Sydney Catchment Authority

Managing Biodiversity in the Sydney Water Supply Catchments

Outcomes of a Workshop held at Warragamba Conference Centre, 12th and 13th October 2000

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1 INTRODUCTION

The Sydney Catchment Authority (SCA) is currently assessing its monitoring obligations as part of a review of its operating licence. This review recognises the indicators of water and catchment condition contained in the previous Sydney Water Board licence and those identified and proposed in the Catchments Audit undertaken under the direction of an independent auditor (SCA 1999). In adopting environmental indicators in its new licence, the SCA must consider the ecological health of the 29 water supply catchments (including vegetation cover, riparian zones and water quality), and flora and fauna biodiversity.

The SCA approached the Cooperative Research Centre for Freshwater Ecology (CRCFE) to provide assistance with the selection of indicators, specifically those related to biodiversity issues. In particular, information was sought to help develop indicators that could be used to identify and protect special areas that may contain endangered communities on land and water.

A specialist workshop was convened on the 12th and 13th October at which biodiversity issues relevant to the Sydney water supply catchment areas were identified and discussed. The workshop was attended by representatives from the SCA, CRCFE, Macquarie University, Department of Land & Water Conservation and ANSTO. This document reports on the issues and discussion that took place at the workshop.

2 KEY QUESTIONS RELATING TO BIODIVERSITY IN THE SYDNEY WATER SUPPLY CATCHMENTS

The loss of biological diversity is perhaps our most serious environmental problem (Australia: State of the Environment 1996). Although legislative Acts and various strategies have been prepared to address biodiversity issues at all levels of government in Australia (Federal, State, Local), the conservation of biodiversity remains a challenge for resource managers. For example, individuals or organisations may interpret biodiversity in different ways, while others may not recognise biodiversity conservation as a management responsibility or pressing issue. This may be especially problematic for conserving biodiversity in freshwater systems that are often relatively rich in species, imperilled from many pressures or activities, and sometimes neglected (Abramovitz, 1996).

Water resource management agencies have traditionally focussed on amenity, i.e. on the protection of water quality for consumptive and agricultural purposes, and on the maintenance of recreational opportunities. Even when organisations acknowledge that they have some responsibility for managing biodiversity, they may find it difficult to accommodate this in day to day operations due to a limited understanding of ecosystem biodiversity and how this relates to other management demands, or the need to manage a number of pressures on biodiversity simultaneously. Some of the pressures on biodiversity in freshwater ecosystems include:

- Change in land use on catchments;
- Changes to water quality and quantity, and timing of its delivery, resulting from resource development (reduced flow and changed flow patterns);
- Habitat modification and degradation reducing habitat available to support biodiversity;
- The fragmentation of ecosystems that disrupts the natural processes that support biodiversity (e.g. changed land use and activity, disruption to the continuity and intactness of riparian zones; instream barriers to migration etc.);
- Negative interaction with alien invaders; and
- Disruption of hydrological connectivity.

A number of important questions were posed at the workshop in order to help clarify what the biodiversity responsibilities of the SCA might be and to identify opportunities for including of biodiversity management in the SCA's current operational framework:

- What is biodiversity?
- Why do we value it?
- What is the connection between biodiversity and amenity (e.g. water quality, public health, ecosystem services, recreation)?
- What regulates biodiversity in natural and modified systems, and what drivers might we manipulate to achieve biodiversity goals?
- How do you measure biodiversity?
- How far can systems be modified before adversely impacting on biodiversity or amenity?

2.1 What is biodiversity?

Biodiversity issues gained prominence in Australia in the early 1980’s before which the focus was mainly on protecting threatened species. It soon became apparent that in directing resources toward conserving a threatened species, a wide range of attendant benefits could be achieved. Threatened species were often viewed as an umbrella where conservation action led to the protection of a wide range of species whose needs were similar or who occupied common ground. Protecting a threatened species and its habitat was also assumed to protect key ecological processes important to overall ecological integrity. These broader considerations soon transcended the focus on threatened species, and the concept of biodiversity conservation emerged. The National Strategy for the Conservation of Australia's Biological Diversity (Environment Australia 1998) defines biodiversity as: "The variety of life forms: the different plants, animals and micro-organisms, the genes they contain, and the ecosystems they form. It is usually considered at three levels: genetic diversity, species diversity and ecosystem diversity." Biodiversity conservation therefore takes on a much broader focus than threatened species conservation or simply the protection of hotspots of species richness or endemism.

Biodiversity is now seen to encompass the concepts of species richness, ecosystem diversity that accounts for diversity above the level of species (e.g. habitats, landscape level), genetic diversity below the level of species, and ecological process. A related concept of ecological integrity has gained prominence in recent years, and is now enshrined in a number of environmental Acts and Regulations, albeit without clear definition. Protecting ecological integrity involves protecting the complex ecological processes that support *a balanced, integrated, adaptive community of organisms with a species composition, diversity and function comparable to that of natural habitat in the area* (Karr 1991). This concept was regarded as useful by the SCA in encapsulating the aspects of biodiversity that go beyond the species focus.

The SCA’s commitment to environmental protection is currently focussed on the management of threatened species and the maintenance of habitat, especially where this is related to the management of catchment processes that protect water quality, public health and public safety. Species richness, genetic diversity and ecosystem diversity were also recognised as the hallmarks of ecological integrity, which includes aspects of community structure and ecological processes.

A commitment to biodiversity conservation may take two forms:

- To protect aspects that are valued by the community (e.g. threatened species - to protect those species we know); or
- To protect systems in a way that conserves the known genes, species and ecosystems and those that have not yet been recorded but may play an important role in maintaining ecological processes. (i.e. to protect both those we know and those we don’t know).

The latter of the two above approaches was recognised as important to the SCA in light of its wish to maintain ecological processes, especially those related to the protection of water quality.

2.2 Why do we value biodiversity?

Biodiversity is important to our culture, both in terms of economic value that can be gained from the biota via materials, medicines and ecosystem services (e.g. provision of clean water), in terms of the ecological sustainability of human societies, and in terms of rich and varied opportunities in recreation and tourism, and our ethical concern for biodiversity in its own right.

Central to considerations of the value of biodiversity to society is the issue of inter-generational equity, whereby we have a commitment to leave the environment at least as healthy and productive as it is now, for future generations. This is the principle that drives such government initiatives as the Natural Heritage Trust (NHT) and Environmentally Sustainable Development (ESD). In particular, we need to ensure that our limited freshwater resources are not degraded.

In line with the above sentiments, many reasons for valuing biodiversity conservation were proposed at the workshop, ranging from philosophical to utilitarian views, and included:

- Maintenance of cultural values;
- Maintenance of recreational values;
- For aesthetic reasons;
- Maintenance of ecological integrity and provision of ecosystem services;
- As a current and future source of natural capital.

While a complete range of values was not compiled, there was agreement that conserving biodiversity was an important management consideration for the SCA. Support for this view was derived from the obligations of the organisation under its charter to protect the environment in areas under its control, but also because of a perceived connection between biodiversity and the ability to deliver on other elements of its charter – water quality, public health and public safety.

2.3 What is the connection between biodiversity and ecological integrity?

SCA manages its catchments to provide amenity related to:

- The provision of water of suitable quantity and quality to meet the needs of Sydney;
- The provision of recreational opportunities;
- The maintenance of the ecosystem services important for maintaining a safe water supply.

The workshop explored the ways in which biodiversity may relate to the above amenity considerations. Some of the key questions raised include:

- What does conserving biodiversity deliver?
- Are diverse systems more resistant and resilient to human-induced perturbation than depauperate systems?
- How far can biodiversity be pushed (i.e. species or processes lost) before amenity is compromised?
- Are some species or processes redundant to ecological integrity?
- Are natural systems threshold systems for which biodiversity collapses when pushed beyond certain limits?

It was accepted by the workshop that the knowledge necessary to answer these questions at a level sufficient to govern management action was not currently available.

For example, it is generally assumed that biodiverse systems are able to sustain ecosystem services better than degraded systems, but this assumption requires confirmation (but see Stone and Wallace 1998).

Our understanding of how systems may be modified before there are adverse biodiversity impacts is also limited (Heywood and Watson 1995). While it was difficult to define how far systems might be pushed (this will vary depending on the system and the nature of pressures on it), there were a number of factors that were regarded as influential:

- There may be hysteresis effects – systems are easy to damage but hard to repair;
- It is unlikely that perturbed systems would return to their pre-disturbed condition upon recovery or rehabilitation;
- Systems may not necessarily recover from disturbance of their own accord -- additional intervention may be required for recovery.

It was accepted that, in principle, many species and processes might be redundant to providing integrity (especially rare species), but that this concept was not operationally useful. An analogy of ‘removing rivets from the wing of an aeroplane’ was provided to help explain redundancy: some rivets could be safely removed, but how many rivets could be removed before the wing failed and the aeroplane crashed? It was agreed that identifying which species and processes were redundant was an impossibility, given uncertainty in what pressures the future might bring. Indeed, the concept of redundancy was regarded as time dependent. Species may be redundant in the short term, but in the longer term, the ‘redundant’ species may be required when others performing a similar function are lost.

In this context, redundancy should be viewed as “capacity held in reserve” to adjust to disturbance. The SCA intends to adopt the assumption that maximising species diversity and ecological integrity is the best strategy for delivering the highest level of ecosystem services in terms of water quality, public health and public safety (cf. the precautionary principle). This stance will also satisfy the objective of protecting the environment. Future scientific studies may clarify the issues of redundancy, resistance and resilience as they relate to management practice, though it was recognised that even if redundancy with respect to amenity or integrity could be identified, the objective of biodiversity conservation rested also on non-utilitarian values.

2.4 What factors regulate biodiversity?

If we are to manipulate biodiversity to achieve conservation or amenity goals, then we need to know what processes regulate it in both disturbed and natural ecosystems.

There is a vast literature on processes that have a bearing on species richness and other biodiversity values, many acting on evolutionary time scales. From this base, management of biodiversity must draw knowledge of those processes that act on ecological time-scales, in order to moderate the effects of human activity on biodiversity or to restore and rehabilitate degraded habitat. This theoretical underpinning has been a neglected area of freshwater conservation ecology.

There are two dimensions to the ecological processes that regulate biodiversity. The first encompasses those factors and processes that make an area able to support high biodiversity. It deals with the interplay between biological attributes of the organisms themselves, such as their reproductive biology and habitat preferences, and abiotic influences, such as the timing and intensity of flooding. This is a research area that lends itself to experimental manipulations to test theories on biodiversity regulation.

The second dimension encompasses those factors and processes that influence the ability of species to gain access to suitable areas, through recruitment and dispersal. In cases where local extinction is a feature of life histories, invasion must occur at a rate equal to or greater than the rate of local extinction. The degree of connectivity or conversely, degree of isolation, have profound effects on biodiversity at all levels – the deme, the population, the species and the community – and on all spatial and temporal scales. Key related issues that have gained prominence in aquatic conservation biology include the impact of habitat fragmentation, of artificial barriers to dispersal, of altered flows and temporal patterns of connectivity (both seasonally and on longer cycles), and of altered channel connections. The impact of these human-induced changes on species depends partly on their respective dispersal capabilities and life history attributes, which are often poorly known. Modern molecular techniques used to study the spatial distribution of genetic markers have dramatically increased our capability to quantify these impacts. Using genetic markers, we can indirectly measure the levels and patterns of dispersal among isolated, semi-isolated or apparently connected sub-populations. We can relate these to historical factors for a better understanding of the spatial distribution of our biota across the catchment, predict the likely consequences for biodiversity if certain developments go ahead, and provide advice on how to moderate the impact of such developments.

In the context of the current activities of the SCA, habitat protection in areas of minimal disturbance, and habitat restoration (particularly riparian habitat) in highly modified areas, are essential components of efforts to achieve biodiversity conservation. The assumption is that if we restore habitat (floristically, structurally and qualitatively) and pay attention to connectivity issues, then biodiversity values and the services they provide will improve. This approach is considered sensible, as detailed knowledge of the factors that regulate biodiversity on a finer scale is simply not available.

2.5 How do we measure biodiversity?

Procedures for measuring biodiversity are essential for monitoring trends in biodiversity over time in the absence of active management, for monitoring and evaluating the effectiveness of management intervention, and for identifying particular areas of high biodiversity value. The SCA intends to monitor biodiversity as an indicator of catchment condition (SCA, 2000), and also to identify and protect any biodiversity hotspots that exist in the catchments it manages. Survey work will be important to help identify the systems and species that make up biodiversity in the SCA catchments (i.e. provide a baseline) and to establish links between biodiversity and ecological services. A baseline will be required to identify what is present, the important components to be managed, to measure change in relation to management objectives or responses to management activities, and disturbance or impacts.

As biodiversity and ecological integrity includes consideration of components such as species richness, genetic diversity, ecosystem diversity and the maintenance of ecological processes, measuring biodiversity will require measures for each of these components. However, this is often not feasible. Lack of taxonomic knowledge is a serious impediment for some groups of taxa, and limited resources prevent detailed measurement of diversity across the full spectrum of species present. To overcome these difficulties, surrogate measures are often chosen as an index to biodiversity in place of absolute measures. Caro and O'Doherty 1998 outline the five categories of surrogates commonly used:

- Health indicators – species used to measure the impact of pollutants or other disturbances or purturbations;
- Population indicators – species used to assess the population trends of other species (cf. predator-prey relationships);
- Biodiversity indicators – the number of species from a well-known taxonomic group is used as a surrogate for the number of species (or other taxa) of sympatric but poorly known taxa;
- Umbrella species – taxa whose presence delineate the size or type of habitat that should be protected;
- Flagship species - these 'charismatic' species are used to attract public attention to conservation issues. Habitat set aside to protect the flagship species (e.g. platypus, Murray cod, spiny crayfish) will also benefit less 'charismatic' species.

These surrogates may then be used for rapid assessment of biodiversity assuming the correlation between surrogate measures and ecosystem biodiversity can be established. While this approach has been used successfully for terrestrial systems it remains largely untested in freshwater systems in Australia, and may be unreliable in some circumstances.

Similarly, ecological integrity is not often measured directly. For example, investigations of community structure may be undertaken but key processes, such as nitrogen cycling, often go unmeasured. It should also be remembered that a system might have high species/community diversity yet be dysfunctional, lacking the key processes that are important for maintaining resistance and resilience to perturbation.

Within streams, lakes and wetlands, macro-invertebrate community composition, fish diversity and condition, riparian or aquatic vegetation diversity and structure may each be used as indicators of ecosystem health and surrogate indicators of biodiversity. The extent and condition of riparian vegetation, structurally and floristically, can be used as an indicator of biodiversity dependent on this ecotone, and a combination of vegetation cover and land use can be used as an indicator of biodiversity in the broader catchment. Indicators based on fish community assessments can apply knowledge about species richness, community structure, the intrusion of alien species, and fish abundance and condition. These attributes can be incorporated into a composite index such as the Index of Biotic Integrity (IBI). The IBI has been developed and validated for use in the SCA catchments (Harris and Silveira 1999), although further refinement would be valuable. **However, each of these approaches requires basic work to establish the link between biodiversity and the particular surrogate measure used.** The issues surrounding biodiversity assessment and monitoring are explored in more detail in section 3.

2.6 SCA Obligations

A number of biodiversity initiatives were recognised as relevant to the SCA as manager of the Sydney water supply catchments, including:

- ***International***
  Rio Convention on Biological Biodiversity (1992)
  Ramsar Convention (1971)
- ***National***
  Inter-governmental Agreement on the Environment (1992)
  National Strategy for Ecologically Sustainable Development (1992)
  National Biodiversity Strategy (1996)
  Environment Protection and Biodiversity Conservation Act (1999)
- ***State***
  NSW Threatened Species Act (1995)
  NSW Fisheries Management Act (1994)
- ***Local***
  National Local Government Biodiversity Strategy (1998).

While many of these may not have an immediate bearing on the activities of the SCA, it is important to note that public scrutiny of developers and government agencies alike is growing. Pressure will ultimately come to bear on agencies like the SCA to demonstrate that it is implementing the key recommendations of these documents in the catchments that it manages. It would be prudent to be proactive and able to demonstrate that measures are in place to conserve biodiversity beyond those simply to meet the needs of amenity.

2.6.1 Adoption of a 'no loss' policy

Obligations to conserve biodiversity are often articulated as "no loss" policies, whereby an agency commits to ensure that no species or biotic communities are lost from the area under their control or from a broader naturally defined region which they jointly manage. Such policies may take the form of:

- No loss (keep what is already there);
- No net loss (some species may be lost but others gained);
- Enhancement/improvement or net gain (add to what is already present by restoration in other rural areas).

Key issues to address in the development of a no-loss policy include:

- To what spatial scale should it be applied - within the jurisdictional boundaries of the lands managed by the SCA, within the natural boundary of the drainage basin, or on a broader regional scale?
- What is the temporal baseline – e.g. does the no-loss policy apply from European settlement or from the formation of the SCA?
- Is a no-loss policy that focuses on species and representative biotic communities sufficient, given the complexities of biodiversity? Operationally, to go further and declare no loss of genetic diversity or of ecological processes is seen as very difficult, and beyond the scale of measures of biodiversity to be applied in practice by the SCA (see 2.5 above).
- How do you monitor whether or not a no-loss policy is being satisfactorily implemented?
- How do you cope with the dynamic nature of plant and animal populations, which wax and wane in their spatial extent as climatic and other environmental conditions change? Their abundance or presence on the SCA lands may be subject to natural cycles, and management expenditure to retain them may be futile or unnecessary.

The SCA is considering a commitment to a no-loss policy applied at the drainage basin scale, involving collaborative arrangements with NPWS, DLWC and local government in order to achieve this objective. Drainage basins provide natural boundaries for freshwater systems. The drainage basin and catchments within are units currently used to define the management responsibilities of the SCA. In undisturbed areas, the SCA is committed to no loss of species or representative biotic communities, whereas in highly modified areas of the catchments, the SCA is committed to a policy of net gain through restoration and rehabilitation to serve both amenity and biodiversity objectives. In terms of monitoring such a policy, clearly the SCA cannot monitor the presence of every species and is considering the adoption of surrogate measures, such as habitat quality and extent. However, this is will require confirmation of the links between surrogate measures and ecosystem biodiversity via biodiversity survey work (see section 3). An index based on the number of species moving in or out of the categories of rare, threatened or endangered might also be useful. The SCA acknowledged that it does not currently have the capacity to design or implement biodiversity surveys or monitoring programs.

3 MONITORING AND ASSESSING BIODIVERSITY IN THE SYDNEY WATER SUPPLY CATCHMENTS

DLWC is developing indicators for NSW State of the Environment reporting. Most of the indicators identified so far focus on river health; biodiversity indicators are not yet fully developed. The SCA is also finalising its list of indicators for state of the catchments auditing and as part of its operating licence; flora and fauna diversity are currently proposed for adoption. The draft indicator list has to be finalised by the end of 2000, with monitoring to have commenced by March 2000. This workshop was an opportunity to help refine the list of river-health indicators and explore how biodiversity management might be included in SCA operations. However, it was soon recognised that there was a mismatch between indicators of catchment or water quality condition and those required for biodiversity monitoring. The steps required to link the management of amenity and biodiversity conservation are now considered in more detail.

3.1 Assessment versus monitoring

Managing biodiversity conservation in the Sydney catchments will require both the **assessment** of the ecological systems present (i.e. identify what is present and develop priorities for management) and then ongoing **monitoring** of how the systems change over time or in response to disturbance or management. Biodiversity surveys will be required to identify the species, communities and ecological processes to be protected and to link these with catchment and waterway condition. Once these links have been established, it will be possible to refine the indicators adopted for monitoring catchment and waterway condition to provide biodiversity measures. This will enable the SCA to include and assess biodiversity management in its future operations.

Surveys should include a suite of measurements, from biota such as fish, invertebrates, terrestrial and riparian vegetation and aquatic macrophytes, to ecosystem processes such as production and respiration, and habitat condition. While monitoring is usually based on standardised habitat (e.g. riffles or pools), measuring biodiversity will require an assessment of all habitats present, at least until useful surrogates are identified. One approach may be to identify correlates for biodiversity that are easy to measure and then examine the trophic levels that support them. For example, fish populations may serve as a biodiversity correlate, as the community structure and the spatial and temporal scales that apply to freshwater fish species are reasonably well understood. The fish in waters of the SCA catchments are relatively well known, as are their trophic level and type of feeding.

3.2 Biodiversity survey

SCA intends to identify and manage biodiversity ‘hot spots’. Hot spots are usually considered to be areas of high biodiversity, high endemism, or where threatened or distinctive species are particularly well represented. The term ‘hot spot’ was refined at the workshop to also include areas with low biodiversity but having distinctive or rare communities or species, recognising that ‘hot spots’ have a biodiversity that is significantly different to that of the broader region.

Identification of hot spots requires the consideration of temporal and spatial scale – hot spots may come and go. For example, temporary wetlands and streams can have a high and unique biodiversity and can serve as a refuge for some plants and animals. A monitoring design that produces statistically valid results in systems where there may be considerable natural variability will require careful thought and planning. Survey work will play an important part in refining and optimising future monitoring programs.

Trial surveys were recommended at the workshop as a means to establish links between biodiversity and ecosystem services (e.g. water quality protection). Some of the factors to consider in such a trial are:

- Standardised methods and a suite of biota, processes and environmental variables are to be established and measured concurrently for each survey site. Analysis of covariance can be used to account for long-term variability such as that resulting from climate change (e.g. El Nino events, global warming). Habitat and hydrology measures such as those adopted for AUSRIVAS or the Index of Stream Condition (ISC) can also be included to assist analyses.
- Survey sites need to be located accurately (e.g. accurate GPS or markers), and standardised photographic records of the site at each survey to monitor structural changes.
- Taxa need to be identified at the finest scale possible for assessment, and to refine future monitoring.
- The collation of survey logistics and methods, and taxonomy and life history information is important to assess the response of taxa to disturbance and help identify appropriate indicators or surrogates for future monitoring.
- For temporary systems, the onset of inundation may serve as an important signal or covariate. The stage of inundation will be an important indicator of succession. It should be remembered that water quality and other conditions may decline naturally as streams and wetlands dry up.
- There will be some difficulty in locating reference sites for lowland rivers; there are no pristine sites and even finding mildly impacted sites will be difficult.

3.3 Indicators of biodiversity

The management of biodiversity across the SCA catchments requires monitoring in aquatic, riparian and terrestrial habitats. It was recognised at the workshop that biodiversity issues need to be related to more pressing concerns of the SCA to maintain water quality, public health and public safety to ensure that adequate resources will be made available for future assessment and monitoring. For example, biodiversity will be greatly enhanced by riparian restoration undertaken to address water quality issues, and little additional expenditure and planning (i.e. to address connectivity issues) will be required to meet biodiversity objectives. Substantial expenditure to restore riparian vegetation to meet biodiversity objectives in isolation is unlikely. A major exception may be for freshwater fish populations that include many catadromous species that migrate from freshwater to breed in marine or estuarine environments. SCA's storage dams all grossly impact on these migrations, with profound effects on upstream (and to a lesser degree, downstream) fish diversity (see Gehrke and Harris 1996; Greene *et al*. 1997; and NSW Fisheries' draft report on Tallowa Dam). Restoring fish biodiversity in the longer term would require the fish-passage issue to be dealt with, an issue now being addressed in the Shoalhaven River system.

3.3.1 Instream and wetland biodiversity

Streams

A suite of indicators that may be useful for monitoring was identified at the workshop. While the list is not comprehensive and a number of assumptions require confirmation, it was considered that the following approaches offered the 'best bet' for adoption by SCA until survey work provides a better basis for setting indicators.

NSW Fisheries has developed the IBI as a river-health indicator for SCA catchments as part of the NSW Rivers Survey (Harris and Silveira, 1997). The IBI predicts the fish community attributes of a river reach of excellent quality, based on regional and river-size data, using metrics of species richness, abundance, community structure and the health of individual fish. Fish communities at test sites may be compared on the basis of IBI scores or qualitative rankings representing Excellent to Very Poor conditions, or No Fish. The metrics to be measured at each site are listed in Appendix 3. The information collected for IBI assessment also lends itself to other forms of analysis (e.g. ANOVA). IBI has advantages in that a relatively small number of sites are required for assessment and sampling on an annual basis is usually sufficient. Factors to consider when using IBI is the limited knowledge available on the intolerance of species to decreasing water quality and information on the habitat preferences of species so that they may be assigned to guilds. Multiple sites (3 recommended) will be required to assess river condition, so sampling all the 29 rivers in the SCA catchments may be cost prohibitive (approximately 100 sites @ approx $2,500 per site for an annual survey). Links with riparian and invertebrates assemblages also needs to be confirmed so that fish may be used as a surrogate for biodiversity.

A similar approach to IBI is being developed for macroinvertebrates by the USEPA (Barbour *et al*. 1999). Invertebrates may be useful for future monitoring but this is best reviewed after survey work has been completed. Spiny crayfish and Phreatoicid isopods may be important local species for use as flagship or surrogate species. Proper curation of specimens collected will be important if macroinvertebrates are adopted for monitoring by the SCA. This will allow the detection of long-term changes or the update of findings in light of new information. The SCA should make it mandatory that samples and photographs of species collected on its behalf are forwarded for their collection.

Monitoring of macroalgae may also be useful, especially if their presence can be linked to flow events. Flow cytometry can also be used to look at unicellular algae (analyses are now quick and relatively inexpensive). Diatoms might also be considered; biodiversity decreases and species change depending on the stress – e.g. salinity, nutrients. A palaeobiological approach (analysis of sediment cores) may be useful to assess sites whose sediments have not been disturbed.

Production/Respiration (P/R) ratios and decomposition rates could be useful approaches for monitoring key ecological processes once flora and fauna surveys have been completed.

Molecular approaches may be used to:

- Assessment/survey to examine genetic diversity in subcatchments
- Identify cryptic species to go beyond dependence on identification of species from morphology (a species identified using morphology may in fact prove to be multiple species when examined at the genetic level).

Genetic approaches may also be used to examine factors such as endemism and methods of dispersal. However, genetic approaches are expensive and are recommended for evaluating threatened or flagship species and/or small subsets of species with different potential for dispersal. If genetic evaluations are included with the broad suite of components recommended for survey, it may be possible to assess how genetic diversity is distributed across subcatchments. This may help to identify subcatchments with particularly high levels of genetic diversity or particularly divergent forms of a range of species (genetic endemism).

Molecular techniques are particularly useful for assessing bacteria and fungi via community DNA analysis using polymerase chain reaction (PCR) gene analysis (e.g. from detritus). Molecular approaches could also be used to assess future management actions. For example, to assess the consequences of interbasin transfers, it is necessary to know how genetically divergent the proposed introduced individuals are from the residents. Mixing of very divergent stocks is unwise due to possible negative effects of hybridisation.

Wetlands
Wetlands systems are amongst the hardest-hit habitats following human development (lost surfaces, lost diversity). The approach recommended for monitoring wetlands is similar to that proposed for streams. However, it should be recognised that less is known about the spatially and temporal variability of Australian wetland systems and the response of biota to this variability. For example, it is not clear if fish are good indicators of biodiversity in wetland systems or not; monitoring vegetation and hydrology is thought to be useful. A condition statement or index would be useful for wetlands; one such index has been developed at Charles Sturt University for the floodplain wetlands of the Murray Darling Basin. (Spencer et al. 1998) and may also be useful for assessing the condition of wetlands in the SCA catchments.

3.3.2 Riparian systems
Riparian areas are critical for stream biodiversity as the harbour distinctive flora and fauna, supply organic material and fauna to streams, serve as wildlife corridors, and process and transform the nutrients transferred from terrestrial systems before they enter waterbodies (Naiman and Decamps 1997, Gregory *et al*. 1991). The community structure of riparian vegetation is best measured along permanent transects to consider:

- Floristics, having the right species composition, with a high proportion of natives;
- Structure, having the groundcover, understorey and overstorey each well developed;
- Topography, so that the water passing from surrounding terrestrial areas is filtered by the riparian zone rather than passing through it in a channel.

Measures of intactness, invasion of weeds, index of regeneration and species composition can also be measured in a similar fashion to that of the Index of Stream Condition adopted in Victoria (White and Ladson 1999).

3.3.3 Remaining terrestrial areas
Terrestrial indicators are important as most rainfall travels across land to waterways; the terrestrial environment therefore plays a very important part in maintaining water quality. Surface active invertebrates (e.g. collembolans, isopods etc.) can be very useful indicators, for example as an early warning of the impacts of urbanisation. Vascular plants (e.g. from mapping and GIS) might be a surrogate but this requires confirmation via survey. It is

recommended that terrestrial and aquatic monitoring sites are located together so that survey work may confirm any links between the terrestrial and aquatic biota and key ecological processes.

One approach to linking biodiversity and catchment condition is to undertake broadscale surveys of the impact of land use on biodiversity and water quality and use this to develop a predictive model (cf Mary River catchment in Northern Territory). This will require that survey sites are matched against key land uses or activities (e.g. piggery) sites. A key step will be to develop a method to assign and measure land use that may be applied easily and still provide meaningful information for SCA (e.g. in response to crop rotations etc.). Connecting land use with biodiversity will then allow the use of GIS to evaluate biodiversity responses to changes in land use and activity. Establishing links between biodiversity, land use and water quality will be necessary to refine the predictive power of GIS. Ground-truthing will be required when developing GIS for predictive purposes. It is recognised that the assessment of riparian condition using GIS generally proves very difficult; GIS has potential but will not provide all the answers required for biodiversity monitoring or assessment.

3.4 SCA Environmental Indicators

The current licence requires the SCA to continue monitoring the environmental indicators previously adopted by Sydney Water. A new set of indicators is to be adopted by the SCA from the 1st March 2001. These indicators must:

- Include currently used Sydney Water indicators;
- Address the ecological health of the Catchment Areas, including:
  - Vegetation cover
  - Riparian zones
  - Water quality
- Consider the impact of SCA activities, including polluting activities;
- Consider appropriate factors including:
  - Physical
  - Biological
  - Chemical
  - Ecological
- Be consistent with any other indicators in the catchment areas such as Special Areas.

Environmental indicators must give consideration to:

- Factors including
  - Nutrients
  - Toxicants including
    - Heavy metals
    - Organochlorine
    - Flora diversity
    - Fauna diversity
- Indicators recommended by the Catchments Audit

A draft list of environmental indicators is provided in Appendix 2. Biological indicators have yet to be developed and have not been included. While the indicators have been developed primarily for assessing catchment and water quality condition, the inclusion of flora and fauna diversity offers an opportunity to include biodiversity monitoring. A key question is ‘what indicators should be adopted’? Potential indicators that might be considered in the absence of other information are listed in Appendix 3. However, the list is best refined after biodiversity survey work has been undertaken.

4 KNOWLEDGE GAPS

The key knowledge gaps identified at the workshop included:

- Need to confirm the links between: biodiversity ⇒ ecological integrity ⇒ ecological services ⇒ maintenance of water quality. These links need to be examined at sites representative of good to poor conditions (e.g. a site with reduced biodiversity may have poor water quality and a low P/R ratio).
- Biodiversity hotspots – where are they and when do they exist. We need to confirm the best approach for identifying hot spots (e.g. endemism, species diversity and richness, species vulnerability or threatened species).
- What is the consequence of the 'upside down' nature of the catchments (development and pressures at the top of catchments rather than in the lowland areas)
- The connection between different components of an ecosystem and their impact on biodiversity (e.g. the link between fish predation and the biodiversity of invertebrates). This may require a descriptive model to define what is causative.
- Distribution of genetic diversity (e.g. mountain galaxias and spiny crayfish) and examination of endemism at the genetic level. Do some subcatchments have higher numbers of endemic forms?
- What parts of the inventory are important locally and regionally (e.g. some species may be considered vulnerable, but in fact are at the end of their range (healthy populations elsewhere)
- Patterns of migration and dispersal and their role in recolonisation in the 'upside down' catchments.

The SCA has agreed to discuss with the CRCFE the conduct of biodiversity surveys in some representative catchments.

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APPENDIX 1 PARTICIPANTS AT THE 12TH AND 13TH OCTOBER WORKSHOP

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APPENDIX 2 DRAFT ENVIRONMENTAL INDICATORS FOR SYDNEY CATCHMENT AUTHORITY

Operational Performance Indicators (for SCA activities)
Impacts to Waterways
Volume of water released from the Authority's major storages
Temperature of water released from the Authority's major storages as compared to the temperature of the receiving waters or inflow waters
Effluent management systems owned by the Authority performing to specification
Impacts to Land
Extent and distribution of hazard reduction burns on Authority owned and managed lands
Type and extent of native vegetation on Authority owned and managed lands
The extent of feral pigs on Authority owned and managed lands
The extent of serrated tussock, willow and blackberry on Authority owned and managed lands
Condition of State Heritage Items owned by the Authority
Consumption of Materials and Resources
Quantity of Chlorine used by the Authority during Bulk Water operations
Quantity of Herbicides used by the Authority during catchment operations
Amount of energy (kWh) used by the Authority per megalitre (ML) of bulk water supplied
Environmental Condition Indicators
Environmental Condition Indicators for Lands
Extent and type of landuse in the water supply catchment area
Estimated number of unsewered properties in the water supply catchment area
Extent and type of native vegetation (including riparian) in the water supply catchment area
Extent and type of erosion in the water supply catchment area
Intersection of transport routes and utility easements with watercourses in the water supply catchment area
Extent of dryland salinity in the water supply catchment area
Flora and fauna species of conservation significance on Authority owned and managed lands
Total area burnt by wildfire in the water supply catchment area
Environmental Condition Indicators for Streams (inflows into the Authority's Storages)
Level and variability of streamflow
Physio-chemical measures of water quality
Occurrence of Cryptosporidium and Giardia
The number of discharges of untreated sewage from licenced Sewage Treatment Plants
The number of weirs with effective fishways
Type and extent of wetlands on Authority owned and managed lands
Environmental Condition Indicators for Storages
Storage volumes and variability of the Authority's major storages
Physio-chemical measures of water quality from the Authority's major storages
Occurrence of Cryptosporidium and Giardia within the Authority's major storage
Number and type of algal blooms for the Authority's major storages

APPENDIX 3 FISH METRICS USED FOR IBI ASSESSMENTS

Category	Metric	Scores and Criteria		
		5	3	1
Species richness and composition	1. Total number of native species	Expectations for metrics 1-5 vary with stream size and region		
	2. Number of riffle-dwelling benthic species			
	3. Number of pool-dwelling benthic species			
	4. Number of pelagic pool species			
	5. Number of intolerant species			
	6. Percent native fish individuals	>67%	33-67%	<33%
	7. Percent native species	>67%	33-67%	<33%
Trophic composition	8. Proportion of individuals as microphagic carnivores	>67%	33-67%	<33%
	9. Proportion of individuals as macrophagic carnivores	>10%	3-10%	<3%
Fish abundance and condition	10. Number of individuals in sample	Expectations for metric 11 vary with stream size and region		
	11. Proportion of individuals with disease, parasites & abnormalities	0-2%	2-5%	>5%

From Harris and Silviera, 1999.

APPENDIX 4 POTENTIAL BIODIVERSITY INDICATORS

The SCA recognise that fish and invertebrates are an obvious starting point for including potential biodiversity indicators in regular monitoring, including the use of AUSRIVAS. It was recognised that the link between AUSRIVAS assessments and biodiversity was assumed and required confirmation by survey work. The use of rapid assessment approaches, such as AUSRIVAS, also require the identification of appropriate reference sites so that relative change from reference may be measured.

A ‘best bet’ list of indicators to be considered by the SCA is summarised below.

Taxon	Method	Habitat			
		Aquatic	Wetlands	Riparian	Terrestrial
Bacteria	Molecular	?	?	?	?
Fungi	Molecular	✓	?	?	✓
Algae	Visual/ Microscopic/ Flow Cytometry	✓	✓	-	-
Vascular plants	Visual/ GIS		✓	✓	✓
Invertebrates	Classical/ RBA*	✓	✓	✓	✓
Fish	IBI	✓	✓	-	-

*rapid biological assessment