

Figure 3: ***Hierarchical sampling design to investigate variability in macroinvertebrates at several spatial scales in Botany Bay***

(Source: Morrisey et al. 1994)



(c) Components of the ecosystem that should be investigated

Most aquatic ecosystems consist of a large number of components that could be affected by a particular project. Some of the components in aquatic ecosystems in NSW are presented in **Appendix 4**.

A component may be considered as a habitat (eg. seagrass meadow or kelp forest), an assemblage of organisms (eg. benthic macroinvertebrates inhabiting kelp holdfasts) or a particular species. For example, components that may be considered to be associated with a river include instream habitats, such as riffles and pools and riparian habitats. Within the instream habitats, assemblages of organisms that could be considered include aquatic plants, aquatic invertebrates, mammals (eg. platypus) and fish. Within the riparian strip, organisms that could be studied include vegetation, amphibians, mammals and birds. Note that there is likely to be overlap; for example, platypus need to be considered not only in terms of their instream requirements but also in relation to banks for their burrows.

In scoping the work required for an EIS, proponents should initially cast their net very wide and not reject any potential component. The components of the ecosystem should then be evaluated in relation to the proposed project and narrowed to a set of components that will be assessed in detail. These components are sometimes referred to as the "decision variables" (Keough and Mapstone 1995) because they will be critical in evaluating the significance of the aquatic environment that could be affected, in predicting the likely effects and ultimately in measuring the effects of the project. It would be highly beneficial, as part of the EIS documentation, to justify the selected decision variables.

Some of the factors used to determine which components are most useful for study can be assessed in terms of broad criteria:

- components of value to humans
- components with intrinsic value
- components as functional units
- components that are good indicators of change.

(Izmir 1993, Jones and Kaly 1996).

Components of value to humans These may include economically important fish and invertebrates and habitats utilised by such species. For example, seagrass beds provide habitat for juvenile of some species of fish, crabs and prawns of fisheries value and rocky reefs are habitat for many adult fishes, abalone, rock lobster, etc. Components of value also include species of value for ecotourism, such as whales, platypus, water birds, corals, large reef fish, etc.

Components of intrinsic value Some ecosystem components may be considered by society to be of intrinsic value and include rare or endangered species, or habitats that support particularly diverse assemblages of organisms or charismatic species such as whales. Species and habitats which are threatened are, in many cases, being considered under threatened species legislation at Commonwealth and State levels.

Components as functional units Some aquatic species may have a large or disproportionate (in relation to their abundance or size) effect on habitat or community structure. Thus, changes to these species may cascade to other components of the ecosystem. One example is the role of grazing gastropods and sea urchins on the structure of habitats on shallow rocky reefs (Andrew 1991, 1993). Such species have traditionally been termed “keystone” species, although the suitability of this definition was challenged recently by Hurlbert (1997).

Components as indicators of change

There are many components of aquatic ecosystems that have been used by ecologists as indicators of change and are considered to reflect the "health" of the ecosystem. These can include a mixture of biotic and abiotic indicators. Some of the major indicators that may be used are discussed as follows.

- **Water quality indicators —** These include chemical and physical variables (see Section 2.3) and biotic variables such as chlorophyll-a concentrations as an indicator of primary production and faecal coliform bacteria as an indicator of sewage pollution. Guidelines used to assess water quality have been developed and should be referred to (ANZECC 2000).

- **Sediment chemistry —** These include chemical and physical variables, particularly in relation to contaminants, as sediments can act as a sink (ie. places where substances accumulate) and a possible source for these. Other indicators of sediment chemistry include depth to anaerobic conditions and occasionally bacterial activity and occurrence of spores of toxic microalgae. The ANZECC water quality guidelines (2000) contains guidance on assessment of sediment impacts which is supported by guidelines derived overseas on sediment quality (eg. Long et al. 1995).

- **Assemblages of organisms** — Scientists often do field studies of assemblages of organisms in particular habitats as indicators of the existing conditions within an area and of change before, during and after environmental perturbation. In some cases, the use of these indicators can be readily justified on the basis of previously demonstrated responses to perturbation. In other cases, indicators have been selected simply on the basis of ease of sampling or understanding of taxonomy. One class of assemblages that is often used includes "macroinvertebrates" which are conveniently defined on the basis of their size (ie. they cannot pass through a 0.5 or 1.0 mm sieve). Smaller invertebrates (often termed "meiofauna" or "microfauna") may be more sensitive to environmental change, but have been largely overlooked in Australia due to difficulties with taxonomy and time constraints associated with sorting samples (Keough and Mapstone 1995).

- **Populations of species —** Where a particular species is identified as being appropriately sensitive to change, or a species is considered to be important within an area, field studies can be done to monitor changes in abundance or population structure (e.g. size and/or age). Population change in a species can be a rather insensitive indicator for several reasons. First, if regulatory authorities wait until a detectable decline in a population occurs, it may be too late to initiate changes to the environmental management of the ecosystem to prevent much greater loss or extinction. Second, populations in one area are often replenished by populations elsewhere, with dispersal of eggs, seeds and/or larvae via the water medium. If the area of the project is a "sink" for dispersal from a "source" area, the population may be maintained even though reproductive ability and/or mortality is relatively high. On the other hand, if the area of the project is a source, and the population suffers a decline in reproductive ability, there may be a decline in populations at a downstream "sink". In some cases, it may therefore be advisable to use physiological measures as indicators of the ecosystem (see item f, below).

- **Toxicological response —** Introducing chemicals into the environment often warrants toxicological studies to determine concentrations at which significant mortality occurs to "test organisms" (usually defined as the LC50, the concentration at which 50% mortality occurs over a standard period of time, say 24 or 96 hours). A limitation of this approach is that test organisms are often species easily maintained in laboratory conditions (eg. amphipods (*Allorchestes*), water fleas (*Ceriodaphnia*) and rainbow trout) but not necessarily representative of the native biota that could be affected by projects. Moreover, many chemicals released into the environment occur in conjunction with other chemicals or under a wide range of conditions (eg. variable temperature or salinity). Thus, there may be synergistic or antagonistic effects that are not accounted for by laboratory testing. One approach that is now being adopted is the use of flow-through systems whereby local assemblages are submitted to chemical testing under ambient conditions (see Chapman, 1995, for review).

- **Physiological and physical condition and behavioural changes** — Aquatic organisms exhibit both physiological and physical changes in response to environmental perturbation. These may include physical deformities associated with chemicals such as selenium, changes in reproductive condition, liver function, blood chemistry, visual acuity and genetic structure. Also, there may be behavioural responses to changes in environmental conditions, such as movement away from areas of low pH or dissolved oxygen, movement to or from warmer waters associated with thermal discharges or increased breathing rate associated with low oxygen levels. By and large, this class of indicators is used rarely in EIS studies in NSW, but should be considered for large projects or those which involve discharge into the water of potentially toxic chemicals.

- **Bioaccumulation —** The uptake of contaminants by aquatic organisms is of concern in relation to EISs that examine discharge of sewage and other forms of effluent, or may cause the release of contaminants stored in sediments. Bioaccumulation occurs typically via two processes, "bioconcentration" which is uptake from the surrounding water and "biomagnification", uptake via the food chain. Chemicals commonly tested for are heavy metals (eg. copper, lead, mercury), organochlorine pesticides (eg. chlordane, DDT, endosulphan), PCBs and polycyclic aromatic hydrocarbons (PAHs). Occasionally there is a need to test for chemicals associated with particular industrial processes, such as dioxins. Processes of bioaccumulation can be highly variable, depending on the chemicals of concern, organisms selected and even the organs tested. Moreover, bioaccumulation varies significantly through time, due to the age and physiological condition of the organism, the rate of discharge of a chemical into the environment (which may be continuous or pulsed) and the rate of breakdown and removal of the chemical from the body of the organism. The choice of species, organs analysed and frequency of sampling will therefore be crucial in ensuring that a proper study is done using bioaccumulation as an indicator of the ecosystem condition. In NSW, some test organisms include wild fish and invertebrates that are collected from the area of interest (eg. Lincoln Smith and Mann 1989a,b) or oysters obtained from commercial leases and deployed in the area of interest for a fixed period of time (eg. Scanes 1992, Ajani 1995 – see also Miskiewicz, 1992, for review).

- **Environmental events** — In scoping the studies that should be done for an EIS, it may become apparent that there have been environmental events that have occurred in the area of interest that may indicate a process or suggest an hypothesis that should be tested to aid in prediction of impacts for the project. One example of this is the occurrence of fish with red spot disease, or kills of fish and invertebrates following rainfall, which may suggest existing problems with acid sulfate soils (see **Case Study 2**).

Scoping Guidance 9: *Examine all the potential components of the aquatic ecosystem that could reasonably be investigated and define those components - the decision variables - that should be used in the assessment process for the proposed project.*

2.5 Determining the appropriate level of investigation in preparing an EIS

One of the most crucial (and often the most difficult) tasks is determining the appropriate level of scientific investigation to be undertaken in the EIS to provide an adequate description of the aquatic environment and a basis for making predictions of effects. Although these guidelines can offer help in this decision, a project-by-project approach will be required. This section discusses general levels of sufficiency that should be considered and relates these to a range of issues associated with EIA.

Due to the time and budgetary constraints associated with most projects, consultants must by-and- large, work within the existing framework of scientific knowledge and not embark on new lines of research. There may be exceptions to this, for example, for some very large projects or the introduction of new chemicals or processes into the environment.

There should also be basic, strategic research to develop new understandings for example when impacts from projects are not as predicted as revealed from the analysis of monitoring data (Underwood 1995a). But this also lies beyond the scope of day-to-day EIA investigations.

Thus, on one hand, stakeholders need to recognise that our understanding of the responses of the aquatic environment to a disturbance is limited and that EIA for a particular proposal must be seen in the context of available scientific information and models. On the other hand, proponents and consultants have the responsibility to use the most up-to-date information and procedures (often called Current Best Practice) in determining the scope of work and subsequent implementation and interpretation of work for predicting effects on aquatic ecology from a proposed project. One way to ensure a balance is through peer review (see Section 2.6).

This section discusses some of the requirements for determining the sufficiency of the studies on aquatic ecology for an EIS. Sufficiency is examined in terms of sampling, analysis and interpretation of data and ways of communicating the findings of studies on aquatic ecology.

(a) Sufficiency of sampling

EISs have been criticised either for providing masses of irrelevant data (Schindler 1976, Hilborn and Walters 1981) or for not having enough information to provide an adequate description of the environment (Fairweather 1989).

The description of the existing aquatic environment provides the foundation for the assessment of a proposed project. Thus, it should be comprehensive, but highly focused on those aspects of the local aquatic environment likely to be affected by the development. This is why it is important to have at least a preliminary understanding of the types of effects that could occur before field studies are designed. Extensive but un-focused work will not aid prediction, nor allow proponents to place areas that may be affected into an appropriate geographical context (Hilborn and Walters 1981, McGuinness 1988).

Broadly, the aquatic ecological investigations done as part of an EIS should seek to:

- describe the aquatic environment within an appropriate geographical (also called “spatial”) and temporal context
- assess the importance of the aquatic environment that may be affected on a local, regional and, if necessary, national and international scale
- identify other human activities in the area and describe how they may interact with the proposed project to cause cumulative impacts
- wherever possible undertake investigations with sufficient scientific rigour that they may contribute to a quantitative baseline to allow testing of predicted impacts after the project is initiated (Beanlands and Duinker 1983)
- wherever possible review studies of the effects of other, similar, projects on the aquatic environment.

There are numerous of approaches to describing the aquatic environment that are seen in EISs exhibited in NSW. These approaches are characterised broadly by Lincoln Smith (1991) and are summarised briefly here. Where field studies are done, it is not sufficient to merely compile a list of species present. Whilst it is important to understand if rare, endangered or economically-valuable species are utilising study area; lists of speices contribute little to the assessment process. Collection of data should focus on particular questions of interest, such as, how assemblage structure or population size varies compared to other areas (often called “control” or “reference” areas) or through time prior to implementation of the project.

Existing information/ qualitative site description

Given the potentially high cost of environmental studies, there is an incentive for proponents to rely on existing information wherever possible, supplemented by a brief site description.

While it would be expected that as part of the ecological investigations, information should be gathered on previous studies done in the area, on the types of habitats that may be affected and on the effects of similar projects in other areas, this information can not usually be relied upon for the prediction of effects of another proposal. Rarely, if ever, will existing information be available on the precise location of the proposed project. Often information gathered for one project may be inappropriate for use in the prediction of the effects of another proposal. By attempting to rely on existing information with a cursory description of the site, there is a high risk that time-consuming delays could occur when the proponent is required to provide supplementary information after the EIS has been exhibited. In the long term, it is more efficient for appropriate studies to be undertaken as part of the initial EIS study. Unless the proposed project is very small in scale and there is agreement among stakeholders that effects will be very small, appropriate studies should be designed for the particular project with existing information providing valuable background information.

Snapshot surveys

Snapshot surveys are site investigations done for an EIS at a single point in time. They presently constitute by far the most common approach to investigations of aquatic ecology for EISs in NSW. Their major drawback is that they present only a static view of dynamic ecological processes (Fairweather 1989). Moreover, the timing of snapshot surveys can be critical. For example, spring settlement of fish larvae into seagrass beds could be overlooked by sampling at other times. Water quality can also be highly variable, showing large changes in response runoff after rain, state of the tide and even time of day. Three snapshot approaches can be considered.

- **Survey only of areas that may be affected by the proposal** — Surveys restricted to the area of potential disturbance are valid only where there is sufficient existing information from elsewhere to place the aquatic ecology of the area into an appropriate spatial and temporal context. This is rarely possible, however. The detection of rare or endangered species in a freshwater stream is one case. Another is the comparison of contaminants in water or biota against appropriate standards (eg. ANZECC 2000, National Health and Medical Research Council maximum recommended limit), although this may still be problematic as standards can vary depending on local conditions, species present and patterns of utilisation by humans. By and large, estimates of abundance and diversity of biota, density of aquatic plants, etc, need to be placed into a context consistent with the geographic scale and timing of the project. Thus, sampling confined to the area that might be affected by the project is not generally recommended.

- **Survey of the areas that may be affected and control or reference areas** — Concurrent sampling of areas that may be affected by a project and control (ie. unaffected by the project) areas is the best way to describe the aquatic environment in an appropriate geographical context. This is because standardised sampling procedures can be used and possible confounding of results due to temporal variation can be minimised or removed. Apart from describing the environment in a way that can be understood and assessed by all stakeholders, it will allow the proponent to assess the ecological importance of the area. Finally, it can contribute to the baseline for measuring the effects of the project, if approved (Beanlands and Duinker 1983, Keough and Mapstone 1995). This approach is recommended for any aquatic ecological investigations associated with small to medium-scale projects. It is also recommended for all large-scale projects, but with sampling at all sites through time. As a bare minimum, at least two control sites should be sampled to provide an appropriate spatial context and in many cases numerous control sites may be required. Keough and Mapstone (1995) present a good summary of the need for multiple controls.

- **Process studies or issue-oriented approach —** Sometimes there is an opportunity to do planned field experiments to improve predictions of effects. For example, predicting the effects of proposed marinas on biota could be improved by surveying the biota at existing marinas in the same area (see Lincoln Smith 1991 for examples). Analogous to this approach is the use of small-scale manipulations in the field and toxicological studies to provide a more direct basis for predicting effects. One example of this might be small-scale experimental dredging of an area to determine rates of recolonisation by benthic invertebrates. Hilborn and Walters (1981) discussed some of the problems associated with process studies - these relate mainly to extrapolating from small-scale experiments to large-scale impacts.

Sampling in space and time

Sampling at the site of the proposed project and at control sites on two or more occasions prior to initiation of the project provides the most comprehensive description of the environment that could be affected by the proposed project. This approach, in conjunction with issue-oriented sampling (which may or may not need to be repeated over time) would provide a suitable basis for assessing the effects of a large-scale project - or one proposed in an environmentally-sensitive area - and would contribute to the baseline for on-going monitoring.

There are two questions that need to be addressed with respect to sampling through time within the framework of EIA.

- **Should sampling be done on a seasonal basis?** The answer to this is no, unless there is very good *a priori* information to suggest that there are clearly defined seasonal patterns in the decision variables selected. In fact, if the question of interest relates to how variables change on a seasonal or event basis (eg. changes in river flow), the most appropriate design would require sampling at 2 or more times within each season over 2 or more years, which would provide a means of discriminating short-term and inter-annual variability from seasonal effects. A better approach is to sample more-or-less haphazardly through time (Stewart-Oaten *et al.* 1986, Underwood 1991, 1993) although this approach may be somewhat constrained by logistical requirements.

- **How many samples are sufficient to compile an appropriate measure of variability through time?** This is likely to depend on:
  - the duration and intensity of the disturbance; and
  - the way in which organisms respond to the disturbance.

  Argument is often presented for sampling periods over 1, 2, 5 or 10 years, but there is little valid justification for such claims. In fact, it is unlikely that we would be able to sample the entire natural range of variability with any sensible sampling program (Hilborn & Walters 1981, Westoby 1991).

There is no simple answer to this question and the duration of sampling must be determined on a case-by-case basis. The commitment by a proponent to commission temporal sampling is a recognition that aquatic ecosystems have dynamic rather than static structures and processes. Interpretation of changes through time will improve by concurrently sampling control sites to provide a context against which temporal variability at the site of interest can be assessed. For those projects that are likely to require monitoring, power analyses using two or more survey times can be used to indicate if more surveys should be done the project is to have a reasonable chance of detecting significant change due to the project (see Parts 3 & 4).

(b) What level of investigation should be undertaken in an EIS?

It is difficult to prescribe the level of detail required for EISs for particular projects. This will depend on the characteristics of the proposal and the waterbody and the natural resources that may be affected as well as the concerns of stakeholders. The level of detail required should be developed in consultation with stakeholders and environmental experts, emphasising the need for consultation early in the scoping phase. Notwithstanding this, methodology has been developed in the guideline to assist proponents and approval authorities in making this decision.

The approach, outlined below, is a risk based approach which considers the relative significance of a range of factors, including value of the ecosystem component, type of disturbance, the likely response of the decision variable(s), the scale of the project and the risk for unpredictable or cumulative effects.

A weighting has been given in relation to the value or importance of the ecosystem component likely to be affected. In addition weightings have also be given in relation to the risk of cumulative effects or the risk of unpredictable effects. These added weighting are consistent with the precautionary principle and apply where there is a lack of information, or where there may be potential for unpredictable events (including accidents). The higher the risks, the greater the need for more detailed ecological studies.

One factor that has not been incorporated directly into the approach is the existing level of disturbance from other anthropogenic sources. It is often considered that the aquatic ecology of degraded areas requires much less study than pristine areas. It is important, however, that proposed projects should either seek to improve the aquatic ecology of degraded areas or cause no further degradation. On this basis, the level of investigation required to achieve these aims sometimes may be greater than for a pristine area.

Scoping Guidance 10: *Within the bounds of current understanding of aquatic ecology, the level of ecological investigation should be based on existing information; and on factors such as the type of disturbance, response of the decision variables, the scale of the project and the risk of unpredictable or cumulative effects.*

Scoping Guidance 11: *Apply the precautionary principle in determining the level of study for a proposed project. for example, where there is a risk of adverse unpredictable or cumulative impacts, proponents should seek a greater level of detail in their studies of aquatic ecology.*

(c) Methodology to assist in determining the level of detail required for an EIS

The following methodology has been developed to assist in determining the level of investigation required for a particular proposal and is based on general types of study approach and factors that should be considered while scoping the works to be done on aquatic ecology for the EIS. Table 2 shows the major factors that should be considered in determining the level of study and Table 3 shows 4 indicative study protocols that are recommended. The two components are linked by the formula:

$$Ls = (T + Ri + Rs + Rr + S) \times Rk \times Cu \times Im$$

Where the level of study Ls = level of sufficiency, ie. the score corresponding to the indicative study protocol in Table 2; T = type of disturbance; relative significance of Ri, = inertia, Rs = stability and Rr = resilience, S = scale of the proposed project, Rk = the degree of uncertainty, Cu = likelihood of cumulative effects and Im = importance of the decision variable considered (Tables 2 & 3).

Considering the circumstances

- ***Where the exact site has already been described previously for a similar project.*** This can occur when a new EIS is prepared for a project. In cases where the aquatic environment was properly described and where the time interval between EISs is relatively small (eg. < 2 years), it may be acceptable to rely on the existing information. It is important to recognise that descriptions of other parts of the same waterway or the same habitat(s) in other waterways, would not constitute an adequate description of the existing environment for many decision variables.

- ***Where the site has not been described previously to the extent required to fully assess the effects of the proposal.*** The sufficiency formula can help with scoping the required level of investigation here.

- ***Where the sufficiency formula indicates the need for quantitative sampling using spatial or temporal controls, but no adequate controls are available.*** There may be cases where there are no adequate spatial controls. Here, it would be desirable to sample at the project site over several times to define the extent of natural variability at the site, and seek to correlate decision variables with a range of environmental variables (eg. state of tide, freshwater flow, etc). There may also be cases where there are inadequate temporal controls, for example when the project is being" fast-tracked". Here it important to consider whether the project should be delayed to provide sufficient time for a proper evaluation. If not, then it would be desirable to have a large number of spatial controls (eg. ≥ 5) to provide a broad spatial context for evaluating the proposal. If there are neither spatial nor temporal controls available, assessment will need to be made on the basis of information on the site and, if possible, the findings of other studies, with a highly precautionary approach taken in assessing the proposal.

- ***Where there are rare, endangered or threatened species, communities or habitats present.*** In such cases, proponents must conform to the relevant provisions relating to threatened species. Moreover, in some cases, the sufficiency formula may not be appropriate – for example, whales and migratory birds function at geographic scales that limit or invalidate many types of study. Other species may be so rare that finding appropriate control locations is impractical or impossible. Notwithstanding this, the sufficiency formula, if used cautiously, may assist in scoping studies for some of these decision variables.

Table 2.Factors to consider in determining level of study detail for an EIS

Factors to consider	Symbol	Level	Relative significance
Type of disturbance	T	Pulse Press Catastrophic	1 2 3
Response of decision variable	Ri	Inertia - High Inertia - Moderate Inertia - Low	1 2 3
	Rs	Stability - High Stability - Moderate Stability - Low	1 2 3
	Rr	Resilience - High Resilience - Moderate Resilience - Low	1 2 3
Scale of proposed project compared to similar approved projects elsewhere	S	Small Medium Large	1 3 6
Degree of uncertainty in predictions	Rk	Low High	1 2
Risk of cumulative effects	Cu	Low High	1 2
Importance of the component in the area that could be affected	Im	Small Moderate High Critical	1 2 4 8

Table 3.Determining the level of study detail for aquatic ecological investigations for an EIS

Level of investigation	***Range of sufficiency scores (Ls)***	***Indicative study protocol***
Level 1	*5-7*	a. Existing information and consultation b. Site description including habitat inventory of area of proposed project
Level 2	*8-29*	a. Existing information and consultation b. Site description including habitat inventory of area of proposed project c. Quantitative snapshot survey of selected ecosystem components in area proposed for project and 2 or more control sites
Level 3	*30-59*	a. Existing information and consultation b. Site description including habitat inventory of area of proposed project c. Quantitative surveys of selected ecosystem components/area of proposed project and 2 or more control sites. Surveys to be done on at least 2 occasions
Level 4	*≥60*	a. Existing information and consultation b. Site description including habitat inventory of area of proposed project c. Quantitative surveys of selected ecosystem components in area proposed for project and 2 or more control sites. Surveys to be done on at least 2 occasions d. Issue-oriented or process studies of critical ecosystem components (eg. decision variables such as toxicity tests, small-scale manipulations, numerical modelling)

Case Studies : Examples of applying the methodology to scope the study required in EIS
Four hypothetical case studies show how to determine the level of investigation for an EIS. In each, sufficiency is examined for several decision variables that may be important, but there are likely to be others that would need to be addressed. There is also a need to consult to obtain some agreement on the relative magnitude of each factor in the formula.

1. Sand extraction from the upper reaches of an estuary
It is proposed to extract 10,000 m^3 sand per year for three years over an area of 1 ha in the upper reaches of an estuary, which was considered to be a small-scale project. Four issues emerged:

- *the effects of dredging on water quality in relation to nutrients, turbidity, suspended solids, dissolved oxygen (DO), pH, chlorophyll-a, salinity and potential for stratification within the dredge hole created);*
- *benthic organisms living in the sand to be extracted;*
- *fish assemblages utilising the area; and,*
- *the effects of dredging on Australian bass, which may spawn in the vicinity of the dredge area.*

Issues related to water quality were given a moderate value, while benthos was given a low value because of a large availability of similar habitat elsewhere in the estuary. Fish were given a moderate value due to local commercial and recreational fishing interests and bass were given a high value because of their importance to recreational fishing. They were also given a high risk because the number of spawning sites within the estuary is limited. ***Table 4*** *indicates that water quality, benthos and fish would require snapshot surveys including control sites, where available.*

For water quality, "snapshot" would require sampling over at least two tidal cycles. For bass, the indicative level of study suggests sampling over time (eg. several times over the spawning period) at the extraction site and control sites. Note that if the proponent undertook to avoid extraction during the periods when bass occurred in the estuary, the risk of unpredictable effects would be reduced and so would the indicative level of investigation for the EIS.

Table 4.Summary of the results of apply the methodology to hypothetical dredging proposal

Decision Variable	Project Phase	Factors to be considered[1]									Study Level
		T	Ri	Rs	Rr	S	Rk	Cu	Im	Ls	
Water quality	Operational	2	2	2	2	1	1	1	2	**18**	**2**
Benthos	Operational	3	3	1	1	1	1	1	1	**9**	**2**
Fish	Operational	1	1	1	1	1	1	1	2	**10**	**2**
Australian bass	Operational	1	2	2	2	1	2	1	4	**36**	**3**

[1] Note: T = type of disturbance; Ri = inertia; Rs = stability; Rr = resilience, S = scale of the proposed project, Rk = the degree of uncertainty, Cu = likelihood of cumulative effects and Im = importance of the decision variable considered; Ls = level of sufficiency

2. Marina development in an estuary
It is proposed to construct a 75-berth marina in a well-flushed section of an estuary. The proposal also entails a one-off dredging of 20,000 m^3 of sediment to provide boat access. There are other marinas in nearby bays, so there may be cumulative effects to consider. During scoping, issues that were identified included the following:

- *water quality with respect to nutrients, turbidity, suspended solids, chlorophyll-a, pH, DO and heavy metals, particularly copper;*
- *sediment quality, with respect to existing levels of heavy metals;*
- *benthos of soft sediments;*
- *a bed of Zostera seagrass occurring adjacent to the project site, which would not be dredged, but may be subject to indirect effects;*
- *fish and mobile invertebrates associated with the seagrass bed.*

Scoping also identified a need to consider the effects of both the construction and operational phases of the project, but cumulative effects would apply only to the operational phase. ***Table 5*** *indicates that,* *in respect of the construction phase, snapshot surveys would be required for water quality and benthos, and that a review of existing information and description of the distribution of sediments would be sufficient for sediment quality. In terms of the operational phase, analysis indicated that level 3 studies would be required for water quality and sediment chemistry and level 4 studies would be required for seagrasses and fish and mobile invertebrates in seagrass beds. Issue-oriented studies could include:*

- *modelling the concentrations of contaminants in the water and the likelihood that they would impinge on the seagrass bed; and*
- *surveys of seagrasses and associated biota near existing marinas in the estuary.*

Table 5.Summary of the results of apply the methodology to hypothetical marina proposal

Decision Variable	Project Phase	Factors to be considered[1]									Study Level
		T	Ri	Rs	Rr	S	Rk	Cu	Im	Ls	
Water quality	Construction	1	2	1	1	3	1	1	2	**16**	**2**
	Operational	2	1	1	1	3	1	2	2	**32**	**3**
Sediment chemistry	Construction	1	1	1	1	3	1	1	1	**7**	**1**
	Operational	2	2	2	3	3	2	2	1	**48**	**3**
Benthos	Construction	3	3	1	1	3	1	1	1	**11**	**2**
	Operational	2	2	2	2	3	1	2	1	**22**	**2**
Zostera bed	Construction	1	1	1	1	3	2	1	4	**42**	**3**
	Operational	2	2	2	1	3	2	2	4	**80**	**4**
Fish in Zostera bed	Construction	1	2	1	1	3	1	1	4	**32**	**3**
	Operational	2	1	1	1	3	2	2	4	**96**	**4**

[1] Note: T = type of disturbance; Ri = inertia; Rs = stability; Rr = resilience, S = scale of the proposed project, Rk = the degree of uncertainty, Cu = likelihood of cumulative effects and Im = importance of the decision variable considered; Ls = level of sufficiency

3. Water extraction from a coastal river

It is proposed to pump 100 ML/day from a river at a pumping station 50 km upstream of the tidal limit. The amount of water pumped would be a large proportion of the total river flow during some seasons and during drought. This type of project would be considered to be large scale, because of its potential to influence a large section of the river downstream of the pumping station. Scoping identified three main issues that needed to be addressed:

- *water flow and its effects on river geomorphology including potential for fish passage, wetted perimeter and sedimentary processes;*
- *macroinvertebrates occurring in riffle beds; and*
- *the distribution of macrophytes.*

The geomorphology was considered to be of critical importance and the other two issues were considered highly important. The constant extraction on a daily basis was considered to represent a press disturbance, although the magnitude of this disturbance would vary in relation to the amount of natural flow in the river. The geomorphology was considered to have a low inertia, but would recover rapidly if extraction ceased. Depending on the shape of the river channel, macrophytes may or may not be very sensitive to reduction in river flow. ***Table 6*** *indicates that geomorphology should be addressed under level 4, while macrophytes and macroinvertebrates would require level 3 investigation. One issue-oriented approach that could be considered for ecological issues related to geomorphology would be to map and measure all riffles downstream of the proposed pumping station and repeat this under a variety of natural flow conditions. In addition, hydrological modelling could be used to predict how barriers to fish passage, wetted perimeter, etc, varied under the proposed pumping regime. One problem that often arises with respect to studying rivers is the difficulty in finding suitable control locations. Where none are available, approaches such as the use of the SIGNAL index (Chessman 1995, Chessman et al. 1997) or the river health models (Davies 1994) may provide the basis for describing assemblages of macroinvertebrates.*

Table 6.Summary of the results of apply the methodology to hypothetical water proposal

Decision Variable	Project Phase	Factors to be considered[1]									Study Level
		T	Ri	Rs	Rr	S	Rk	Cu	Im	Ls	
Flow, fish passage, etc	Operational	2	3	1	1	6	1	1	8	**104**	**4**
Riffle Invertebrates	Operational	2	3	1	1	6	1	1	4	**52**	**3**
Macrophytes	Operational	2	2	1	1	6	1	1	4	**48**	**3**

[1] Note: T = type of disturbance; Ri = inertia; Rs = stability; Rr = resilience, S = scale of the proposed project, Rk = the degree of uncertainty, Cu = likelihood of cumulative effects and Im = importance of the decision variable considered; Ls = level of sufficiency

4. Release of treated industrial effluent

*A Company proposes to discharge up to 20 ML/day of treated industrial effluent, containing a variety of waste chemicals, which are diluted with warm freshwater. Other industry releases effluent in the area, so there is a potential for cumulative effects and there is uncertainty about the toxicity of the effluent. The discharge is at the mouth of an embayment, where there are rocky shores near the discharge pipe, but mangroves occur at the head of the bay. Because the effluent is likely to "float" on the cooler saline water, the greatest concern is for impacts to occur in the intertidal zone, either in the mangroves or rocky shores. Decision variables are selected as water quality, mangroves in the bay, epifauna in the mangrove forest, rocky plants and animals and bioaccumulation of contaminants in oysters and a species of gastropod (**Bembicium auratum**) which both occur on the rocky shores and in the mangrove forest. The type of disturbance is considered to be a press and the scale of the project moderate, but with a high degree of uncertainty and potential for cumulative effects (**Table 7**). On this basis, it was concluded that water quality and mangrove components would require a level 4 investigation, while rocky shores and bioaccumulation would require level 3. In this case, issue-oriented studies may include toxicity testing – preferably using test species from the planktonic and mangrove habitats - and modelling plume behaviour in relation to the mangrove forest and to the plumes of other sources of effluent in the waterway.*

Table 7.Summary of the results of apply the methodology to hypothetical project proposal

Decision Variable	Project Phase	Factors to be considered[1]									Study Level
		T	Ri	Rs	Rr	S	Rk	Cu	Im	Ls	
Water quality	Operational	2	2	1	1	3	2	2	2	**72**	**4**
Mangroves	Operational	2	1	1	1	3	2	2	2	**64**	**4**
Mangrove epifauna	Operational	2	2	1	1	3	2	2	2	**72**	**4**
Bioaccumulation: oysters	Operational	2	2	2	2	3	2	2	1	**44**	**3**
Rocky shore biota	Operational	2	2	1	1	3	2	2	1	**36**	**3**

[1] Note: T = type of disturbance; Ri = inertia; Rs = stability; Rr = resilience, S = scale of the proposed project, Rk = the degree of uncertainty, Cu = likelihood of cumulative effects and Im = importance of the decision variable considered; Ls = level of sufficiency

(d) Sufficiency of analysis of data and interpretation of results

In scoping the work to be done for an EIS, it is important to determine, at an early stage, how the data obtained will be analysed and presented, and the approach to be used to interpret the results. Some approaches and suggestions for statistical analyses are provided in Part 3. If the analysis parameter are not considered at the outset, inappropriate information may be collected (eg. using inappropriate methods, non-independence of data, detection limits for chemical analyses above recommended water quality guidelines, etc), making it valueless in providing an objective interpretation of the condition of the existing environment. Thus, in the scoping studies for an EIS, it is crucial that:

- provision be made for data to be presented, analysed and interpreted objectively so stakeholders and any peer reviewers can interpret results independently
- consultants define the questions that the data collected will be used to address and that they know how data will be analysed before they collect them.

These two steps can help proponents to avoid the need for gathering data after the EIS is submitted.

Scoping Guidance 12: *Define the questions of concern and determine, in as much detail as possible, how data will be analysed statistically before collecting them.*

(e) Sufficiency of communication

As part of the scoping of aquatic ecological studies for an EIS, it is important that proponents determine what information they will need to receive from other stakeholders and how they will communicate information to the stakeholders.

Scoping Guidance 13: *Identify government departments, local groups and commercial interests that will need to be consulted regarding aquatic ecology and identify protocols by which information gathered will be communicated to these bodies.*

2.6 Scoping procedures

This section provides practical steps for scoping studies of aquatic ecology for an EIS. It follows the stages identified in Figure 1 and includes the period from when proponents start planning a project until they receive the Department of Planning Director-General Requirements, which may be considered to be the formal commencement of the EIS process. Guidance is presented here for inputs into the process and the outputs that might be expected at each stage. Other stages of the process shown in Figure 1 are discussed in Part 3.

(a) Scoping studies

Inputs to the scoping study

At least five sources of information should be considered when scoping the studies for an EIS to identify any types of disturbance to the aquatic environment (Figure 1). These include:

- An understanding of the proposal (even if only preliminary)
- Lessons on the effects of other projects
- Interdisciplinary exchange and peer review
- Consultation with government agencies and other stakeholders
- Preliminary investigations or Pilot studies

Exchange of information between consultants examining aquatic ecology, water quality, hydrology, sediment chemistry and other relevant disciplines will further help focus on issues that need to be considered. Where possible, specialists should work at matching spatial scales to maximise the relevance of information to other specialists. Water quality specialists should collect water samples from similar sampling locations to aquatic ecologists, so that differences in water quality may be related to any differences in aquatic biota. To have relevance in assessment of aquatic ecology, chemical analyses must be done at detection limits that can be related to water quality guidelines for maintenance of aquatic ecosystems (eg. ANZECC 2000).

Also, specialists in hydrology should provide information on river flow, tidal exchange, currents, etc that are at a suitable scale for ecological interpretation. Two-dimensional modelling of tidal exchange may be sufficient for some assessments, but for others the crucial issue may be the change in salinity with water depth on each tidal cycle. Early discussion of these issues enables coordination of study programs and the data needs of each group of specialists.

Scoping Guidance 14: *Obtain advice on aquatic ecology early in the design of the project, ensure that data collected by all specialist consultants, wherever possible, matched at similar spatial and temporal scales and that study programs are co-ordinated.*

During scoping, the consultation process should begin with relevant Government authorities (and other guidelines - Appendix 5) local interest groups (eg. fishers and oyster farmers) and conservation groups. Consultation helps identify issues of local importance to residents, commercial interests, etc.

If proponents are to incorporate peer review (also called technical review) into the process, this should be initiated before study designs have been finalised. According to Beanlands and Duinker (1983, page 42): "...emphasis on 'front-end' peer review, at the inception and design stages, would help to ensure appropriate levels of scientific integrity in the ecological investigations. Without front-end review, proponents and consultants will continue to run the risk of having to repeat studies in the event the reviewers are unhappy with their design or conduct." The use of peer review is important for quality control to ensure that proposed projects are assessed in an open and environmentally responsible manner.

Scoping Guidance 15: *Where peer review is used by proponents to provide independent assessment of aquatic ecological studies, the reviewers should be engaged before study designs are finalised.*

Preliminary investigations

Preliminary investigations or pilot studies should aim to provide an overview of the area that may be disturbed by the proposal and to assist with developing the optimal sampling design for later studies. Specifically, preliminary investigations should address five tasks:

- **Review existing information** Review existing information on the area of the waterway that could be affected by the project This includes examining published and unpublished accounts of aquatic ecology and fisheries of the waterway of interest.
- **Preliminary map of habitats** It is important to have a basic understanding of habitats occurring in the area of interest. This information should be obtained from a site visit and, if available, aerial photographs and earlier mapping of habitats (eg. West *at al.* 1985).
- **Identify other existing developments** Early understanding of how a proposed project may interact with other human activities – developments, activities, etc will help in initial assessments of impacts and in designing further studies.
- **Select Control locations** Pilot investigations should be used to make a preliminary selection of control locations that can be used to place the area that may be affected into an appropriate geographical context and potentially for monitoring the effects of the project. Control areas do not (and probably cannot) be identical to the project site and will vary in their aspect, geomorphological characteristics and assemblages of organisms. They obviously need to support the same type of habitat and assemblages and, the more that control sites vary amongst each other, the greater the need to have a large number of controls to compare against the project site.
- **Determine the optimal sampling design** Pilot studies are an important tool used to determine how best to allocate sampling effort, yet are rarely seen in EISs exhibited in NSW. Good reviews of the use of pilot studies are given by Underwood (1981), Andrew and Mapstone (1987), Fairweather (1990) and Keough and Mapstone (1995). Pilot studies can be used to determine the optimal spatial scales at which to sample, the optimal allocation of sampling effort at each scale and the number of samples (generally referred to as "replicates") that should be obtained for each decision variable selected (see Part 3).

***Scoping Guidance 16**: Preliminary investigation or pilot studies should be considered as part of scoping procedures to assist with the design of ecological studies for an EIS.*

Outputs from the scoping study

The output from the scoping studies should result in a well-defined aquatic ecology study brief for the EIS that can be used to evaluate a proposal. There will be preliminary information on:

- the aquatic environment that could be affected including boundaries of disturbance, ecosystem boundaries/linkages and ecosystem components
- the nature of the likely effects that may occur including a provisional list of issues
- provisional study design including how the consultants propose to undertake baseline studies and the appropriateness of decision variables in terms of testable hypotheses

Importantly, this stage of the process provides an early opportunity to assess the sustainability of the project and decide whether to continue with it, or modify it to make it more sustainable (and therefore more likely to be approved).

(b) Planning focus meeting

Inputs The Planning Focus Meeting (PFM) is an important component of the early consultative process and brings together proponents, regulatory authorities and interest groups. The results of scoping studies should be used to inform discussions at the PFM. The PFM provides an excellent opportunity to test the appropriateness of the proposed study design.

Outputs Three major outputs from the PFM should be a final draft of the study design for aquatic ecological investigations, a refinement of the proposal and a preliminary views on the sustainability of the project from government authorities and other stakeholders.

(c) Director-General's Requirements

Inputs The Department of Planning Director-General Requirements (DGRs) list the matters which must be addressed in the EIS. Department of Planning will consult other relevant approval authorities in preparing the DGRs. It is in the proponents interests to provide adequate information on the project and intended studies including consultation, minutes of PFMs, preliminary investigations, etc so that the DGRs are focused on those matters key to decisions making.

Outputs The outputs will include specific requirements from the Director, which will reflect both the level of detail given by the proponent in initial correspondence and any specific concerns issues identified by Department of Planning and other government agencies.

2.7 Overview of Part 2 of the guideline

Determining the scoping of aquatic ecological studies to be undertaken for an EIS is the key outcome of this first step. It involves consultation, interaction among specialists and the use of current best practice to design preliminary and main investigations.

Part 2 of this Guideline provides a framework in which an appropriate level of investigation can be developed. The scoping appraisal (**Appendix 1**) is one way that stakeholders and authorities can evaluate study needs and how proponents will seek to address them.

Clearly, many decisions must be made on a project-by-project basis and it is desirable that there is extensive consultation with regulatory authorities and stakeholders during the early phases of the project. The Planning Focus Meeting and other meetings with stakeholders can contribute at this preliminary stage in scoping the issues to be considered in the study design.

3. PREPARING THE AQUATIC ECOLOGY STUDIES

3.1 Introduction

The next Part of the Guideline examines the design and implementation of studies for aquatic ecology related to EIA. Important topics include sampling or experimental design, sampling methods, quality assurance, peer review, report presentation and storage of data. Some of the issues initially raised in relation to scoping are now discussed from the perspective of implementation.

To aid in the assessment process, information gathered should have the following components:

- a description of aquatic habitats present that may be affected by the proposal;
- sufficient data to provide an assessment of the significance of the aquatic ecosystem(s) that may be affected, relative to locality, region and other habitats;
- sufficient data to provide an understanding of the ecology of the area to predict responses of the aquatic flora and fauna to the proposed project; and
- a contribution to a baseline that may be required for future monitoring

The design and implementation of surveys and/or field experiments of aquatic ecology have received a great deal of attention in recent years (eg. Green 1979, Hurlbert 1984; Stewart-Oaten *et al.* 1986, Underwood 1981a, 1989, 1997; Keough and Mapstone 1995). It is not the aim of this Guideline to provide a detailed approach to aquatic surveys, but rather to provide some general principles that should be considered and to suggest where proponents and their consultants may obtain further advice.

In Part 3, guidance is provided in the undertaking of aquatic ecology investigations. These are labelled "Investigation Guideance" and summarised as an Investigation Appraisal in **Appendix 2**. While the Scoping Appraisal (**Appendix 1**) should be done prior to commencement of investigations on aquatic ecology, the Investigation Appraisal is most likely to be done on the draft EIS or the final EIS during its exhibition. Appraisal of the draft EIS is preferable, as it helps identify and address shortcomings before the proponent has committed the EIS to public display.

3.2 Use of existing information

An obvious and essential starting point for designing aquatic surveys is to review any existing information (including maps, aerial photographs, etc) on the area that may be affected by a proposed project.

- If no existing information is available, the studies done for an EIS will need to compile a description of the area and then undertake further, more detailed investigations on the flora and fauna present.

- If there is some existing information, further studies may involve sampling habitats or locations not sampled previously but that are potentially affected by the proposal. Alternatively, further studies may involve repeating earlier samples to obtain a measure of temporal variability, or sampling under different environmental conditions (eg. fast versus slow flow in rivers; summer versus winter conditions, etc.).

Reliance on existing information to provide an adequate description of the environment for assessment of impact is unlikely to be sufficient for most EISs (Section 2.5(a)). Not only is there unlikely to be enough information on the project area to provide assessment for a specific project, but existing information can be out of date, incorrect or misinterpreted. This was highlighted in a critique of existing information on the aquatic ecology of Botany Bay (McGuinness 1988).

Existing information can also be used to assess the potential effects of a proposed project by examining responses of aquatic organisms to similar projects occurring in similar habitats elsewhere. Understanding ecological responses to particular impacts should assist in both the design of investigations and predicting the effects of the proposal being assessed. This latter role is addressed further in Part 4.

Investigation Guidance 1: *Review and critically evaluate existing information on the aquatic ecology of the location of the proposed project. Identify the strengths and weaknesses of this information and ensure that sampling programmes: 1) supplement existing information and 2) address the types of effects likely to be associated with the proposed project.*

3.3 Sampling methodology

This Guideline does not provide detailed methods for sampling but a brief review, with references, is presented to provide an overview of some of the methods currently in use. Data obtained from field studies should provide an objective basis for the EIA process. Sampling methods should be repeatable and, in most cases, quantitative data should be obtained.

Proponents selecting consultants to do field studies should expect them to be familiar with and preferably have a practical experience of, the methods required to sample the decision variables selected.

(a) Describing aquatic habitats

Describing aquatic habitats likely to be affected by a proposed project is fundamental to the EIA process. By knowing what habitats are present, it may be possible to infer the types of plants and animals that will also be present. Moreover, by knowing the extent of the habitats that may be affected, the impact can be placed within the local, regional and state contexts. Two approaches are used commonly –

- a simple inventory of habitats
- quantitative measures of extent and distribution (eg. Morris and Therivel 1995).

Whichever approach is used, it may be useful to obtain photographs of different habitats to provide a permanent record prior to development.

Habitat inventory

The simplest description normally made is to visit the site and compile an inventory of habitats present. Within an estuary, for example, there may be seagrasses, mud or sand banks, deep holes, mangroves, saltmarshes or rocky substrata (natural and artificial) (Burchmore *et al*. 1993). Within a river, habitat inventories should include the presence of aquatic macrophytes, deep holes, snags, adjacent wetlands and billabongs/anabranches.

A limitation with this approach is that it fails to provide an objective indication of the size of various habitats, which could be used for assessing importance in a regional context, for assessing the potential impact or for measuring the extent of change. This limitation is of greater concern where habitats are fragmented within the landscape and where some measure of the extent of habitats and their relationships to one another is needed. A good example of this is on rocky reefs, where habitats often occur as a mosaic of patches (eg. kelp, turfing algae, rock barrens, etc) within the reef structure (Underwood *et al*. 1991).

This example also raises the issue of the coarseness of habitat definition that may be appropriate. In some cases its may be sufficient to simply identify the presence of rocky reef. In others may be important to identify the range of reek habitats occurring within the rocky reef. This issue also arises in studying saltmarshes, where there a numerous species occurring with different distributions within this broad habitat type.

Quantitative description of habitats

Where scoping studies identify an aquatic habitat that is likely to be lost, reduced or otherwise modified by a proposed project, it is usually important to obtain a quantitative estimate of the size of the habitat present. This allows the magnitude of changes to be predicted and to place them in a local or regional context. Adopting this framework has the advantage of allowing habitat information to be layered within Geographic Information Systems (GISs) and can be used as a valuable tool in impact assessment by incorporation into "constraints mapping" (Morris and Therivel 1995; see also Part 4).

Methods used to describe quantitatively habitats will depend upon the proposed project and the spatial scale of interest to the investigation. Four types of quantitative description are seen in EISs, including:

- habitat mapping from the ground using base maps or remote imagery (eg. aerial photographs and satellite imagery)
- defining the boundaries of habitats or features within habitats
- determining patch size of features within habitats or within a mosaic of habitats
- modelling the extent of habitats under different environmental conditions.

Some EISs attempt to model quantitatively the extent to which habitats vary under different environmental condition, both natural and human-induced. For one EIS, changes to beach habitat and intertidal rocky shores were modelled in relation to changes in wave energy (Metromix 1993). In another, changes to water depth, sedimentary processes and wetted perimeter of a river were modelled in relation to changing flow conditions (Dames & Moore 1996). Modelling changes in habitat due to natural variation can allow the assessment of the effects of the proposed project in relation to the natural background. This could be potentially limited by the need to calibrate such models with real data and then validate them by applying them to a real situation in nature.

Some habitats may be difficult to quantify, for example the habitat provided by snags within a river. It is possible to count the number of snags over set distances of river, but the irregular shapes and sizes of the snags are difficult to quantify. Depending on the question of interest and the nature of the waterway, it may either be possible to count snags or develop a measure that take into account categories of type and size of snags.

NSW generally has a good coverage of aerial photos. These are often available for the same places at different times, sometimes spanning several decades. Aerial photos were used to map the distribution of seagrasses, mangroves and saltmarshes in estuaries and embayments along the NSW coast in the mid-1980's (West *et al*. 1985). Aerial photos can be digitised to provide very accurate mapping and determination of areas. Satellite imagery also has the potential for use in defining habitats, but has as yet rarely been seen in investigations of aquatic ecology in NSW.

Key issues that should be considered in using remote images are:

- the need to define boundaries of habitats accurately
- the need for ground-truthing to verify the habitats.

For example, rocky reefs, algal beds and seagrass beds may look similar in remote images and can all coexist within a small area.

For some investigations, it may not be critical that the area of a certain habitat is known, but it may be important to define where the boundary of that habitat occurs in relation to a proposed project. Aerial photos may readily be used to define boundaries of some features. Where these are obscured in the image, or photos are unavailable, it may be possible to mark the edge of each boundary to determine its relationship to the proposed project, or to measure precisely changes in boundaries through time.

At smaller spatial scales, it may be important to define patches of habitat or the extent to which habitats are fragmented. This may be important, for example, when assessing the effects on adjacent seagrasses from mooring chains and boat operations associated with a dredging operation.

One method used frequently to quantify patch size and/or percentage cover is a line-intercept procedure. Typically, transects are laid within the area of interest and the type of cover is recorded at pre-determined points or intervals along the transect (eg. Morris and Therivel 1995). This method can be used on coral and rocky reefs, seagrass beds, mangroves, saltmarshes, etc. It is also used in rivers, where habitats can be described along or across the river.

Investigation Guidance 2: *Define or describe aquatic habitats with sufficient detail to allow them to be placed into an appropriate geographical context; where possible, define habitat boundaries and spatial patchiness.*

(b) Sampling biota within habitats

Mapping of habitats alone is usually insufficient to provide an adequate basis for assessing impacts, because different flora and fauna may use similar habitats at different times and places. For example, work done in seagrass beds (Bell *et al.* 1988, McNeill *et al.* 1992) and rocky reefs (Lincoln Smith *et al*. 1993) demonstrates very large variability among similar habitats sampled from different locations. Thus, while it may be possible to generalise about the broad assemblages utilising particular habitats, often it will be necessary to sample biota within habitats to assess the potential effects of a proposal on specific areas.

Warwick (1993) and Keough and Mapstone (1995) discuss advantages and disadvantages of sampling different biota within aquatic habitats. The aims of sampling biota are to:

- identify the presence or likelihood of occurrence of rare or endangered species
- provide an indication of the diversity of species
- measure the abundance of selected taxa that will be used for predicting impacts and as part of the baseline for eventually measuring impacts.

Key elements of quantitative sampling of biota are the use of reference or control areas to place the location of the proposed project within an appropriate spatial context (Green 1979, Lincoln Smith 1991) and the use of replication (eg. Carpenter 1989, Underwood 1981a, 1991, Andrew and Mapstone 1987, Keough and Mapstone 1995).

These Guidelines present an overview of sampling biota in relation to common aquatic habitats in NSW. A summary of different methods that are often used is presented in **Appendix 4**, but it must be recognised that selection of biota to be sampled depends on the project itself and the cost-effectiveness of sampling.

Marine and estuarine habitats

- **Planktonic environment —** The water medium is the means by which most aquatic organisms obtain food, disperse their eggs, larvae and spores, and remove wastes from their proximity. It also provides the means by which aquatic organisms may recolonise areas disturbed by human activities or natural phenomena. Thus, nearly all assessment of the effects of proposed projects on the aquatic environment need to consider impacts to the surrounding water and the planktonic and pelagic organisms occurring there.

  Despite this importance, and apart from measuring chlorophyll-*a* and faecal bacteria as indicators of water quality, very few EISs in NSW include studies of plankton. Similarly, pelagic fishes and large mobile invertebrates such as squid are rarely sampled specifically for EISs, although they are often collected while sampling more sedentary species.

  Some recent studies, however, have focused on the effects of sewage effluent on the distribution, abundance and occurrence of physical deformities in larval fishes in relation to monitoring the effects of Sydney's deepwater outfalls (Gray 1996, 1997).

  Planktonic components of the marine environment tend to be overlooked because, while sampling may be relatively straightforward, sorting and identification of specimens is time-consuming and requires specific expertise. Also, interpretation of results can be difficult because planktonic and pelagic assemblages can vary dramatically over very short spatial and temporal scales. For proposed projects where there is likely to be a relatively large, long-term disturbance, particularly to water quality, there is good reason to consider planktonic organisms as part of sampling for an EIS. To provide meaningful results, however, proponents and their consultants must measure variability at several spatial and temporal scales, which requires sampling over months or years before starting the project.

- **Unvegetated sediments —** Unvegetated sand and muddy substrata constitute the most common habitat types in NSW estuaries and along the open coast (Fairweather 1990a). Superficially, they appear to be relatively bare but they can be extremely productive, supporting organisms living on the surface of the substratum ("epifauna") or within it, often in burrows ("infauna"). Often, these organisms are called macrobenthos or simply benthos. A wide range of physico-chemical and biological factors can structure benthic communities. These include the nature of the sediments (eg. grain size) and the overlying waters (eg. oxygen concentration). Biological factors include creation of microhabitats for other organisms by tube-builders and disturbance by feeding stingrays.

  Studies of benthos associated with soft, unvegetated substrata are often done for EISs in NSW. Sampling of benthos is done usually either with a grab sampler operated from a boat or by using divers to collect cores of sediment. An advantage of using divers is that direct observations of the substratum can be made. Rarely, studies have counted burrows in the sediment as an index of benthic productivity. This approach, however, has not been validated for subtidal benthos in NSW (although some work has been done in relation to crabs living on intertidal flats in mangrove forests - see below) and doubts have been raised about using invertebrate burrows in studies done overseas (eg. Suchanek, *et al*. 1986). Therefore, counting burrows as an index of benthic productivity is not generally recommended for ecological investigations in NSW, unless the methods are validated.

  Collection of core and grab samples is relatively straightforward, although sorting of samples is time-consuming and taxonomy of invertebrates requires specialised skills. These drawbacks can be reduced by identifying organisms to higher taxonomic levels (eg. families) than species. Other issues that need to be considered are the fact that we do not have a good understanding of exactly how benthic invertebrates in Australian estuaries and coastal regions respond to particular perturbations and the spatial and temporal scales at which benthic communities vary (see **Case Study 3**).

  Fish are sampled using a variety of nets, traps, fishing lines and by visual census. The selection of methods will depend closely on the target species, environmental conditions and questions of interest.

- **Mangroves, seagrasses and saltmarshes —** Mangroves, seagrasses and saltmarshes include intertidal and subtidal vascular plants that form habitats for animals and other plants. They are considered to be important components of aquatic ecosystems, fulfilling several functions, including structuring coastal geomorphology, contributing to estuarine productivity and providing food and/or shelter for birds, invertebrates and fish. These habitats are given a high conservation status and there have been numerous investigations of the effects of human activities on them (eg. McGuinness 1988, Hutchings and Saenger 1987, Larkum *et al.* 1989, CSIRO 1994, Fitzpatrick and Kirkman 1995).

In NSW, two species of mangroves are common - the grey mangrove (*Avicennia marina*) and the river mangrove (*Aegiceras corniculatum*), although several other species occur in small numbers in northern estuaries (West 1985). Seagrasses are dominated by Zosteraceae (mainly eelgrass, *Zostera capricorni*, but several other species occur in southern NSW), strapweed (*Posidonia australis*, which occurs from the NSW/Victoria border to Wallis Lake) and paddleweed (*Halophila ovalis* and *H. decipie*ns, which occur in estuaries along the NSW coast). In addition, *Ruppia* spp. occurs in brackish coastal lagoons and upper estuarine areas. In NSW, *Posidonia* is considered most sensitive to disturbance, as it appears to be very slow to recolonise areas where it has been removed and efforts to restore beds by transplantation have been unsuccessful, so far (West *et al*. 1990). Saltmarshes comprise many more species in NSW than mangroves or seagrasses. They also contain species with different growth forms, including small succulent species, rushes and herbaceous plants.

Studies of the animals living in mangroves, seagrasses and saltmarshes show that these habitats support diverse and abundant assemblages. These assemblages can vary through time, depending on the state of the tide, time of year and the intermittent presence of many fish and invertebrates, which often use these habitats in their early stages of growth.

Where mangroves, seagrasses and saltmarshes occur in or near a proposed project, they usually require a high priority within the assessment process and are protected under the Department of Primary Industries *Fish Habitat Management Plan No. 2*. Investigations should include mapping the extent and distribution of these habitats, compiling an inventory of plants and animals present and quantitative sampling of variables selected during the scoping studies. Some of the variables sampled are listed in **Appendix 4**. A range of sampling methods has been reported within EISs in NSW, including corers and grabs for infauna, quadrats and transects for epifauna and nets such as beam trawls, seine nets and gill nets for fish and large, mobile invertebrates.

- **Rocky shores and reefs —** Rocky shores and reefs contain some of the most diverse assemblages of aquatic flora and fauna in NSW. They are also amongst our most-studied ecosystems, with detailed research done on physical and biological processes. Most of the work has focused previously on shores along the coast, but there is now a growing body of information on rocky shores within estuaries. This information can be helpful for predicting the effects of solid structures, such as breakwaters, which sometimes are constructed around marinas.

  Intertidal plants and animals of rocky shores show a distinct zonation in relation to the tidal levels (Underwood 1981b) and are structured by both physical and biological factors. For example, removal of grazing gastropods on the-mid shore can lead to a dramatic increase in the growth of algae. Subtidally, rocky reefs can also show very distinctive zonation (Underwood *et al.* 1991), but often habitats are highly fragmented due to a variety of factors. Common subtidal habitats include turfing algae, large brown algae (usually dominated by kelp, *Ecklonia radiata* in the north and central regions and bubbleweed, *Phyllospora comosa*, in the south), encrusting red algae (called white rock or barrens and containing many algal grazers, such as sea urchins) and sponge gardens, which are often popular dive locations. Intertidal zones are well utilised by fish - either temporarily at high tide or over longer time-scales in rock pools. Subtidally, fish are a very prominent feature of rocky reefs, but there is also a diverse assemblage of invertebrates, including abalone, octopus and cuttlefish, sea urchins and rock lobsters. In recent years, scientists have also sampled small invertebrates associated with algae, such as kelp holdfasts. These assemblages have been used to monitor the effects of sewage effluent on rocky reefs (eg. Smith 1996).

Rocky shores and reefs are surveyed using a variety of techniques, generally based on the use of quadrats and transects. Subtidally, researchers often use underwater visual census to survey fish (Lincoln Smith 1989, Lincoln Smith and Jones 1995). They also use video or still cameras to record features of the seabed. A quantitative method using a camera mounted on frame ("photoquadrats" - see Chapman *et al.* 1995 and Roberts 1996) is often used to collect as much data as possible in the limited time available to scuba divers, or where depth precludes the use of divers. Further guidance on sampling temperate reef habitats is presented in Kingsford and Battershill (1998).

Freshwater habitats

There has been much attention given to the condition of freshwater ecosystems in Australia, including NSW, in recent years. Part of this has involved the development of methods for monitoring the health of rivers, adapted largely from overseas procedures. Further information is available in Davies (1994) and Norris (1997) and invertebrates and Harris and Gehrke (1997) for fish.

- **Planktonic environment —** As in the marine environment, planktonic and pelagic organisms tend not to have been studied for EISs involving freshwater ecosystems in NSW. Some studies have looked at invertebrate drift in rivers while a few others have looked at phytoplankton. In recent years there has been an increase in interest in the presence of phytoplankton, particularly with respect to blooms of toxic blue-green algae and this issue should be investigated where there are likely to be significant inputs of nutrients into waterways, disturbance of riverine or reservoir sediments, etc.

- **Filamentous and unicellular attached algae —** Algae attached (often very loosely) to hard surfaces are often termed "periphyton" and have been used as an indicator of the condition of rivers and reservoirs (Chapman 1996, Hellawell 1986). Studies have shown that periphyton can vary in response to hydraulic conditions (e.g. frequency of flooding), light regime and nutrient enrichment (eg. Biggs 1995, Lester *et al.* 1996). All these factors can be modified by human activities. In NSW, periphyton has not been used extensively in environmental impact assessment, although Norris and Thurtell (1992) studied periphyton in the Upper Thredbo River in relation to discharge of sewage effluent. It is likely that periphyton will become increasing evaluated in relation to impact studies in NSW and should be considered as part of scoping studies.

- **Freshwater and brackish macrophytes —** The presence of macrophytes is regarded as significant in freshwater ecosystems. In NSW there are many species of macrophytes having a variety of growth forms, including emergent reeds and rushes (eg. cumbungi), submerged plants (eg. freshwater strapweed - *Vallisneria*) and floating forms (eg. duckweed, water hyacinth). Sainty and Jacobs (1981) provide a field guide to most of the freshwater macrophytes likely to be encountered in NSW.

  Apart from the macrophytes themselves, there are often diverse and abundant assemblages of fish and invertebrates associated with these instream habitats. Sampling fish usually involves a variety of techniques, including electrofishing, gill netting, fyke netting, seine netting, dip netting and small traps (Harris and Gehrke 1997). In clearer waters, fish and other vertebrates may be sampled visually by divers. Sampling invertebrates is done using small nets, emergence traps or by harvesting known amounts of macrophytes and sorting-out attached invertebrates (eg. insects and gastropods) (Hellawell 1986, Davies 1994).

- **Riffles, runs, rocks and other features —** Apart from beds of macrophytes, streams and to a lesser extent reservoirs contain a large variety of "microhabitats" that are utilised by fish and invertebrates. One approach to sampling invertebrates within a stream is to take a holistic approach by collecting specimens from as many microhabitats as possible and combining the data obtained. This semi-quantitative method includes some of the rapid visual techniques that have been developed overseas. In NSW, one rapid technique that has been used is the SIGNAL Biotic index (Chessman 1995), developed for use in streams of poor water quality in the Hawkesbury-Nepean River System. This technique has also been used within single microhabitats, such as riffles (Growns *et al*. 1995).

  Where a more quantitative approach is warranted, there is a variety of quantitative methods. Some examples of methods used for invertebrates include Surber samplers used in riffles and runs, emergence traps for aquatic insects and corers and grabs for collecting sediment. Some researchers also use sweep or dip nets which are pushed over a standardised patch size of the river. Sampling of fish is often done using an electrofisher (with standardised pulse times), fyke nets, seine nets and gill nets. Further information on these procedures is provided in Turak and Bickel (1994) and papers in *The Australian Journal of Ecology*, Volume 20 (1) 1995.

Investigation Guidance 3: *Ensure that sampling methods are objective and that sampling is done by properly trained workers; where possible, seek to use or adapt methods that already have been evaluated - either in pilot studies or by other researchers.*

Investigation Guidance 4: *Identify any limitations to sampling and how these may affect the investigations and their interpretation.*

(c) Laboratory work

Biota investigations

Most aquatic ecological investigations involve laboratory work on samples collected in the field. This may include sorting and identification of biological samples; drying of tissue samples to obtain dry weight measurements; dissection of tissue samples for chemical analysis; and chemical analysis of water, sediment and tissue samples. It is not the role of these Guidelines to provide laboratory protocols for various activities, but it is critical that the laboratory activities have appropriate quality control and assurance.

Sorting, identification and counting of biota is time-consuming and requires skill. This applies particularly to invertebrate samples and often to fish samples containing many species, such as those often obtained from seagrass beds. To assure the quality of ecological investigations, biota should be examined by trained taxonomists and compared against reference collections. The samples or a reference collection of biota should be stored at least until after determination of the project, so identifications can be checked.

In the past decade there has been an examination by many scientists of the need to identify biological specimens to various taxonomic levels (e.g. James *et al*. 1995, Warwick 1988). This has lead to the concept of "taxonomic sufficiency" which simply means determining the level of taxonomic resolution required to address the questions of concern. Large cost savings can be made by identifying organisms to family level rather than species and hopefully these saved resources would be allocated to collecting the maximal number of samples. In other words, rather than collecting relatively few samples and identifying the biota present to species, it is often better to collect many samples whose biota are identified to family. Notwithstanding this, by retaining samples there is a safeguard if, during the determination process, there is a need to resolve the samples to a finer taxonomic level.

> ***Investigation Guidance 5:*** *For studies of abundance and diversity retain frozen or in preservative invertebrates that have been collected until after determination of the proposed project. if this is not possible, retain a reference collection.*

Water, sediment and tissue samples

Collection, storage, processing, dispatch and analysis of water, sediment and tissue samples for various chemicals requires care, standardisation and accountability. Consultants undertaking ecological investigations requiring chemical analysis of samples should, as part of their quality assurance program, have clear instructions on handling samples. To facilitate statistical analysis and enhance quality assurance, there should be provision for analysis of replicate samples (ie. > 1 sample taken from each sampling location) and duplicate samples (ie. 2 sub-samples taken from each of a number of samples). The number of replicates obtained and the number of samples from which duplicates are taken will vary from one investigation to the next and should be determined as part of the scoping studies.

Nowadays, most of the testing laboratories can provide properly prepared storage containers and instructions on handling (eg. whether or not samples should be stored on ice). Transport of samples to laboratories should be accompanied by chain-of-custody forms to ensure accountability and samples should be labelled clearly and uniquely. To ensure impartiality, the labelling supplied to the testing laboratory should not indicate which samples came from putatively contaminated sites or control sites, or which samples are replicates and/or duplicates. Finally, it is important to ensure that laboratories have their own QA procedures applicable to the study being done.

Investigation Guidance 6: *Ensure that samples sent to chemical laboratories are labelled clearly but do not signify to the testing laboratory specific sites, replicates or duplicates. Ensure that replicate and duplicate samples are supplied as a quality assurance measure.*

Water quality analysis

Currently, there are guidelines for levels of temperature, salinity, pH suspended solids, turbidity and a range of chemical substances in water (ANZECC 2000).

ANZECC guidelines also assist in the interpreting of the possible ecological significance of the concentrations of pollutants in sediments. In addition, scientists often compare data to background levels, which may be determined by comparison with samples from reference areas, or by analysing sediments taken by cores from a depth below the substratum considered to be prior to European settlement or before the pollution event of concern (Burton 1992). Some scientists also examine guidelines developed overseas as an indicator of the likely effects of pollutants in sediment. Long *et al.* (1995) developed sediment guidelines for a range of organic and inorganic contaminants based on the effects reported on biota at different concentrations. Ultimately, the toxicity of sediments may be assessed reliably only by testing experimentally the response of biota to particular sediments (e.g. Morrisey *et al.* 1992). This area of study is changing rapidly and there is a need for both consultants and managers to keep up-to-date on advances.

Guidelines for the levels of some contaminants in the edible portions of fish and invertebrates ("shellfish") have been set by the National Health and Medical Research Council (NHMRC). These guidelines provide a reference against which bioaccumulation can be examined, but results need to be interpreted cautiously for the following reasons.

- First, the guidelines apply to the edible portion and should not be applied for tissue not usually eaten by humans, such as liver and gills (although whole fish may be eaten and some people do eat organs such as gonads in the form of fish roe). Therefore, some assessment of whether an organism is a common food item and what parts are eaten should be made before collecting the samples.
- Second, the amount of risk is related to rates of consumption, therefore, assessment of impact to humans must consider the likelihood and frequency of consumption.
- Third, relating levels of contaminants in biota to NHMRC guidelines provides no indication about how the organism or the ecosystem is being affected.

When engaging a testing laboratory to undertake analysis of samples, it is critical that the limit of detection is specified to ensure that meaningful results are obtained. For example, the ANZECC (2000) guideline for copper in water for maintenance of aquatic ecosystems is 5 ug/L. If the detection limit for a particular study were set at 5 or 10 ug/L, results of "not detected", must be interpreted, on a precautionary basis, as being at or above the ANZECC guideline, respectively. Whilst initially more expensive, it is clearly in the long term interests of the proponent to ensure that analyses are done at detection limits well below the relevant guidelines (preferably by a factor of 5 to 10 times) they may be compared to.

Investigation Guidance 7: *Ensure that detection limits used by chemical laboratories are set below the concentrations of concern (e.g. ANZECC guidelines and NHMRC maximum recommended limits, etc).*

3.4 Analysis of data and interpretation of results

Chronologically, the analysis of data and interpretation of results occur after the samples have been collected and processed and the data tabulated and, as generally occurs nowadays, entered into a computer database or spreadsheet, and finally proofed and corrected. In planning an aquatic ecological investigation, however, the analysis of data must be considered at the very earliest stages of the process to ensure that the data collected will enable proponents and their consultants to address the questions identified during the scoping phase. This part of the Guideline presents a brief overview of statistical testing and interpretation of results.

(a) Statistical tests

Why do statistical tests?

Generally, it is not possible, feasible or economical to investigate a decision variable by sampling the whole population in the area of interest (Winer *et al*. 1991, Underwood 1997). Thus, although it may be useful to count every fish in a river prior to changing flow characteristics of a river, in order to determine the size and diversity of the assemblage present, to do so would be essentially impossible. Therefore, scientists take **samples** of the fish in (hopefully) and objective way, and infer that these samples are representative of the entire **population** of fish present. Statistics are used to evaluate objectively how much confidence we can have in the inferring that the sample actually does represent the population and therefore provides a sound basis for decison making.

Statistical tests have become an essential part of ecology and their use in the last two decades has become widespread and often highly sophisticated. They are also becoming more common in environmental management and are likely to become more so as they are a means of objectively (as far as possible) interpreting information collected about the environment and the effects of humans upon it. Unfortunately, statistical analyses are not widespread in studies of aquatic ecology for EISs.

Statistical tests are based on the notion of determining the likelihood or probability that sampling data collected are consistent with a pre-determined hypothesis or question (e.g. that populations of a species are less abundant, on average, at one site than at others). By convention, scientists give themselves a 5% chance of accepting that there was an hypothesised effect when in fact there really wasn't one. (At this time there is no such convention for accepting or rejecting the opposite condition, ie. concluding there was no effect when in fact there was one - see below.) Apart from being relatively objective, the great strength of statistical design is that, if done properly, it should compel researchers to collect their data within a logical framework to address specific questions of concern. Moreover, the more explicit the question, the more likely we are to obtain an unambiguous result (ie. there was a difference or there wasn't). One potential difficulty of statistical testing is that it is often difficult to present the non-technical implications of statistical tests. This difficulty requires considerable effort to ensure that statistical findings are comprehensible to all stakeholders.

Notwithstanding their potential complexity, a statistical test allows researchers to assess if differences observed from sampling are likely to represent true differences between treatments (e.g. times, sites, impact versus reference, etc) being compared or merely a chance effect of observations in a random order (Manly 1991). A critical step in the process is defining hypotheses that are to be tested. Green (1979) and Underwood (1990) provide a good background to the logics of statistical testing in ecology and this can be readily extended to environmental impact assessment (eg. Green 1979, Underwood 1993, Keough and Mapstone 1995).

In applying statistical tests, it is important to distinguish between what is statistically significant and what may be ecologically, economically or socially significant (Yoccoz 1991). Clearly, the results of statistical tests should be considered as part of the decision-making process and not elevated to the status of the decision-making criterion (Stewart-Oaten 1996).

Investigation Guidance 8: *In using statistical testing, try to define the direction and magnitude of differences that may be ecologically, economically or socially significant, rather than relying simply on what is statistically significant.*

Selection of tests

Many ecological studies use two basic kinds of statistics to evaluate the aquatic environment: univariate and multivariate statistics. Within each of these, there are parametric and non-parametric tests. Parametric tests are based on measures of central tendency (usually the mean) and dispersion (usually the standard deviation) and make assumptions regarding the distribution of the data (usually assuming a normal distribution). Non-parametric tests are usually based on ranks, which do not assume an underlying distribution of the data. By-and-large, parametric tests are more powerful, can be used to evaluate highly complex or multifactorial questions (see below) and, thus, tend to be preferred. Recently, statisticians have developed computer-intensive randomisation tests which compare a test statistic for the sample data against a distribution created by randomising the sample data many times and re-calculating the test statistic each time (Manly 1991). Whilst rarely seen in EISs in NSW, these tests are likely to become common in future and consultants should ensure that they are familiar with their application.

- **Univariate tests —** Univariate tests examine hypotheses about a single dependent variable and its relation to one or more independent variables. A departure from this is correlation analysis, where variables compared may be dependent on each other or dependent on some other variable. Dependent variables include counts of organisms, size of individuals, concentrations of a particular chemical in water, sediment or tissue samples, etc. Dependent variables may also include "derived variables", which are measures synthesised from sample data. Examples include total abundance (ie. individuals of all species within a sample), species richness (ie. the number of species within a sample) and community indices (eg. diversity, evenness and similarity measures). Independent variables are used to try to predict responses in the dependent variable and may include factors such as location, time, rainfall, altitude, salinity; or may represent experimentally-varied factors such as chemical concentrations, temperature, etc, which, under experimental conditions, are manipulated by the investigator.

In EIA, projects (eg. dredging, effluent disposal, etc) can be seen as experimental conditions potentially affecting a number of dependent variables (Beanlands and Duinker 1983, Carpenter 1989, Lincoln Smith 1991, Underwood 1995a). In the terminology established earlier in these Guidelines, independent variables manipulated by humans can be considered as the **disturbance**, which may or may not cause a measurable **response** in the **decision variable(s)** measured.

Parametric univariate tests commonly seen in EISs include t-tests, correlation, regression and analysis of variance (ANOVA). Goodness-of-fit tests, including the Chi-squared test, are used to compare the observed proportions of a dependent variable against what might be expected by chance alone. Analogous non-parametric tests exist for t-tests, ANOVA and correlation, and there are several tests of concordance that measure the degree of association between ranked values for selected variables. Descriptions of these tests are found in numerous texts (eg. Snedecor and Cochran 1980, Siegel and Castellan 1988, Sokal and Rohlf 1995 and Winer *et al*. 1991). Underwood (1981a, 1997) provides detailed discussion of the use of ANOVA in marine ecology.

The selection of univariate tests to examine hypotheses must be considered carefully. Also, the use of parametric tests requires that the assumptions underlying their use be tested. Violation of some of the underlying assumptions can be mitigated by transforming the data (eg. to a logarithmic scale) or by conservative interpretation of the results (eg. by reducing the acceptance level from 5% to 1%; or, for some questions, by increasing it to say, 10% - see below). Notwithstanding this, failure to either properly design programs for data collection or to use tests appropriately, can lead to false conclusions with potentially costly consequences (see Scoping Guidance 12 and 14 in Sections 2.5.2 and 2.6.1, respectively).

Investigation Guidance 9: *Carefully select the statistical test(s) to be used and ensure that underlying assumptions have been addressed.*

- **Multivariate tests —** Multivariate statistics include a large variety of procedures that essentially cluster groups of objects according to their similarity or dissimilarity (Stephenson 1980, Field *et al*. 1982, Faith *et al*. 1991, 1995, Clarke 1993). When originally developed, they were used for depicting complex patterns or generating hypotheses without a rigorous framework for hypothesis testing. More recently, both parametric and non-parametric procedures for testing hypotheses have been developed. Parametric tests, including multivariate analysis of variance (MANOVA) are often avoided because of difficulties with satisfying the underlying assumptions of the test (Johnson and Field 1993). However, a range of non-parametric procedures such as ANOSIM (analysis of similarities) have been developed based on randomisation tests (Field *et al*. 1982, Clarke 1993). While ANOSIM procedures are applicable to many data sets, they are currently limited to more simple designs than are being evaluated using univariate tests such as ANOVA.

Multivariate analyses may be applied to samples containing an assemblage of organisms, often analysed at the species or family level and used to compare locations and or times of interest. They may be applied to water quality variables and contaminants within tissue samples. Recently, multivariate analyses have been used to indicate the taxa in an assemblage that contribute most to the dissimilarities between the factors of interest, such as sites (SIMPER analysis - Clarke 1993).

Although the question or hypothesis of interest will determine the type of statistical procedure used, aquatic ecologists often use both univariate and multivariate statistics to examine data sets collected as part of an EIA. This allows an assessment of variability for assemblages (ie. how does the group of organisms sampled vary as a whole?) and populations of organisms in the assemblage. The latter is important where there is concern about the response of a particular species to a proposed project - either because it is of commercial or recreational significance, or we have prior knowledge that it may be sensitive to the effects likely to be associated with the proposed project.

Investigation Guidance 10: *In statistically examining the flora and fauna of aquatic habitats, seek to use both univariate and multivariate procedures to evaluate variation at the level of populations and assemblages, respectively.*

The power of statistical tests

Statistical probabilities reflect the possibility that an observed pattern or change could have occurred by chance alone. A statistical test may be correct in two ways or incorrect in two ways. It may be correct in concluding that a response to disturbance occurred upon the decision variable when in reality it did; or it may be correct in inferring that no response occurred when in fact there was none.

Similarly, we may conclude incorrectly that a response occurred when in fact there was none. This occurs when the probability of the test statistic was equal to or less than 0.05 (ie. $P \leq 0.05$, or whatever acceptance criterion we selected prior to doing the test), but the sample data did not truly reflect the condition in nature. Being wrong in this way is generally denoted as a Type I error and the probability of making this type of error is symbolised by alpha (α). Alternatively, we may incorrectly conclude from our study that there was no response caused by the disturbance, when in fact there was. This would happen when $P > 0.05$, or some other acceptance criterion. This type of mistake is generally called a Type II error and the probability of making this type of error is symbolised by beta (β). **Table 5** summarises these outcomes.

Arising from these alternatives is the notion of statistical power, which basically asks: how effective is the sampling program at answering the question of interest? Or, more formally, the power of a statistical test ($1-\beta$) is the probability of rejecting the null hypothesis when it really is false (and thus, should be rejected)(Siegel and Castellan 1989).

The concept of statistical power is fundamental to statistical testing in environmental impact assessment. In considering how to use power analysis in aquatic ecological investigations for EIA, there are four matters that are noteworthy in relation to EISs.

Table 8. Statistical outcomes in relation to detecting environmental impacts through an hypothesis-testing approach

Source: Fairweather 1991 - See Section 3.4(a) of text for full description.

		Prediction or conclusion of study	
		Impact	**No Impact**
Real state of nature	**Impact**	Correct	Type II Error (beta)
	No impact	Type I Error (alpha)	Correct

Use of power in describing the existing environment

Most authors discuss power analysis in relation to monitoring under the general question of: what effect is this project having on the decision variables being studied? It is important to recognise, however, that power analysis is equally important for studies done as part of the approval process. For example, if the site of a proposed project is being compared to other sites, we may wish to know if a particular species is more or less abundant at the project site, or if assemblages are more diverse at that site. A weak study design may conclude incorrectly that there is no difference between the site of the proposed project and the reference sites, which may falsely support an argument of acceptable loss (see Part 4).

Investigation Guidance 11*: Where statistical tests are non-significant, examine the differences between the treatments compared and assess whether there was sufficient statistical power to distinguish an effect that might be ecologically significant.*

Power and the precautionary principle

The concept of statistical power can be cast within a precautionary framework (Deville and Harding 1997, Underwood 1997b). Thus, one may argue that it is better, from the point-of-view of the environment, to commit a Type I error (ie. to conclude that there was a response to a disturbance when in fact there was none) than a Type II error (ie. to conclude there was no response when in fact there was). If this view is adopted, we may increase the criterion to accept that a response has occurred from $\alpha = 0.05$ to say, 0.10 to reduce the chance of a Type II error (see below). This may be appropriate if the cost of an environmental impact is great (eg. loss of an important fishing ground). It is important to recognise that the approach used may lead to greatly increased and possibly unnecessary cost to the proponent (eg. if an impact is incorrectly inferred) or to the environment and possibly the community at large (eg. if a non-impact condition is incorrectly inferred). These issues are discussed by Eberhardt and Thomas (1991), Underwood (1993, 1997b), Keough and Mapstone (1995) and Mapstone (1995).

Scope for varying power and determination of effect size

Researchers have some scope for varying the power of a statistical test. Power is affected by the sample size, thus collecting more samples increases statistical power. It is also affected by the acceptance criterion as discussed above, but this approach has the drawback of increasing the potential for committing a Type I error. Power is also affected by the extent of variability in the system being studied. Thus, thus large variability leads to small power. This factor cannot be controlled by the researcher other than by trying to maximise precision by increasing sample sizes and possibly by rejecting decision variables that require huge sample sizes to be able to detect differences (Keough and Mapstone 1995). Finally, statistical power is affected by the size of the difference (or effect) that may be considered important. As the "effect size" increases, so does statistical power. Thus, if we are seeking to detect subtle responses to a disturbance, we would normally need to have very large sample sizes to maximise the statistical power to detect such responses.

Determining effect size should be an important part of the scoping and approval phases of environmental impact assessment. The effect size may be based on socio-economic considerations (eg. acceptable change in populations of exploited fish). It may also be based on the sizes of effects detected by monitoring of other projects that cause similar disturbances. In the absence of these types of information, it may be necessary to base effect sizes on prior knowledge of natural variability in decision variables selected. For example, if a population varies naturally in its abundance by 25%, it would be unrealistic to select an effect size of <25% change. Depending on the sample variability, it may be more realistic to select an effect size of, say, 40 - 50% change at the project site compared to control sites. An alternative approach is to simulate data (based on pilot studies) and use these to determine the size of an effect that could be detected for a given sampling design.

If a suitable sampling design is developed and implemented during the preparation of an EIS, the data collected for the EIS can be used to evaluate what might be realistic effect sizes for future monitoring.

A priori vs post hoc power analyses

Power analysis can be used broadly in two ways. It can be used to design further studies, by using pilot data for selection of sample sizes, effect sizes and decision variables that are cost-effective. If this role is considered during the EIS phase of a project, sampling done for the EIS can be used as the basis for designing a subsequent monitoring program, if the project is approved. Second, it can be used to evaluate a study program that has been completed (ie. by asking: how confident can we be in the conclusions drawn from statistical testing, particularly where non-significant results were reported?). This application of power analysis should be an important part of auditing monitoring programs (see Part 4).

It is important to recognise that there are some problems with the use of power analysis, particularly in specifying realistic effect sizes and in applying power to complex sampling designs. These is one area of research that consultants should keep well informed about and get advice from statistical experts to ensure that costly mistakes are not made.

Fairweather (1991) provides a good discussion of the uses of power analysis in aquatic ecology. Other relevant publications of interest include Underwood (1981a, 1997a), Koele (1982), Cohen (1988), Peterman (1990), Keough and Mapstone (1995), Mapstone (1995) and Schmidt and Osenberg (1996).

Investigation Guidance 12*: Consider the power of statistical tests done as part of pilot investigations, the main EIS studies and in the preparation of designs for monitoring. get advice from statistical experts to minimise the risk of making costly mistakes.*

(b) Statistical software

There are many computer programs available to do the types of statistical analyses required for environmental impact assessment. Some of the programs used commonly include MINITAB, SAS, SPSS, SYSTAT and Statistica for univariate and multivariate parametric and non-parametric tests; GMAV5 for analysis of variance; and PATN and PRIMER for multivariate statistics. Some of the spreadsheet and database programs can also be used for statistical testing, although the number and complexity of tests available often limits them.

Researchers using such programs should know:

- how to arrange data so that the program reads columns and rows correctly
- how the data are treated by the program.

For example, in analysis of variance it is important to specify whether factors are fixed or random; or nested or orthogonal (Underwood 1997a). Failure to do so will lead to default settings being used that may provide an incorrect result for the test due to the design used. Also, some programs will analyse unbalanced or unreplicated data sets. If such data sets must be used, the underlying assumptions and models used by the program should be understood.

When using an unfamiliar computer program for statistical analysis it is highly desirable that analyses done on more familiar programs are repeated using the new program to ensure that the same result is obtained. Some statistics texts (eg. Winer *et al.* 1991) provide worked examples of tests with the raw data that can be used to evaluate a new program. Finally, researchers should graph their data (usually summarised as means and standard errors or confidence intervals) to ensure the statistical interpretation is consistent with the graphical one.

> ***Investigation Guidance 13****: Carefully evaluate data input and test outputs of statistical computer software. Check new programs by running data sets with known outcomes and compare test results with plots of the data to ensure consistency.*

3.5 Presentation of findings

Typically, EISs are made up of a main document presenting all elements of the assessment process and appendices, which include specialist reports, correspondence and other supplementary material. EISs for small projects may need little specialist input or no appendices. It is important that, wherever specialist reports are prepared, their information is accurately integrated into the EIS for two reasons.

- First, having the specialist report available allows other specialists and stakeholders the opportunity to review the technical content including methodology, assumptions and interpretation of results and to consider the likely interaction with other issues.
- Second, it allows stakeholders to evaluate the consistency of statements made in the specialist report with those in the EIS. Thus, it is possible to evaluate whether the author of the EIS has summarised or interpreted properly the findings of the specialists. To minimise the risk of any inconsistencies, it is recommended strongly that specialists review all sections within the EIS that refer to their work.

***Investigation Guidance 14**: Ensure that any specialist reports are available for review when the EIS is being exhibited and that the main report of the EIS is consistent with the results and interpretation of specialist reports.*

(a) Report structure

Department of Planning EIS Guidelines provide general information on what is required for EISs for particular types of projects. However, in most cases, the specialist reports on aquatic ecology should approximately follow the general format of a scientific paper or thesis but this may vary according to the nature of the proposed project, the brief circulated by the proponent and the Department of Planning Requirements:

- **Summary**, including a non-technical description of the investigation and its findings.
- **Introduction**, including background to the study, aims and reviews of relevant existing information.
- **Methods**, including study sites and sampling times, survey and laboratory procedures, specialist equipment used, data handling and analysis and procedures of quality assurance.
- **Results**, including general observations, mapping of habitats and statistical analysis.
- **Discussion**, including interpretation of results in relation to other studies any shortcomings of the study and further questions that may need to be addressed.
- **Assessment of Impacts**, including a brief description of the proposal (emphasising aquatic ecology issues) predictions of effects within an appropriate framework (Part 4) and measures for mitigation of adverse effects and possibly enhancement of positive effects.
- **Recommendations**, including further work required to address any other matters arising and a brief outline of any monitoring, should that be required as part of the approval process.
- **References**, including all documents cited within the report with author, year of publication, title of publication, journal volume and pages and/or name of publisher.
- **Appendices**, including copies of relevant correspondence, data or appropriate data summaries, laboratory reports, summaries of statistical analyses and supplementary work (eg. pilot investigations, etc).

***Investigation Guidance 15**: Construct an outline plan for specialist reports on aquatic ecology and ensure that, as a minimum requirement, the report flows from a presentation of background information and study aims to methods used, results, discussion and assessment of impact. Present a non-technical summary.*

(b) Text, tables and figures

The text of a report on aquatic ecological investigations should be concise and minimise the use of jargon. Where technical terms are used, they should be defined clearly either in the text or in a glossary. The scientific names of all species (or other taxa, depending on taxonomic resolution) should be cited at least once along with the common name (if there is one); thereafter the common name may be used alone. This practice minimises ambiguity about the identity of the species sampled, while making the document more readable. If there is no common name, however, do not make one up!

Where statistical testing is done, a full description should be provided of the test, the model, experimental design, how assumptions of the test were evaluated and any data transformations. Although such a description may be highly technical, it is critical that it be presented so expert reviewers have no doubt about the approach used. Investigators may consider placing this information within a separate appendix to minimise the technical content of the report.

Reports should be broken down into major chapters (eg. Introduction, Methods, etc) and into sections and subsections. This helps to give the report a well defined and logical structure and helps readers find critical sections easily. It is important, however, that the sections within a report have a logical flow from one to the next.

Wherever possible, information should be summarised within maps, tables and graphs. To avoid redundant information, a separate table and graph should not be used to present the same data and investigators should consider carefully how best to present the data. Text discussing tables or graphs should provide a commentary, rather than repeat the information already graphed or tabulated.

Where the results of statistical tests are presented, the probability of the test and the means and errors of the treatments compared should be reported (Yoccoz 1991). Where average values are presented in tables or figures, they must be presented with error bars - typically standard errors, standard deviations or confidence limits.

> ***Investigation Guidance 16****: Plan to present summaries of information in tables or graphs; do not repeat this information in the text and always provide error bars (eg. standard errors) with averages.*

> ***Investigation Guidance 17****: When providing results of statistical tests, present the probabilities, even where these are non-significant.*

(c) Use of appendices

Appendices are a good way of removing large data sets or highly technical or supplementary information from the main report to ensure that the main findings of the report are emphasised.

- For all studies where samples are collected, the data must be presented - either as raw data or means and standard errors - to allow an independent evaluation of the conclusions.
- Where means and standard errors are presented, they should be calculated on replicates taken for the smallest sampling unit,

not pooled up to larger scales. For example, where sampling is done at several sites over several times, means and standard errors should be presented for each site at each time, not pooled over times for each site or over sites for each time.
- Finally, where chemical testing is done, the laboratory reports should be appended.

Other information that should be considered for appendices includes pilot studies, which would appear in an appendix as a "mini-report", with its own introduction, methods, etc.; detailed descriptions of methodology, such as statistical testing; and correspondence.

Investigation Guidance 18: *Appendices should be used to present raw data (or means and standard errors), highly technical information and supplementary information such as pilot studies.*

3.6 Storage of data

The data obtained for individual assessments is important for the proposed project being evaluated and to assist with determining possible effects sizes for that project and other, similar projects. These data can also contribute to the knowledge of the aquatic ecology of NSW. By presenting the raw data within specialist reports for the EIS, data are made permanently available for review and re-analysis.

Data collected after publication of the EIS (eg. requirements for supplementary information, monitoring programs, etc) may not be as readily assessable but may be scientifically very valuable. Keough and Mapstone (1995) recommend that all monitoring data should be publicly available, to allow other interested parties to cross-check the conclusions, or identify patterns in the data not evident to those running the monitoring program. These authors also identify characteristics they consider to be important in preserving data for future examination.

Investigation Guidance 19: *Proponents and their consultants should make provision for proper storage of data (on computer and as hard copy) collected during all stages of the environmental impact assessment process.*

3.7 Quality assurance

There are increasing requirements for ecologists (and other specialists) to maintain quality assurance systems for all aspects of their work. In some respects, these Guidelines may be seen as a supplementary form of quality assurance - by addressing each guideline, proponents and their consultants, government authorities and the community can evaluate the extent to which proposed projects have been properly scoped and investigated. Notwithstanding this, consultants must be able to assure the quality of their work, particularly in the areas of design and implementation of field studies, laboratory practice and cleanliness, and data entry proofing, analysis and storage.

4. Prediction, mitigation, and monitoring guidelines

4.1 Introduction

Having determined the scope of work required (Part 2) and described the existing aquatic environment that may be affected (Part 3), proponents and their consultants are required to predict or forecast what would happen to the aquatic environment in the presence of the proposed project.

The significance of predicted effects must be assessed, so that stakeholders can weigh predicted benefits against predicted drawbacks. A consistent criticism of EISs has been that they fail to make precise predictions about effects (Buckley 1989). Both Buckley and other authors (eg. Fairweather 1989, Lincoln Smith 1991, Underwood 1995) urged that predictions of impacts be made as precisely as possible, preferably within the framework of testable hypotheses, to ensure that any required monitoring is sensible. Moreover, the basis of predictions made in an EIS should be made explicit.

This Part discusses issues associated with prediction, mitigation and monitoring the effects of proposed and approved projects and provides guidelines (called Assessment guidances) in relation to each. Appraisal of these components can be assisted using **Appendix 3**.

4.2 Forecasting

(a) The basis for predicting effects

Predicting the response (if any) of a decision variable to a disturbance can be very difficult and, in the absence of firm scientific information, requires a precautionary approach. An EIS should explicitly define the basis of each predicted effect on aquatic ecosystems and obtain the following information in deriving each prediction:

- a good understanding by aquatic ecologists of the nature of the proposed project, including project design, construction activities and timing;
- detailed predictions of physical and chemical changes (often provided by other specialists) resulting from the proposed project;
- a description of habitats and selected decision variables;
- knowledge of how decision variables respond to the proposed disturbance;
- knowledge of the outcomes of similar projects elsewhere; and
- knowledge of past, existing or other approved projects nearby which may cause interactive or cumulative impacts with the project being assessed.

In some cases, predictions are based on modelling or simulation of data. It is important to ensure that models are properly calibrated and independently validated with empirical data and that any assumptions are clearly identified. The EIS should identify the extent to which predictions of effects could be limited by failure to validate models. Finally, in the absence of a firm objective basis, predictions are often based on the professional opinion of the aquatic ecologist. Where this happens, the logic used to derive the prediction(s) should be described and the subjective basis of the prediction acknowledged.

Assessment guidance 1: *Present predictions of effects as explicitly as possible and present the basis of each prediction.*

(b) Frameworks for prediction of effects

Predicting impacts for a proposed project should be done within a structured framework (eg. Morris and Therivel 1995, Thomas 1998). Some frameworks are discussed here, with examples, and it is clear that there is scope for considerable overlap among frameworks. Haug *et al.* (1984) also addressed this issue and attempted to define what "significant impacts" might be. Izmir (1993) examined ways in which environmental impacts could be valued. It is often relatively straightforward to identify and define physical and chemical effects, but more difficult to predict the consequences for aquatic ecology and how this may flow on to human activities.

(c) Direct and indirect effects

Direct effects (also often called primary effects) can include the removal or creation of habitat, emplacement of barriers, etc. Indirect effects (also called secondary or tertiary effects) occur as a consequence of direct effects. An example of a direct effect would be the removal of seagrasses as part of a dredging project and the size of the effect can be quantified in terms of the area lost.

An indirect effect might be the impact of the loss of seagrass on fish and crabs and the subsequent effect on local fishers. Quantifying indirect effects can be very difficult because it requires either knowledge or the need to make assumptions about the extent to which organisms may depend on the component of the ecosystem that is affected directly.

(d) Short and long-term effects

Distinction is often made between different time periods of predicted effects on the aquatic environment. For example, a short term-effect associated with a dredging proposal might be the creation of a turbid plume while dredging is occurring, but a long term effect would be the alteration of substratum in the area dredged. In this case, both impacts are direct effects.

In defining short and long term effects, it is also important to consider whether the consequences are short or long term (Glasby and Underwood 1996). For example, creation of a turbid plume might disrupt a significant settlement of aquatic organisms, which could have long term consequences for that population.

Alternatively, whilst the dredging may alter habitat for years or decades, biological recolonisation may be rapid and have only short-term consequences on the productivity of the area. Thus, the duration and magnitude of physical effects may not be related directly to those of the ecological effects.

(e) Construction, operational and decommissioning effects

Many projects can be evaluated in terms of their construction and operational phases and distinctive impacts may be associated with each. Examples of these include construction of sewage outfalls, marinas and foreshore development.

During construction, there can be impacts associated with site access (e.g. by roads and/or boats, barges, etc), runoff from cleared areas, noise from construction machinery, blasting and drilling effects, disposal of dredge spoil, etc.

Operational effects include discharge of effluent, leachate of antifouling paints from boats, increased boating activity and boat wash, etc.

Many projects associated with mining or extraction include a phase for decommissioning once the resource has been utilised. This phase entails removal of machinery and stockpiles and rehabilitation of habitats. In such cases, additional assessment of the effects of this phase should be included in the EIS.

(f) Intermittent, periodic and permanent effects

Activities during both the construction and operational phases of a project can lead to intermittent, periodic or permanent effects, which are often similar to the short and long term effects discussed above.

In the context of the construction phase, an intermittent effect would be runoff from cleared areas during rainfall; a periodic effect might be related to dredging done for certain periods each day and permanent effects may be associated with disposal of dredge spoil.

In the context of the operational phase, an intermittent effect would include accidental spills (e.g. from fuel pumps on a jetty), periodic effects might be related to seasonal rainfall that leaches acids from acid sulfate soils while a permanent effect might include permanent loss of habitat due to reclamation.

(g) Opportunities and constraints

Irrespective of the framework in which effects of a proposed project are assessed, it is often useful to identify concisely the opportunities and constraints (ie. predicted positive and negative impacts) associated with the project.

Opportunities may include positive steps that could be taken to improve an area already disturbed by human activities (eg. removal of unwanted alien species); constraints may include the presence of endangered or threatened species, fishing grounds or habitat that should be preserved as part of the project design.

(h) Isolated, interactive and cumulative effects

The effects of a proposed project are often predicted in relation to other human development or activities within the waterway of interest and/or its catchment. Proposed projects are generally assessed in isolation of other projects, but there is an increasing requirement for interactive effects to be considered due to increasing pressure for development of waterways and the realisation that numerous small projects potentially can have large cumulative effects. A major difficulty associated with predicting cumulative effects is that there is often a lack of information on the effects of other projects.

Two suggestions that may be suitable for predicting cumulative effects are as follows:

- **Direct loss or creation of aquatic habitat**. Cumulative effects can be predicted by estimating how much of a particular habitat has been lost or created in a waterway due to previous development, by predicting the potential change associated with the project being considered and examining predicted changes from other proposed projects. Estimates of earlier loss or creation may be made by reference to historical aerial photographs, bathymetry and earlier habitat maps (eg. West *et al*. 1985), etc.

- **Introduction of nutrients, pathogens and toxic chemicals.** Cumulative effects can be estimated by modelling the change in water quality indicators in relation to the existing background concentrations. Here it may be important to know the relative input from non-natural sources or it may simply be a case of estimating if the changed water quality indicators are within specified water quality guidelines.

Assessment guidance 2*: Define a framework for presenting predictions of effects appropriate for the specific project being considered; evaluate effects over different phases of the life of the proposed project and consider cumulative effects.*

(i) Prediction of effects in terms of ESD

Legislation in NSW requires that projects subject to an EIS be evaluated in terms of Ecologically Sustainable Development (ESD). It is therefore important that proponents and their consultants consider the effects of proposed projects on aquatic ecology in terms of the following principles of ESD (Green *et al*. 1992).

- **Maintain intra-generational equity** — Effects of proposed projects should be predicted in terms of how they may affect others who may be dependent on aquatic ecology (eg. commercial and recreational fishers, oyster farmers, divers, etc) – consider the short to mid term implications.
- **Maintain inter-generational equity** — Effects of proposed projects should be predicted in terms of how they may affect future generations that may be depend on aquatic ecology – consider the mid and long term implications
- **Conserve biodiversity** — The effect of proposed projects on biodiversity should be predicted as part of the EIA process. Hammer *et al*. (1993) asserted that biodiversity should be considered in terms of species diversity, genetic diversity, functional diversity and spatial and temporal diversity. Habitat diversity is also generally added to this list.
- **Deal cautiously with risk** — This principle forms the basis of the Precautionary Principle. Green *et al*. (1992) described three approaches to risk in relation to human projects. The "**reactive approach**" relies on technological advance in the future to repair damage caused by a project. The "**anticipatory approach**" promotes research, environmental evaluation, long term integrated planning and the application of new technology. Finally, the "**precautionary approach**” seeks to modify the manufacture, use of products or services, or the conduct of activity, consistent with scientific and

technical understanding, to prevent serious or irreversible environmental degradation. Clearly, the reactive approach is not recommended whereas the second two approaches offer a basis for impact assessment and future management.

- **Consider global issues** — The effects of proposed projects should, wherever possible be predicted in terms of global issues and responsibilities. One example is the protection of cetaceans and Australian commitments under international bird treaties (eg. RAMSAR).
- **Consider economic diversity and resilience** — Large projects may generate economic wealth but they should also be considered in the context of other forms of economic activity in the area. In relation to aquatic ecology, issues under this principle include effects on fishing, eco-tourism and aquaculture. The sale of some products, such as oysters, can be very susceptible to public perception. Thus, projects that release effluent in close proximity to oysters need to consider both specific effects and public perception.

> ***Assessment guidance 3****: Predict the effects of proposed projects in relation to the principles of ecologically sustainable development.*

Important and trivial effects

Predictions regarding the effects of a proposed project should be evaluated in terms of their relative importance. Some impacts may be trivial whilst others are very important. The significance of predicted negative effects is often evaluated in terms of the magnitude of spatial scale and duration, the inertia, resilience and stability of the decision variables and the value of the ecosystem.

Acceptable and unacceptable effects

A final example presented is for effects on the aquatic environment that are predicted to be acceptable or unacceptable. By defining an effect as "acceptable" a proponent acknowledges that the proposed project would have an effect, but it is justifiable in terms of the benefits associated with the project. An "unacceptable" effect would obviously be a serious, if not fatal, impediment to a proposed project. Hopefully, this type of effect would be identified during the scoping phase of a project, in which case the proponent may decide that the project is not sustainable (and therefore not proceed) or seek to develop mitigative measures to minimise (ie. make acceptable) or remove that effect.

> ***Assessment guidance 4****: Identify the relative importance and consequences of what would happen if predicted negative effects occurred or if predicted positive effects did not occur.*

4.3 Mitigation of effects

The development of a proposed project may pass through several stages in which the project is modified to remove or minimise predicted effects or minimise risks. This process of "impact mitigation" is iterative and may extend through time from well before the exhibition of the EIS to beyond its exhibition, when submissions on the EIS are presented to consent authorities.

There is scope for mitigating the effects of a project in the way it is designed, construction activities, long-term operational aspects and timing of activities associated with construction and operation. Each of these should be considered within an EIS. If specialists in aquatic ecology are consulted early in the design process, they may identify issues that could avoid the need for costly redesign.

(a) Design of the project

There are often ways in which some aspects of a proposed project can be designed to minimise predicted effects. The following examples illustrate this. Laying pipelines or building roads may be done to avoid damaging sensitive habitats and to avoid isolating habitats, such as wetlands, from sources of water. Construction of marina facilities may be designed to minimise disturbance of aquatic habitats and the boats within a marina may be reduced to minimise the concentrations of copper leaching into a waterway from antifouling paints. It should be noted that there is often a statutory requirement to minimise or prevent any damage to aquatic environments – this applies particularly to aquatic vegetation, which is protected under the Fish Habitat Management Plan No. 2, administered by Department of Primary Industries. In freshwater ecosystems of NSW, a major concern in the construction of impoundments that prevent migration of fishes. This may be addressed by the incorporation of fishways into the project design (Harris & Gehrke 1997).

Part of the design of projects should also entail what measures would be taken at the end of the life of each project. This concept is readily accepted for projects on mining or extraction and EISs often provide detailed discussion of how sites are to be rehabilitated. This may include removal of equipment, replanting of disturbed ground to minimise runoff and replanting of riparian habitats. There should also be consideration given to how aquatic habitats may be rehabilitated following completion of a project.

(b) Construction activities

There are numerous ways in which effects of construction can be mitigated to avoid un-necessary damage to the aquatic environment. Examples applicable to areas adjacent to waterbodies include measures to prevent runoff of excess suspended solids, nutrients or contaminants, or to avoid un-necessary noise. Another example is the disposal of spoil, which, if managed improperly, can have long-term effects on the aquatic environment (Case Study 1). In most cases specific approval will need to be sought from the NSW DECC, but it is advisable to present a detailed discussion of measures to mitigate constructions activities within the EIS, so that all stakeholders may be able to assess the measures proposed.

(c) Long-term operational aspects

There are many projects that may have long-terms effects on aquatic ecosystems. One example is the discharge of domestic or industrial effluent. It is possible to design mitigative measures that are linked to the results of monitoring (Lincoln Smith 1991, Gray and Jensen 1993) and this forms part of the next major section of these Guidelines. An example of this approach is the discharge of sewage effluent, which could be mitigated by changing the level of treatment say, by introducing a phosphorus reduction programme in the event of increased algal growth. By considering these issues during the design of the project, it may be possible to facilitate upgrades or other changes without incurring undue expense.

(d) Timing of construction or operational aspects

The final way in which mitigative measures may be considered is in terms of the timing of activities to avoid major disturbances to aquatic processes. This approach acknowledges the dynamic nature of the aquatic environment. For example, removal of water from coastal streams in NSW can affect movement of fish by lowering water levels and creating physical barriers. Australian bass migrate downstream to estuaries to spawn in winter in response to increased water levels. Upstream migration of adults and juveniles occurs in the following spring and summer. Proposals for water abstraction can mitigate potential impacts to bass by maintaining environmental flows close to the natural flows during the critical migratory periods. Another example is the timing of activities that may disturb seagrasses to avoid disturbances in spring, when there is usually settlement of large numbers of juvenile fish of economic importance into this habitat (eg. McNeill *et al.* 1992).

In the examples presented on all types of mitigation discussed here, there is a potential cost to the proponent associated with mitigation of impacts. Failure to mitigate negative effects, however, could entail a large cost to the aquatic environment that might have been avoidable by taking a precautionary approach. Clearly, mitigation needs to be considered in relation to the magnitude of the effect, and the benefits and costs of the mitigation.

> ***Assessment guidance 5****: Investigate ways to mitigate potential effects of a project by altering design of the project, construction activities, operational activities and timing.*

> ***Assessment guidance 6****:Eengage specialists on aquatic ecology early during the design of a project to identify any mitigative measures that can be incorporated into the design early to minimise or prevent impacts to aquatic ecosystems*

(e) Environmental management plans

It is often useful to develop an Environmental Management Plan (EMP) to specify how construction and operational activities would be managed in terms of the aquatic environment. This could be integrated into the EMP to manage the project as a whole.

The EMP would also identify decision variables that would be monitored, the size of effects that would trigger a management response (see below) and the nature of the response. It is often useful to present the principles and broad outline of an EMP within the EIS, with details following the approvals process and often linked to conditions of consent.

Assessment guidance 7: *Consider developing an environmental management plan (EMP) to specify how the project would be managed, how management would respond to monitoring results and the nature of the response.*

4.4 Monitoring and feedback to management

(a) *Compliance* versus *effects* monitoring

Distinction is often made between **compliance** monitoring and **effects** monitoring in EIA (eg. Bernstein *et al.* 1993) although, broadly, this distinction is often vague. Compliance monitoring refers typically to collecting data which are compared to specific criteria, such as water quality guidelines, sediment quality guidelines (which are currently being developed for Australia) or levels of contaminants in biota.

This approach assumes, implicitly, that if compliance criteria are exceeded, it is likely that there will be an adverse effect on the aquatic environment and, where they are not exceeded, there is no adverse effect. Recent examples are ANZECC (2000) water quality guidelines and development of criteria for sediments in the USA by Long *et al.* (1995). Their criteria were based on the concentrations of contaminants in sediments for which negative effects on benthic invertebrates were detected.

One difficulty with relying on compliance monitoring is that it may not be an appropriate reflection of the actual effects of the project on the aquatic environment. Effects on the aquatic environment may occur where levels of pollution comply with guidelines - for example there may be synergistic effects among two or more pollutants that individually comply with guidelines (eg. Hellawell 1986). Alternatively, there may be no effect where concentrations exceed compliance levels. This may occur, for example, where contaminants bond closely to sediment particles and become relatively inert (eg. Burton 1992).

Effects monitoring examines more directly the effect of a project on the aquatic environment and this includes most ecological monitoring done for EIA. Broadly, it seeks to determine whether there has been a change in decision variables at the project site that coincides with the initiation of the project. If this monitoring incorporates proper spatial and temporal controls, we may be confident that the change in the decision variable was caused in some way by the project, but note, this evidence would not constitute absolute proof.

The distinction between compliance and effects monitoring becomes blurred in two ways.

- First, by selecting a set of decision variables to monitor, we are essentially stating that the project must comply by showing no ecologically significant effect in relation to those variables - as an indicator of aquatic ecology.
- Second, a properly designed monitoring program should specify the size of an effect considered to be ecologically

important (see Section 3.4 (a)).

The remainder of this section deals with effects monitoring, but the relationship between effects and compliance monitoring should be kept in mind.

(b) The aims of *effects* monitoring

Approval of a project may be subject to requirements for modification (see previous section) and/ or for monitoring. The EIS process has, in the past, been criticised for failure to monitor the effects of approved projects (Buckley 1989, Fairweather 1989) and it is likely that there will be more emphasis placed on monitoring for future developments.

If monitoring is not designed and implemented properly, resources will be wasted and/or inconclusive or misleading results obtained. Monitoring must be designed to address specific questions, which in turn should be based on specific predictions of effects arising from the EIS process.

Broadly, there are four aims of monitoring:

- **To test predictions of the effects of the proposed project** — These predictions may have been included within the EIS, or they may have been presented in submissions commenting on the EIS. It is unlikely that every prediction made about a proposed project would be monitored, so there is a need to decide what processes will be selected and, therefore, what to measure. Such decisions could be based on the logistical considerations, the ability to discriminate an effect or the perceived importance of a certain effect occurring (or not occurring). Clearly, it is important that all stakeholders are aware of - and hopefully agree on - which variables will be monitored.
- **To assist in formulating strategies to mitigate unforeseen effects** that may be identified after the proposal has commenced.
- **To provide information that can be used to make better predictions** about effects of subsequent similar projects elsewhere.
- **To provide information that can be used to make better predictions** about effects of similar or different projects in the same area (ie. cumulative effects).

These aims are linked closely to management because they should trigger management responses, depending on the outcome of the monitoring. Some authors (eg. Gray and Jensen 1993, Bach *et al.* 1997) have argued that explicit linkages (feedback) should be established between the outcomes of monitoring and management response, preferably **before** monitoring the project has commenced. The issue of concern for each decision variable to be monitored should be framed as specific hypotheses to be tested.

> ***Assessment guidance 8****: Select those decision variables that are to be monitored and specify issues of concern as hypotheses to be tested.*

(c) Optimal and suboptimal monitoring designs

Protocols for monitoring have received much attention over the past 20 years (Eberhardt 1976, Green 1979, Bernstein and Zalinski 1984, Stewart-Oaten *et al*. 1986, Eberhardt and Thomas 1991, Underwood 1991, 1992, 1993, 1995, Keough and Mapstone 1995, Schmidt and Osenberg 1996). It is beyond the scope of these Guidelines to review the development of monitoring protocols, but it is important to define broadly those elements that should constitute an optimal sampling design.

The objective of the design should be to distinguish effects associated with a project from natural variation or other anthropogenic effects. To achieve this, monitoring must include sampling of appropriate multiple spatial and temporal controls.

Optimal spatial and temporal controls

At **least two** spatial controls that are not affected by the project are required to provide an appropriate measure of variation among sites that can be contrasted to variation at the project site. Temporal controls involve sampling the project site and spatial controls at **least twice** before any impact due to the project may occur.

The number of sites and times sampled will vary depending on the individual study and should be determined by pilot studies. The use of these controls forms the basis of the BACI (Before-After; Control-Impact) design presented by Green (1979) and expanded as the Beyond-BACI design by Underwood (1991, 1992, 1993, 1995). An important component of Underwood's designs is that they can be expanded readily to incorporate different spatial and temporal scales (Underwood 1993). Recently, Keough and Mapstone (1995) developed additional designs that also require multiple spatial and temporal controls, but assume that the spatial and temporal scales at which effects are likely to occur are known in advance.

Optimal sampling designs for monitoring effects of projects incorporate multiple spatial and temporal controls. Such designs provide a relatively unambiguous test of the effect of a project on selected decision variables in the context of natural variability. Any monitoring program seeking to distinguish natural from anthropogenic effects that does not incorporate appropriate spatial and temporal controls **must** be considered suboptimal (Green 1979) and, hence, does not provide an unambiguous test of the effects of the project.

Dealing with unforeseen effect

There are circumstances, however, where a suboptimal design is the only option available. Green (1979) presented a "decision" key to the main sequence categories of environmental studies. If, for example, an unforeseen effect is claimed to have occurred as a result of a project, there may be no "before" data to evaluate this claim. Here, monitoring would need to utilise as many control sites as logistically possible and effects would need to be inferred from spatial patterns alone.

The conclusion about whether an effect did or did not occur relies on the untested assumption that the project site was ecologically similar to other areas prior to initiation of the project. Having a large number of control sites improves our ability to infer effects because it provides a larger spatial context against which the project site can be compared. If, on the other hand, there are no spatial controls available, effects must be inferred from temporal change alone. Given that populations can vary to extinction due to natural causes, relying on temporal change alone is likely to be very difficult to justify.

Assessment guidance 9: *Seek to use optimal sampling designs using multiple spatial and temporal controls. Where no* ***before*** *data are available, seek to maximise the number of control sites sampled after project initiation.*

(d) Feedback to management

There is little point in monitoring the effects of a project if there is no feedback to management, including plans for how to respond to the results of the monitoring and how to communicate the findings of monitoring to all stakeholders. Management should plan for response to the findings of monitoring in four ways.

Changes to the project

Where adverse effects have been detected by monitoring, it may be possible, for some projects, to alter operational activities to mitigate impacts (Fig. 2). For example, if discharges of effluent were having an unacceptable effect, it may be possible to alter the quality of the effluent (by further treatment) or the quantity (by disposal by other means). In some cases, the impacts may still be unacceptable and the project may need to be terminated as being unsustainable. The proponent prior to seeking approval for a project should consider the risk of this occurring.

Changes to other projects

Information obtained on the effects of projects on aquatic ecology forms the cornerstone for predicting and managing the effects of other, similar projects. Essentially, projects where monitoring has been done properly and reported with appropriate detail can become case studies for subsequent projects of a similar type. Importantly, information form case studies may be used to define effect sizes (Section 3.4) that can be used to improve the efficiency of future monitoring.

Modification of monitoring

Results of monitoring should be used by management to assess ongoing monitoring for each project. Here there are several categories that apply (see also Figure 2).

- **No effect is detected and the sampling design has enough statistical power to detect ecologically significant changes.** There should be some agreed, pre-determined period of time over which monitoring should be done and, if at the end of that time, no effects have been detected, monitoring should end.

- **No effect is detected, but statistical power is poor as determined from *post hoc* power analysis.** Graphical inspection of the data may suggest an effect, but statistical tests may fail to provide an objective confirmation of this due to low power. This may occur because the monitoring program was designed poorly in the first place, or because variances were larger than when *a priori* power analyses were done on pilot data, diminishing the power of the program. This change in variances could, if confined to the project site, indicate an effect of the project and the Beyond-BACI framework allows these variances to be examined statistically (Underwood 1993, 1995b).

  If no effect still has been detected by tests with low power, further monitoring may be required. If the effect appears to be a press disturbance, there **may** be a long-term impact (ie. a press response - Glasby and Underwood 1996) and continued monitoring could increase the power to objectively demonstrate this effect. This type of approach has been considered in relation to exploitation of fisheries (Peterman 1990) and may be applicable in EIA.

If, however, the effect seems to be a pulse disturbance, continued monitoring will be problematic and a precautionary approach is warranted. Where the pulse is unlikely to recur, the lesson for management is to allocate more resources for monitoring this particular effect in any subsequent projects. Where the pulse may recur for that project, there are three management responses that should be considered. First, assume, on a precautionary basis, that an effect **will** occur and initiate mitigative measures to remove or minimise the effect. Second, increase the power of statistical testing when incorporating new monitoring data by increasing the significance criterion (eg. increase α from 0.05 to 0.10). Third, redesign the monitoring program by increasing within-site replication, the number of control sites sampled, the frequency of sampling around the predicted time of the pulse, etc. The latter response may be the least desirable because it limits the ways in which we can use the **pre-effect** data.

- **An effect is detected**. It is expected that, if an effect is detected, management will initiate a pre-determined response. Monitoring can then be used either to evaluate whether there was a recovery in the environment (eg. from a press disturbance that has now been removed) or whether the effect has occurred again (eg. following a pulse disturbance). Ongoing monitoring using the same sampling design can be incorporated readily into an analysis of variance framework, by simply expanding the time periods, as the following example illustrates.

  Consider the construction of a small effluent outfall with secondary treatment. It is predicted that there will be no impact on the percentage cover of intertidal green algae. This effect, however, has been identified in other studies (eg. Fairweather 1990b). As a precautionary measure, management has provided to upgrade treatment to tertiary level with nutrient removal if percentage cover of green algae increases beyond a certain level relative to three control sites and the pre-outfall condition within 50 m of the outfall. Here, monitoring provides for three times of sampling before project initiation (done during and just after the EIS phase) and three times after. Therefore, there will be before and after periods that are compared, with three times in each period to evaluate small-scale temporal variability. After the third time of the after period, analysis of data identifies a significant effect between periods. In response, management initiates treatment upgrade and monitoring is done three more times, during the recovery period. Analysis can then be done to compare the before, after and recovery periods and small-scale temporal variability within each of these periods.

Assessment guidance 10*: Establish mechanisms for feedback of monitoring results to management, consider management response to monitoring results and how monitoring can be adapted in relation to management response.*

Communicating monitoring results and management response to stakeholders

Stakeholders who may be affected by a project have concerns covering social, economic, conservation, recreational, educational and, in some cases, research issues (eg. where a study site may affect scientific studies or control sites for monitoring other projects). It is therefore essential that proponents and their consultants provide mechanisms for communicating the results of monitoring and how they propose to respond to these results, to relevant stakeholders.

This Guideline strongly recommends that proponents develop such mechanisms as an integral part of the project and provide opportunity for stakeholders to have input into potential management response. Peterson (1993) provides a useful discussion of stakeholder involvement in EIA, including the use of independent panels for evaluating monitoring results of large projects.

***Assessment guidance 11**: Establish ways in which monitoring results and management response can be communicated to stakeholders.*

(e) Management and statistical power

Much of the discussion in the previous two chapters involved using statistical tests to provide an objective test of the presence or absence of differences between the project site and other places that can provide a context against which the project site can be compared. In relation to the preparation of an EIS for a proposed project, the test is about whether the proposed project site has more species, or greater abundances of certain species, or more extensive habitat, etc., than other places. In the context of monitoring the effects of a project, the test is about whether changes that occur there are different to what we might expect in nature. Because most components of nature can vary by orders of magnitude, we use spatial and temporal controls to provide a measure of relative change.

Understanding the nature of anthropogenic change, how we detect and measure it and its implications for a project requires that managers increasingly understand the concept of statistical power, even if they do not understand the mechanics of how power is calculated. Mapstone (1995) provides an excellent insight into how power can be used to assist in decision-making about whether an effect has occurred. It is important that proponents and their consultants recognise that, without some *post hoc* evaluation of statistical power for a monitoring program, any finding of **no-effect** will be subject to the criticism that the program simply did not have enough power to detect an ecologically significant effect. This could invalidate the monitoring program and waste resources and effort.

***Assessment guidance 12**: Without some evaluation of statistical power, a statistically non-significant result for monitoring should not be used as basis for future management of a project.*

4.5 Environmental audit

It is increasingly likely that monitoring programs will be subject to environmental audit to ensure that procedures have been followed properly and that the findings are correct (Tomlinson and Atkinson 1987, Buckley 1989, Ambrose, *et al*. 1996). Four components of a monitoring program that need to be considered during auditing are discussed as follows.

(a) Design and proposed methodology

Auditing should begin with an appraisal of the sampling design and proposed methodology and whether they will provide a logical basis for addressing the question(s) of interest, which, in turn, should be based on the predictions made during the EIS process. The Scoping Appraisal provided in Appendix 1 could be used to evaluate how ecological investigations have been designed and initiated.

> ***Assessment guidance 13****: Ensure that study designs and sampling methodology is appropriate to address the questions of importance.*

(b) Quality assurance on actual methodology

Aquatic ecologists should maintain a quality assurance plan detailing information on all elements of field sampling, laboratory processing and testing, data entry and proofing and statistical analysis of data. A major problem identified with data storage is that it is often poorly referenced and inadequately coded, so that independent analysis of data is not possible (Carney 1996, Keough and Mapstone 1995). The Investigative Appraisal developed for this Guideline (**Appendix 2**) can be used to focus on how proponents and consultants have gone about their research.

> ***Assessment guidance 14****: Ensure that QA procedures have been followed and that site positions, sampling dates, reference specimens and data have been stored to validate study findings.*

(c) Matching results and interpretation

The results obtained from study designs utilising spatial and temporal controls can often be difficult to interpret. It is important that aquatic ecologists ensure that these results are correctly interpreted and not oversimplified. The best way for consultants to ensure that their findings are properly interpreted is by peer review. Assessing the validity of interpretations (and recommendations following) is a critical step in the process of auditing.

> ***Assessment guidance 15****: Ensure consistency between conclusions, recommendations and study findings.*

(d) *Post hoc* evaluation of statistical power

Auditing the statistical power of monitoring programs is one way that auditors can evaluate the interpretation of results. Fairweather (1991) and Cohen (1988) discuss procedures for *post hoc* power analyses. Essentially, they are used to evaluate non-significant statistical results and address the question: given the sampling size used and the variability observed in the data collected, what was the power of the test(s) used to detect a hypothesised difference?

> ***Assessment guidance 16**: Ensure that study results are assessed in terms of their power to detect predicted (hypothesised) effects.*

4.6 Conclusion

These Guidelines present three parts to ensure aquatic ecology issues are appropriately considered in the EIA process - for investigations of aquatic ecology from scoping through the preparation of an EIS to prediction of effects, mitigation, monitoring and audit.

The references cited should provide aquatic ecologists, managers and stakeholders with both a broad background and specific details of procedures of EIA in relation to aquatic ecology.

It must be recognised that the application of aquatic ecology within the process of EIA is undergoing rapid change, both in terms of procedures used and the expectations of the public. Those using the Guidelines should therefore also recognise that current best practice is changing rapidly and new developments must be incorporated as soon as they become accepted. Therefore, these Guidelines will need to be updated as new approaches become available.

Appendix 1. Scoping Appraisal for Assessment of Aquatic Ecology

This table should be photocopied and used when appraising individual EISs

Scoping Guidance	Section No	Guideline Content	Scoping sufficiency for EIS				Action Required?
			N/A	Low	Mod	High	
1. The Nature of the Proposal:							
SG1	2.2	Define the types of physical, chemical &/or biological disturbance in the aquatic environment that may be associated with/caused by the proposal					
SG2	2.3(a)	Assess the extent to which the proposed project may physically alter any waterbodies.					
SG3	2.3(a)	Determine presence of aquatic species whose migratory patterns could be directly affected by creation of barriers & assess if unnecessary impacts could be avoided by timing aspects of the proposal.					
SG4	2.3(a)	Evaluate the extent to which the proposal may affect physical properties of waterbodies including sediment characteristics. Consider the potential for unexpected events (storm-related turbidity)					
SG5	2.3(b)	Evaluate the extent to which the proposal may affect the chemical properties of waterbodies - Consider the potential for unexpected events (eg chemical spillages).					
SG6	2.3(c)	Identify any species or stocks genetically distinct from existing stocks, that may be introduced into an area - intentionally or by accident - as a result of the proposal.					
2. The Nature of the Aquatic Environment:							
SG7	2.4(a)	Clearly define the spatial extent of the aquatic ecosystem, habitats, etc, that may be affected by the proposal, specify how the area may change through time and identify potential linkages to other locations or ecosystems.					
SG8	2.4(b)	Define appropriate spatial and temporal scales that should be considered to provide a proper assessment of effects; if these are not known, incorporate two or more scales for consideration.					
SG9	2.4(c)	Examine all potential components of the aquatic ecosystem that could reasonably be investigated and define those components - the decision variables - that should be used in the assessment process for the proposal.					

Scoping Guidance	Section No	Guideline Content	Scoping sufficiency for EIS				Action Required?
			N/A	Low	Mod	High	
3. Determining the Appropriate Level of Investigation							
SG10	2.5(a)	Aim to base the level of ecological investigations on an understanding of existing information, the type of disturbance, response of the decision variables, the scale of the project and the risk of unpredictable or cumulative effects.					
SG11	2.5(a)	Apply the Precautionary Principle in determining the level of investigation for the proposal, particularly in relation to the risk of unpredictable or cumulative effects and importance of components of the ecosystem that may be affected.					
SG12	2.5(b)	Define precisely the questions of concern and determine, in as much detail as possible, how data will be statistically analysed before finalising the study programme.					
SG13	2.5(c)	Identify government departments, local groups and commercial interests that will need to be consulted regarding aquatic ecology and identify protocols by which information gathered will be communicated to these entities.					
4. Scoping Procedures							
SG14	2.6(a)	Obtain advice on aquatic ecology early in the design of a project, ensure that data collected by all specialists are, wherever possible, at similar spatial and temporal scales and that study programs are co-ordinated from the earliest possible stages.					
SG15	2.6(a)	Where peer review is used by proponents to provide independent assessment of aquatic ecological studies for an EIS, they should be engaged before study designs are finalised.					
SG16	2.6(a)	Pilot studies should be considered as part of scoping procedures to assist with the design of ecological studies for an EIS.					

Appendix 2. Investigation Appraisal for Assessment of Aquatic Ecology

This table may be photocopied and used when appraising individual EISs

Investigation Guidance	Section No	Guideline Content	Scoping sufficiency for EIS				Action Required?
			N/A	Low	Mod	High	
1. Use of Existing Information:							
IG1	3.2	Review and critically evaluate existing information & ensure sampling supplements existing information & addresses the types of effects likely to be associated with the proposal					
2. Sampling Methodology:							
IG2	3.3(a)	Define or describe aquatic habitats with sufficient detail to allow them to be placed into an appropriate geographical context; define habitat boundaries & spatial patchiness					
IG3	3.3(b)	Ensure that sampling methods are objective & that sampling is done by properly trained workers; where possible, seek to use or adapt methods already evaluated, either in pilot studies or by other researchers					
IG4	3.3(b)	Identify any limitations to sampling & how these may affect investigations & their interpretation					
IG5	3.3(c)	Retain samples, or at least a reference collection of samples, until determination of the proposed project					
IG6	3.3(c)	Ensure that samples sent to chemical laboratories are labelled clearly, but do not signify to the labs specific sites, replicates or duplicates. Supply replicate/duplicate samples for QA					
IG7	3.3(c)	Ensure that detection limits used by chemical laboratories are set below the concentration(s) of concern					
2. Analysis of data and interpretation of results:							
IG8	3.4(a)	For statistical tests, try to define the direction & magnitude of differences that may be ecologically, economically or socially significant.					
IG9	3.4(a)	Define the questions to be answered in detail before collecting the data; carefully select statistical tests to be used & ensure that underlying assumptions have been met.					

Investigation Guidance	Section No	Guideline Content	Scoping sufficiency for EIS				Action Required?
			N/A	Low	Mod	High	
IG10	3.4(a)	Seek to use both univariate and multivariate procedures to evaluate variation at the level of populations and assemblages.					
IG11	3.4(a)	Where statistical tests are non-significant, examine differences between treatments & assess if there was sufficient power to distinguish an effect that may be ecologically significant.					
IG12	3.4(a)	Consider statistical power in relation to pilot investigations, the min EIS and preparations of designs for monitoring. Get advice from statistical experts to minimise the risk of costly mistakes.					
IG13	3.4(b)	Evaluate data input & test outputs of statistical computer software. Check new programs by running data sets with known outcomes and compare test results with plots of the data to ensure consistency.					
4. Presentation of results							
IG14	3.5	Ensure specialist reports are available for review during the EIS exhibition and that the main EIS report is consistent with results & interpretation of specialist reports.					
IG15	3.5(a)	Construct an outline plan and ensure continuity of flow through sections of the report. Present a non-technical summary.					
IG16	3.5(b)	Present summaries of information in tables of graphs without repeating in the text; always present error bars (eg. standard errors, confidence limits) with averages.					
IG17	3.5(b)	When providing results of statistical tests, present probabilities, even where non-significant					
IG18	3.5(c)	Appendices should be used to present raw data (or means/standard errors), highly technical information and supplementary information					
4. Presentation of results							
IG19	3.6	Provision should be made for proper storage of data collected during all stages of the EIA process					

Appendix 3. Assessment Appraisal for Prediction, Mitigation, Monitoring and Audit of Effects Related to Aquatic Ecology

This table may be photocopied and used when appraising individual EISs

Assessment Guidance	Section No	Guideline Content	Scoping sufficiency for EIS				Action Required?
			N/A	Low	Mod	High	
1. Predicting Effects:							
AG1	4.2(a)	Present predictions of effects as explicitly as possible and present the basis of each prediction.					
AG2	4.2(b)	Define a framework for presenting predictions of effects appropriate for the specific project being considered; evaluate effects over different phases of the life of the proposed project and consider cumulative effects.					
AG3	4.2(b)	Predict the effects of proposed projects in relation to the principles of Ecologically Sustainable Development.					
AG4	4.2(b)	Identify the relative importance and consequences of what would happen if predicted negative effects occurred or if predicted positive effects did not occur.					
2. Mitigation of Effects:							
AG5	4.3(d)	Investigate ways to mitigate potential effects of a project by altering project design, construction activities, operational activities and timing.					
AG6	4.3(d)	Engage specialists on aquatic ecology early during the design of a project to identify any mitigative measures that can be incorporated early to minimise or prevent negative effects.					
AG7	4.3(e)	Consider developing an environmental management plan (EMP) to specify how the project would be managed, how management would respond and the nature of response. Present he general principles of the EMP in the EIS, with details following the approvals process					

Assessment Guidance	Section No	Guideline Content	Scoping sufficiency for EIS				Action Required?
			N/A	Low	Mod	High	
3. Monitoring & Feedback to Management:							
AG8	4.4(b)	Select those decision variables that are to be monitored and specify issues of concern as hypotheses to be tested.					
AG9	4.4(c)	Seek to use optimal sampling designs using multiple spatial and temporal controls. Where no "before" data are available, seek to maximise the number of control sites sampled after project initiation.					
AG10	4.4(d)	Establish mechanisms for feedback of monitoring results to management, consider management response to monitoring results and how monitoring can be adapted in relation to management response.					
AG11	4.4(d)	Establish ways in which monitoring results and management response can be communicated to stakeholders.					
AG12	4.4(e)	Without some evaluation of statistical power, a statistically non-significant result from monitoring should not be used as a basis for future management of a project.					
4. Environmental Audit:							
AG13	4.6(a)	Ensure that study designs and sampling methodology are appropriate for the questions of importance.					
AG14	4.6(b)	Ensure that QA procedures have been followed and that site positions, sampling dates, specimen references and raw data have been stored properly and that they validate the study findings.					
AG15	4.6(c)	Ensure that conclusions and recommendations are consistent with the study findings.					
AG16	4.6(e)	Ensure that study results are assessed in terms of their power to detect hypothesised effects.					

Appendix 4. Examples of common decision variables used in studying types of project in different aquatic ecosystems

Aquatic ecosystem	Common types of proposal*	Some common categories of decision variables	Some sampling methods for biota
Rivers	▪ mining/extraction ▪ flood mitigation ▪ water supply	▪ geomorphological & flow characteristics ▪ water quality ▪ riparian vegetation ▪ aquatic macrophytes ▪ macroinvertebrates ▪ fish ▪ amphibians ▪ reptiles ▪ birds ▪ mammals	▪ **macrophytes** - transects & quadrats ▪ **macroinvertebrates** - surber samplers push net ▪ **fish** - electrofishing, fyke, gill & seine nets, baited traps ▪ **amphibians** - transects, call-detection, spotlight ▪ **mammals & reptiles** - pit traps, spotlight, point counts ▪ **birds** - transects, call-detection, point counts
Wetlands	▪ residential development ▪ roadworks	▪ plant diversity & density ▪ macro-invertebrates ▪ birds ▪ mammals ▪ amphibians ▪ reptiles	▪ **plants** - mapping, transects & quadrats ▪ **macroinvertebrates** - quadrats, insect traps ▪ **fish** - fyke, seine nets, pop nets ▪ **amphibians** - transects, call-detection, spotlight ▪ **mammals & reptiles** - pit traps, spotlight ▪ **birds** - transects, call-detection
Estuaries	▪ port works & marinas ▪ mining/extraction & dredging ▪ industry on foreshores ▪ residential development	▪ distribution & density of seagrasses & mangroves ▪ shoot length, epiphyte growth of seagrasses ▪ macroinvertebrates of soft substrata ▪ fish ▪ birds	▪ **sessile animals & plants -** mapping, transects & quadrats; ▪ **macroinvertebrates** - corers and grabs ▪ **fish -** beam trawl, seine and gill nets ▪ **birds -** transects, call-detection
Continental shelf	▪ sewage disposal ▪ spoil disposal	▪ intertidal & subtidal plants & animals of rocky substrata ▪ macroinvertebrates of soft substrata ▪ pelagic & demersal fish	▪ **sessile animals & plants** - mapping, transects & quadrats photoquadrats & video ▪ **soft sediment macroinvertebrates** - corers and grabs ▪ **fish** - otter trawl, purse seine, trap, line, visual counts on shallow reef ▪ **birds** - transects, call-detection

** source of information: M. Lincoln Smith (unpublished data)*

Appendix 5. Relevant Government Policies, Information & Guidelines

Useful web sites
www.planning.nsw.gov.au, www.dpi.nsw.gov.au, www.environment.nsw.gov.au.

Department of Planning

- ASSMAC Acid Sulphate Soil Manual (1998)
- EIS Guidelines (various)
- NSW Coastal Policy (1997)
- Coastal Wetlands of NSW: A Survey and Report. NSW Coastal Council (1985)
- Guidelines: Wetland Restoration Plans (1999)
- Coastline Management Manual (1990)
- Estuary Management Manual (currently being updated)
- Estuary Management Policy
- Floodplain Management Manual: the management of flood liable land (2001)
- NSW Coastal Policy 1997: A Sustainable Future for the New South Wales Coast
- NSW Groundwater Policy
- NSW Wetland Management Policy
- State Rivers and Estuaries Policy
- The Constructed Wetlands Manual 1998
- The New South Wales Coast - Government Policy
- Total Catchment Management Policy

Department of Primary Industries

Fishery profiles and management documents

- Aquatic Habitat Management and Fish Conservation - Policy and Guidelines (1999)
- Aquatic Inventory of NSW (1985)
- Barriers to Fish Passage (2001)
- Cold Water Pollution (2001)
- Fishcare - Our Freshwater Rivers and Streams (1995)
- Fishcare - Our Freshwater Wetlands (1995)
- Fishcare - Saving Our Mangrove Forests (1998)
- Fishcare - Saving our Seagrasses (1995)
- Fishways - Solutions for Fish Passage, State Fishways Program (2000)
- Habitat Protection Plan 3: The Hawkesbury-Nepean River System (1998)
- Management of Macroalgae (Seawead) in New South Wales Waters (1999)
- Management of Wobbegong Sharks in NSW NSW (2001)
- Policy and Guidelines for Bridges, Roads, Causeways, Culverts and Similar Structures (1999)
- Riparian Vegetation (2001)
- River Regulation and Environmental Flows (2001)
- Snags (large woody debris) (2001)
- Water Quality (Pesticides) (2001)
- Wetlands and Floodplains (2001)

Managing pests

- Alien Fish (2001)
- Banded Grunter - Noxious Fish in NS (2001)
- Invasive Seaweed Caulerpa Taxifolia (2001)

Protection of threatened species

- Aquatic Habitat & Fish Conservation - Policy & Guidelines (1998)
- Black Rock Cod - A Protected Fish (1994)
- Conservation of Threatened Aquatic Species (1998)
- Conservation of Threatened Species - Obligation of Local Councils (1998)
- Eastern (freshwater) Cod - A Threatened Fish in NSW (2000)
- Estuarine Management Guidelines (1993)

- Fish Habitat Management Plans (1997-8)
- Freshwater Management Guidelines (1993)
- Great White Shark Protection in NSW (1997)
- Protected Marine Fish Species Sighting Sheet Program - Status Report 1997
- Protecting our Native Freshwater Fish (1996)
- Protecting Seashore Animals
- Threatened Species in NSW - Trout Cod (2001)

NSW Department of Environment and Climate Change

- Approved Methods for the Sampling and Analysis of Water Pollutants in NSW (1999)
- Beachwatch Partnership Pilot Program. Draft Information Package and Field Manual for Monitoring and Reporting Coastal Recreational Water Quality (2002)
- Biological Indicators of Freshwater Ecosystems (1994)
- Coastal Resource Atlas(s) for Oil Spills
- Guidance for the Use of Herbicides Near Waters - Draft (2000)
- Best Management Practice for Marinas & Boat Repair Facilities (1999)
- Protocol for Investigating and Reporting Fish Kills (1996)
- Stormwater Council Resource Kit (2000)
- The Hawkesbury-Nepean River: Recreational Water Quality (1995)

ANZECC (Australian and New Zealand Environment and Conservation Council)

- Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2000).
- Australian Guidelines for Water Quality Monitoring and Reporting (2000).
- Consultancy Study on Sea Dumping of Dredged Spoil, Phase I Report (1994)
- Interim Marine and Coastal Regionalisation for Australia - an ecosystem-based classification for marine and coastal environments (1998)
- Ocean Disposal Guidelines (1998).
- Code of Practice for Antifouling and In-water Hull Cleaning and Maintenance (1997)

Commonwealth Department of Environment, Water, Heritage and the Arts

- A Conservation Assessment of the Australian Coastal Zone (1992)
- Artificial Reefs – Fact Sheet
- Australia's Marine Protected Areas: Protecting our Oceans
- Coastal Engineering Guidelines (1998)
- Coastal Tourism - A Manual for Sustainable Development (1997)
- Commonwealth Coastal Policy (1995)
- Commonwealth Marine Protected Areas: Assessment and Declaration Processes
- Dumping Wastes at Sea – Fact Sheet
- Good Practice Guidelines for Integrated Coastal Planning (1998)
- Lord Howe Island Marine Park (Commonwealth Waters) Management Plan (2002)
- Maintaining Biodiversity in Sustainable Marine Fisheries - a Review and Scoping of Future Directions (1999)
- Reducing the Impacts of Shipping Operations on the Marine Environment: An Information Register (1996)
- Report of the National Taskforce on the Prevention and Management of Marine Pest Incursions (2000)
- Report Series - Coasts and Clean Seas
- Solitary Islands Marine Reserve (Commonwealth Waters): Management Plan
- Terrestrial and Marine Protected Areas in Australia (1997)
- Water Quality Targets: A Handbook (2002)

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